ADVANCES IN SPORT SCIENCE: LATEST FINDINGS AND NEW SCIENTIFIC PROPOSALS

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ADVANCES IN SPORT SCIENCE: LATEST FINDINGS AND NEW SCIENTIFIC PROPOSALS

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Editorial: Advances in Sport Science: Latest Findings and New Scientific Proposals

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Editorial of the Research Topic

Editorial: Advances in Sport Science: Latest Findings and New Scientific Proposals

Although sport as an activity has been practiced for much of modern history, sports sciences were not considered a discipline of academic tradition until the 20th century (Fernández and García, 2018). The purpose and function of sport sciences are to investigate questions about motor behavior and performance, which must be solved on a scientific basis.

According to data from PubMed, scientific research on sport sciences has increased in the last 10 years. Specifically, it is possible to affirm that more scientific studies were published in the 2010–2020 decade than in the entire previous period (1945–2009) (Maneiro, 2021). This brings us closer to the idea that this area of knowledge is in full expansion and apogee, in which sports scientists have a fundamental role.

Analyzing more specifically the different fields of study, it is possible to affirm that some fields have more robust growth, while in others their growth is more moderate. Specifically, areas such as rehabilitation, exercise, or biomechanics show very notable growth, while others such as sports injuries, motor behavior analysis, performance analysis, or strength training show less notable growth (González et al., 2018).

This special Research Topic entitled "*Advances in Sport Science: Latest Findings and New Scientific Proposals*" began with a double objective: on the one hand, to offer a space where scientists can continue to delve into the most consolidated scientific disciplines; and on the other hand, to open a path where those areas that still need more research could have a place. As a result, the great impact it has had on the community is noteworthy, to the extent that 27 articles have been published by 130 authors, and with a total global impact of almost 61,000 visits from multiple different countries, which has increased and improved knowledge on the following topics: performance analysis in individual and team sports (15 articles), the impact of COVID-19 on performance (3 articles), executive functions and physical fitness at an early age (3 articles), physical activity in older people (1 article), and psychological profiles in performance athletes (6 articles).

OVERVIEW OF CONTRIBUTIONS

The analysis of sports performance has been the subject that research has most concentrated on. This is no coincidence, since the abundance of currently existing sports disciplines demands research that results in potential recommendations with empirical support. More specifically, football is the sport that has been the subject of most research, specifically with five studies, and they have focused on the comparison of goal scoring patterns in the main European leagues (Li and Zhao), the peak performance age of top-level soccer players (Oterhals et al.), differences in technical and space management actions in three UEFA Champions League finals (Amatria et al.), the analysis of one of the most important rules of the game in soccer, such as offside (Zhao), and the opinion of game analysts on different aspects of the game (Aguado-Méndez et al.). All these studies have allowed us to increase our knowledge about different variables that may be modulating success in performance football. The analysis of other team sports, such as volleyball, assessed the efficiency of the training process with different methodologies (Fernández-Echevarría et al.), the influence of the yips (psycho-neuromuscular disorder characterized by involuntary movements that disrupt the execution of automatic fine motor behavior) in college baseball players (Aoyama et al.), the analysis of ultimate frisbee from different criteria such as where more passes are made and what behaviors differentiate the winning teams from the losers (Lam et al.) and, finally, it has been shown that in sports such as rowing (Gavala-González et al.) there is a relationship between the academic record of athletes and sports performance. Specifically, rowers who obtain better academic grades have higher levels of involvement in the tests, and therefore better sports results.

On the other hand, individual sports have also had a special space within the topic. An example is the study by León-Guereño et al., where they analyze the influence of different variables such as age, sex, or marital status on the motivation toward endurance sports such as athletics; on the other hand, badminton (an individual or dual sport) has also had a special mention with two articles: the study by Torres-Luque et al. has proposed the design and validation of an observation instrument for the analysis of technical and tactical behaviors in badminton; and the study by Guo et al., where they analyzed the effect of combined balance and plyometric training on change of direction performance in a 6-week program. Finally, the work of Núñez-Barriopedro et al., with a sample of 682 karate fighters, analyzed the strategies of karate federations to attract and retain competitors through variables such as happiness and how it modulates performance.

Of course, this special Research Topic could not ignore the influence of the COVID-19 pandemic on both the training and sports performance of athletes. In this sense, three studies have focused their efforts on the impact not only of COVID, but also the performance within the bubble in world championships. More specifically, the work of Gentile et al. analyzes how the pandemic influenced different psychological variables such as stress and the ability to fall asleep in the "bubble" at the 2020 World Samboo Championships; on the other hand, the work of McLean et al., using the STS (sociotechnical systems) theory shows that the sports teams of the Australian Football League can take advantage of the circumstances of the pandemic to improve the efficiency of their departments; and finally, the study by Bobo-Arce et al. collects 302 interviews with rhythmic gymnastics coaches from 26 different countries, where they conclude that although gymnasts continued training during confinement, almost 3 out of 4 reported some abandonment of sports practice, also proposing training advice for future lockdowns.

A novel feature of this Research Topic has been the attention paid to early ages from two perspectives: the assessment of physical fitness in boys and girls, as well as their related executive functions. In this sense, the work of Escolano-Pérez et al. examined the influence of early environmental variables such as the type of feeding or the mode of delivery and some biological variables (sex and age) on pre-school motor skills, finding notable differences between them based on sex and type of delivery, among others. The study by Veraksa et al., with a sample of 261 boys and girls from 5 to 6 years of age, tried to identify the possible different levels of physical fitness among them, in addition to an analysis of their executive functions. Lastly, the ambitious study by Iglesias-Soler et al., entitled "Percentiles and principal component analysis of physical fitness from a big sample of children and adolescents aged 6–18 years: the DAFIS Project" with more than 15,000 young people from Galicia, concluded that the physical condition was better in boys than in girls, and that the distribution of fat mass and muscle performance had a high proportion of variation in physical fitness. On the other hand, physical activity in older people has also had a special place in this Research Topic with the article "Physical activity and life satisfactions: an empirical study in a population of senior citizens" by Wöbbeking et al., where, with a sample of 300 older subjects, the influence of various sociodemographic variables (age, sex, institutionalization, and level of education) on the performance of physical activity is analyzed, demonstrating that people with a higher level of education present differences in physical and motivational reserves, and that the latter affect healthy cognitive aging.

Another novel research focus in the current Research Topic has been the inclusion of studies on eye fixation and the "quiet eye" effect. The study of Dahl et al. monitored eye behavior and vision in a similar context to e-sports in more than 2,600 trials, stating that increased cognitive load delayed the onset of gaze fixation, and that the duration of the last fixation before a motor action predicted performance outcome.

Finally, the psychological approach in performance analysis was addressed in five different studies, and four different sports. In the first place, the study by Uriarte et al. focused on judo, and found that the performance indicators that made the greatest difference were psychological aspects such as motivation, stress, and team cohesion, with the motivation variable being the most important for success. On the other hand, there have been two studies that have focused on psychological aspects in archers. The study by Wu et al. studied the effects of a mindfulness intervention program (mindfulness-based peak performance, MBPP) on sports performance in 23 archers, showing that the MBPP program significantly improved shooting performance, multiple cognitive functions, and the level of negative ruminations decreased significantly. On the other hand, the investigation of Li et al. (43 archers and shooting specialists were analyzed) intended to investigate the relationship between the level of experience and interoceptive attention capacity in shooting and archery, concluding that elite athletes outperformed amateurs in different aspects and variables considered. Likewise, Peng et al. studied the relationship between competitive cognitive anxiety and motor performance in Chinese college basketball players, concluding that ego and task orientations and the "goal profile" moderate the relationship between competitive anxiety and motor performance. Finally, in the work of Mitic et al., the differences in the psychological profiles of elite and non-elite athletes are analyzed, stating that the former are characterized by a positive score toward self-efficacy, emotionality, low negative past time perspective, emotional competence, and future time perspective, while the latter have completely opposite features. Finally, in the study entitled "Use of Stroop Test for sports psychology study: cross-over design research" by Takahashi and Grove, they used the Stroop psychological test to investigate the benefits of exercise on cognitive function, finding that there was no significant effect on the exercise mode for both Stroop and reverse Stroop interference.

FUTURE LINES OF RESEARCH

In view of the large number of published articles, all of them of high methodological and substantive quality, the present Research Topic has responded to those objectives that the editors have aspired to: to help increase scientific support around sport from different disciplines and perspectives, with the ultimate objective that these studies result in better decision-making in the practical field.

From this editorial, scientists are encouraged to continue focusing their efforts on consolidating the areas of research that have the most outstanding growth, but without forgetting areas of study that do not yet have robust scientific development, and which also need the support provided by empirical data.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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ORIGINAL RESEARCH
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Do Sex, Age, and Marital Status Influence the Motivations of Amateur Marathon Runners? The Poznan Marathon Case Study

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The purpose of this research was to describe reasons for participating in a marathon and their association with marital status, age, and sex. Four hundred and ninety-three runners in total, 144 of whom were women and 349 of whom were men, completed the Polish version of the Motivations of Marathoners Scale (MOMS), containing nine dimensions, which was released through an online survey at the Poznan Marathon in Poland (2019). Athletes' age (ranges 19–25, 26–35, 36–50, 51–70 years) and marital status (single, married, divorced) were asked of the participants. The results showed that statistical significant associations were found between athletes' motivational aspects and athletes' sex and age. To this end, three MOMS dimensions were statistically associated with athletes' sex, a further three dimensions were different age-wise, and, lastly, marital status did not show differences in any of the dimensions. Moreover, statistical differences were not found in the multivariate analysis comparing marital status, sex, and age range according to MOMS. Recreational runners' reasons for participating in a marathon are different depending on certain sociodemographic variables; therefore, these characteristics should be considered when addressing different athletes in order to provide them with the most suitable information for taking part in such events.

Keywords: running, marathoners, motivation, age, sex difference, marital status

INTRODUCTION

Recreational running has become one of the most common physical activities worldwide, and the number of running events has increased proportionally (Breedveld et al., 2015; Hallmann et al., 2015; Dallinga et al., 2019; Kozlovskaia et al., 2019), as has the number of marathons hosted by different cities in the world (Hulteen et al., 2017). The latter gather thousands of people with different levels of skill who are keen to run such a distance (Buning and Walker, 2016). Due to this popularity, a wide-ranging approach has analyzed these mass sports events, in an attempt to describe, among other aspects: the physical health benefits of running (Hulteen et al., 2017; Oja et al., 2017; Mujika-Alberdi et al., 2018; Kozlovskaia et al., 2019); psychological benefits and mental change (Mazyarkin et al., 2019), finding, for instance, that marathon runners' mental health was better than that of non-athletes (Raglin, 2007; Boudreau and Giorgi, 2010); endurance running performance-related research (Ferrer et al., 2015); social, tourism, and leisure-related research (Shipway and Jones, 2007; Waśkowski, 2011; Nowak and Chalimoniuk-Nowak, 2015; Summers et al., 2016; Malchrowicz-Mośko and Rozmiarek, 2018; Malchrowicz-Mośko et al., 2019), coaching-related research (Malchrowicz-Mośko and Rozmiarek, 2018), and research involving analyzing psychosocial factors related to marathon running (Summers et al., 2016); and psychological motivational characteristics of amateur or recreational runners (Larumbe et al., 2009; Hammer and Podlog, 2016).

Since running events have increased significantly in the last few decades, organizers have started trying to understand the reasons why athletes would take part in different sports events and to define the reasons why a person decides to participate in such events (Scheerder et al., 2015). A distinction is thus drawn between certain groups with specific characteristics that need to be taken into account when organizing an endurance event (Buning and Walker, 2016). In this regard, a great body of literature has tried to describe the reasons that have led athletes to take part in different sports endurance events, e.g., triathlons (Croft et al., 1999; Wicker and Weimar, 2012; López-Fernández et al., 2014; Myburgh et al., 2014) and cycling events (Lachausse, 2006; Heesch et al., 2012; Malchrowicz-Mośko et al., 2019). Apart from the previously cited sporting contexts, the Motivations of Marathoners Scale (MOMS), developed by Masters et al. (1993), has been used in different running contexts, such as adventure races (Doppelmayr and Molkenthin, 2004), a 5 km running event (Bell and Stephenson, 2014), half marathons (Bell and Stephenson, 2014; Malchrowicz-Mośko et al., 2018), and ultramarathons (Doppelmayr and Molkenthin, 2004; Frick, 2011; Malchrowicz-Mośko and Rozmiarek, 2018; Waśkiewicz et al., 2019a), and for trying to distinguish athletes' reasons for participation depending on the distance, comparing half marathon, full marathon, and ultramarathon runners' reasons for participation (Hanson et al., 2015). Other variables such as the type of event, traditional sports events vs. non-traditional sports events (Buning and Walker, 2016), cause-related vs. non-cause-related endurance events (Rundio et al., 2014), first-time marathoners' motivations, and pre-race dropout reasons (Havenar and Lochbaum, 2007) have been analyzed using the MOMS scale, in order to distinguish and understand what drives athletes to participate in those events. Along these lines, some research has tried to cluster athletes according to their motivational profiles (Ogles and Masters, 2007; Parra-Camacho et al., 2019) or according to their family context, for instance (Goodsell et al., 2013), in an attempt to establish different target groups that may be considered when organizing a sports endurance event.

Athletes' motivation is the psychological aspect that has been analyzed most, since it helps to explain their participation in a marathon (Ruiz-Juan and Zarauz Sancho, 2014). Several studies have focused on the motivation of recreational runners due to the importance they place on participating in such events (León-Guereño et al., 2020). Many of them have been conducted on the basis of self-determination theory (Deci and Ryan, 2000), whereby athletes' motivation is divided into two main dimensions, namely, intrinsic and extrinsic motivation (Ruiz-Juan and Zarauz Sancho, 2014). Nevertheless, the creation of MOMS (Masters et al., 1993) was one major development, showing a multidimensional questionnaire designed specifically to assess marathoners' motives. MOMS, as its name "Motivations of Marathoners Scale" suggests, was created specifically in order to measure marathon athletes' reasons for participation, and therefore, athletes' motivations have been analyzed in many marathons from within different social contexts, e.g., in Greece (Nikolaidis et al., 2019), Poland (Malchrowicz-Mośko et al., 2019; Waśkiewicz et al., 2019a), Spain (Ruiz-Juan and Zarauz Sancho, 2014; Parra-Camacho et al., 2019), and especially in the United States (Ogles and Masters, 2003; Rundio et al., 2014; Hanson et al., 2015; Buning and Walker, 2016), the context in which the scale was initially created. The variables associated with different reasons for participating have also been diverse, with the following being the most analyzed variables: runners' sex (Waśkowski, 2011; Summers et al., 2016; Malchrowicz-Mośko and Rozmiarek, 2018; Malchrowicz-Mośko and Poczta, 2019) and runners' age (Ogles and Masters, 2003; Reed and Gibbs, 2016; Poczta et al., 2018; Nikolaidis et al., 2019). This constitutes an attempt to describe whether the reasons for a person taking part in an endurance event depend on athletes' sex and age. Other variables such as years' experience running (Ogles and Masters, 2003; Malchrowicz-Mośko et al., 2020) or training experience (Waśkiewicz et al., 2019b) and athletes' performance (Ferrer et al., 2015; Nikolaidis et al., 2019) have also been associated with athletes' motivations.

Nevertheless, marital status has yet to be analyzed in relation to marathon athletes' participation motives. Taking into account how peoples' lives can change depending on their marital status, and the changes that may take place from being single to being married, and also from this latter marital status to being divorced, it would seem to be an interesting variable when analyzing athletes' participation motives in a sporting event. This may be even more relevant when the sports event in question is a marathon, as this is a very demanding race, with a heavy load or training sessions that need to be completed. Goodsell et al. (2013), in an American sample, concluded that family context was an important influence on peoples' motivation behind running and that it should be taken into account by researchers and those who wish to encourage long-term engagement in active leisure.

As regards the Polish social context, mass sports events and the ideology of healthism have been developing in the last few years, in view of how Poles' physical activity has in turn increased over the last two decades. Socio-cultural and economic aspects have influenced this growth of physical activity, with Poles now being better educated, being wealthier, and having more free time for leisure, having seen their quality of life increase (Malchrowicz-Mośko and Poczta, 2019). Within this context, Poles had taken Western countries' lifestyles on board, and reasons for taking part in sports events such as marathons have increased exponentially.

Thus, it is especially interesting to understand this construct, since a huge social change took place within a quite-short period, and athletes' motivation has also changed too.

Reviewing the literature on the subject showed that most previous research has focused on other countries (Ogles and Masters, 1995, 2003; Rundio et al., 2014; Nikolaidis et al., 2019) rather than specifically on the Polish social context, even though marathoners' motivational characteristics were analyzed in Poland over 10 years ago (Waśkiewicz et al., 2019b). With this research, we attempt to provide up-to-date information about athletes' reasons for participating in marathons. On the other hand, marital status has yet to be suitably addressed, this being an innovative perspective put forward by this research. Therefore, in this research, the main aim will be to show why amateur athletes take part in marathons in Poland, and to this end, runners' motivations will be analyzed and associated with participants' sex, age, and marital status – this last mentioned factor, as we have already mentioned, has tended to be underestimated in literature. In line with this objective, the main hypothesis of this research is that amateur athletes' motivational aspects differ according to their age, sex and, marital status.

MATERIALS AND METHODS

Participants and Study Design

Approval was obtained from the Ethics Committee of the University of Deusto, Spain, and the study was consistent with the Helsinki declaration of 2013. Participants were treated ethically under the American Psychological Association code of ethics regarding consent, anonymity, and responses. It is a cross-sectional study, whose total sample comprised 493 participants in the Poznan Marathon; both females (n = 144) and males (n = 349) filled out the questionnaire. All of them provided written informed consent for participation in the survey, with those athletes who did not ultimately participate in the event being excluded from the study. Participants were recruited via intentioned selection. Individuals took part in the 20th Poznan Marathon in Poland in October 2019. The Poznan Marathon is one of the biggest marathons in Poland and, in fact, one of the biggest in central Europe. 2019 was the 20th year the competition was held. For the first 10 years it was organized, it was the premier running event in Poland, and 6,092 marathoners completed the Poznan Marathon in 2019.

Measurements

Sociodemographic State

Participants, as shown in **Table 1**, were asked about sex (male, female), age range (ranges <18, 19–25, 26–35, 36–50, 51–70 years), and marital status, to determine the most accepted status (single, married, divorced).

Athletes' Motivation

The Polish version of the multidimensional MOMS scale was used (Dybała, 2013), developed initially by Masters et al. (1993). Athletes' motivation was measured via 56 items or reasons for participating in a marathon, organized using a seven-point Likert scale, with the highest score being 7 and the least-valued motive rated 1. This scale shows nine dimensions that authors divided into four main broader groups of motive: (1) psychological motives, involving self-esteem, psychological coping, and life meaning; (2) achievement-related motives, including personal goal achievement and competition; (3) social motives, showing recognition and affiliation motives; and (4) physical health motives, including general health orientation and weight concern (Masters et al., 1993).

TABLE 1 | Column profile according to athletes' age ranges and sex.

	<18		19–25		26–35		36–50		51–70		Total	
Gender	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Male	2	40	26	57	115	69	185	73	21	88	349	71
Female	3	60	20	43	51	31	67	27	3	12	144	29

Procedure

The online survey was set up using Google Docs technology (Šmigelskas et al., 2019). Athletes were contacted via the Internet the same weekend that the 20th PKO Poznan Marathon was taking place in October 2019 and were provided with detailed information about the research by the organizers. Previously, the event organizer was suitably informed about this study, which they passed on to all the participants in the marathon.

Data Analysis

The statistical analysis was carried out by R Core Team in this quantitative analysis. A Principal Component Analysis (PCA) variable graph was calculated to show an outline of the association and direction of the nine MOMS dimensions (Shahid et al., 2016), thus summarizing the information obtained from the correlation matrix (**Supplementary Table A1**) and giving an overall view of the correlations among athletes' different reasons for taking part in a marathon. One-way ANOVA was used in order to analyze the association between athletes' reasons for participating and the three independent variables selected for this research: age, sex, and marital status. Normality in terms of distribution was verified by the Shapiro–Wilk test, and the assumption of homogeneity of variance was ascertained using Levene's test. Multivariate analysis of variance was applied to ascertain the importance of marital status (single, married, divorced), age range (<18, 19–25, 26–35, 36–50, 51–70), and sex (female, male) differences in terms of MOMS variables. Multiple *post-hoc* comparisons with Bonferroni corrections and eta square (η^2) were also used, the latter being a multivariate measure of effect size. The results were considered statistically significant when $p \leq 0.05$.

RESULTS

The results obtained from this research attempted to describe the reasons for participation by amateur athletes and their association with runners' marital status, sex, and age. **Figure 1** –

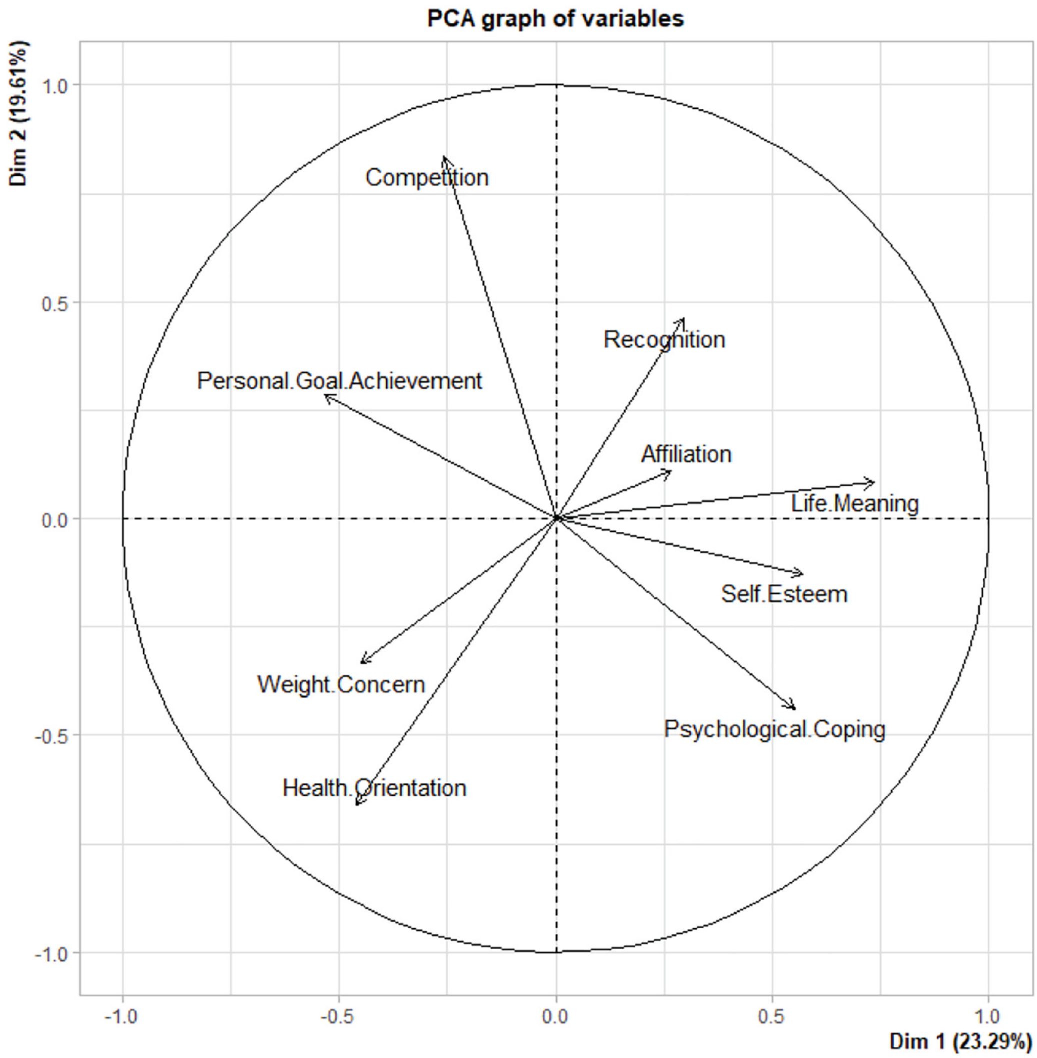

FIGURE 1 | Principal Component Analysis (PCA) graph of variables, showing data for the nine Motivations of Marathoners Scale (MOMS) dimensions.

the variables graph (PCA) – showed an outline of the association and direction of the nine dimensions or reasons for participation on the part of marathon runners. The horizontal dimension showed 23.3% of the variation, and the vertical dimension, 19.6%, thus totaling 42.9% of the total variation. **Figure 1** presents each motivational dimension of athletes represented by an arrow, thus showing the motives and direction taken by participants, summarized in two axes, enabling us to gain an insight into participants' motivation. Horizontal and vertical dimensions show two groups referring to dimension, displaying the main motives and direction taken by those participating in a marathon.

The horizontal or main dimension showed opposing directions in terms of reasons for participation, with health orientation, weight concern, personal goal achievement, and competition in one direction and psychological coping, life meaning, and self-esteem in the other direction. In the vertical dimension, **Figure 1** shows how competition and recognition are to be found on the upper part of the graph, while conversely, health reasons for participating are on the lower part of the graph. The opposing directions of personal goal achievement and affiliation can be observed on the upper part of the graph in **Figure 1**.

Table 2 shows that personal goal achievement ($p < 0.05$), competition, and psychological coping ($p < 0.001$) evidenced statistical differences between male and female runners, showing small to medium effect size values. Conversely, the rest of the MOMS dimensions did not show any significant differences in terms of sex.

Table 3 shows statistical differences according to age ranges in three MOMS dimensions: health orientation ($p < 0.001$), with a medium to large effect size, and affiliation ($p < 0.05$) and self-esteem ($p < 0.05$), with small to medium effect size. Conversely,

TABLE 2 | One-way ANOVA of nine Motivations of Marathoners Scale (MOMS) dimensions according to sex.

MOMS	Women		Men		F	p	d
	M	SD	M	SD			
Health orientation	5.50	1.24	5.38	1.32	0.986	0.321	0.03
Weight concern	4.10	1.73	4.25	1.61	0.832	0.362	0.14
Personal goal achievement	5.16	1.34	4.78	1.43	8.052	0.005	0.26
Competition	3.18	1.51	2.59	1.43	16.364	0.000	0.41
Recognition	3.07	1.35	2.9	1.25	1.598	0.207	0.32
Affiliation	3.49	1.65	3.56	1.52	0.207	0.650	0.25
Psychological coping	4.13	1.34	3.78	1.45	15.528	0.000	0.20
Life meaning	3.78	1.46	3.95	1.37	1.464	0.227	0.09
Self-esteem	4.64	1.39	4.91	1.38	3.734	0.054	0.17

the rest of the dimensions did not show any significant differences according to age.

Table 4 did not show significant differences in terms of the nine MOMS dimensions (all, $p > 0.05$). In addition, the effect size value was small to medium in terms of the nine MOMS dimensions according to marital status.

Table 5 shows the comparison between motivations of men and women based on their marital status according to the nine MOMS dimensions. No statistically significant differences were found in any of the dimensions (all, $p < 0.05$).

DISCUSSION

The aim of this research was to describe why athletes decide to take part in a marathon, i.e., runners' reasons for participation, focusing on some characteristics of participants, such as their age, sex, and marital status, with some of these variables being previously analyzed in other endurance races (Nikolaidis et al., 2019; Waśkiewicz et al., 2019b) and in other social contexts (Buning and Walker, 2016; Malchrowicz-Mośko et al., 2019; Parra-Camacho et al., 2019). The main findings showed that some of the variables analyzed, namely, sex and age, influence the reasons for participation by amateur athletes, while marital status did not evidence any such association. As previous research shows, age and sex have been analyzed in a binomial way, in order to ascertain whether sex–age makes a difference, how far it extends, or in which direction these differences exist in marathon race participants (Reed and Gibbs, 2016; Nikolaidis et al., 2018). One of the most analyzed variables has been athletes' sex when trying to understand endurance athletes' reasons for practicing their sport. In this case, this study shows that amateur athletes' reasons for participating in a marathon in Poland are significantly different in three of the MOMS dimensions according to sex, i.e., male amateur runners' reasons for participating in a marathon are significantly greater in terms of personal goal achievement ($p < 0.005$) and competition ($p < 0.001$) compared to female runners. At the same time, female amateur runners' reasons for participation are greater than in men in terms of psychological coping ($p < 0.001$). These results are partially in keeping with Stempień (2014), who found that non-performance-related variables were preferred by Polish lady runners, with results showing that male and female runners' reasons for participating in a marathon were statistically different. Along the same lines, female marathoners in the classic Athens race showed greater reasons for participation in psychological coping and self-esteem than male runners, although personal goal achievement was found to be a meaningful characteristic in the Greek contexts (Nikolaidis et al., 2019). Conversely, in our research, personal goal achievement was male runners' key factor in taking part in a marathon, and life meaning was a significant reason for participation on the part of Polish female marathoners. In the USA context, Ogles and Masters (1995) analyzed athletes' reasons for participation in terms of sex, and the results obtained support our findings, i.e., women and men differ in their reasons for participating in a marathon, showing that weight concern, affiliation, self-esteem, life meaning, and psychological coping were more key factors for women than for men; on the other hand, health orientation, personal goal achievement, competition, and recognition would explain male runners' participation in marathon events – results that coincide partially with the findings of our research. Within these results, in the Polish context, psychological coping was the motive that showed statistical differences among women, while personal

TABLE 3 | One-way ANOVA of nine MOMS dimensions in terms of age.

MOMS	≤18 years n = 5		19–25 years n = 46		26–35 years n = 166		36–50 years n = 252		51–70 years n = 24		F	p	d
	M	SD	M	SD	M	SD	M	SD	M	SD			
Health orientation	4.57	2.44	4.99[a−b]	1.39	5.27[a−b]	1.23	5.63[a]	1.21	6.16[b]	0.99	6.444	0.000	0.03
Weight concern	3.40	1.99	4.11	1.95	3.94	1.69	4.32	1.63	3.90	1.74	1.601	0.173	0.14
Personal goal achievement	4.60	1.80	5.36	1.27	5.22	1.36	4.90	1.37	4.92	1.47	2.238	0.064	0.26
Competition	2.50	1.78	3.04	1.47	3.16	1.49	2.93	1.52	2.86	1.42	0.789	0.532	0.41
Recognition	2.80	2.01	3.14	1.30	3.14	1.38	2.89	1.26	3.25	1.32	1.253	0.287	0.32
Affiliation	3.30	2.23	3.42	1.63	3.28[a]	1.65	3.60	1.54	4.38[a]	1.70	2.849	0.023	0.25
Psychological coping	4.16	1.83	4.58	1.21	4.34	1.37	4.14	1.37	4.46	1.18	1.444	0.218	0.20
Life meaning	3.83	2.13	3.93[a]	1.46	3.89	1.45	3.76	1.39	4.34	1.45	0.981	0.418	0.09
Self-esteem	4.53	2.23	5.21	1.12	4.72	1.42	4.59[a]	1.36	5.18	1.56	2.745	0.028	0.17

*Between-group comparisons are shown in **Table 3** with different superscripts (a, b). One mean is significantly different from another mean if they have different superscripts.*

TABLE 4 | One-way ANOVA of nine MOMS dimensions' association with athletes' marital status.

MOMS	Single *n* = 108		Married *n* = 355		Divorced *n* = 30		*F*	*p*	*d*
	M	*SD*	*M*	*SD*	*M*	*SD*			
Health orientation	5.30	1.43	5.49	1.23	5.69	1.05	1.458	0.234	0.03
Weight concern	4.36	1.72	4.07	1.39	4.25	1.63	1.274	0.281	0.14
Personal goal achievement	5.09	1.39	5.06	1.35	4.74	1.61	0.806	0.447	0.26
Competition	3.08	1.61	3.01	1.47	2.66	1.43	0.941	0.391	0.41
Recognition	3.17	1.38	2.99	1.28	2.76	1.45	1.402	0.247	0.32
Affiliation	3.56	1.69	3.50	1.57	3.50	1.84	0.060	0.942	0.25
Psychological coping	4.39	1.30	4.23	1.37	4.19	1.41	0.654	0.520	0.20
Life meaning	3.99	1.44	3.77	1.41	3.90	1.58	1.010	0.365	0.09
Self-esteem	4.84	1.38	4.69	1.39	4.70	1.46	0.506	0.603	0.17

goal achievement and competition were the main reasons for participating among men.

Our results coincide partially with previous research, finding an age effect with regard to the reasons for participating in a marathon, with the motives associated with competition being greater in younger athletes than in older runners (Poczta et al., 2018; Nikolaidis et al., 2019). Likewise, in our research, marathoners' reasons for participating were different depending on their age, with these results being of greater importance alongside personal goal achievement in younger athletes than in older ones, in line with Poczta et al. (2018) and Nikolaidis et al. (2019). However, our research showed that athletes' reasons for participation also differ statistically age-wise in health orientation, with more concern about health being shown the older the runners get, i.e., the youngest runners evidenced the lowest scores or reasons for participating in this dimension, while it gains importance as athletes get older. Weight concern was also different according to athletes' age, with the 36–50 age range of athletes showing the most concern about this dimension. Conversely, personal goal achievement lessened in importance as age rose, and affiliation also showed differences among age ranges, with this dimension being of greater concern as athletes get older. Self-esteem showed statistical differences among age ranges, with a decreasing trend the older athletes get. Therefore, our results are, to a great extent, in line with previous results, showing, in general, that younger athletes focus on results and personal reasons for participating, while older runners focus more on meeting other runners and social reasons or on health-related reasons (Poczta et al., 2018).

Little research has been conducted linking runners' motivations and family context, although this is a very important issue. Moreover, athletes' motivations need to be understood beyond psychological aspects, and social factors need to be taken into consideration (Goodsell et al., 2013). For many amateur runners, a marathon is a demanding activity, and while being immersed in it, they enter the running social world and undergo a process involving identity transformation. This process encompasses immersion into a zone that is often outside the partnership of marriage and includes absorption into social networks that are unlimited in time and place and, consequently, may jeopardize the marriage (Shahid et al., 2016) – a reason why marital status could be associated with athletes' participation motives. Within runners' social context, marriage, marital status or the birth of a child might have a great influence on athletes' motivational aspects (Goodsell et al., 2013). Our results showed that marital status, i.e., being married, divorced, or single, was not significant in the case of any of the reasons related to the MOMS dimensions. None of the reasons identified by the MOMS showed significant differences when the interaction between age, marital status, and sex was taken into account. These results are in line with Goodsell et al. (2013), as they did not find a statistically significant relationship between marital status and the intention to run. However, they did find a significant association in athletes to continuing running (Goodsell et al., 2013). Lastly, based on these results, marital status was not found to exert a significant association in any of the motivations expressed by marathon runners, after taking into account factors such as sex or age.

However, these results need to be viewed carefully, since they describe the reasons for participation in a marathon within a specific social context, and the research was carried out using a cross-sectional design that did not allow for any causal inferences among the variables. Moreover, personal variables such as type of job or health status and variables such as the birth of a child or the number of children in the family have not been taken into account within the family context – these are some limitations of the research. In future research, collecting data at different times or moments would provide a wider view of the range of athletes' reasons for taking part in an endurance event (Nikolaidis et al., 2018). Moreover, affiliations could be taken into account from a cultural standpoint in future research (i.e., religion, race), thus providing more specific information associated with family and cultural context, in order to help understand its relationship with athletes' reasons for running (Södergren et al., 2008). However, analyzing the variable of marital status can be considered a strength of this research.

TABLE 5 | Multivariate analysis comparing marital status and age range according to MOMS dimensions: comparison between women and men.

MOMS		Male										Female										η^2	*F*	*p*
		<18		19–25		26–35		36–50		51–70		<18		19–25		26–35		36–50		51–70				
		M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE			
Health orientation	Single	3.75	0.88	4.94	0.33	5.41	0.20	5.40	0.28	6.83	0.88	5.06	0.72	4.97	0.37	4.88	0.37	6.45	0.47	–	–	0.010	1.149	0.333
	Married	–	–	4.67	0.36	5.59	0.15	5.59	0.10	6.22	0.32	–	–	5.50	0.41	4.94	0.20	5.69	0.17	5.00	0.88			
	Divorced	–	–	5.38	–	5.69	0.62	5.69	0.34	6.08	0.62	–	–	–	–	4.66	0.88	5.83	0.51	6.50	1.24			
Weight concern	Single	1.88	1.18	4.36	0.45	4.33	0.27	4.26	0.38	5.75	1.18	4.42	0.97	5.05	0.51	3.95	0.51	4.61	0.63			0.007	2.372	0.497
	Married	–	–	2.79	0.48	3.80	0.20	4.24	0.14	3.85	0.43	–	–	4.33	0.56	3.87	0.27	4.49	0.23	1.37	1.18			
	Divorced	–	–	–	–	3.19	0.84	4.63	0.46	4.50	0.84	–	–	–	–	4.75	1.18	3.92	0.68	3.50	1.68			
Personal goal achievement	Single	3.58	0.95	5.19	0.36	5.27	0.22	5.21	0.31	5.33	0.95	5.28	0.78	5.12	0.41	4.62	0.41	4.50	0.51	–	–	0.003	0.678	0.828
	Married	–	–	5.68	0.39	5.41	0.16	5.07	0.11	4.73	0.35	–	–	5.50	0.45	5.16	0.22	4.48	0.18	2.75	0.95			
	Divorced	–	–	–	–	4.41	0.67	4.59	0.37	6.17	0.67	–	–	–	–	3.92	0.95	4.36	0.55	6.33	1.35			
Competition	Single	1.38	1.04	3.02	0.39	3.38	0.24	3.53	0.34	2.75	1.04	3.25	0.85	2.73	0.44	2.68	0.44	2.04	0.56			0.009	2.449	0.344
	Married	–	–	2.98	0.43	3.34	0.17	3.16	0.12	2.88	0.38	–	–	3.56	0.49	2.77	0.24	2.34	0.20	1.37	1.04			
	Divorced	–	–	–	–	3.31	0.74	2.19	0.41	3.87	0.74	–	–	–	–	1.63	1.04	2.92	0.60	1.75	1.48			
Recognition	Single	1.67	0.92	3.09	0.35	3.26	0.21	3.48	0.30	3.83	0.92	3.56	0.75	3.06	0.39	2.97	0.39	2.62	0.49	–	–	0.018	3.548	0.08
	Married	–	–	2.78	0.38	3.15	0.15	2.96	0.11	3.37	0.34	–	–	3.81	0.43	2.99	0.21	2.73	0.18	1.41	0.92			
	Divorced	–	–	–	–	4.25	0.65	1.99	0.36	3.92	0.65	–	–	–	–	2.09	0.92	3.14	0.53	1.33	1.30			
Affiliation	Single	1.59	1.12	3.48	0.42	3.72	0.25	3.74	0.36	6.00	1.12	4.45	0.91	3.56	0.48	2.59	0.48	3.36	0.60			0.013	3.851	0.189
	Married	–	–	2.97	0.46	3.03	0.19	3.56	0.13	4.52	0.41			3.74	0.53	3.47	0.26	3.79	0.22	2.08	1.12			
	Divorced	–	–	–	–	4.17	0.79	2.79	0.44	4.46	0.79					2.25	1.12	4.42	0.65	3.17	1.58			
Psychological coping	Single	3.61	0.95	4.08	0.36	4.51	0.22	4.13	0.31	4.56	0.95	4.52	0.78	5.14	0.41	4.20	0.41	4.33	0.51	–	–	0.005	1.15	0.637
	Married	–	–	4.30	0.39	4.02	0.16	4.02	0.11	4.67	0.35	–	–	5.05	0.45	4.72	0.22	4.52	0.18	3.17	0.95			
	Divorced	–	–	–	–	4.89	0.67	3.71	0.37	4.42	0.67	–	–	–	–	4.94	0.95	4.39	0.55	3.89	1.34			
Life meaning	Single	3.08	1.00	3.51	0.38	4.10	0.23	4.15	0.33	4.86	1.00	4.33	0.82	3.99	0.43	3.91	0.43	3.92	0.54	–	–	0.009	2.034	0.403
	Married	–	–	3.86	0.41	3.66	0.17	3.66	0.11	4.47	0.37	–	–	4.63	0.47	3.83	0.23	3.90	0.19	2.14	1.00			
	Divorced	–	–	–	–	4.40	0.71	3.19	0.39	4.71	0.71	–	–	–	–	3.14	1.00	4.74	0.58	4.29	1.42			
Self–esteem	Single	3.75	0.97	4.78	0.37	4.68	0.22	4.94	0.31	5.75	0.97	5.04	0.79	5.59	0.41	4.76	0.41	4.45	0.52	–	–	0.020	4.45	0.052
	Married	–	–	5.12	0.40	4.62	0.16	4.51	0.11	5.18	0.35	–	–	5.56	0.46	4.87	0.22	4.82	0.19	2.82	0.97			
	Divorced	–	–	–	–	5.84	0.69	3.78	0.38	5.75	0.69	–	–	–	–	3.88	0.97	5.17	0.56	6.63	1.37			

According to this study, Polish amateur runners' reasons for participating in a marathon are different depending on whether the athlete is male or female and on their being younger or older, although marital status did not show any such association. Our results suggest that sporting event organizers, health promotion specialists, and coaches should consider how female runners evidence statistically greater motivation than men in personal and social dimensions such as psychological coping, while men are more motivated with result-oriented dimensions such as personal goal achievement, competition, and recognition, in line with previous research (Waśkiewicz et al., 2019b). It is thus understood from these results that women may gain more psychological benefits from running than men (Reed and Gibbs, 2016).

CONCLUSION

In conclusion, this study shows that amateur runners' sex and age matter to a greater or lesser extent when it comes to their reasons for participation. However, no relationship was found between marital status and athletes' motivational dimensions. It would therefore be interesting for event organizers to use this information when releasing or promoting such sporting events as a marathon, in order to ensure participants' continued support for these types of competition by meeting different participants' needs and reasons for participation.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the University of Deusto, Spain. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

PL-G, EM-M, and MT-S contributed to the conception and design of the study. PL-G and AC-B organized the database, performed the statistical analysis, and wrote the first draft of the manuscript. PL-G, AC-B, and EM-M wrote sections of the manuscript. All authors contributed to manuscript revision and read and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.02151/full#supplementary-material

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Use of Stroop Test for Sports Psychology Study: Cross-Over Design Research

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Background: In sports psychology research, the Stroop test and its derivations are commonly used to investigate the benefits of exercise on cognitive function. The measures of the Stroop test and the computed interference often have different interclass correlation coefficients (ICC). However, the ICC is never reported in cross-over designs involving multiple variances associated with individual differences.

Objective: We investigated the ICC of the Stroop neutral and incongruent tests and interference (neutral test—incongruent test), and reverse Stroop task using the linear mixed model.

Methods: Forty-eight young adults participated in a cross-over design experiment composed of 2 factors: exercise mode (walking, resistance exercise, badminton, and seated rest as control) and time (pre- and post-tests). Before and after each intervention, participants completed the Stroop neutral and incongruent, and the reverse-Stroop neutral and incongruent tests. We analyzed for each test performance and interference and calculated ICC using the linear mixed model.

Results: The linear mixed model found a significant interaction of exercise mode and time for both the Stroop and reverse-Stroop tasks, suggesting that exercise mode influences the effect of acute exercise on inhibitory function. On the other hand, there was no significant effect of exercise mode for both the Stroop and reverse-Stroop interference. The results also revealed that calculating both the Stroop and reverse-Stroop interference resulted in smaller ICCs than the ICCs of the neutral and incongruent tests for both the Stroop and reverse-Stroop tasks.

Conclusion: The Stroop and reverse-Stroop interferences are known as valid measures of the inhibitory function for cross-sectional research design. However, to understand the benefits of acute exercise on inhibitory function comprehensively by cross-over design, comparing the incongruent test with the neutral test also seems superior because these tests have high reliability and statistical power.

Keywords: inhibitory function, random effect, individuality, experimental design, statistical power

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INTRODUCTION

Several studies have demonstrated that exercise has beneficial effects on brain structure and cognitive function (Colcombe et al., 2006; Pedersen et al., 2009). For example, regular exercise can increase brain volume of older people (Colcombe et al., 2006). To elucidate the mechanism of how exercise affects the structure and function of the brain, researchers have investigated intensity, duration, and mode of exercise (Lambourne and Tomporowski, 2010; Voss et al., 2011; Chang et al., 2012). The Stroop task (Stroop, 1935) which can measure the inhibitory function is extensively applied in research (Etnier and Chang, 2009). The Stroop task is commonly composed of a neutral test, a congruent test, and an incongruent test. For the neutral and congruent test, individuals are required to name the color of irrelevant letters (e.g., XXXX), a color patch, or the corresponding color word (e.g., "Red" is printed in red ink). In the incongruent test, individuals suppress reading the meaning of the word and respond to the color of the ink which is not matched to the color name (e.g., "Red" is printed in blue ink). Typically, the incongruent test yields a longer response time relative to both the neutral and congruent test. The delay of the response in the incongruent test is called "Stroop effect," and it is associated with activation in brain regions (e.g., prefrontal cortex, anterior cingulate cortex) associated with the control executive function (Ruff et al., 2001; Zysset et al., 2001; Song and Hakoda, 2015).

The reverse-Stroop task is a derivation of the Stroop task employed to measure inhibitory function. During the reverse-Stroop task, individuals are asked to respond to the word while ignoring the color of the text rather than identifying the color and ignoring the word. Although the reverse-Stroop task is thought to measure inhibitory function as well as the Stroop task, there are the results which the brain regions associated with the reverse-Stroop task differs from those of the Stroop task (Ruff et al., 2001; Song and Hakoda, 2015). The reverse-Stroop task has been used by researchers to investigate how acute exercise influences executive function (Tsukamoto et al., 2016a,b). These studies have obtained large effect sizes with relatively small samples, suggesting that the reverse-Stroop task is sensitive to the effect of exercise.

Although the Stroop and reverse-Stroop tasks are adopted to assess the inhibitory function, there is still debate around the method of measurement (Scarpina and Tagini, 2017). Scarpina and Tagini (2017) systematically reviewed studies in which used the Stroop task, suggesting that researchers should report not only test performance (e.g., reaction time or the number of correct responses) but also the Stroop interference which is defined as the difference between the neutral/congruent test and the incongruent test. The neutral and congruent tests which do not involve cognitive conflict are categorized as a test of the information processing (Chang et al., 2012). Given that the incongruent test might be affected by information processing constraints, it seems that the interference which partials out the contribution of information processing is a better index than the incongruent test. Indeed, several studies reported that the Stroop interference is associated with specific structures of the brain, cortical activation, and psychological arousal (Takeuchi et al., 2012; Byun et al., 2014; Song and Hakoda, 2015), suggesting that the interference is a valid and useful measurement of the inhibitory function.

On the other hand, there is a possibility that incongruent test performance is a better measure of inhibitory function than interference in complex experimental research designs. This is because the intraclass correlation coefficient (ICC) associated with incongruent performance could be higher than for interference (Siegrist, 1997; Strauss et al., 2005; Hedge et al., 2018). Specifically, in cross-over or mixed designs (Barnhart et al., 2007; Nakagawa and Schielzeth, 2010), higher ICC enhances statistical power. Although a number of previous studies investigated the reliability of the Stroop task using ICC (Franzen et al., 1987; Kozora et al., 2004; Strauss et al., 2005; Wallman et al., 2005; Portaccio et al., 2010; Mohammadirad et al., 2012; Register-Mihalik et al., 2012; Bajaj et al., 2015; Martínez-Loredo et al., 2017), the manners of the Stroop task and the assessment of interference were varied and how to test ICC has been not formatted yet (Parsons et al., 2019). Therefore, the ICC about the Stroop task and its interference seems to has not been adequately examined.

Previous studies involving test-retest designs revealed that each test of the Stroop task showed a higher ICC, than Stroop interference (Siegrist, 1997; Strauss et al., 2005; Hedge et al., 2018). ICC is defined as the ratio of the variance between participants and the sum of the between participants and the residual variances (Shrout and Fleiss, 1979). Hedge et al. (2018) also explained that calculating interference did not affect the residual variance but it reduced the variance associated with individual differences. In experimental research, the effect of exercise on the inhibitory function may be masked due to low ICC and statistical power. Therefore, the Stroop incongruent test performance might be better suited to experimental research than the Stroop interference.

If calculating the interference selectively reduces the variance between participants, the ICC of the Stroop interference might decrease more substantially in a cross-over design. Test-retest research measures of the Stroop task involve only two observations per participant. On the other hand, cross-over designs involve at least four measures per participant (e.g., experimental condition and control condition × pre-test and post-test). Given that the positive impact of exercise on the inhibitory function is small to medium (Lambourne and Tomporowski, 2010; Voss et al., 2011), cross-over designs need to enhance statistical power using measurements with high ICC. However, to the best of our knowledge, no previous investigations have reported ICC of the Stroop test performance and interference for cross-over designs. Therefore, we investigated the ICC of the Stroop task in a cross-over design investigating the effect of exercise on inhibitory function.

One of the reasons why ICC in cross-over design research has not been reported is concerned with statistical analysis. The ICC is commonly calculated using the outputs of one- or two-way analysis of variance (ANOVA) in which one factor is participants. The ANOVA uses the moment method to estimate variance components. This method cannot directly distinguish the variance between participants and the residual variance. Even in a simple test-retest design with both between participants variance and the residual variance as random effects, the moment method cannot distinguish between the two variances. However, the moment method estimates the between participants variance by subtracting from the total random effects' variance (the sum of the variance between participants and the residual) to the residual variance (Shrout and Fleiss, 1979). Therefore, this method can yield a negative ICC when a sum of variance components of individual differences is smaller than a residual variance, which is substantially meaningless. This disadvantage is a challenge to apply ANOVA in cross-over designs in which there are multiple variances associated with individual differences.

To be able to calculate ICC in a cross-over design, Nakagawa and Schielzeth (2010) and Hedge et al. (2018) suggest using the linear mixed model (LMM), also known as a multilevel model or a hierarchical linear model. The LMM, unlike ANOVA, can estimate each parameter using maximum likelihood (ML) or restricted maximum likelihood (REML), computing multiple variances associated with individual differences separately from the residual variance. Brouwer et al. (2012) and Demetrashvili et al. (2016) demonstrated that the ICC can be calculated using the LMM even in complicated research designs which have multiple variances associated with individual differences. We aimed to calculate the ICC for the Stroop task in a cross-over design investigating an acute exercise effect on inhibitory function and to consider the ICCs' influence on revealing the effect of acute exercises. We also calculated ICC of the reverse-Stroop task. As described above, although the reverse-Stroop task is a useful measurement, no previous reports have reported the ICC for reverse-Stroop tasks.

We expected that individual tests will show higher ICCs than the interferences for both of the Stroop and reverse-Stroop tasks, and each test with higher ICCs may be more likely to reveal the effects of exercises more than interferences. In this study, we analyzed the dataset composed of a 4 × 2 cross-over design: exercise mode 4 levels (walking, resistance exercise, badminton, and seated rest as a control condition) × time 2 levels (pre- and post-exercise).

MATERIALS AND METHODS

Participants

The sample size was calculated using power analysis for a one-way repeated ANOVA with partial eta squared ($\eta_p{}^2$) of 0.05, power (1–β) of 0.95, expected ICC of.50, and α at 0.05. This analysis indicated the sample size was 43 adequate. Participants consisted of undergraduate students from Tohoku Gakuin University who volunteered to participate in the study. A total of 48 healthy participants (25 men, 23 women) were included in the final analysis. All participants were determined to be free of any cardiopulmonary and metabolic disease and visual disorder. The participants were asked to refrain from alcohol use and strenuous physical activity for 24 h before each experiment, and from smoking, food or caffeine consumption for 2 h preceding the experiments. Written informed consent was obtained from all participants before the first experiment. The Human Subjects Committee of Tohoku Gakuin University approved the study protocol. **Table 1** shows the characteristics of the participants.

Procedure

Day 1

Participants were required to visit the sports physiology laboratory in the gymnasium on five different days (average interval, 4.5 ± 1.6 days). During the first visit, each participant received a brief introduction to this study and completed informed consent. Their height and weight were measured using a stadiometer and a digital scale, respectively. Next, a Stroop/reverse-Stroop color-word test (Hakoda and Sasaki, 1990) was administered to familiarize participants with the test. A fitness assessment that measured 10-repetition maximum (RM) of 3 resistance exercises (chest press, seated row, and leg press) and aerobic fitness (peak oxygen uptake: $\dot{V}O_2$peak) was then conducted.

Day 2–5 Experimental Sessions

Laboratory visits 2 to 5 were experimental sessions. Participants completed 4 treatment interventions (walking, resistance exercise, badminton, and seated rest). To minimize the learning effect on the Stroop/reverse-Stroop test, the orders of experimental sessions were counterbalanced. We then confirmed there was no bias between order and exercise mode [$\chi^2(9) = 2.3$, $p = 0.985$]. After arriving at the laboratory, participants rested on a comfortable chair for 10 min, then they wore a heart rate (HR) monitor (Model RS800cx; Polar Electro Oy, Kempele, Finland). Before and after each intervention, participants lay on a bed for 5 min to calm their HR, then completed the Stroop and reverse-Stroop test. HR was monitored throughout experimental session, oxygen uptake ($\dot{V}O_2$) was also measured by a portable indirect calorimetry system (MetaMax-3B; Cortex, Leipzig, Germany) during each intervention for 10 min. HR and $\dot{V}O_2$ were averaged for last 7 min.

During the walking condition, walked briskly on a motor-driven treadmill (O2road, Takei Sci. Instruments Co., Niigata, Japan). The speed of brisk walking was set at 6.0 km·h^{-1}. Participants were instructed to walk at a brisk but comfortable pace. However, none changed their speed, and all participants completed the brisk walking at the initial speed. During the resistance exercise, participants performed least two sets of 10

TABLE 1 | Characteristics of participants (Mean ± SE).

Variables	Total (*N* = 48)	Men (*N* = 25)	Women (*N* = 23)
Age (years)	20.5 ± 0.2	20.7 ± 0.2	20.3 ± 0.2
Height (cm)	165.6 ± 1.4	173.6 ± 0.8	156.8 ± 0.9
Weight (kg)	62.8 ± 2.2	73.5 ± 2.4	51.1 1.4
BMI (kg·m^{-2})	22.7 ± 0.6	24.4 ± 0.9	20.8 ± 0.5
$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1})	46.5 ± 1.0	50.2 ± 1.2	42.6 ± 1.2
HRpeak (bpm)	196.2 ± 1.1	197.3 ± 1.4	194.9 ± 1.8
10-RM chest press (kg)	32.1 ± 1.9	42.0 ± 2.2	21.4 ± 0.8
10-RM seated row (kg)	37.2 ± 1.8	46.2 ± 2.1	27.5 ± 0.9
10-RM leg press (kg)	70.8 ± 4.0	93.0 ± 3.9	46.7 ± 1.7

repetitions at 10-RM for three exercises (chest press, seated row, and leg press) using a series of machines (Life Fitness Pro2 series models, Life Fitness, IL) in the gym adjacent to the laboratory. Participants were given a 30 s rest between each set and exercise. During the badminton condition, participants played a singles game against one of three experimenters who had experience in instruction of badminton in the arena adjacent to the laboratory. The investigators played at a level of proficiency that matched the participant's level and also provided the participants with advice for improvement during the games. During the game, the scores were not recorded and "victory or defeat" was not determined. During the control intervention, participants were seated on a comfortable chair with their smart phones and were instructed to spend time operating their smartphones as normal.

Physical Fitness Assessment

Participants performed a graded exercise test on the motor-driven treadmill. The initial speed was set 7.2–9.6 km·h^{-1} according to estimated physical fitness levels of each participant. Each stage lasted 2-min and was increased by 1.2 km·h^{-1} per stage until volitional exhaustion occurred. $\dot{V}O_2$ was measured throughout the test (MetaMax-3B) and the average of the final 30 s was defined as the $\dot{V}O_2$peak. HR was monitored throughout the test, and rating of perceived exertion (RPE) was taken at the end of each stage.

To determine the load of the resistance exercise, 10-RM for chest press, seated row, and leg press were measured using the weight stack machines. After warm-up trials, following the advice of an instructor, participants performed 10 repetitions at an initial load selected by participant's perceived capacity for the 3 exercises. After a 3 min rest, participants performed 10 more repetitions at a load adjusted by the participant based on their perception of the previous set. Participants selected the load of the resistance exercise from one of the two sets closest to the 10-RM.

Stroop and Reverse-Stroop Task

The Stroop/reverse-Stroop test is a pencil and paper exercise that requires manual matching rather than oral naming of items. It consists of four tests arranged in the following order: First is the reverse-Stroop neutral test. Here, a color name (e.g., red) in black ink is in the leftmost column and five different color patches (red, blue, yellow, green, and black) are placed in right side columns. Participants are asked to check the patch corresponding to the color name. Second is the reverse-Stroop incongruent test. Here, a color name (e.g., red) is written in colored ink (e.g., blue) in the leftmost column and five different color patches are in the right-side columns. Participants are instructed to check the patch corresponding to the color name in the leftmost column. Third is the Stroop neutral test. Here, a color patch (e.g., red) is in the leftmost column and five different color names in black ink are in the right-side columns. Participants are asked to check the color name corresponding to the color patch in the leftmost column. Forth is the Stroop incongruent test in which a color name (e.g., red) written using a colored ink (e.g., blue) is in the leftmost column and five color names in black ink are in the-right side columns. Participants are instructed to check a word corresponding to the color of the word in the leftmost column. Each test consists of 100 items and the materials are printed on an A3-size paper. Each test includes practice trails (10 items in 10 s) that precede each test. In each test, participants were instructed to check as many correct items as possible in 60 s. We measured the number of correct responses in each test and then calculated the Stroop- and reverse-Stroop-interferences by subtracting the number of correct responses in the incongruent test from those in the neutral test. Hakoda and Sasaki (1990) recommended the interference ratio (incongruent test score—neutral test score/neutral test score) because the value of the difference between the neutral test score and the incongruent test score for the inhibitory function varies depending on the neutral test score when investigating inhibitory function in a cross-sectional study. However, we employed the interference (incongruent test score—neutral test score) for two reasons. One reason is that both the interference and the interference ratio are substantially equal in a well-controlled longitudinal study that compares the inhibitory function changes over time-course. In practice, we confirmed that there were extremely high correlation coefficients between the interference ratio and the interference divided into each exercise mode and time (pre-, and post-test) (Reverse-Stroop task: $r \geq 0.937$; Stroop task $r \geq 0.978$). The other reason is that several previous reliability studies used the interference (Strauss et al., 2005; Hedge et al., 2018; Parsons et al., 2019). Therefore, we feel the interference can provide more relevant information than the interference ratio.

Statistical Analysis

All measurements were described as group mean ± standard error. Statistical analyses were conducted using IBM SPSS 25 (SPSS Inc., Chicago, IL, United States). To examine the exercise intensity of each intervention, %$\dot{V}O_2$peak and %HRmax were compared by the LMM with exercise mode as a fixed effect and participant as a random effect. A significant main effect of exercise mode was followed up with the Bonferroni method.

To calculate the ICC of the performance of each the Stroop, reverse-Stroop test, and the interferences throughout the whole of interventions, the following statistical model in the LMM was used.

$$y_{ijk} = \mu + \alpha_j + \beta_k + (\alpha\beta)_{jk} + b_i + (b\alpha)_{ij} + (b\beta)_{ik} + e_{ijk}$$

where, y_{ijk} is the number of correct responses in each test or the Stroop or reverse-Stroop interferences of participant $i = 1,\ldots, I$ observed in the exercise mode $j = 1,\ldots, J$ at time point $k = 1,\ldots, K$, with μ the grand mean, α_j the fixed effect of the exercise mode, β_k the fixed effect of time, $(\alpha\beta)_{jk}$ the fixed effect of the interaction of exercise mode and time, $b_i \sim N(0, \sigma_p{}^2)$ the random effect of participant, $(b\alpha)_{ij} \sim N(0, \sigma_{pm}{}^2)$ the random effect as the interaction of participant and exercise mode, $(b\beta)_{ik} \sim N(0, \sigma_{pt}{}^2)$ the random effect as the interaction of participant and time, and $e_{ijk} \sim N(0, \sigma_e{}^2)$ the residual. The REML was used to estimate parameters. The structure of the random effects was assumed as variance components. Following the manner by

Brouwer et al. (2012) and Demetrashvili et al. (2016), the ICC was calculated by following equation.

$$ICC = \frac{\sigma_p^2 + \sigma_{pm}^2 + \sigma_{pt}^2}{\sigma_p^2 + \sigma_{pm}^2 + \sigma_{pt}^2 + \sigma_e^2}$$

In Equation 2, the numerator is a sum of the random effects concerned with individual differences, and the denominator is the sum of the random effects and the residual variance. If individual performance is consistent throughout the whole experiment, the ICC should be high. We then calculated a 95% confidence interval of the ICC using the F-approach by Demetrashvili et al. (2016). Based on Shrout (1998), we assessed ICCs as follows: "substantial" is 0.81–1.00; "moderate" is 0.61–0.80; "fair" is 0.40–0.60; "slight" is 0.10–0.40; "virtually none" is 0.0–0.10. To investigate the fixed effects, if the interaction (exercise mode × time) was significant in the LMM model, another LMM model, in which a fixed effect is exercise mode and a random effect is participant, and the Bonferroni methods were conducted for pre-test and post-test, respectively.

RESULTS

Intensity of Interventions

Table 2 represents intensities of each intervention. The results of the LMM for $\%\dot{V}O_2$peak and %HRpeak revealed significant main effects [$F(3, 141) \geq 276.2$, $p < 0.001$], badminton showed significantly higher $\%\dot{V}O_2$peak and %HRpeak than other interventions ($p < 0.001$, Cohen'$d \geq 1.59$). The seated rest showed significantly lower $\%\dot{V}O_2$peak and %HRpeak than the other interventions ($p < 0.001$, Cohen'$d \geq 3.53$). Differences of $\%\dot{V}O_2$peak and %HRpeak between the walking and resistance exercise were not significant ($p \geq 0.056$, Cohen'$d \leq 0.438$).

Fixed Effects on Cognitive Performances

Table 3 represents each test performance and interference across exercise mode and time. The LMM showed significant interactions for the reverse-Stroop neutral test [$F(3, 141) = 3.9$, $p = 0.010$] and the Stroop incongruent test [$F(3, 188) = 5.5$, $p = 0.001$]. Results of the *post hoc* analysis indicate that while no main effects of exercise mode were revealed on pre-test for both of the reverse-Stroop neutral and Stroop incongruent test [$F(3, 141) < 0.3$, $p > 0.814$], significant main effects of exercise mode were found on post-test for both the reverse-Stroop neutral test and Stroop incongruent test [$F(3, 141) > 3.2$, $p \leq 0.026$]. Badminton significantly enhanced performance of the reverse-Stroop neutral test ($p = 0.018$, Cohen's $d = 0.378$) and the Stroop incongruent test ($p = 0.006$, Cohen's $d = 0.369$) relative to control. For the reverse-Stroop incongruent and Stroop neutral tests, although there were no significant interactions [$F(3, 188) < 2.0$, $p \geq 0.111$] and main effects of exercise mode [$F(3, 141) < 1.7$, $p \geq 0.161$], main effects of time were significant [$F(3, 188) > 22.3$, $p < 0.001$]. For the Stroop and reverse-Stroop interferences, main effects of exercise mode [$F(3, 141) \leq 0.9$, $p \geq 0.425$] and time [$F(1, 47) \leq 2.0$, $p \geq 0.162$], and interactions [$F(3, 141) \leq 2.4$, $p \geq 0.067$] were not significant.

TABLE 2 | Intensities of each intervention (Mean ± SE).

Variables	Intervention	Mean ± SE
$\%\dot{V}O_2$peak (%)	Walking	45.2 ± 1.4^{a}
	Resistance exercise	41.3 ± 1.0^{a}
	Badminton	$74.3 \pm 1.6^{a,b,c}$
	Control	$9.9 \pm 0.3^{b,c,d}$
%HRpeak (%)	Walking	60.2 ± 1.3^{a}
	Resistance exercise	64.3 ± 1.4^{a}
	Badminton	$79.2 \pm 1.3^{a,b,c}$
	Control	$35.4 \pm 0.6^{b,c,d}$

[a] *Significant difference from Control, $p < 0.05$ adjusted by Bonferroni method.*
[b] *Significant difference from Aerobic exercise, $p < 0.05$ adjusted by Bonferroni method.*
[c] *Significant difference from Resistance exercise, $p < 0.05$ adjusted by Bonferroni method.*
[d] *Significant difference from Badminton, $p < 0.05$ adjusted by Bonferroni method.*

Random Effects on Cognitive Performances

When the LMM were conducted for the Stroop and reverse-Stroop tasks, it appeared that the variance of the random interaction of the participant and time gradually transited to the random effect of the participant. Finally, the variance of the random interaction of the participant and time calculated as 0.0, indicating that the covariance parameter was redundant. Yamazaki et al. (2018) reported that individuals with a lower performance before exercise tend to increase greatly in performance after exercise. The results of Yamazaki et al. (2018) implies that there might be a multiple co-linearity between the random effect of the participant and the random interaction of the participant and time. The multiple co-linearity might cause redundant random interactions. Therefore, we modified the model by removing the redundant parameter from the models.

Figure 1 shows each random effect and the residual across each test condition. For the Stoop and reverse-Stroop task, while there were no differences in the residual in all of the indices, random effects in the interferences became much smaller than the neutral and incongruent test. **Table 4** shows the ICC for each test and interference. The ICCs of all tests were more than "moderate" ICCs (ICC $\geq$ 0.745). Notably, reverse-Stroop neutral test, Stroop neutral test, and Stroop incongruent test showed "substantial" ICC (ICC $\geq$ 0.833). On the other hand, the ICCs of both the reverse-Stroop interference (ICC = 0.392) and the Stroop interference (ICC = 0.362) were "slight" ICC.

DISCUSSION

This study investigated ICCs of the Stroop and reverse-Stroop tasks in a cross-over research design. The main finding of this study was that different results were found in the Stroop tests and interference. There was the significant interaction of exercise mode and time for the Stroop incongruent test,

TABLE 3 | Each test of the Stroop and reverse-Stroop tasks (Mean ± SE) across exercise modes and time.

Task	Exercise mode	Neutral test		Incongruent test		Interference	
		Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Stroop task	Walking	54.3 ± 1.1	56.5 ± 1.0	50.5 ± 1.2	52.6 ± 1.2	3.7 ± 0.5	3.9 ± 0.7
	Resistance	53.9 ± 1.1	57.3 ± 1.0	50.4 ± 1.3	52.7 ± 1.1	3.4 ± 0.5	4.7 ± 0.7
	Badminton	54.7 ± 1.1	57.7 ± 0.9	50.3 ± 1.2	54.8 ± 1.1*	4.4 ± 0.7	2.9 ± 0.7
	Control	54.2 ± 1.0	55.7 ± 1.1	50.1 ± 1.2	51.8 ± 1.2	4.2 ± 0.7	3.9 ± 0.6
Reverse-Stroop task	Walking	74.9 ± 1.2	77.6 ± 1.2	61.6 ± 1.2	62.6 ± 1.2	13.4 ± 0.7	15.0 ± 1.0
	Resistance	74.5 ± 1.3	78.2 ± 1.2	61.5 ± 1.2	64.4 ± 1.4	13.0 ± 0.9	13.8 ± 1.0
	Badminton	75.5 ± 1.2	79.5 ± 1.1*	62.5 ± 1.0	65.2 ± 1.2	13.0 ± 0.7	14.4 ± 1.0
	Control	75.5 ± 1.4	76.5 ± 1.2	60.5 ± 1.3	62.2 ± 1.3	15.0 ± 0.9	14.3 ± 0.8

**Significant difference from Control in pre- and post-test each, $p < 0.05$ adjusted by Bonferroni method.*

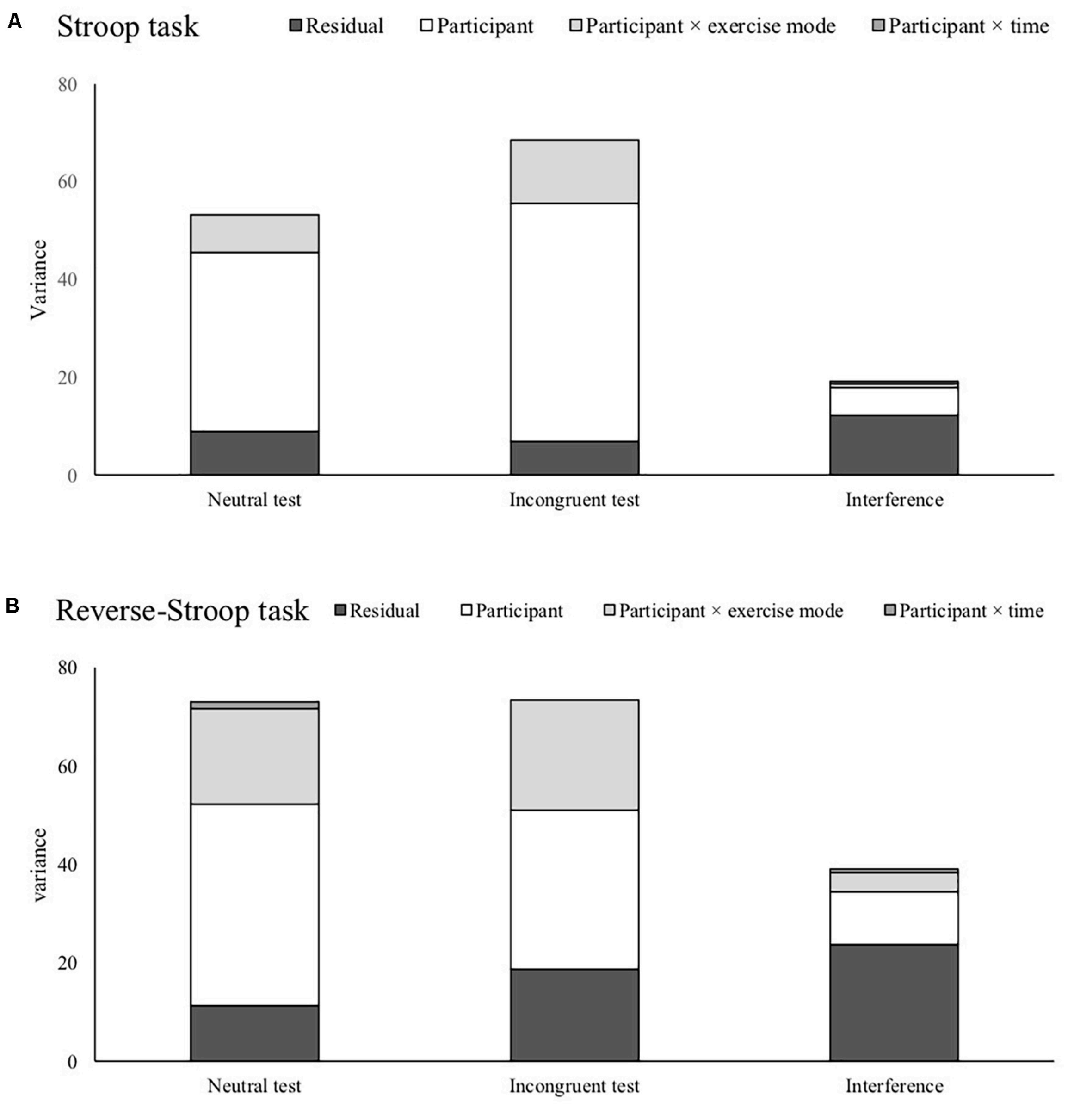

FIGURE 1 | Comparison of variances concerned with participants individuality and the residual variance for the Stroop task **(A)** and the reverse-Stroop task **(B)**.

TABLE 4 | The intraclass correlation coefficients (ICCs) and 95% confidence intervals (95% CI) for each test and interference.

Test/Interference	ICC (95% CI)
Stroop neutral test	0.833 (0.761–0.882)
Stroop incongruent test	0.901 (0.856–0.931)
Stroop interference	0.362 (0.213–0.504)
Reverse-Stroop neutral test	0.846 (0.782–0.890)
Reverse-Stroop incongruent test	0.745 (0.661–0.810)
Reverse-Stroop interference	0.392 (0.247–0.527)

while the LMM did not reveal a significant interaction for the Stroop neutral test. The *post hoc* analysis for the incongruent test revealed that the badminton selectively enhanced the incongruent test performance compared with the control, suggesting that the effects of acute exercise on inhibitory function are influenced by exercise modes. The results that the badminton, which is a hard intensity and open-skilled exercise, improves cognitive functions more than a light intensity and closed-skilled exercise agree with the results of systematic reviews (Chang et al., 2012; Gu et al., 2019). There were also large random effects associated with participants comparing with the residual variance for the Stroop tests. The large random effects and small residual yielded "substantial" ICCs throughout the whole experimental procedure, suggesting that the Stroop tests are highly reliable measures for cross-over design researches.

In contrast to the Stroop tests, the LMM did not reveal fixed effects concerned with exercise modes on inhibitory function for the Stroop interference. The Stroop interference also showed much lower ICC relative to both the Stroop tests. These results suggest that calculation of the interference might attenuate the individual differences as the numerator of ICC, resulting in low reliability and statistical power. Given these results, for cross-over design investigating how acute exercise benefits inhibitory function, analyzing the performances of the Stroop neutral/congruent and incongruent tests separately and comparing their changes might be a better approach than calculating and analyzing the Stroop interference. The Stroop interference is known as a valid measure for inhibitory function for cross-sectional studies (Takeuchi et al., 2012; Byun et al., 2014; Song and Hakoda, 2015; Fagundo et al., 2016; Scarpina and Tagini, 2017). However, because of the possibility of low reliability and statistical power with the Stroop interference, employing Stroop interference as a dependent variable could reduce the likelihood of finding the effects of exercises for cross-over design study.

The reverse-Stroop test showed different results from the Stroop tests about the fixed effects. While the LMM found a significant interaction of exercise mode and time for the neutral test, there was no significant interaction for the incongruent test. We also did not find significant effects of exercise mode, time and interaction for reverse-Stroop interference. These results suggest that there is no effect of acute exercise on inhibitory function measured by the reverse-Stroop task. We expected that the reverse-Stroop task would be more sensitive to an effect of acute exercise because the previous studies (Tsukamoto et al., 2016a,b) showed that the reverse-Stroop incongruent test and the reverse-Stroop interference were significantly enhanced by acute exercises. There is a possibility that the different measurement methods between the previous studies and the present study seems to cause different results. The previous studies (Tsukamoto et al., 2016a,b), employing small sample sizes (N = 12 and N = 10, respectively), measured the Reverse-Stroop neutral and incongruent tests by a computerized test. They found large significant effects of acute exercise on the Reverse-Stroop interference ratio. Although the effect sizes for the previous studies (e.g., Cohen's d or partial η square) were not reported, considering the small sample size, we expected that the Reverse-Stroop tests would be more sensitive to the effect of acute exercise. However, in spite of the relatively large sample size (N = 48), unexpectedly, the LMM did not reveal any effects of exercise on the Reverse-Stroop tests measured by a pencil and paper method in the present study. Given that the effect of exercise on the Stroop tests in the present study is similar to the systematic reviews (Chang et al., 2012; Gu et al., 2019), the difference between computerized test and pencil and paper test might be a critical factor in the Reverse-Stroop task.

Although the LMM showed differences in fixed effects among the Stroop and reverse-Stroop tests, Random effects and ICCs for the reverse-Stroop tests were similar to the Stroop tests. The neutral test and incongruent test for the reverse-Stroop task showed larger random effects concerned with individual differences relative to the residuals, resulting in more than "moderate" ICCs. The results suggest that the two reverse-Stroop tests are reliable measurements as well as the Stroop tests. The changes of random effects for the reverse-Stroop task from each test to the interference were also similar to the Stroop task. For the reverse-Stroop interference, random effects concerned with individual differences vastly decreased compared with those of the neutral and incongruent tests. Still, the residuals did not much differ from each test to the interference. This discrepancy of changes for random effects and residual seems to be the leading cause of the low reliability of the interferences for the cross-over design.

The comparison of each variance across tests and interferences revealed that the main reason for reduced ICC for the interferences was due to the reduction of random effects concerned with individual differences. These results strongly support our hypothesis that the Stroop and reverse-Stroop tests show higher ICCs than the interferences. Given the small to moderate effect of exercise on cognitive function (Lambourne and Tomporowski, 2010; Voss et al., 2011), experimental studies investigating how exercise benefits inhibitory function, employing the interferences for the Stroop and reverse-Stroop tasks with low reliability as a dependent variable might mask the significance of the effect of an acute exercise. The Stroop and the reverse-Stroop incongruent test appear to be affected by inhibitory function and information processing. Therefore, interference that partial out the influence of information processing by subtracting the neutral/congruent tests from the incongruent test might be a reasonable method of assessment.

Indeed, substantial cross-sectional studies employed interference to investigate the association between interferences and brain structure or behavioral measurements (Takeuchi et al., 2012; Fagundo et al., 2016; Peven et al., 2018). However, several experimental studies which detected a selective effect of interventions on inhibitory function have used the incongruent test as the dependent variable (Ferris et al., 2007; Nouchi et al., 2013; Ishihara et al., 2017). The results of this study might explain why the previous experimental studies used the Stroop or reverse-Stroop incongruent test not but interference. It seems that interference with "slight" ICC is not sensitive to the impact of exercise or any factors (i.e., time ore learning effect). Given more than "moderate" ICCs of the neutral and incongruent tests for the Stroop and reverse-Stroop tasks, analyzing the neutral and the incongruent tests, respectively, and comparing outputs of the analyses for both of the Stroop tasks also might be a better approach to understand comprehensively how acute exercise works on inhibitory function.

LIMITATION

One notable difference between the present study and previous research is in the measurement method. We used a paper and pencil matching test to measure each performance of the Stroop and reverse-Stroop task, showing that the calculation of interference for the Stroop and reverse-Stroop tasks decreases the ICC and might mask the fixed effects in cross-over design research. These results and our interpretation correspond to most of the previous studies that measured the Stroop and reverse-Stroop tasks in their experiments. Other studies were detected the fixed effects by analyzing the Stroop interference (Hyodo et al., 2012; Byun et al., 2014) and reverse-Stroop interference (Tsukamoto et al., 2016a,b). Particularly, the difference in measurement methods might selectively influence the performance of Reverse-Stroop tasks. As described above, we had expected that Reverse-Stroop tasks would be sensitive to exercise based on previous studies (Tsukamoto et al., 2016a,b) that showed the Reverse-Stroop performance measured by a computerized test is extremely sensitive to exercise. However, we did not find any effects of exercise on the Reverse-Stroop tests in the present study. This inconsistency between the present study and previous studies might be due to differences between a computerized test and a pencil and paper test. There are fewer studies that have used Reverse-Stroop tasks relative to Stroop tasks, so that we could not interpret that inconsistency about Reverse-Stroop tasks. Therefore, other measurement methods, such as a computerized test or an oral test, might change the influence of calculation of the interference on the ICC. To clarify an interaction between test manners and types of cognitive function, further studies would be needed in the future.

CONCLUSION

In conclusion, the performance of each neutral and incongruent test for the Stroop and reverse-Stroop tasks has a high ICC while calculating the interference decreases ICC in cross-over design research. We have shown that the cause of the decrease of ICC is the reduction of variances associated with individual differences. The interference for the Stroop and reverse-Stroop tasks are valid indices for the inhibitory function. However, to investigate the effect of exercise on the inhibitory function with adequate statistical power in cross-over design research, researchers should also draw attention to incongruent test performance for the Stroop and reverse-Stroop tasks.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Human Subjects Committee of Tohoku Gakuin University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ST: conception of this research, data collection, analysis and interpretation, and writing original draft. PG: supervision and review and editing. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.614038/full#supplementary-material

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Design, Validation, and Reliability of an Observational Instrument for Technical and Tactical Actions in Singles Badminton

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Technical and tactical actions are decisive in terms of badminton player competitive performance. The main objective of this research was to design, validate, and estimate the reliability of an observational instrument for the analysis of the tactical and technical actions in individual badminton. The process was carried out in four different steps: first, there was a review of the scientific literature and a preliminary list of variables was made; second, a qualitative and quantitative assessment was completed by 10 badminton expert judges; in the third step, the content validity was estimated using Aiken's V coefficient; finally, intra-observer reliability and interobserver reliability were tested by two observers specialized in badminton using the Cohen's Kappa coefficient and the intraclass correlation coefficient. Strokes were used as the unit of measure by our observational instrument; every time badminton players hit the shuttlecock, 22 variables (eight contextual variables, seven variables related to the result of the match, and seven variables related to the game) are observed. The minimum Aiken's value was 0.58, and reliability was 0.63. In spite of these values, none of the variables had to be removed, but there were modifications in terms of drafting in some of them. The main findings confirmed the validity and the usefulness of this instrument.

Keywords: racket sports, badminton, test, performance analysis, observational methodology

INTRODUCTION

Nowadays, the observational methodology has become an essential tool that allows coaches to improve their training programs, athletes to make better technical tactical decisions, sports organizations to manage teams more effectively, and academic researchers to develop a better understanding of sports performance (O'Donoghue, 2014). With the objective of guaranteeing the quality of research, the observational methodology needs to validate reliable procedures with respect to the design of variables and categories (Lago Peñas et al., 2020). This requires the participation of coaches, experts, and observers in the entire validation process (Ortega et al., 2008a; Moreno and Gómez, 2017).

Different methods are used by sports sciences to carry out this type of studies (Figueira et al., 2018). In recent years, in spite of the technological advances (Mateus et al., 2017), the observational methodology (Anguera et al., 2011; Maneiro et al., 2018; Fernández-García et al., 2020) has been used by researchers to extract valuable information about sport actions, since it allows to know different actions that are executed during the game time, as well as the contexts where they occur. Likewise, it is a method that requires rigor at the time of observational instrument design and in the process of observation and data analysis (Gorospe et al., 2005; Valldecabres et al., 2019).

In the sports field, studies about validating a specific observational instrument have been increasing. Some of these have been carried out in physical education (Ortega et al., 2008a,b) and some team sports such as soccer (Fernandes et al., 2019; Ortega-Toro et al., 2019), basketball (Ibáñez et al., 2019), handball (Morillo et al., 2017), rugby (Villarejo et al., 2014), and volleyball (Palao et al., 2015a). Studies of these characteristics have also been carried out in individual sports like judo (Rodríguez et al., 2016) and, in particular, in other racket sports, as well as in tennis (Gorospe et al., 2005; Torres-Luque et al., 2018) or table tennis (Pradas et al., 2012). Depending on each investigation, the procedure is described in different steps: to review the scientific literature; to design the instrument with the system of conducts and categories to be observed; to evaluate the instrument quantitatively and qualitatively; to calculate the content validity of the instrument; to test the reliability.

In badminton, which is characterized by high-speed movements and shot executions (Abdullahi and Coetzee, 2017), observational methodology has been used to obtain information about different game aspects (Abián et al., 2014; Abdullahi and Coetzee, 2017), but the rules and characteristics of this sport make it difficult to observe and analyze the game. In this sense, previous studies carried out in similar disciplines such as squash (Brown and Hughes, 1995) or table tennis (Pradas et al., 2012) have been taken into account, whose observational instruments have been created *ad hoc* in order to solve this problem.

Therefore, it is important to explain the design and validation process of the instrument that is used to collect this information. Thus, the main goal of this study is to design and validate an observational instrument for researchers and badminton coaches to assess the technical tactical motions in singles badminton with reliability, objectivity, accuracy, and validity.

MATERIALS AND METHODS

The design, validation, and testing of the reliability of the badminton observational instrument was completed in four stages. The first consisted of the observation instrument design that was a mixed category system and field format (Anguera and Hernández-Mendo, 2015; Anguera et al., 2018); the established categories were exhaustive and mutually exclusive (E/ME). The second consisted of the quantitative and qualitative evaluation of the instrument. The third consisted of the validation and calculation of the content. The fourth consisted of a reliability test (Kinrade et al., 2010).

Preparing a draft list of the conducts to be studied after a scientific literature review, mainly in the Web of Science databases with the keyword "badminton" (**Tables 1–3**), was the purpose of the first stage. The result showed a first list of variables with their definitions and categories to which they should belong. Three groups of variables were established: (a) contextual variables, including all those that defined the conditions of a match (gender, competition level, type of event round, game mode, court surface, shuttlecock type, and player laterality). The analysis unit was the match; (b) variables related to the result of the match, including all score statistics (match winner or loser, analyzed set, sets in favor, sets against, winner or loser of the analyzed set, game scoring, and analyzed point loser or winner). The unit of analysis was the match; (c) variables related to the game (stroke sequence, point duration time, type of technical and tactical stroke, trajectory, tactical intentionality, hitting area, and stroke effectiveness). The unit of analysis was the point.

Table 1 showed a preliminary list of contextual variables, variables related to the result of the match, and variables related to the game and their respective categories with suggested behaviors in the review of scientific literature that make up the observational instrument.

In the second stage, a qualitative and quantitative assessment of the observation instrument was completed by 10 badminton expert judges with the minimum following requirements: (a) Sports Technician certificate on the highest national level; (b) an experience of more than 10 years in teaching badminton; (c) Master in Sport Sciences or Physical Activity. For the assessment, the experts completed a survey (**Table 4**) with the following questions about the variable: (a) level of interest to include the variable (inclusion); (b) level of adequacy in the variable and categories definition (adequacy); (c) level of drafting of the variable and categories definition (drafting); (d) the quantitative assessment was to score from 1 to 10 the adequacy and drafting sections, while the qualitative part of the assessment consisted of responding to the inclusion section "Yes" or "No" (observation). Therefore, the answers were made individually, including a quantitative and qualitative part. All data were registered, and a descriptive analysis was completed (average, median, and mode of every continuous variable and also relative and absolute frequency in the case of categorical variables).

Table 2 presented a sample questionnaire that was sent to the 10 badminton expert judges with a variable "stroke effectiveness" as an example.

The third stage aim was to calculate the content validity through Aiken's V coefficient (Aiken, 1980; Penfield and Giacobbi, 2004). Using the Visual Basic 6.0 software application described by Soto and Segovia (2009), Aiken's V coefficient (Aiken, 1985) was used to determine the criteria for the modification or elimination of the variables. The obtained data were 0.70 (p = 0.05) and 0.81 (p = 0.01). Then, as a critical level of Aiken's V was determined to reject the null hypothesis, it was decided to remove the variables whose data were lower than 0.70 and to modify the variables whose data were between 0.70 and 0.81. The variables data higher than 0.81 were accepted.

TABLE 1 | List of contextual variables, variables related to the result of the match, and variables related to the game and their respective categories that make up the observational instrument after the first phase.

Contextual variables	**Categories**	
Gender of the players*	• Male • Female	• Mixed
Competition level*	• Professional badminton • Semi-Professional badminton • National badminton • Regional badminton	• Provincial badminton • Amateur badminton • Others
Type of tournament*	• Olympic Games • World Cup • European Championship • Open • Master 1000 • Master 500 • Master 300	• Spanish Championship • National competitions • Regional competitions • Provincial competitions • Local competitions • Non-federated championships • Others
Tournament round*	• League phase • Final • Semifinals • Quarter finals	• Round of sixteen • Sixteenths • Treintaydosavos •
Game mode*	• Best of 3 sets of 21 points with a • difference of 2 up to a limit of 30 • Best of 3 sets of 15 points with a difference of 2 up to a limit of 21 • Best of 3 sets of 11 points with a difference of 2 up to a limit. . .	• Best of 1 set of 21 points with a • difference of 2 up to a limit of 30 • Best of 1 set of 15 points with a difference of 2 up to a limit of 21 • Best of 1 set of 11 points with a difference of 2 up to a limit. . .
Court surface*	• Carpet • Parquet	• Rubber • Others
Shuttlecock type*	• Natural	• Synthetic
Laterality of the players*	• Right handed	• Left handed
Variables related to the result of the match	**Categories**	
Winner or loser of the match*	• Winner	• Loser
Analyzed set*	• 1st set • 2nd set	• 3rd set
Sets in favor*	• No set in favor	• A set in favor
Sets against*	• No set against	• A set against
Winner or loser of the analyzed set*	• Winner of the set	• Loser of the set
Game score*	• 0/0 • 1/0	• 0/1 • . . .
Winner or loser of the analyzed point*	• Winner of the point	• Loser of the point
Variables related to the game	**Categories**	
Stroke sequence*	• Serve • Return • 2nd stroke of the point, 3rd stroke of the point. . .	• Penultimate stroke of the point • Last stroke of the point
Point duration time*		
Kind of technical and tactical stroke*	• Right serve • Reverse serve • Offensive serve • Defensive serve • High serve • Flick serve • Drive serve • Short serve • Clear from right to high hand • Clear from right to medium height	• Right hand drive • Left hand drive • Drive to high hand • Drive to medium height • Parallel drive • Cross drive • Right net drop • Left net drop • Net drop to medium height • Net drop to low hand

(Continued)

TABLE 1 | Continued

Contextual variables	Categories	
	• Clear from right to low hand • Clear from left to high hand • Clear from left to medium height • Clear from left to low hand • Offensive clear • Defensive clear • Parallel clear • Cross clear • Right drop • Left drop • Drop to high hand • Drop to medium height • Drop to low hand • Parallel drop • Cross drop • Slow drop • Fast drop • Drop shot • Reverse drop • Right smash • Left smash • Parallel smash • Cross smash • Smash in jump	• Offensive net drop • Defensive net drop • Parallel net drop • Cross net drop • Right lob • Left lob • Lob to medium height • Lob to low hand • Offensive lob • Defensive lob • Parallel lob • Cross lob • Right brush • Left brush • Right kill • Left kill • Parallel kill • Cross kill • Right push • Left push • Parallel push • Cross push
Trajectory*	• Parallel	• Cross
Tactical Intentionality*	• Offensive	• Defensive
Hitting area*	• Inside the court, serve and background zone, in the right area • Inside the court, serve and background zone, in the central area • Inside the court, serve and background zone, in the left area • Serve zone in the right area	• Serve zone in the central area • Serve zone in the left area • Near the net in the right area • Near the net in the central area • Near the net in the left area
Stroke effectiveness*	• Winner • Total continuity	• Partial continuity • Error

Suggested behaviors in the review of the scientific literature (first phase).

TABLE 2 | Sample questionnaire sent to the 10 badminton expert judges.

Stroke effectiveness

Variable: effectiveness of the stroke performed by the player.

Categories:

1. Winner. Stroke performed by the player with the one that gets the point directly, without his/her opponent touched the shuttlecock.

2. Total continuity. Transitional stroke performed by the player, who sends the shuttlecock to the opposite field continuing his/her rival the point (without failure).

3. Partial continuity. Stroke performed by the player, who sends the shuttlecock to the opposite field, causing his/her rival to hit the shuttlecock sending it out of the regulatory area of the court, to the net, to the roof or to their own field (with failure).

4. Error. Stroke performed by the player, who sends the shuttlecock out of the regulatory area of the court, to the net, to the roof or to their own field, losing the point.

(a) Inclusion: Do you consider it necessary to include this variable in the observation sheet? YES/NO

(b) Adequacy: Do you think that the definition of the variable and its categories is adequate?

•
• Very inadequate 1-2-3-4-5-6-7-8-9-10 Very suitable
•

Drafting: Do you consider adequate the wording of the definition of the variable and the definition of each of the categories?

•
• Very poorly drafted 1-2-3-4-5-6-7-8-9-10 Very well drafted

Observations:

Variable stroke effectiveness

TABLE 3 | Final list of contextual variables, variables related to the result of the match, variables related to the game and their respective categories that make up the observational instrument.

Contextual variables	Categories	
Gender of the players*	• Male • Female	• Mixed
Tournament level*	• Professional badminton • Semi-Professional badminton • National badminton • Regional badminton	• Provincial badminton • Amateur badminton • Others
Type of tournament**	• Olympic Games • World Cup • European Championship • Open • Master 1000 • Master 500 • Master 300	• Spanish Championship • National competitions • Regional competitions • Provincial competitions • Local competitions • Non-federated championships • Others
Tournament round*	• League phase • Final • Semifinals • Quarter finals	• Round of sixteen • Sixteenths • Treintaydosavos
Game mode*	• Best of 3 sets of 21 points with a difference of 2 up to a limit of 30 • Best of 3 sets of 15 points with a difference of 2 up to a limit of 21 • Best of 3 sets of 11 points with a difference of 2 up to a limit…	• Best of 1 set of 21 points with a difference of 2 up to a limit of 30 • Best of 1 set of 15 points with a difference of 2 up to a limit of 21 • Best of 1 set of 11 points with a difference of 2 up to a limit…
Court surface**	• Carpet • Parquet	• Rubber • Others
Shuttlecock type*	• Natural	• Synthetic
Laterality of the players*	• Right handed	• Left handed
Variables related to the result of the match	**Categories**	
Winner or loser of the match*	• Winner	• Loser
Analyzed set*	• 1st set • 2nd set	• 3rd set
Sets in favor*	• No set in favor	• A set in favor
Sets against*	• No set against	• A set against
Winner or loser of the analyzed set*	• Winner of the set	• Loser of the set
Game score*	• 0/0 • 1/0	• 0/1 • …
Winner or loser of the analyzed point*	• Winner of the point	• Loser of the point
Variables related to the game	**Categories**	
Stroke sequence**	• Serve error • Serve • 2nd stroke of the point, 3rd stroke of the point…	• Penultimate stroke of the point • Last stroke of the point
Point duration time*		
Kind of technical and tactical stroke*	• Right serve • Reverse serve • Clear from right to high hand • Clear from right to medium height • Clear from right to low hand • Clear from left to high hand • Clear from left to medium height • Clear from left to low hand • Right drop • Left drop • Right smash • Left smash • Smash in jump • Drive from right to high hand	• Lob from right to medium height • Lob from right to low hand • Lob from left to medium height • Lob from left to low hand • Right brush • Left brush • Right kill • Left kill • Right push • Left push

(Continued)

TABLE 3 | Continued

Contextual variables	Categories	
	• Drive from right to medium height • Drive from left to high hand • Drive from left to medium height • Net drop from right to medium height • Net drop from right to low hand • Net drop from left to medium height • Net drop from left to low hand	
Trajectory*	• Parallel	• Cross
Tactical intentionality*	• Offensive	• Defensive
Hitting area*	• Inside the court, serve and background zone, in the right area • Inside the court, serve and background zone, in the central area • Inside the court, serve and background zone, in the left area • Serve zone in the right area	• Serve zone in the central area • Serve zone in the left area • Near the net in the right area • Near the net in the central area • Near the net in the left area
Stroke effectiveness**	• Winner • Total continuity	• Partial continuity • Error

**Behaviors selected after the first phase; **Behaviors with modifications suggested by experts (third phase).*

TABLE 4 | Values of pertinence, definition (Aiken's V coefficient), and interobserver and intra-observer reliability (Cohen's Kappa and ICC) of definitive variables and categories of the badminton observational instrument.

Variables	Pertinence (V Aiken)	Definition (V Aiken)	Intra-observer 1 Reliability (Cohen's kappa)	Intra-observer 2 Reliability (Cohen's kappa)	Interobserver reliability (Cohen's kappa)
Contextual					
Gender of the players	0.89	0.89	1	1	1
Tournament level	0.81	0.81	1	1	1
Type of tournament	0.78	0.69	1	1	1
Tournament round	0.81	0.85	1	1	1
Game mode	0.85	0.86	1	1	1
Court surface	0.58	0.69	1	1	1
Shuttlecock type	0.79	0.82	1	1	1
Laterality of the players	0.86	0.86	1	1	1
Result					
Winner or loser of the match	0.72	0.67	1	1	1
Analyzed set	0.83	0.87	1	1	1
Sets in favor	0.86	0.90	1	1	1
Sets against	0.75	0.79	1	1	1
Winner or loser of the analyzed set	0.77	0.77	1	1	1
Game scoreboard	0.89	0.84	1	1	1
Winner or loser of the analyzed point	0.86	0.79	1	1	1
Game					
Stroke sequence	0.86	0.65	1	1	1
Point duration time	0.77	0.73	1 (ICC)	0.87 (ICC)	
Kind of technical and tactical stroke	0.82	0.60	0.91	1	0.87
Trajectory	0.90	0.77	1	1	0.94
Tactical intentionality	0.84	0.69	0.86	1	0.63
Hitting area	0.88	0.76	1	0.92	0.96
Stroke effectiveness	0.90	0.66	1	1	1

ICC, intraclass correlation coefficient.

In the same way, a minimum inclusion value of at least 80% "Yes" from the expert judges was accepted for the inclusion section. After those modifications, the next step was to create a new and definitive observation manual with a list of variables and categories that take to the writing of the observation instrument, which included the variables with the grouped categories of each one, their definitions and coding ("Observation instrument for singles badminton," see **Supplementary Annex 1**).

In the fourth stage, the observation instrument reliability was tested following other studies (Gamonales et al., 2018; Torres-Luque et al., 2018). According to the studies by Anguera (2003) and Losada-López and Manolov (2015), three observers were trained by the main research supervisor through three sessions of 2 h each with a break of 10 min once they reached 55 from the observation using the fourth stage of the designed observation manual. In this case, to evaluate the reliability, two observers, both of them with masters in Primary Education with a mention in Physical Education and specialized in badminton, carried out the assessment twice within a week, 30 strokes of one badminton match. For the inter-observer and intra-observer reliability of all variables, a Cohen's Kappa coefficient was used, except for the variable "duration of the point," in which the intraclass correlation coefficient (ICC) was used.

As a last resort, it is very important and necessary to work out the specific protocol for the correct use of the observational instrument. Firstly, the observers must be in an elevated position behind a baseline of the badminton court, providing a good view of all lines (at least at the height of the players). The observational data collection in relation to the service area, hitting area, and shuttlecock end area was carried out according to the zones described in the observation manual.

The data were collected in an Excel-designed spreadsheet, where each row corresponds to a stroke of a player (each unit of measurement is a stroke by one player). The main reason of this recording is to understand the sequence of strokes in the interaction between players. For the purpose of optimizing the recording time of all variables and their categories, was defined as follows: (a) variables to record every stroke [results (game scoring and loser or winner of the analyzed point) and game development (stroke sequence, kind of technical-tactical stroke, hitting area, trajectory and stroke effectiveness)]; (b) variables to register every point [results (lost and won points on the set)]; (c) variables to register every set [results (analyzed set, lost and won sets, and loser and winner of the analyzed set)]; (d) variables to analyze every match [contextual (gender, event level, type of event, event round, game mode, court surface, type of shuttlecock, and player laterality) and results (loser or winner of the match)].

RESULTS

Table 1 shows the results of the observational instrument design after the scientific literature review. All game variables were determined, thanks to the researchers' input and previous researches, and they were used as a basis to design the observational instrument. Finishing the first phase, 22 variables formed the observational instrument: eight contextual variables, seven variables related to the result of the match, and seven variables related to the game.

After performing the qualitative and quantitative assessment of the observation instrument by a group of experts ($n = 10$) and calculating the content validity using the Aiken's V coefficient (Penfield and Giacobbi, 2004), a total of five modifications were carried out in the defined ones, two related to contextual variables and three related to game variables. All changes were endorsed with a lower Aiken's V value and also when more than 80% of the expert judges respond positively to be included.

As can be seen in **Table 3**, there were not many changes after the evaluation, the main changes were found in the following variables: (a) court surface, the experts did not consider it necessary; (b) type of tournament, the experts proposed a change in nomenclature or join this variable with the competition level; (c) stroke sequence, the experts proposed to analyze a determined number of strokes; (d) tactical intentionality, the experts considered important to add more intentions (neutral intent, for example); (e) stroke effectiveness, the experts proposed to redefine the concepts due to their inaccuracy.

Table 3 showed a definitive list of contextual variables, variables related to the result of the match and variables related to the game and their respective categories that make up the observation instrument.

The 22 final variables were eight contextual variables, seven variables related to the result of the match, and seven variables related to the game (**Table 3**). Then, all variables with a value ≥ 0.81 in the Aiken's V were considered for the observation instrument (**Table 4**). One hundred percent of the expert judges responded positively for the inclusion of all cases.

The values of pertinence, definition, and interobserver and intra-observer reliability of definitive variables and categories of the badminton observational instrument are shown in **Table 4**.

Table 4 showed the results from the fourth phase, which indicated high reliability values in general. As it can be observed, the variable "tactical intentionality" obtained the lowest value in Cohen's Kappa coefficient, both in the intra-observer test (0.86) and in the interobserver test (0.63). The ICC was used for the variable "point duration time" with values of 1 and 0.87.

DISCUSSION

The present study has been carried out in order to show and explain all the stages for designing, validating, and testing the reliability of the observational instrument that analyzes the technical and tactical behaviors in singles badminton. Therefore, the designed observational instrument is valid and reliable to analyze the technical and tactical actions that take place during a rally in a badminton match. To this effect, the methodological procedures suggested by Anguera and Hernández-Mendo (2013) have been followed, just as other similar studies that have been carried out in different sports (Pradas et al., 2012; Villarejo et al., 2014; Palao et al., 2015a,b; Torres-Luque et al., 2018; Parada and Vargas, 2020). By this way, a valid and reliable tool has been generated for this sport.

A total number of 10 expert judges and two observers have participated in the design and validation of the observational instrument. In this respect, it should be noted that the particularity of the subject matter limits the existence of the experts in this area of knowledge. In spite of this, the number of experts was the same or higher than in other studies carried out in singles sports such as judo (Rodríguez et al., 2016) or table tennis (Pradas et al., 2012) and in other investigations done in collective sports like soccer (Parada and Vargas, 2020) or beach volleyball (Palao et al., 2015b).

The high qualification of the different expert judges, who follow the three criteria of inclusion, master in Physical Activity and Sports Sciences, with a coach diploma, and more than 10 years of training experience, should be noted. This level of qualification has provided the theoretical, together with their badminton experience, giving valuable information to researchers (Escobar-Pérez and Cuervo-Martínez, 2008; Gamonales et al., 2018; Ibáñez et al., 2019). Their qualitative and quantitative input was crucial for the design of the observational instrument and, thanks to them, the tool has been improved because some variables could be modified to clarify the definitions and their relevance to the different categories. The two observers have also been very important throughout the process, helping to define the criteria for the different categories and as a consequence simplifying the registration instrument.

In terms of statistics, the selected variables give an adequate content validity to the observational instrument, being valid to assess the technical and tactical actions in singles badminton, since the Aiken's V value shows a positive evaluation of the different variables both in pertinence and in definition (Zartha et al., 2018). All values that have been obtained in this study outweigh the critical level proposed by Aiken (1985) or Penfield and Giacobbi (2004), who considered that from 0.50, the validity of the instrument can be accepted. In any case, most of the variables are higher than the critical level of 0.70, as proposed by Charter (2003) or Soto and Segovia (2009). Hence, it can be said that the results obtained show that the design of the variables of the observational instrument has indicators of content validity, since they are above the exact critical level proposed by experts.

The third stage of this research, as well as in the study carried out by Gamonales et al. (2018), consisted of modifying or eliminating those items that did not reach optimal Aiken's V coefficient values according to the criteria proposed (García Martín et al., 2016). On the one hand, the quantitative assessment carried out by the experts was very fruitful to establish the variables and their categories (Bulger and Housner, 2007; Padilla et al., 2007). On the other hand, the qualitative assessment carried out by the experts was very fruitful to define the variables and their categories. In this study, despite the fact that expert judges had made contributions to improve the drafting of some variables, it had not been necessary to delete any of them.

With respect to reliability, the observation manual and the observers' training helped them to get the skills for carrying out the observation (Losada-López and Manolov, 2015), increasing the effectiveness of the observation and improving the coding criteria. It should be emphasized that the intra-observer analysis evidences high levels of reliability, minimizing the observation mistakes that may come from the observer himself (Gamonales et al., 2018), but the different interpretations of the behaviors among the observers can cause disagreements (Losada-López and Manolov, 2015). Nevertheless, the interobserver analysis evidences high levels of reliability too, supporting the reliability of the observation (Liu et al., 2013).

The design of this observational instrument has some limitations, as the number of expert judges who have participated or the recording of some data related to the game development or physical components that may be interesting. In accordance with Lebed (2006), behaviors in sports are affected by an undermining number of factors. In badminton, the specificity of the players' behaviors, together with the high speed, makes the recording difficult, as in the case in other sports such as table tennis (Pradas et al., 2012). Nevertheless, it is complex to use collection information systems for evaluating players' performance in competition (Villarejo et al., 2014). With the aim of improving, future studies should take into account these aspects when designing observational instruments.

CONCLUSION

Therefore, the designed observational instrument is valid and reliable to analyze the technical and tactical actions that take place during a rally in a badminton match. Thereby, it is possible to analyze the differences between winners and losers and establish relationships between strokes during the sequence, which can affect the development and result of the point.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Jaen (JUN.18/10.TES). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

GT-L and EO-T: conceptualization. JB-T, JG-E, and EO-T: methodology. GT-L, JB-T, JG-E, DC-M, and EO-T: formal analysis. JB-T, JG-E, and DC-M: investigation. GT-L, JB-T, JG-E, and EO-T: writing—original draft preparation. JG-E, EO-T, and GT-L: writing—review and editing. EO-T and DC-M: supervision. GT-L and EO-T: funding acquisition.

All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.582693/full#supplementary-material

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Studying Well and Performing Well: A Bayesian Analysis on Team and Individual Rowing Performance in Dual Career Athletes

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On many occasions, the maximum result of a team does not equate to the total maximum individual effort of each athlete (social loafing). Athletes often combine their sports life with an academic one (Dual Career), prioritizing one over the over in a difficult balancing act. The aim of this research is to examine the existence of social loafing in a group of novice university rowers and the differences that exist according to sex, academic performance, and the kind of sport previously practiced (individual or team). Therefore, a study was conducted from a probabilistic perspective using the Bayesian Network analysis methodology. The results confirm the existence of the Ringelmann effect or social loafing. The Bayesian analysis let us confirm that having a good student who practices a team sport, even in the individual rowing concept, increases the probability of obtaining greater performance (higher number of strokes and more power in each one). Therefore, when rowing partnerships are formed, the occurrence probability chain is quickly simplified, along with values of the top and bottom variables. Finally, the instantiations undertaken on the bottom variable that appears to be common in the two BNs, the watt input, enhance the results obtained. In short, rowers who have a better academic record are more involved in team testing, so this characteristic is defining when it comes to achieving better performance in team testing.

Keywords: dual career, social loafing, rowing, team crew, Bayesian analysis

INTRODUCTION

Research on the psychological variables that may affect the performance of sports teams has a long tradition in sports psychology, with key concepts such as sports cohesion (Carron and Brawley, 2000) and cooperation (Garcia-Mas et al., 2006), in addition to recent developments in the synthesis of the currently existing different conceptual frameworks addressed to explain psychological dynamics of the team, e.g., coordination, identification, collective efficacy, or integration (Garcia-Mas et al., 2019). Despite these attempts to clarify the psychological variables responsible for team dynamics, often other basic variables, such as group size, hierarchy, conformity, or social laziness are not considered as relevant either theoretically or practically.

Social loafing is defined as the reduction of individual effort when participating in a group task (Latané et al., 2019). Towards the end of the 19th Century, Maximilien Ringelmann (1913)Ringelmann () studied for the first time the social loafing effect in a tug of war competition. He stated that the maximum result of a team does not equate to the total maximum individual effort (Kosonogov, 2015), with the differences between the real performance and the envisaged performance of the group broadening as the number of members increased. Since then, an extensive line of research has been undertaken on the phenomenon of social loafing, which is now understood as a common phenomenon that occurs in numerous tasks and by both genders (Caracuel et al., 2011; Haugen et al., 2016; Karau and Williams, 2016). In particular, public evaluation or making public the contribution of each member to the total performance of the group, have been highlighted as key situational factors in inhibiting part of social loafing, supporting the idea that this phenomenon could be explained as a loss of motivation caused by a lower degree of recognition or evaluation(Kerr and Bruun, 1983; Harkins, 1987; René et al., 2006; Gavala González, 2010; Gavala-González, 2012; Hagen, 2015; Latané et al., 2019). Furthermore, this effect appears to significantly reduce when the participants feel that they belong to a cohesive group, are satisfied with their role in the team, see high levels of collective performance (Hogg and Vaughan, 2010; Høigaard et al., 2010), are top-level athletes (Jaenes et al., 2018), previously knew the teammates (Kerr and Bruun, 1983; Harkins, 1987) or regularly compete in teams (Czyż et al., 2016). In terms of motivation, when the group atmosphere is perceived as part of the task, social loafing also reduces due to the existence of performance self-referencing rather than the social comparison inherent to an ego-centric atmosphere (Høigaard et al., 2013).

One of the personal variables that has not been studied in depth regarding social loafing is the dual career (DC) of athletes, a social concept that is gradually becoming more relevant in studies on performance athletes. Synthetically, DC is understood to mean the act of combining a sports career and academic studies (Ryba et al., 2015). It is currently very common among all kinds of athletes, regardless of the sport practiced, the country of residence, sex, socio-economic status, and years of experience (Ceciæ Erpiè et al., 2004). According to some authors, it is one of the main challenges faced by top-flight athletes between the ages of 12 and 25, as they have to successfully combine education and high-performance sport (Ryba et al., 2017). Wyllemann and Lavallee (2004) defines four basic stages in athletic careers: initiation, development, mastery, and discontinuation. The Wyllemann and Lavallee model fits into a holistic concept of athletic careers, as it considers the sports dimension together with the other facets that intervene in personal/athletic development, such as the development of personality and self-concept, psychosocial relationships, and academic/vocational aspects, as well as economic and financial aspects.

This model is usually used to understand athletes from a global perspective, which allows critical moments in their DC to be understood in order to prevent situations of conflict and to increase the possibility of living a satisfactory public and private life, maintaining health and wellbeing (Stambulova and Wylleman, 2015). However, we know that it is not always easy to maintain such duality in a healthy way and, as such, pressure and anxiety often arise, along with the abandonment of one of the areas (Gustafsson et al., 2008; Aquilina, 2013; O'Neill et al., 2013; Torregrosa et al., 2015; Sorkkila et al., 2017; Gavala-González et al., 2019).

Following this model, discovering the connection – which has long been studied, – between academic and athletic performance is an area of interest that continues to be a focus of dispute (Holland and Andre, 1987). From a "negative" perspective, some authors have argued that sports practice is an obstacle to academic success (Helsen et al., 1987). In the same vein, other authors (Montecalbo-Ignacio et al., 2017) have tried to show that sport and academic success cannot be achieved at the same time, while only one study found that there was no significant correlation between the academic performance of students and their sporting performance (Acevedo, 2015). Conversely, various studies (Fredricks and Eccles, 2006; Smith et al., 2006; Khan et al., 2016; Deeba et al., 2017; Wretman, 2017) suggest that sport actually improves academic performance for a number of reasons. Among those suggested by authors, is that sports practice reduces leisure time that distracts students, although it is not known if that is solely due to physical practice (individual sports) or to the interaction with a group of people (team sports) (Fox et al., 2010).

Once the area and the conceptual framework that theoretically and empirically underpin it were established, rowing was chosen as the sport of interest for this study on social loafing. Rowing is a mentally and physically challenging sport (Volianitis and Secher, 2009) that requires physical conditioning, endurance, and psychological and physical preparation to compete. Competitions often take place on water, but much of the physical conditioning, training and performance testing takes place on rowing machines (Volianitis and Secher, 2009). These machines accurately simulate the movement pattern and the real rowing situation, falling short only in representing the swaying of the boat and weather conditions.

Regarding the methodology of this study, Bayesian Networks (BNs) are beginning to be widely used in social sciences (Fuster-Parra et al., 2017; Chen and Huang, 2018) and were recently presented as a useful methodology in sports psychology, given their ability to provide information on the probability of occurrence of events related to performance in sports or, for example, the likelihood of sports injuries. BNs also referred to as causal networks or beliefs networks, are a form of statistical modeling which allow us to obtain a graphical network describing the dependencies and conditional independencies from empirical data. The graphical representation of BNs captures the compositional structure of the relations and the general aspects of all probability distributions that factorize according to that structure. They have proven to be a promising tool for discovering relationships between negative features in sport (as is the case of this study; Fuster-Parra et al., 2013), and in many other sport-related studies, such as cooperative teamwork, motivation and types of sporting cooperation among players in competing teams, motivational climate and competitive anxiety, psychological variables related to athlete injuries, and the relative effect of age (Ishigami, 2016; Ponseti et al., 2016a; Olmedilla et al., 2018). Quite recently, a number of papers have been published that use a new approach, namely Dynamic BNs, which strive to predict and then mitigate the probability of injuries occurring in athletes (Peterson and Evans, 2019).

In accordance with the foregoing, the aim of this study is to evaluate the possible existence and its degree – by means of a Bayesian analysis of the Ringelmann effect (or social loafing) in a sample of novice university students rowers. The analysis will include some others variables such as their sex, academic performance, and the kind of sport previously practiced (individual or team).

MATERIALS AND METHODS

Participants

The sample comprised 131 (47 females and 84 males) young adults, all university students, of an average age of 22.36 (SD = 2.01). Regarding the consideration of the participants as Dual-career athletes, the DC global model considers not only the top-level (or elite) athlete-students as a DC persons, but also the athletes of competitive and performance sports, although they are not officially classified as Top Level (Riccardo-Brustio et al., 2020). In this case, we would like to point out that in Spain, the title of High-Level Athletes is granted by the "Consejo Superior de Deportes" (dependent on the Spanish Government) and that of High-Performance Athletes is granted by the Sports departments of the Autonomous Communities (regions). In 2019 (date of the study), there were only 545 people recognized as High Level Athletes, and only 270 athletes were considered High Performance Athletes in the region where the University where the study is located.

The participants of this study were university students and federated athletes who compete at the highest level, they practice daily in their sport discipline and compete at a high level in their sport in leagues and cross-national competitions, but they are rowing novices (without quantifiable experience).

Ethical Approval

This study was undertaken within the framework of the ERASMUS+ ELIT-in Project and it was approved by the Ethics Committee of the University of Trás-os-Montes and Alto Douro (UTAD), Doc.20/CE/2018 (UTAD 23/2018), which includes the undertaking of the study in line with the Declaration of Helsinki.

Material and Instruments

In this study, two identical Concept-2 Model D Indoor Rowing Machines were used. This machine replicates on-water training with great efficiency and crossover. It instantly records and stores the following parameters: total test time, partial time every 500 m, meters covered, strokes per minutes, and watt input.

In addition, data corresponding to age, sex, sporting experience in individual and/or team sports, and the academic record of each participant were recorded.

Experimental Design

The participants were assessed according to a longitudinal strategy in the two different conditions (individual performance and team performance). Several measurements comprising were used: number of meters covered by each rower in three minutes, number of strokes per minutes and the average power exerted (in watts) achieved by each rower in three minutes.

Procedure

The testing took place in a ventilated and suitable room that the students knew well and often frequented, and where they felt comfortable. The aim was to achieve complete cooperation from the participants, explaining to them the importance of their participation in both tests, which also served to get them as ready as possible for forthcoming competitions.

The rowing machines were placed in the testing room with their display screens covered up so that they had no reference point other than their own perception of effort. Firstly, the participants did their usual warm-up exercises and the procedure was explained to them: A test of 3 min max., first individually (Condition 1) and, after a 24-h rest period, the same warm-up as before and the second condition, as a group in randomly allocated pairs (Condition 2) for the same duration.

In Condition 1, they were individually asked to perform with maximum intensity and separated from the other participants. The instructions were the same for all participants: "You have to try to cover the maximum number of meters possible in three minutes. Please try to give your best performance in this test."

After a one-day rest period, the time often deemed suitable for total recovery, the "group testing" (Condition 2) was carried out, placing two rowing machines in line formation, replicating the positions in a couple-rower boat. The warm-up and the instructions were the same as in Condition 1, with the exception of informing them that the final evaluated performance would correspond to the total results of both rowers (participants row on their own machines and team score is built with the sum of their individual performance). Although for the study, data were analyzed independiently.

Data Analysis

As a preliminary step, a descriptive analysis on the variables studied was undertaken, subsequently conducting a t-test to evaluate the differences between them and the eventual statistical significance. The prior verification of the supposed normality of the scores was conducted using the comparative Kolmogorov–Smirnov test. Furthermore, given the nature of the data, a correlation analysis was conducted using Pearson's R between the performance variables.

The study was undertaken creating BNs, making it necessary to determine the structure of the BN via a Directed Acyclic Graph (DAG) and to assign conditional probabilities to each node of the DAG. The DAG can be obtained only from the data set or using the data set and adding some prior or expert knowledge during the structure learning. Neither expert knowledge nor prior knowledge was used to obtain the model; only our dataset was used. Learning a BN involves the following two tasks: (i) structural learning, in other words, identifying the topology of the BN and (ii) parametric learning, or estimating the numerical parameters (conditional probabilities) given the network's topology.

Structural learning was used to obtain the BN through the "bn learn package" using R language (Rosselet, 1987). To obtain the structure, the options were to use either a search and score algorithm (Korb and Nicholson, 2010), which assigns a score to each BN structure and selects the model structure with the highest score, or a constraint-based search algorithm (Spirtes et al., 1993), which establishes a conditional independence analysis on the data to generate an undirected graph and convert it into a BN using an additional independence test. The score-based algorithm Tabu (Korb and Nicholson, 2010) was used, which was a plausible model for our data, looking for the structure that best improves the score, e.g., using the highest score.

After building the BN, some instantiations were conducted (injection of hypothetical probabilities) to the bottom variables, as well as observation on how the node and top variables change their probability values. With these instantiations we apply intercausal reasoning to discover the differences in other variables when the bottom variables were artificially changed in their probability. When different causes of the same effect can interact, we called it intercausal reasoning. This type of reasoning allows to observe mutual causes of a common effect and constitutes a very common pattern in human reasoning.

RESULTS

Subsection

Table 1 shows the descriptive data of the variables studied in the two research conditions, while **Table 2** shows the Pearson correlations between the performance variables in the two conditions. As such, the correlations between the meters covered and the watt input (power) are very high and significant, around 9, but the correlation between the number of strokes in the two conditions (despite also being significant 0.000), is much lower, not reaching the 0.7 value.

Table 3 shows that there are significant differences between the median values of meters covered and the watt input in both tests (Conditions 1 and 2). That is not the case, however, with the median values in the number of strokes, where no significant differences are observed.

TABLE 2 | Correlations of paired samples (Pearson's r).

	N	*r*	Sig.
Individual meters and team meters	131	0.853	0.000
Individual watts and team watts	131	0.867	0.000
Individual strokes and team strokes	131	0.638	0.000

On verifying the significant differences and the correlation between the median values of the variables, a decision was made to conduct a Bayesian analysis by creating two probability trees corresponding to each of the two separate conditions.

Figure 1 is a graphic showing the probability values of the BN corresponding to Condition 1 or individual performance. All the variables form one tree. The top or predecessor variables being: the type of sport (at 50% probability between the teams and individuals); the academic record (with a high probability, around 80%); strokes and meters covered. The age and sex are intermediate variables of different probability of occurrence (almost 80%, age, and almost 70%, male). The only bottom variable is the amount of energy exerted by the rower (watts) with a probability distribution of 50% between High and Low.

In **Figure 2**, we can see the DAG graphic and the BN, which are very different both morphologically and in terms of their values with the network corresponding to Condition 1. The tree has lost three variables, which are isolated: the academic record, the number of strokes and the age, which were previously tops and nodes, respectively. The top variable (predecessor) of this tree is the type of sport (with the same probabilistic distribution of the "individual" network). The bottom variables, that is, without a probabilistic impact on the others, are sex (greater probability toward the male sex) and the watts provided by the rowers, which, compared to the individual Condition, is displaced from 60 to 80% of Low probability.

The general picture that we see in the two BN indicates that the probabilities of occurrence of the energy exerted by the rowers are mainly affected by the probability that the rowers have a particular previous history (academic record and type of sport practiced). On the other hand, the condition of practicing a

TABLE 1 | Descriptive values of the variables studied.

	mean	SD	trimmed	Mad	min	max	range	skew	kurtosis	se
Sex	1.36	0.48	1.32	0	1	2	1	0.58	−1.67	0.04
Individual meters	759.31	88.04	760.58	108.23	482	934	452	−0.21	−0.6	7.69
Individual watts	216.32	71.63	213.97	81.54	54	391	337	0.19	−0.62	6.26
Individual strokes	32.94	4.29	32.95	4.45	23	42	19	0.05	−0.37	0.38
Team meters	742.76	89.51	743.24	106.75	557	980	423	−0.05	−0.85	7.82
Team watts	207.52	72.4	204.3	81.54	83	452	369	0.39	−0.16	6.33
Team strokes	32.39	4.03	32.39	4.45	22	45	23	0.1	0.12	0.35
Age	22.36	2.01	22.3	1.48	18	29	11	0.5	1.11	0.18
Sport type	1.4	0.59	1.45	1.48	0	2	2	−0.4	−0.73	0.05
Academic record	7.77	0.53	7.8	0.43	6.05	8.88	2.83	−0.6	0.32	0.05

TABLE 3 | Differences between the median values of the variables studied (*t*-test).

	X	SD	Median of standard error	95% difference reliability range		*t*	*gl*	Sig.(bilateral)
				Low	High			
Individual meters – Team meters	16.550	48.159	4.208	8.225	24.874	3.933	130	0.000***
Individual watts – Team watts	8.802	37.125	3.244	2.384	15.219	2.713	130	0.008**
Individual strokes – Team strokes	.550	3.548	0.310	−0.064	1.163	1.773	130	0.079

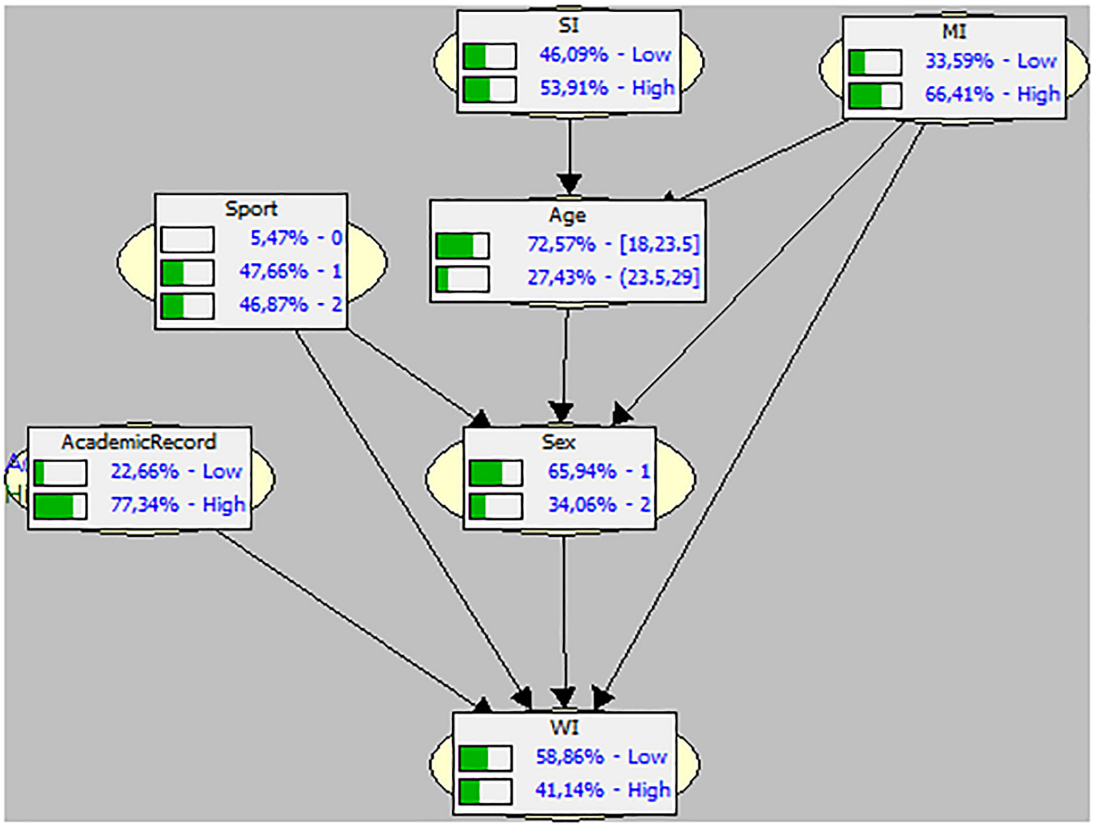

FIGURE 1 | Direct Acyclic Graph (DAG) and Bayesian Network on the studied variables in Condition 1 (individual). MI, meters in individual performance; WI, watts in individual performance; SI, strokes in individual performance.

team sport loses probabilistic weight. Thus, we could say, in other words, that the prior learning and background of the athletes studied can be considered as a trigger in the chain of probabilities found.

The BN was validated using a 10-fold cross validation, taking the area under the curve (AUC), accuracy, sensitivity, and sensibility into consideration. Certain terms should first be defined in order to understand the validation used: true positive (TP), true negative (TN), false positive (FP), and false negative (FN). If an observation is labeled correctly within its class, it is considered TP. On the contrary, if an observation is labeled correctly as not belonging to a specific class, it is TN. Both TP and TN suggest a consistent result in the classifier.

However, no classifier is perfect and if the model incorrectly labels an observation as belonging to a certain class, it is considered to be FP; and when incorrectly labeled as not belonging to a certain class, it is designated as FN. Both FP and FN indicate that the results from the classifier are contrary to the actual label (Lalkhen and McCluskey, 2008).

Sensitivity, specificity, and accuracy are described in terms of these concepts: Sensitivity = TP/(TP+FN); Specificity = TN/(TN+FP); and Accuracy = (TN+TP)/(TN+TP+FN+FP).

The AUC shows that the probability of a randomly chosen positive datum being correctly ranked is much higher than for a randomly chosen negative datum (Lalkhen and McCluskey, 2008). The readings provide a complete overview of the performance of the BN. As **Tables 4**, **5** shows, the validation tables provided some good results (specially in all the individual outcomes), as along with some medium values (mostly in the team Condition). In both conditions, the lesser values correspond with the sport typology, and – in part – with the number

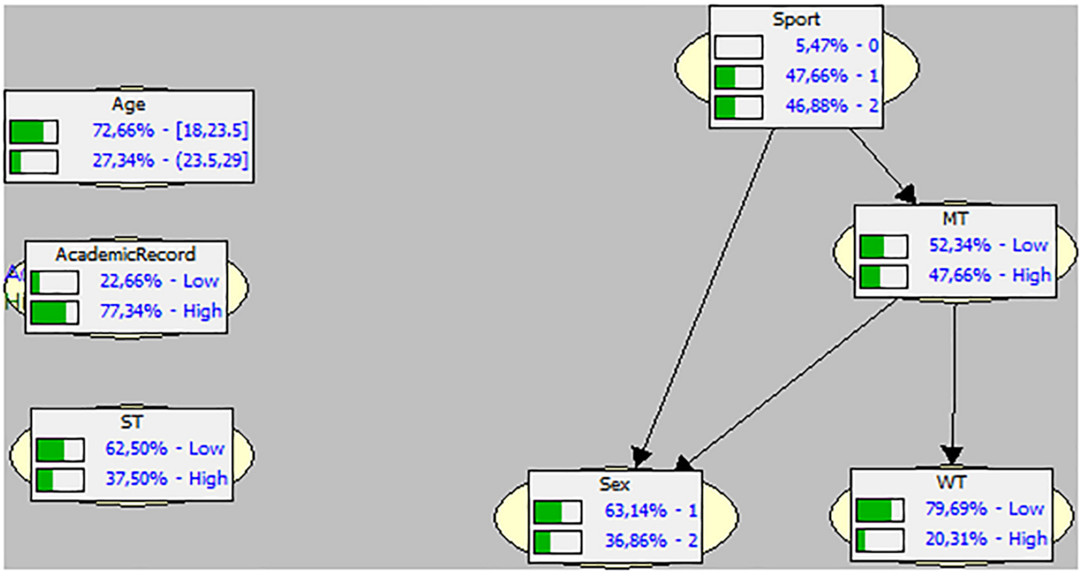

FIGURE 2 | Direct Acyclic Graph (DAG) and Bayesian Network on the studied variables in Condition 2 (team). MT, meters in team performance; WT, watts in team performance; ST: strokes in team performance.

of strokes. These validation values should be considered when drawing up both the next step in the Bayesian analysis process (the instantiations) and the final conclusions.

Instantiations

Following the procedure made up in earlier publications C instantiations means the injection of hypothetical vales (usually, the maximum High or Low probability) to some variables according to two conditions: (1) the variables to be instantiated were the ones that turned out to be the bottom variables in the BN and (2) these variables formed part of some of the study's objectives. In our case, the only variable accomplishing the two conditions is the amount of watts expended in both conditions.

The aim of the instantiations is to outline the changes to be made in the other BN variables, when the instantiated ones where artificially changed in their probability of occurrence. In other words, when a variable is instantiated, the degree of belief about its probability rises towards the variables that are its predecessors and on which it depends probabilistically. The instantiations are used in a complementary way to the BN building, and may provide confirmation of their probability values.

Firstly, there were no prohibited instantiations, but some variables were unaffected by the injection of hypothetical values. Obviously, among them there are those that, in the BN corresponding to Condition 2, were unconnected and others are described in detail. In general, the findings obtained with the instantiations positively parameterize, albeit very selectively, the probability values found in the BN.

In **Table 6**, we may observe that two variables don't show any change after the watt (energy produced) instantiations to 100% High in Condition 1 (Individual) was made: sport type and Age. Two more, number of strokes and academic scores shows only very slight changes increasing their High probability of occurrence. The only real and important change appears in the meters variable, increasing its High probability of occurrence in more than 30%.

The most relevant data that can be seen (**Table 7**) in the instantiations made to the variable watts (energy produced) both towards 100% High and 100% Low does not cause changes in three variables: academic scores, age and sport types. The remaining two that are affected do so in the same direction, decreasing their probability value when watts is instantiated to

TABLE 4 | Validations of the variables of the BN in the individual Condition (1).

	AUC	Accuracy	Sensitivity	Sensibility
Meters	0.83	0.89	0.90	0.88
Watts	0.83	0.86	0.83	0.89
Strokes	0.59	0.63	0.04	0.81
Age	0.55	0.74	0.96	0.18
Academic record	0.57	0.80	0.19	0.99
Sex	0.87	0.90	0.92	0.87
Sport type	0.59	0.59	0.76	0.42

TABLE 5 | Validations of the variables of the BN in the team Condition (2).

	AUC	Accuracy	Sensitivity	Sensibility
Meters	0.78	0.79	0.87	0.70
Watts	0.51	0.80	1	0
Strokes	0.51	0.61	1	0
Age	0.52	0.70	0.98	0
Academic record	0.51	0.76	0	1
Sex	0.85	0.85	0.81	0.91
Sport type	0.55	0.55	0.83	0.27

TABLE 6 | Instantiation made on the watts produced in Condition 1 (individual) from the obtained values to the maximum High occurrence probabilistic value (100%).

	Obtained BN		Instantiation: 41.14–100% HIGH	
Variables	**High**	**Low**	**High**	**Low**
Academic	77.34	22.66	80.73	19.27
Meters	66.41	33.59	97.26	2.74
Strokes	53.91	46.09	54.05	45.95
Sex	**Male**	**Female**	**Male**	**Female**
	65.94	34.60	95.96	4.02
Age	**18–24 years**	**24–29 years**	**18–24 years**	**24–29 years**
	72.57	27.43	72.57	27.43
Sport type*	**Individual**	**Team**	**Individual**	**Team**
	47.66	46.88	47.30	48.65

**There is a residual 5.47% without previous sport practice.*

100% Low, and increasing their probability value (High) when instantiating the watts to the maximum value of High (100%). The first one, the number of rowed meters increases by 30% and decreases by more than 10%; while the second, the sex variable, increases 33% (male probability) in High mode, and decreases less than 10% in Low mode.

DISCUSSION

Usually, the majority of the studies conducted are based on the analysis of the connections that arise between different psychological variables. However, there is little tradition of analyzing the connection between one or several of these variables and direct indicators of sports performance (Ponseti et al., 2016b; Núñez-Prats and Garcia-Mas, 2017), or even indirect ones (Leo et al., 2013), which constitute the fundamental objective of this study. In our case, performance was measured through an objective and direct indicator, combining three parameters: number of strokes and meters covered, as well as the watts exerted by each rower.

As regards the results obtained, it should be indicated, pursuant to an extensive tradition of studies on the Ringelmann effect, in our study, through the simulation of the sports discipline of rowing, that the results are congruent with those results found by previous studies (Kugihara, 1999; Caracuel et al., 2011; Haugen et al., 2016; Karau and Williams, 2016) demonstrating clear differences between all the objective performance parameters, as a classical statistical analysis is used, followed by a Bayesian analysis creating two different probability trees, one for each of the two conditions of the study.

However, in the individual rowing condition in the sample studied, the probability values found in our sample clearly indicate that the changes in the probability of the two "epidemiological" tops: academic record (with a really high probability value) and type of sport practiced (individual or team), together with the two behavioral variables, the strokes (at 50% between High and Low) and the meters covered (high probability of occurrence), have an impact on the two nodes and, above all, on the bottom one, which is the value of the watt input or energy exerted (its probability seems to be almost 50% between high and low). The fact that the number of strokes (observable behavior and more easily quantifiable) are not in any case a bottom variable or "daughter" of the other variables, but the watts (the force exerted in each one of them in the two conditions) are, is a very relevant datum that has not previously been observed (Kerr and Bruun, 1983; Caracuel et al., 2011; Høigaard et al., 2013; Czyż et al., 2016; Haugen et al., 2016; Jaenes et al., 2018).

Age, as a node, does not appear to be relevant in terms of its possible impact. In the second tree (Condition 2) the majority of the old nodes are left out of the network, drastically simplifying the chain of probabilities. The academic record, the strokes done and the age, lose probabilistic relevance. But the only predecessor, "father" or trigger variable is the sport practiced by the rowers, the probability of which remains the same as in Condition 1.

The instantiations undertaken on the bottom variable that appears to be common in the two BNs, the watt input, enhance the results obtained. In the individual condition, enhancing the High probability of watt input to 100% does not entail a change in the probability of hardly any variable (including the type of

TABLE 7 | Instantiation made on the watts produced in Condition 2 (individual) from the obtained values to the maximum High occurrence probabilistic value (100%).

Variables	**Obtained BN**			**79.89–100% LOW**			**20.31–100% HIGH**		
	High	**Low**		**High**	**Low**		**High**	**Low**	
Academic*	77.34	22.66		77.34	22.66		77.34	22.66	
Meters	47.66	52.34		35.29	64.71		77.34	22.66	
Strokes*		37.50	62.50		37.50	62.50		37.50	62.50
Sex	**Male**	**Female**		**Male**	**Female**		**Male**	**Female**	
	63.14	36.86		54.86	54.14		96.76	4.24	
Age*	**18–24 years**	**24–29 years**		**18–24 years**	**24–29 years**		**18–24 years**	**24–29 years**	
	72.66	36.86		72.66	27.34		72.66	27.34	
Sport type**	**Individual**	**Team**		**Individual**	**Team**		**Individual**	**Team**	
	47.66	46.88		47.30	48.65		49.03	38.90	

**In Condition 2 (Team), these variables have no probabilistic impact on others.*
***There is a residual 5.47% without previous sport practice.*

sport), with the exception of the number of meters covered, which increases by a third. This datum poses an interesting aspect, given that no feedback was given through the rowing machine display.

When the same value is set (to 100% High and to 100% Low of watt input, the majority of the variables – in the same line as that shown in the second BN – do not undergo any change in their probabilities. However, the meters covered once again appear to be affected as that observed in the instantiation in the individual condition. Surprisingly, it seems that being a male athlete somehow "prevents" the emergence of the social loafing effect, as when the amount of watts is set to achieve 100% High, more male rowers probability is required, and to achieve a hypothetical 100% Low, that probability has to be inversely reduced.

This datum has not been sufficiently reflected in prior studies on team performance and sex or gender (Kerr and Bruun, 1983; Harkins, 1987; René et al., 2006; Caracuel et al., 2011; Hagen, 2015; Haugen et al., 2016; Karau and Williams, 2016; Latané et al., 2019), nor in those that evaluate the psychological dynamics in team sports (Kerr and Bruun, 1983; Harkins, 1987; Hogg and Vaughan, 2010; Høigaard et al., 2010, 2013; Czyż et al., 2016; Jaenes et al., 2018).

Added to that, in the individual rowing condition, the top variables, that is, those whose probability of occurrence have a cascade effect on the other variables, are the academic record – the higher the probability that the rower is a good student and practices a team sport, even in the individual rowing condition, the higher the probability will be of giving a better performance, which is quantifiable in the higher number of strokes and, above all, in the exertion of force in each one.

The impact on these data on the concept of dual academic career is evident, focusing on an aspect not previously commonly observed. No precedent has been found neither in the prior studies on DCs (Ceciæ Erpiè et al., 2004; Wyllemann and Lavallee, 2004; Gustafsson et al., 2008; Aquilina, 2013; O'Neill et al., 2013; Stambulova and Wylleman, 2015; Stambulova et al., 2015; Torregrosa et al., 2015; Ryba et al., 2017, 2015; Sorkkila et al., 2017; Gavala-González et al., 2019), nor in the majority of those that focus on the link between academic and sporting performance (Helsen et al., 1987; Holland and Andre, 1987; Acevedo, 2015; Montecalbo-Ignacio et al., 2017).

The results can be considered from a different point of view too: academic performance may be a contributing factor to sports performance, beyond its well-studied role as a relevant psychosocial factor. In this strict sense, it has not been possible to find direct precedents about it in the extensive existing literature on the subject (Ceciæ Erpiè et al., 2004; Wyllemann and Lavallee, 2004; Gustafsson et al., 2008; Aquilina, 2013; O'Neill et al., 2013; Stambulova and Wylleman, 2015; Stambulova et al., 2015; Torregrosa et al., 2015; Ryba et al., 2017, 2015; Sorkkila et al., 2017; Gavala-González et al., 2019), nor in the majority of those that focus on the link between academic and sporting performance (Helsen et al., 1987; Holland and Andre, 1987; Acevedo, 2015; Montecalbo-Ignacio et al., 2017). The only finds obtained in that sense (Fredricks and Eccles, 2006; Smith et al., 2006; Khan et al., 2016; Deeba et al., 2017; Wretman, 2017) attribute this link it to the fact that sports practice or the interaction with a group of people (team) reduces their leisure time, which increases the probability of them focusing more intensely on the activity (sport or studies) that they are doing at the time (Fox et al., 2010).

CONCLUSION

Firstly, we cannot speak of only one objective performance indicator, as it has been demonstrated that the strokes done, meters covered and watts contributed do not behave the same with regard to the probabilities of occurrence. This fact may reaffirm the existence of the Ringelmann effect, as, in team rowing, the rhythm of the strokes is usually maintained due the constant synchronization of the rowers (equal number of strokes), but under no circumstance does this mean that they contribute the same watts of energy in each stroke. Furthermore, an external observer (coach, spectator and even in the usual video feedback) do not perceive differences in the effort of rowers, even though they exist.

Secondly, in the individual rowing condition, the top variables, that is, those whose probability of occurrence have a cascade effect on the other variables, are the academic record – the higher the probability that the rower is a good student and practices a team sport, even in the individual rowing condition, the higher the probability will be of giving a better performance, which is quantifiable in the higher number of strokes and, above all, in the exertion of force in each one.

The strictly behavioral variables lose their probabilistic impact capacity and the experience of being a member of a sports team only becomes a predecessor or trigger variable and, as a sole bottom variable – that is, that which is affected by the probabilities of occurrence of all the other variables, is the variable of watt input or energy and effort exerted by the rowers in the strokes, confirming that observed in the individual condition.

Finally, the instantiations undertaken on the bottom variable that appears to be common in the two BNs, the watt input, enhance the results obtained. In the individual condition, enhancing the High probability of watt input to 100% does not entail a change in the probability of hardly any variable (including the type of sport), with the exception of the number of meters covered, which increases by a third. This datum poses an interesting aspect, given that no feedback was given through the rowing machine display, in the same line as the proprioceptive feedback that appears in the BN of the team condition: could it be that there is an internal perception of the meters covered, which in some way substitutes – completely or to a large extent – knowledge of the standard results, in rowers with more experience and who are trained to mentally calculate the number of strokes done and meters covered with each one? Further research will have to be conducted on this line of study.

When the same value is set (to 100% High and to 100% Low of watt input, the majority of the variables – in the same line as that shown in the second BN, do not undergo any change in their probabilities. However, the meters covered once again appear to be affected – in the same sense, both in terms of increase and decrease – as that observed in the instantiation in the individual condition. Surprisingly, it seems that being a male athlete somehow "prevents" the emergence of the social loafing effect, as when the amount of watts is set to achieve 100% High, more male rowers probability is required, and to achieve a hypothetical 100% Low, that probability has to be inversely reduced.

This datum has not been sufficiently reflected in prior studies on team performance and sex or gender (Kerr and Bruun, 1983; Harkins, 1987; René et al., 2006; Caracuel et al., 2011; Hagen, 2015; Haugen et al., 2016; Karau and Williams, 2016; Latané et al., 2019), nor in those that evaluate the psychological dynamics in team sports (Kerr and Bruun, 1983; Harkins, 1987; Hogg and Vaughan, 2010; Høigaard et al., 2010, 2013; Czyż et al., 2016; Jaenes et al., 2018). Given its practical implications, it deserves to be thoroughly studied in future research.

Finally, it has appeared that the influence of the sex of the rowers is relevant for the effectiveness of the team, altering the effect of social laziness.

LIMITATIONS OF THIS STUDY

There was a relevant methodological limitation that corresponds to the low number of variables studied, which clearly affected their validity on completing the BN. This fact has been reflected in the scope and generalization of discussion on the results and conclusions. This is mainly due to the characteristics of the Bayesian analysis that, even though the missing variables are suitably supported, are affected by the low number of variables included in the study or, conversely, by their high number (Scanagatta et al., 2018).

Secondly, the use of instantiations through the "injection" of hypothetical data, was cautiously considered when forming conclusions and, above all, the practical consequences of them.

PRACTICAL APPLICATIONS AND FUTURE DEVELOPMENTS

The data obtained in this study produce some practical effects. It must be taken into account that the competition rowers are selected from laboratory tests, so the biomechanical control of the stroke movement, or the use of some feedback criteria different to that used to date, should be improved.

In addition, considering that no attention is usually paid to the condition of the rowers' team, it is possible to think about the prevention of social loafing during the formation period, and in the competitive stage. With raining rowers on team building, or similar techniques, that increases the strength of the psychological team dynamics, particularly in terms of coordination, cohesion, and cooperation (Bruner and Spink, 2010; Leo et al., 2013; Olmedilla et al., 2018), they can gain weight in the design of psychological-technical approaches aimed at improving crew performance with more than one rower.

Although it is already seriously considered at present, the protection of the academic career of not only elite athletes, but also those of performance, should be extreme, given the positive synergy observed.

Finally, regarding the data obtained, could it be that there is an internal perception of the meters covered, which in some way substitutes –completely or to a large extent – knowledge of the standard results, in rowers with more experience and who are trained to mentally calculate the number of strokes done and meters covered with each one? Further research will have to be conducted on this line of study.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study was undertaken within the framework of the ERASMUSCC ELIT-in Project and it was approved by the Ethics Committee of the University of Trás-os-Montes and Alto Douro (UTAD), Doc.20/CE/2018 (UTAD 23/2018), which includes the undertaking of the study in line with the Declaration of Helsinki. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JG-G. and AG-M: conceptualization, investigation, writing—review and editing, writing—original draft preparation, and project administration. JG-G, FP, and AG-M: methodology. BM and FP: software, validation, data curation, and visualization. BM, FP, and AG-M: formal analysis. JG-G, BM, FP, and AG-M: resources. AG-M: supervision. FP and AG-M: funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Comparison of Goal Scoring Patterns in "The Big Five" European Football Leagues

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The objective of the study was to compare goal scoring patterns among the "Big Five" European football leagues during the 2009/2010–2018/2019 seasons. A total of 18 pattern dimensions related to the offense pattern, the shooting situation and the scoring time period were evaluated. Kruskal–Wallis analyses revealed significant pattern differences among the five leagues. The Spanish La Liga showed a greater proportion of goals from throw-ins. The English Premier League had a higher tendency to score from corner kicks. The German Bundesliga had the greatest number of goals from counterattacks and indirect free kicks, and the Italian Serie A had the greatest proportion of penalties. Ligue 1's scoring ability is weaker than that of the other leagues, especially Bundesliga. The Bundesliga had an overwhelming advantage in goals scored on big chances with assists, while the Premier League had an advantage in goals scored with assists that were not from big chances. However, the differences among the five leagues in the mean goals scored in the last 15 min and the goals from elaborate attacks and direct free kicks were not statistically significant. These results provide a valuable addition to the knowledge of different goal patterns of each league and allow us to better understand the differences among the leagues.

Keywords: performance analysis, match analysis, player profiles, goal, scoring patterns, European soccer leagues

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INTRODUCTION

Powered by the so-called "Big Five" football leagues, the English Premier League, the German Bundesliga, the Spanish La Liga, the Italian Serie A, and the French Ligue 1, football has become one of the most profitable areas for the sports and entertainment industry. Europe's big five leagues are five out of the top seven supported leagues in world football (Poli et al., 2019), and their stellar performances generate enormous television revenues for media groups.

The identification of goal-scoring characteristics and successful attacking strategies is one of the most important components for success in modern elite soccer (Pratas et al., 2018). However, although some studies have partially described how goals are scored in different European leagues (Hughes and Franks, 2005; Armatas et al., 2009; Tenga et al., 2010; Tenga and Sigmundstad, 2011; Wright et al., 2011; Kempe and Memmert, 2018; Zhao and Zhang, 2019), very few studies have compared the differences among top leagues (Mackenzie and Cushion, 2013).

To date, the available studies investigating different leagues have essentially focused on anthropometric measurements (Bloomfield et al., 2005), motor activity performance

(Dellal et al., 2011), competitive profile (Vales-Vázquez et al., 2017), competitive balance (Goossens, 2006; Groot, 2008), referee decisions (Prüßner and Siegle, 2015), content analysis (Sarmento et al., 2013), and home advantage (Pollard and Gómez, 2014), while few match analysis studies have been conducted. In particular, Alberti et al. (2013) indicated similar patterns of temporal goal scoring distribution among the English, Italian, Spanish, and French top leagues (2008/09, 2009/10, and 2010/11). Oberstone (2011) compared the English, Italian, and Spanish leagues (2008/09) and found that Serie A was the best passing league with the highest percentage of tackles, while the Premier League had the highest number of tackles and fewer fouls and yellow and red cards. Moreover, La Liga had the highest percentage of shots on target and the highest number of shots converted into goals. However, Yi et al. (2019) suggested Serie A players achieved lower numbers of ball touches, passes and lower pass accuracy per match in UEFA Champions League than players from any of the other four leagues. Konefał et al. (2015) showed that the full-backs from the Spanish La Liga executed the highest number of passes and crosses as well as ball touches in the attacking zone. They also performed the lowest number of passes in the midfield and defensive zones; the highest percentage of passes in these zones was achieved by the full-backs from the German league teams.

Sapp et al. (2018) investigated differences in aggressive play in the top five European football leagues and suggested that the English Premier League is the league with most fouls and cards. After studying 68 matches from four domestic leagues (La Liga, Serie A, Bundesliga, and English Premier League) and Champions League, Sarmento et al. (2018) found differences in the effective offensive sequences between the two. More recently, Mitrotasios et al. (2019) compared goal scoring opportunities in the top four European football leagues. Their result illustrated the significant differences in the four leagues, such as La Liga was good at combination of various offensive methods, English Premier League showed a high degree of direct play, Bundesliga had the most number of counter-attacks, and Italian Serie A showed the shortest offensive sequences.

Since soccer has evolved tactically at the highest level in recent years (Wallace and Norton, 2014; Bradley et al., 2016) and the globalization process has promoted the flow of coaches and players between countries and continents, it would be valuable to investigate the goal scoring characteristics of the top football leagues. Thus, the object of the study was to search for the key similarities and differences among these leagues as well as to find evidence to identify the key factors on the pitch that are associated with a team's scoring ability within its respective league.

MATERIALS AND METHODS

Samples

Data from the first divisions of the English Premier League (EPL), French Ligue 1 (Ligue 1), German Bundesliga (Bundesliga), Italian Serie A (Serie A), and Spanish La Liga (Liga) were obtained through online sources[1] with permission. The data resources from Whoscored.com are supported by Opta Sports. Opta debuted its current real-time data collection process for football matches in 2006, leading to an expansion in new data offerings across different sports. Opta data is used in the betting industry, the print and online media, sponsorship, broadcasting, and professional performance analysis. The reliability of the tracking system (OPTA Client System) has been verified by Liu et al. (2013). This study was approved by the local institutional ethics committee.

For the comparisons among leagues, the last nine (2010/11–2018/19 for shooting situations) and ten (2009/10–2018/19 for offense patterns and time periods) seasons were analyzed. Information on the offense pattern, time period, and shooting situation for home and away teams was obtained for each individual match, and both teams were analyzed in each match over the seasons. While the English Premier League, French Ligue 1, Italian Serie A, and Spanish La Liga have 20 teams, the German Bundesliga has 18. Thus, for each season, there were 380 matches used as observations in the first four leagues and 306 for the Bundesliga, meaning we had data for a total of 18,260 matches and 49,483 goals (In the 2013–2014 season of French Ligue 1, victory was awarded to Bastia after Nantes fielded suspended player Abdoulaye Touré. Bastia gained three points, and Nantes' two goals were cancelled. We still counted the goals from both these teams in the total number of goals). It should be mentioned that we use the average number of goals (different types) scored by a single team in a single season as the sample.

Variables

The scoresheet records were divided into three main categories. The first category is the time period. The study divided the total time of the game into time periods of 15 min in addition to the time added to the last 15 min at the end of each half (Zhao and Zhang, 2019). The playing time was split into six time periods: 1st–15th min, 16th–30th min, 31st–45th + min, 46th–60th min, 61st–75th min, and 76th–90th + min (hereafter referred to as TP1, TP2, TP3, TP4, TP5, and TP6, respectively).

The second main category is the offense pattern, which is the kind of offense through which the goal was scored. The patterns were divided into eight groups: elaborate attack, counterattack, direct free kick, indirect free kick, corner, throw-in, penalty, and own goal.

The third main category is the goal-shooting situation, which is divided into four groups: goal from a big chance with an assist (Shooting 1), goal with an assist but not from a big chance (Shooting 2), goal from a big chance without an assist (Shooting 3) and goal without both big chance and an assist (Shooting 4). Goal data for the 2009–2010 season were excluded because of a lack of information on big chances and goal assists.

Big Chances: A situation where a player should reasonably be expected to score, usually in a one on one scenario or from very close range when the ball has a clear path to goal and there is low to moderate pressure on the shooter (OPTA, 2019).

[1] Whoscored.com

Goal Assist: The final touch (pass, pass-cum-shot or any other touch) leading to the recipient of the ball scoring a goal. If the final touch (as defined in bold) is deflected by an opposition player, the initiator is only given a goal assist if the receiving player was likely to receive the ball without the deflection having taken place. Own goals, directly taken free kicks, direct corner goals and penalties do not get an assist awarded (OPTA, 2019).

Statistical Analysis

Longitudinal data were analyzed using a Kruskal–Wallis *H* test with league as the independent variable. Effect sizes were calculated using the E_R^2 (Tomczak and Tomczak, 2014),which was classified as trivial (<0.01), small (>0.01–0.06), moderate (>0.06–0.14), and large (>0.14), based on guidelines from Kirk (1996). Mann–Whitney *U post hoc* tests were used to compare leagues. To control for type I error, Bonferroni's correction was applied by dividing the α level by the number of pairwise comparisons being made. Thus, an operational α level of 0.005 ($P < 0.05/10$) was used for league comparisons of each dependent variable.

All analyses were executed in IBM SPSS® Statistics for Windows, version 20.0 (SPSS Inc., Chicago, IL, United States). Offense pattern, shooting situation, and time period data are presented as the mean ± standard deviation (SD).

RESULTS

Analysis of the League Effect in Scoring Methods

Between 2009/2010 and 2018/2019, the descriptive results indicate that Bundesliga had the highest mean number of goals from counterattacks (**Table 1**). This difference in counterattacking is further shown by the very significant league effect ($H = 136.604$, $P < 0.001$, $E_R^2 = 0.14$). Bundesliga's mean number of goals from counterattacks was significantly higher than that of the other four leagues [$P < 0.005$; Bundesliga(0.15) > La Liga(0.099) > Ligue 1(0.075) = EPL(0.071); Bundesliga(0.15) > La Liga(0.099) = Serie A(0.09), The mean value in brackets, > means significantly greater than, = means no significant difference]. La Liga's mean number of goals from counterattacks was significantly higher than those of EPL and Ligue 1. Similarly, there was a significant league effect in the mean number of goals from indirect free kicks in the five leagues ($H = 29.827$, $P < 0.001$, $E_R^2 = 0.03$), and Bundesliga showed a strong advantage over the other four leagues [$P < 0.005$; Bundesliga(0.113) > La Liga(0.093) = Ligue 1(0.093) = EPL(0.091) = Serie A(0.083)].

Moreover, a Kruskal–Wallis test to identify differences in goals from throw-ins among the five leagues showed the significant effect of the Bundesliga and La Liga groups ($H = 68.823$, $P < 0.001$, $E_R^2 = 0.07$). In addition, *post hoc* analysis yielded a significant difference between Bundesliga and La Liga and the other three leagues [La Liga(0.024) = Bundesliga(0.02) > EPL(0.014) = Ligue 1(0.008) = Serie A(0.008)].

However, EPL's mean number of goals from corners ranks first of all the five leagues (**Table 1**). A significant league effect was suggested, as shown in **Table 1** ($H = 22.556$, $P < 0.001$, $E_R^2 = 0.023$). EPL scored significantly more corner goals than Ligue 1 or Serie A [$P < 0.005$; EPL (0.173) > Serie A (0.151) = Ligue 1(0.139)].

In terms of own goals, the statistical results are similar to those for corner kicks. EPL had a significantly higher mean number of own goals than La Liga and Serie A [$H = 18.558$, P = 0.001, $E_R^2 = 0.019$; EPL (0.051) > Serie A (0.036) = La Liga (0.035)].

Finally, an additional *post hoc* analysis showed that there was a significant difference in the number of penalty goals only between Serie A and EPL. It is obvious that more penalty goals took place in Serie A than in EPL [$P < 0.005$; Serie A (0.123) > EPL (0.097)]. There is no significant difference in the mean number of goals from elaborate attacks or from direct free kicks among the five leagues.

Analysis of the League Effect in Shooting Situations

The comparison of the mean number of goals from the four shooting situations across the five leagues showed significant differences among the leagues (**Table 2**). In shooting situation

TABLE 1 | Mean frequency values of goals scored by teams according to different offense patterns (*N* = 980).

	EPL *n* = 200	Ligue 1 *n* = 200	Bundesliga *n* = 180	Serie A *n* = 200	La Liga *n* = 200	*H*	*P*	E_R^2
Elaborate attack	0.842 ± 0.338	0.756 ± 0.295	0.834 ± 0.342	0.797 ± 0.29	0.82 ± 0.407	7.913	0.095	0.008
Counter attack	0.071 ± 0.059	0.075 ± 0.06	0.15 ± 0.081[EFIS]	0.09 ± 0.074	0.099 ± 0.082[EF]	136.604	0.000	0.14
Direct free-kick	0.036 ± 0.033	0.039 ± 0.035	0.04 ± 0.04	0.043 ± 0.035	0.039 ± 0.037	8.138	0.087	0.008
Indirect free-kick	0.091 ± 0.052	0.093 ± 0.055	0.113 ± 0.063[EFIS]	0.083 ± 0.049	0.093 ± 0.056	29.827	0.000	0.03
Corner	0.173 ± 0.078[FI]	0.139 ± 0.069	0.161 ± 0.069[F]	0.151 ± 0.069	0.154 ± 0.075	22.556	0.000	0.023
Throw-in	0.014 ± 0.025	0.008 ± 0.017	0.02 ± 0.025[EFI]	0.008 ± 0.016	0.024 ± 0.034[EFI]	68.823	0.000	0.07
Penalty	0.097 ± 0.055	0.108 ± 0.065	0.103 ± 0.06	0.123 ± 0.065[E]	0.11 ± 0.063	17.478	0.002	0.018
Own goal	0.051 ± 0.041[IS]	0.04 ± 0.035	0.035 ± 0.034	0.036 ± 0.032	0.035 ± 0.03	18.558	0.001	0.019

In the Kruskal–Wallis H test, [E]signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to English Premier League (P < 0.005); [F]signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to French Ligue 1 (P < 0.005); [G]signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to German Bundesliga (P < 0.005); [I]showed a significant difference to Italy Serie A (P < 0.005); [S]showed a significant difference to Spain La Liga (P < 0.005).

1 (goal from a big chance with an assist), Bundesliga scored significantly more goals than the other four leagues [$H = 60.611$, $P < 0.001$, $E_R^2 = 0.069$; Bundesliga(0.617) > La Liga(0.527) = EPL(0.468) = Ligue 1(0.465) = Serie A(0.452)].

In shooting situation 2 (goal with an assist but not from a big chance), the EPL scored significant more goals than Ligue 1, Bundesliga and La Liga ($H = 26.455$, $P < 0.001$, $E_R^2 = 0.03$), while there was no significant difference in this shooting situation between EPL and Serie A [EPL(0.463) > La Liga(0.421) = Bundesliga(0.402) = Ligue 1(0.38); EPL(0.463) = Serie A(0.432)].

The analysis of the mean number of goals scored in shooting situation 3 (goal from a big chance without an assist) showed a significant league effect in all leagues, in that Ligue 1 scored the fewest goals, and Serie A scored the most goals [$P < 0.005$; Serie A(0.276) > Ligue 1(0.248)].

Post hoc analyses showed that EPL scored the most goals of the five leagues from shooting situation 4 (goal without both a big chance and an assist) [$H = 14.128$, $P = 0.007$, $E_R^2 = 0.016$; EPL (0.194) > Ligue 1(0.162)].

Analysis of the League Effect in Different Time Periods

Table 3 presents data on the mean number of goals scored in the six identified time periods across the five leagues. From time periods one to five, Bundesliga scored the most goals, while Ligue 1 scored the fewest goals ($P < 0.005$). This suggests that there is a significant difference between Bundesliga and Ligue 1 in the first five time periods. However, a Kruskal-Wallis test revealed that there was no significant difference among all the leagues in time period six ($P > 0.05$).

DISCUSSION

In this paper, we aimed to compare goal scoring patterns in the top five European football leagues over 10 seasons. After exploring the league effects within eight goal types, four shooting situations and six scoring time periods across five major European soccer leagues, we find that different goal types, shooting situations and scoring time periods show varying degrees of league effects.

Some noticeable differences were observed in offense patterns among the different leagues, suggesting differences in either the playing style or the physical demands of the league.

It should be mentioned that counterattack has become an increasingly important means of offense (Maneiro et al., 2019a). And association football have been experienced an evolutionary trend which focus on the defensive and offensive transition (Sarmento et al., 2017). And Sgrò et al. (2016) pointed out that the winning teams tried to maintain a high percentage of ball possession using more accurate and longer pass sequences while the direct play is preferred by the losing team.

Bundesliga have a significant advantage in counterattack goals compared to the other four leagues. Our results are in line with the study of Mitrotasios et al. (2019), in which the Bundesliga had the greatest number of counterattacks in the top five leagues. Another factor to consider is that the full-backs from the German league executed the highest number of inaccurate passes in the defensive and midfield zones compared

TABLE 2 | Mean frequency values of goals scored by teams in different goal-shooting situations ($N = 882$).

	EPL *n* = 180	Ligue 1 *n* = 180	Bundesliga *n* = 162	Serie A *n* = 180	La Liga *n* = 180	*H*	*P*	E_R^2
Shooting 1	0.468 ± 0.214	0.465 ± 0.209	0.617 ± 0.25^{EFIS}	0.452 ± 0.191	0.527 ± 0.281	60.611	0.000	0.069
Shooting 2	0.463 ± 0.169^{FGS}	0.38 ± 0.127	0.402 ± 0.157	0.437 ± 0.156^{F}	0.421 ± 0.181	26.455	0.000	0.03
Shooting 3	0.249 ± 0.098	0.248 ± 0.117	0.271 ± 0.109	0.276 ± 0.105^{F}	0.264 ± 0.118	12.510	0.014	0.014
Shooting 4	0.194 ± 0.088^{S}	0.172 ± 0.077	0.172 ± 0.073	0.169 ± 0.072	0.162 ± 0.076	14.128	0.007	0.016

In the Kruskal–Wallis H test, ^{E}signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to England Premier League ($P < 0.005$); ^{F}signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to French Ligue 1 ($P < 0.005$); ^{G}signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to German Bundesliga ($P < 0.005$); ^{I}showed a significant difference to Italy Serie A ($P < 0.005$); ^{S}showed a significant difference to Spain La Liga ($P < 0.005$).

TABLE 3 | Mean frequency values of goals scored by teams in different time periods ($N = 980$).

	EPL *n* = 200	Ligue 1 *n* = 200	Bundesliga *n* = 180	Serie A *n* = 200	La Liga *n* = 200	*H*	*P*	E_R^2
TP1	0.169 ± 0.083	0.156 ± 0.08	0.182 ± 0.092^{F}	0.168 ± 0.08	0.17 ± 0.088	9.003	0.060	0.009
TP2	0.199 ± 0.091	0.176 ± 0.079	0.217 ± 0.095^{F}	0.194 ± 0.085	0.204 ± 0.112	14.994	0.005	0.015
TP3	0.222 ± 0.096	0.198 ± 0.093	0.23 ± 0.101^{F}	0.21 ± 0.09	0.219 ± 0.113	11.314	0.023	0.012
TP4	0.24 ± 0.109	0.211 ± 0.097	0.251 ± 0.107^{F}	0.234 ± 0.095	0.233 ± 0.109	11.442	0.022	0.012
TP5	0.235 ± 0.101	0.219 ± 0.098	0.254 ± 0.109^{F}	0.231 ± 0.098	0.232 ± 0.123	9.561	0.049	0.01
TP6	0.309 ± 0.13	0.299 ± 0.119	0.323 ± 0.124	0.294 ± 0.107	0.315 ± 0.141	6.742	0.150	0.007
Total	1.375 ± 0.442^{F}	1.259 ± 0.401	1.457 ± 0.444^{F}	1.331 ± 0.381	1.373 ± 0.537	25.060	0.000	0.026

In the Kruskal–Wallis H test, ^{E}signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to England Premier League ($P < 0.005$); ^{F}signify that the Bonferroni-adjusted Mann–Whitney U test showed a significant difference to French Ligue 1 ($P < 0.005$).

to their counterparts in the English Premier League, Spanish La Liga, and Italian Serie A (Konefał et al., 2015). This would encourage their opponents to adopt counterattacking tactics since the players lost ball possession in the defensive and midfield zones.

At the same time, La Liga had more goals from fast breaks than Serie A on average—La Liga scores more (although not significantly more), and they are significantly the best of the three at scoring from counterattacks (La Liga, EPL, and Ligue 1).

Full-backs from the Spanish La Liga performed the most passes, crosses and ball touches in the attacking zone (Konefał et al., 2015). They also executed the lowest number of passes in the midfield and defense zones. Therefore, the Spanish defenders tend to press on the side of the opposition, which leaves the defensive zone empty and improves the success rate of the opponent's counterattack.

A popular assumption is that Serie A is primarily defensive and uses the counterattack to win games (Oberstone, 2011). Its mottos are "do not concede" and "get ten behind the ball" as soon as a goal is scored (Oberstone, 2011). However, the data suggest that this is not how Serie A teams actually play. In fact, Serie A fell in the middle of the top five European leagues in terms of their counterattacking goals. This finding is in agreement with previous research (Oberstone, 2011).

The EPL has a lower number of penalty goals than the other four leagues on average. A possible explanation might be that the referees in the EPL have become more lenient than those in the other leagues (Oberstone, 2011; Sapp et al., 2018).

In regard to the corner kicks goals, De Baranda and Lopez-Riquelme (2012) have compared successful and unsuccessful teams with specific reference to corner kicks and Maneiro et al. (2019b) have identified significant differences in the male and female model of corner kicks execution.

An interesting result is that more own and corner kick goals were scored by the EPL than by the other leagues. Given the EPL's reputation as an intense league, these results suggest that English Premier League teams are correctly characterized as direct-play teams (Sarmento et al., 2013). One important factor that can explain the differences in corner-kick goals found in this study is the strong heading ability of EPL defenders (Dellal et al., 2011). Dellal suggested that forwards in the EPL lost a greater percentage of heading duels than their La Liga counterparts. Because corner kicks are the main way for a defender to participate in the offense and placing defenders at the goalposts increases the chances of a successful corner kick occurring (De Baranda and Lopez-Riquelme, 2012), the superb heading ability shown by EPL defenders may increase the number of corner kick goals.

Moreover, the EPL is characterized as the toughest marking and fastest game among the EPL, La Liga, and Serie A (Oberstone, 2011). EPL is assumed to have more own goals than are scored in the more elaborate and skilled playing style of La Liga.

The between-league analysis of the shooting situations revealed that Bundesliga excels at goals from shooting situation 1 (goal from a big chance with an assist). As mentioned before, this advantage should be attributed to the poor performance of the German full-backs. According to Bloomfield's research (Bloomfield et al., 2005), players in the Bundesliga were significantly taller and heavier than players in the other three leagues (all except Ligue 1). Thus, the lack of agility in the Bundesliga's full-backs could have led to more goals from situation 1.

The EPL does have the highest number of goals from shooting situations 2 and 4 and has significantly more than La Liga, the Bundesliga, and Ligue 1 with respect to shooting situation 2. The EPL, as the "fanciest" league, has earned its reputation as attacking artists when confronted with a solid defense. EPL's team composition (such as player nationality, game style, statures) may be different from other leagues, which may explain these differences. As far as we know, this has not been explored. Future work should focus on comparing shooting situations between the English Premier League and the lower professional leagues (i.e., Champions League, League 1, and League 2) to investigate whether there are differences.

The five leagues showed nearly identical time period characteristics. The only difference is that the Bundesliga tends to score more goals than Ligue 1. The differences were evident for the French league, probably due to their lower scoring ability. The higher number of goals per match in the Bundesliga may be due to the lower number of matches per season of the league. According to our estimation, in England, the maximum number of competitive games a Premier League club may have to play in 2019/2020 is 74 (38 EPL, eight FA Cup, six League Cup, and 22 Europa League). This is five more games than in Spain (69), nine more than in Italy (65), eight more than in French (66), and 12 more than in Germany (62). If FA cup replays are counted, the gap between the Premier League and the other four leagues becomes even greater.

Last, some of the most interesting findings are those goal scoring patterns that do not statistically separate the five leagues: (1) the mean goals from elaborate attacks per game, (2) the mean goals from direct free kicks per game, and (3) the mean goals scored in the last 15 min. Our study illustrates the similar patterns in the temporal goal scoring distribution among the English, Italian, Spanish, and French leagues, which supports evidence from previous observations (Alberti et al., 2013).

In conclusion, the observed disparities in scoring patterns among leagues may be further explained by cultural differences. Each league has a unique style of play that is undoubtedly influenced by its country's physical culture and economic, social, and sporting points of view. Further, football has traditionally been proven to be highly resistant to the commodification of its culture. A limitation is that our data do not tell us anything about these cultural differences. Future studies may explore how these parameters account for differences in goal scoring patterns among leagues.

CONCLUSION

In summary, our study showed both similarities and differences in various aspects of goal scoring patterns among five major European soccer leagues. There were no significant differences among the five leagues in terms of mean goals scored in the last

15 min or the goals from elaborate attacks and direct free kicks. The Spanish La Liga was better at scoring through throw-ins, the English Premier League showed a high degree of goals from corner kicks, the German Bundesliga had the greatest number of counter-attacks, the Italian Serie A made a higher number of penalty goals and the French Ligue 1 had a weaker scoring ability. These findings have provided valuable source of information adding to our knowledge of understanding the different scoring patterns of each league.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of School of Physical Education and Health, Wenzhou University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

CL contributed to the study conception and design. YZ and CL performed the material preparation, data collection, and analysis. YZ wrote the first draft of the manuscript and both authors commented on previous versions of the manuscript. Both authors read and approved the final manuscript.

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With Crisis Comes Opportunity: Redesigning Performance Departments of Elite Sports Clubs for Life After a Global Pandemic

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The suspension of major sporting competitions due to the global COVID-19 pandemic had a substantial negative impact on the sporting industry. As such, a successful and sustainable return to sport will require extensive modifications to the current operations of sporting organizations. In this article we argue that methods from the realm of sociotechnical systems (STS) theory are highly suited for this purpose. The aim of the study was to use such methods to develop a model of an Australian Football League (AFL) club's football department. The intention was to identify potential modifications to the club's operations to support a return to competition following the COVID-19 crisis. Subject Matter Experts from an AFL club participated in three online workshops to develop Work Domain Analysis and Social Organization and Cooperation Analysis models. The results demonstrated the inherent complexity of an AFL football department via numerous interacting values, functions and processes influencing the goals of the system. Conflicts within the system were captured via the modeling and included pursing goals that may not fully reflect the state of the system, a lack of formal assessment of core values, overlapping functions and objects, and an overemphasis on specialized roles. The current analysis has highlighted potential areas for modification in the football department, and sports performance departments in general.

Keywords: football, complexity, sociotechnical systems, COVID-19, sport, cognitive work analysis, systems analysis

INTRODUCTION

On the 11th March 2020, the World Health Organization (WHO) declared the COVID-19 outbreak as a global pandemic (World Health Organisation, 2020). In the days and weeks that followed, the global sporting industry was brought to a sudden halt (Evans et al., 2020; Parnell et al., 2020; Toresdahl and Asif, 2020). This began with the National Basketball Association (NBA) in the United States suspending competition after a player tested positive for COVID-19. This was quickly followed by the suspension of all other major sporting competitions, including the world's biggest sporting event, the Olympic Games, to be held in Tokyo in July 2020 (Sato et al., 2020). To put the situation in context, the scheduling of the Olympic Games has only previously been interrupted due to the second World War. From March 2020 onward, elite sport worldwide entered largely unchartered territory.

The public health crisis associated with the COVID-19 pandemic has been extensively documented by the media, governments, WHO, and via academic commentary and editorials (Heymann and Shindo, 2020; World Health Organisation, 2020). In addition to the public health crisis, is the impending financial crisis brought about by the lock down of entire countries and industries (Goodell, 2020; Zhang et al., 2020). While the overall financial impact of the COVID-19 pandemic is not yet clear (Zhang et al., 2020), short term financial impacts are already being realized within the sporting industry (Evans et al., 2020). As a result of the suspension of play, sporting organizations have been unable to generate revenue from media, memberships, merchandise and ticket sales (Evans et al., 2020). This has led to a requirement to reduce spending, which has contributed to mass unemployment within the sporting industry (Evans et al., 2020). It is anticipated that the public health and economic impacts of the pandemic will be ongoing and will impact sport in both the short and long term (Goodell, 2020; Heymann and Shindo, 2020). As such, the sporting industry will be required to adapt and potentially to re-invent itself upon the resumption of competitive sport (Evans et al., 2020). In the short term, for example, a safe and successful return to play will require significant modifications to current practices such as coaching, training, and injury prevention management. Moreover, severe financial constraints will require sports organizations to revisit the structures and processes currently used to optimize performance. Sporting organizations will need resilience to cope with potential intermittent suspensions in the event of future global pandemics. A successful return to competition will require agility, innovation, and ultimately substantial modifications to current operations to ensure the sustainability of sporting organizations.

In order to understand the inherent complexity of the COVID-19 crisis for sporting organizations, appropriate approaches are necessary. There is a growing body of research applying complexity and systems thinking-based methods to understand and optimize sports systems (Bittencourt et al., 2016; McLean et al., 2017, 2019a; Hulme et al., 2019; Salmon and McLean, 2019; Salmon et al., 2021). Such methods are useful as they can be used to describe sports organizations, their key functions, and the factors that influence performance at the athlete, the team, and at the organizational level. Sociotechnical systems (STS) theory (Clegg, 2000; Read et al., 2018) is one such approach that is used to optimize work systems. It was developed during a program of research undertaken at the Tavistock Institute that focused on the disruptive impacts of new technologies on human work (Trist and Bamforth, 1951; Eason, 2014). The approach encapsulates a focus on both the performance of the work system and the experience and well-being of the people performing the work (Clegg, 2000). Joint optimization, as opposed to optimization of solely the social or technical aspects is required for efficient and healthy system performance (Badham et al., 2006). There is a large body of work demonstrating the positive benefits of adopting STS principles in organizational redesign. A meta-analysis of over 130 STS studies found that almost 90% reported improvements in safety and productivity and over 90% reported improvements in workers' attitudes and quality of outputs (Pasmore et al., 1982). Although the approach appears highly suited to the design of sports organizations and practices, it is yet to be applied in this context. Despite this, it is our view that STS provides a novel and highly useful approach to support sports organizations in responding to COVID-19.

The aim of this study was therefore to apply methods from an STS framework to analyze the current functioning of an Australian Football League (AFL) club's football department. The intention was to use the framework to identify potential modifications to the clubs' operations in the wake of the impacts associated with the COVID-19 crisis.

MATERIALS AND METHODS

Study Design

This qualitative study applied two phases of the Cognitive Work Analysis (CWA) framework (Vicente, 1999), Work Domain Analysis (WDA), and Social Organization and Cooperation Analysis (SOCA) to develop and analyze a complex systems model of an AFL club football department. The WDA and SOCA development were conducted across three subject matter expert (SME) workshops via the Zoom video conferencing software. Five SMEs from the participating AFL club participated in the current study.

Cognitive Work Analysis

CWA is a sociotechnical systems analysis and design framework that has been used extensively for understanding the structure and behavior of complex systems (Bisantz and Burns, 2008; Stanton et al., 2017). An important feature of CWA is that it provides a series of analytical methods that focus on identifying the constraints present within a system and the resulting impacts on behavior. This allows analysts to understand what constraints exist, what impact the constraints have on behavior, and how constraints can be modified to improve system performance. The formative nature of the framework allows analysts to explore the possibilities for changing behavior through the removal of existing constraints, the addition of new constraints, or through changing the nature of constraints. These unique features have ensured that CWA has become one of the most popular systems analysis and design methods within the discipline of human factors and ergonomics (HFE), and safety science (Stanton et al., 2017). Recently, CWA has been used across a wide range of domains (Bisantz and Burns, 2008; Stanton et al., 2017), including recently in elite sport for organizational analysis (Hulme et al., 2019), performance analysis (McLean et al., 2017, 2019a), and talent identification and development in soccer (Berber et al., 2020).

The CWA framework comprises five phases, each being used to model behavior from differing perspectives: WDA; control task analysis (ConTA); strategies analysis; SOCA; and worker competencies analysis (WCA). An overview of the two phases used in this project, WDA and SOCA, is provided below.

Work Domain Analysis

Work domain analysis is used to provide an event and actor independent description of the system under analysis (**Figure 1**): in this case a current AFL football department "system." The aim is to describe the purposes of the system and the constraints imposed on the actions of those performing activities within it (Vicente, 1999). This involves using the abstraction hierarchy method to describe the system across five levels of abstraction (**Table 1**).

A key element of the abstraction hierarchy is that it uses means-ends relationships to link nodes across the five levels of abstraction. For example, the object-related process of "Treatment of player injuries" is undertaken to achieve the function of "Injury prevention, management and rehabilitation" and involves the use of the physical object "Medical equipment." This feature of the abstraction hierarchy enables analysts to understand why functions and processes are undertaken, and what is used to achieve them.

TABLE 1 | Work domain analysis (WDA) descriptions of levels of abstraction.

Level of abstraction	Description
Functional purpose	The overall purposes of the system and the external constraints imposed on its operation
Values and priority measures	The criteria that organizations use for measuring progress toward the functional purposes
Purpose-related functions	The general functions of the system that are necessary for achieving the functional purposes
Object-related processes	The functional capabilities and limitations of the physical objects within the system that enable the generalized functions
Physical objects	The physical objects within the system that are used to undertake the generalized functions

Social Organization and Cooperation Analysis

Social organization and cooperation analysis is used to identify how functions and processes are distributed across human and non-human agents within the system. A formative element also enables analysts to determine how functions and processes could

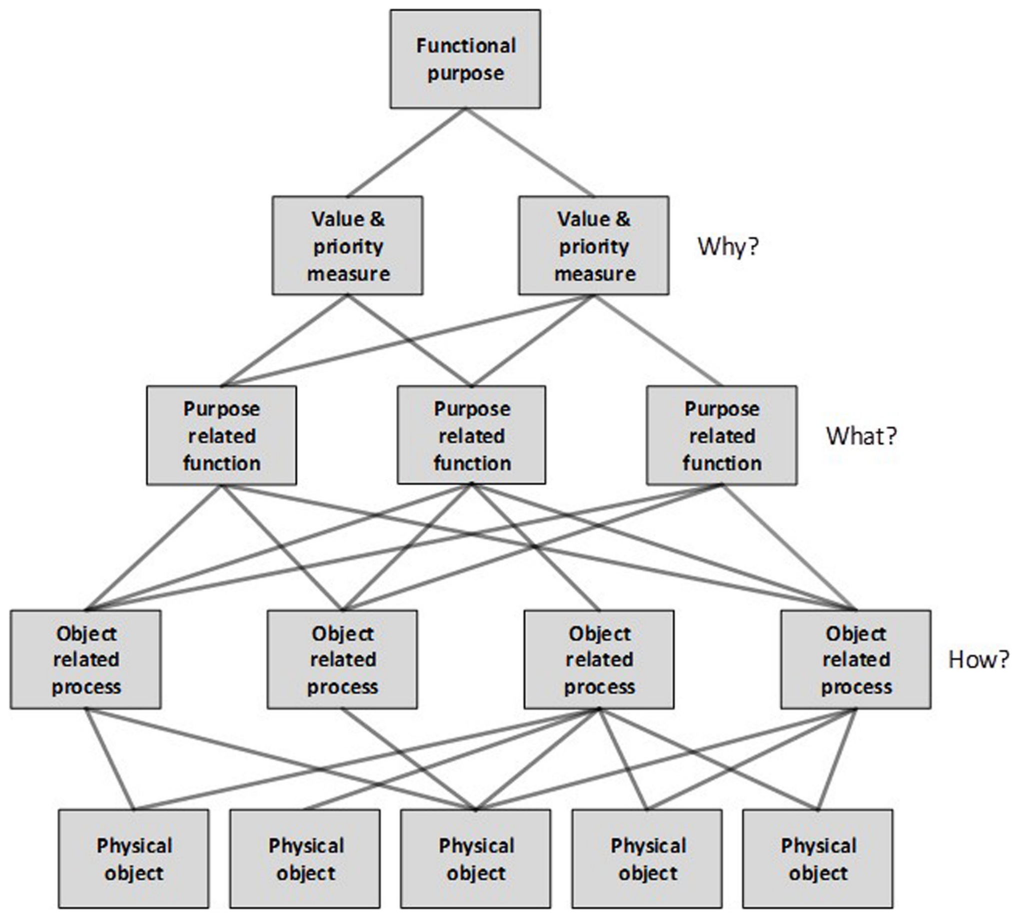

FIGURE 1 | Work domain analysis (WDA) framework showing the levels of abstraction, and the means-end links "how-what-why" triad.

be allocated following redesign. By assessing the WDA to identify who/what currently does what, and who/what could do what, SOCA aims to specify an optimum allocation of functions for the system under analysis.

Procedure

The SMEs had extensive experience in the AFL (16.2 ± 6.1 years), across a range of different roles including players, football director, general manager of football, strength and conditioning, biomechanics, performance analysis, high performance management, AFL governance, coach innovation and education, football strategy and innovation, and playing list management. The SMEs had been employed in these positions at seven different AFL clubs, the AFL, and at the Australian Institute of Sport. In addition, the SMEs had experience in other professional sports including sports science positions in cricket, and tennis. Prior to commencement of the workshops, the SMEs from the participating AFL club's football department were provided with written information which included an overview of WDA and SOCA as well as a set of preparatory questions for a WDA development workshop. A WDA development workshop was held via Zoom with the SMEs and two researchers with extensive experience in applying WDA (Salmon et al., 2016; McLean et al., 2019a), and the SMEs. The SMEs were asked to respond to a set of WDA prompt questions which were presented in conjunction with relevant keywords and examples [**Table 2**, adapted from Naikar (2013)]. One researcher used the CWA software tool (Jenkins et al., 2007) to construct an initial draft abstraction hierarchy, using a shared screen function. Following the workshop, the two researchers completed the means-end-links.

A second Zoom workshop was held with the same SMEs to review and refine the draft abstraction hierarchy and undertake the SOCA phase. The SMEs reviewed the WDA components and the means end links. Any modifications were discussed and revised to achieve the final WDA model (**Supplementary Material**). For the SOCA phase, SMEs were asked to create a list of all actors (employees, consultants, and volunteers) who currently hold a role in the AFL club's football department. A list of actors was compiled, and the SMEs were asked to identify which of the actors are associated with the Functional Purposes, Values and Priority Measures, Purpose-Related Functions, Object-Related Processes, and Physical Objects specified in the WDA. Actors were identified and associated with the WDA nodes as described in **Table 3**.

The WDA and SOCA were reviewed and refined by the two researchers, following which a third and final workshop was held to complete the SOCA analysis and discuss initial insights from the model. Discussions were documented by the research team and were used to supplement the insights obtained from the WDA-SOCA model.

RESULTS

Work Domain Analysis

The AFL club football department abstraction hierarchy is presented as **Supplementary Material**. Given the complexity and size of the model, a summary is presented in **Figure 2**.

According the abstraction hierarchy, the club's football department has two functional purposes: to "Win premierships," and to achieve a "Sustainably successful and progressively improving football program." A total of 25 values and priority measures were identified. These can be broadly grouped into seven categories. The first set includes values relating to player and team performance and development, such as "Matches won," "Percentage," "Maximizing player talent," and "Continual player improvement." The second set includes values relating

TABLE 2 | Work domain analysis (WDA) development questions and prompts.

Stage	Question	Keywords	Examples
1. Functional purposes	Why does the football department exist?	Reasons, goals, objectives, aims, intentions, mission	To win games/grand final Player/team development Implement club strategic plan
2. Values and priority measures	How can we tell whether football department is achieving its purposes?	Criteria, measures, benchmarks	Club reputation Player and team performance Match and Season outcomes Staff and player satisfaction Staff and player retention
3. Purpose-related functions	What functions must be performed by club staff for the football department to achieve its purposes?	Roles, responsibilities, tasks, jobs, occupations, positions, activities, operations	Talent identification and recruitment Performance analysis Coaching and training Load and injury management Manage staff and player health and wellbeing
4. Object-related processes	What processes are physical objects used to achieve within the football department?	Uses, applications, characteristics, limitations, processes	Data collection and analysis Development of physical strength and athletic capacity Communication
5. Physical objects	What physical objects are used within the football department	Tools, equipment, technology, kit, gear, buildings, facilities, infrastructure, staff, people, terrain	Strategic plan Training equipment Gymnasium Finances

TABLE 3 | Social organization and cooperation analysis (SOCA) descriptions for the levels of abstraction.

Level of abstraction	Description
Functional purpose	Actors who contribute to the functional purpose as part of their work in the football department
Values and priority measures	Actors who hold the value and priority as part of their work in the football department
Purpose-related functions	Actors who undertake the function as part of the work in their football department
Object-related processes	Actors who undertake the object-related process as part of their work in the football department
Physical objects	Actors who use the physical objects as part of their work in the football department

to player health and wellbeing, such as "Players physical conditioning," "Minimizing injuries," and "Maximizing players health and wellbeing." The third set includes values relating to club finances, including "Optimizing department spend" and "Optimizing player spend" (salary cap). The fourth set includes values relating to staff health and wellbeing. The fifth set of values relate to compliance such as "Minimizing positive drug tests" (both illicit drugs and performance enhancing drugs) and "Maximizing compliance with AFL rules and regulations." The sixth set includes values which relate to the development and maintenance of club culture, such as "Player inspiration," "Player and staff engagement," and "Embracing and supporting diversity in the playing list." Finally, the seventh set includes values which contribute to maintenance of the club's reputation, such as, "Club culture" and "Embrace and support diversity in playing list."

Forty purpose-related functions were identified. These include functions relating to "Coaching," "Training and match preparation," "Playing matches," "Performance analysis and research," "Injury prevention and rehabilitation," "Management of facilities," "Player and staff recruitment," "Engagement and retention," "Community engagement," "Stakeholder management and engagement," and "Media."

At the bottom level of the abstraction hierarchy, thirty-eight physical objects were identified, including "Training and playing facilities" and "Equipment," "Medical equipment," "Recovery equipment," "Performance analysis software," "Communications and logistics equipment," "Website and social media," "Finances," "Strategic and operational documents," "Contracts and agreements," and "Policies and procedures." According to the abstraction hierarchy, the physical objects support 28 object-related processes including "Training and matches," "Injury prevention and rehabilitation," "Data collection and analysis," "Communications," "Financial operations," "Strategic guidance," "Processes and procedures," and "Agreements, roles and responsibilities."

Social Organization and Cooperation Analysis

A list of the AFL club football department actors considered in the SOCA is presented in **Table 4**.

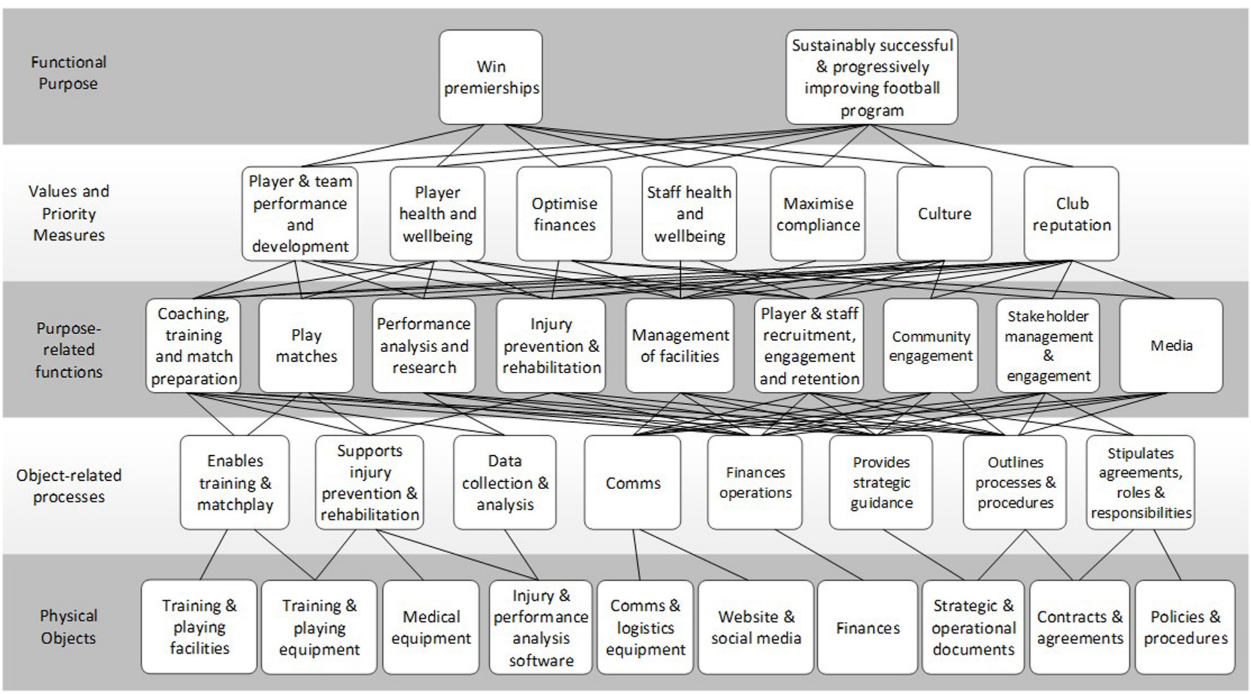

FIGURE 2 | Summary abstraction hierarchy of the AFL club football department. Each level contains summary nodes that encapsulate multi nodes from the overall model. For example, the value and priority measure node of "Player and team performance and development" included "Matches won," "Percentage differential," "Continual player improvement," and "Maximizing player talent."

TABLE 4 | AFL club football department actors.

Code	Actors	Code	Actors
1	Players	30	Player welfare assistant
2	Leadership group (players)	31	Indigenous welfare
3	Football director	32	COO/GM of football
4	Head coach	33	Head of football
5	Coach	34	Assistant to football department
6	Coach	35	Head of women's football
7	Coach	36	Head of list management
8	Development coach	37	National recruiting manager
9	Development coach	38	State recruiting manager
10	Coach	39	Opposition analyst/pro scout
11	Leadership consultant	40	Football Program Advisor (list consultant)
12	Leadership and development coach	41	Psychologist
13	Head of Football operations	42	Head trainer
14	Head of Performance	43	Podiatrist
15	Head of sport science	44	Yoga/Pilates
16	S and C coaches	45	Lead football analyst
17	S and C rehabilitation	46	Football analyst
18	Development S and C	47	Football analyst
19	GPS analytics	48	Football analyst
20	Doctor	49	Senior analyst
21	Part time Doc	50	Sleep consultant
22	Part time Doc	51	Legal Counsel and Special Projects
23	Physiotherapist	52	Pastor (part time)
24	Physiotherapist (part time)	53	Massage therapists X 6
25	Physiotherapist (part time)	54	Recruiting administrator
26	Dietician/nutritionist	55	Recruiting scouts x 6
27	Kit man	56	Match day help
28	Facilities manager/staff x 2	57	Analytics interns X 6
29	Player welfare manager	58	Nutrition/S and C interns X 4

S and C denotes strength and conditioning.

The results of the SOCA are presented in **Tables 5–8**. The SOCA results demonstrate how functions and processes are distributed across the actors within the system. **Table 5** shows that all actors within the football department are associated with seven Values and Priority Measures, these include Matches won, Percentage, Continual team improvement, Embrace and support diverse playing list, Club culture, Maximize club reputation, Compliance with AFL rules and regulations. **Table 6** shows that the coaching staff (actors 4–10), head of performance, sports scientists, the head of football, and the COO/GM of football perform a large number of the Purpose Related Functions relative to other actors. **Table 7** shows the Object Related Processes associated with the most actors include Playing games, Enhances physical performance, Protects players, and assessment of player health and well-being. Finally, **Table 8** shows the coaches and players utilize the majority of physical objects identified in the abstraction hierarchy relative to other actors. A table is not presented for the Functional Purposes level as all actors were deemed to contribute to both. Within **Tables 5–8**, the variables associated with each level of abstraction listed in the left-hand side column, with the corresponding columns relating to each the actors from **Table 4**. Shading is used to denote where actors contribute to each variable. Totals are also presented for the absolute number of actors associated with each value and priority (far right-hand side column) and the absolute number of values and priority measures associated with each actor (bottom row of the table).

DISCUSSION

This study applied two methods from the CWA (Vicente, 1999) framework to provide a detailed analysis of the functional structure of an AFL football department with a view to identifying opportunities for redesign. The analysis produced multiple insights which are relevant for the optimization of sports performance departments in general, and for streamlining current football department operations post COVID-19.

Complexity of the Football Department

The initial finding of the current study demonstrates the inherent complexity of an AFL football department via the multiple and interacting factors that influence the behavior, and the diverse set of actors who share responsibility for the performance of the system. As such, the department can be conceptualized as a STS in which social actors (e.g., athletes, coaches, facilities staff) interact with one another and with technologies (e.g., equipment, facilities, websites) to achieve common goals (Walker et al., 2008). In addition, the means-end-links in the abstraction hierarchy indicates a high level of connectivity among the system components and behaviors and demonstrate instances where there is either redundancy (i.e., many resources supporting a node above) and where there are potential fragilities (i.e., few resources supporting a node/purpose). These results are consistent with previous research which indicates that sporting organization performance and functioning is an emergent property of the complex interactions between all system components and actors (Jones et al., 2009; Hulme et al., 2019; Salmon and McLean, 2019).

What Does Systems Modeling Tell Us About the Football Department?

The current analysis identified strengths of the AFL clubs' department, as well as potential conflicts between systems components. Several strengths of the football department were identified in the WDA including important functions outside of playing football such as community engagement, finances, staff wellbeing, and the development of culture and club reputation (Jones et al., 2009). In line with the aim of the study, the remainder of the discussion will focus on areas for potential improvement and provide recommendations to modify and enhance the club's current football department in the wake of the impacts associated with COVID-19.

Whilst the two functional purposes are appropriate given the context is elite sport, it seems pertinent to consider the potential adverse impacts of the Functional Purpose of "Win premierships." As an aspirational Functional Purpose this may

TABLE 5 | SOCA showing the football department actors associated with the values and priority measures identified in the abstraction hierarchy.

Actor code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
Matches won	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	58
Percentage	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	58
Player physical conditioning	■	■		■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■	■																■	■	■						■			■					■	28
Maximize existing talent	■	■		■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■	■			■	■	■		■			■	■	■	■	■	■				■	■	■	■	■										37
Maximize identified playing style	■	■		■	■	■	■	■	■	■				■	■																		■																										12
Continual player improvement	■	■		■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■	■			■	■	■		■			■	■	■	■	■	■				■	■	■	■	■									■	38
Continual team improvement	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	58
Minimize injuries	■	■		■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■	■			■	■											■	■	■	■						■			■	■				■	31
Team and players training and match performances	■	■		■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■			■	■	■	■	■	■				■	■	■	■	■					■			■	■	42
Player health and wellbeing	■	■		■	■	■	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■			■	■	■	■	■	■	■	■					■	■	■	■						■		■	■					■	39
Player empowerment	■	■		■	■	■	■	■	■	■				■	■	■	■	■					■	■	■	■							■								■																		20
Optimize player spending (salary cap)			■	■										■	■																	■	■			■	■	■	■	■														■	■				13
Optimize department spend			■	■									■	■																		■	■			■																							7
Attraction and retention of players	■	■		■	■	■	■	■	■	■	■	■		■	■	■	■	■		■			■	■	■				■	■	■	■	■			■	■	■	■	■		■			■							■		■					34
Attraction and retention of staff				■										■																		■	■			■																							5
Player engagement	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■			■	■	■	■	■	■		■					■	■										■							34
Staff engagement	■		■	■	■	■	■	■	■	■			■	■	■					■			■						■			■	■	■		■					■	■									■								22
Minimize positive drug tests (illicit)	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■			■			■	■	■	■	■								■									■	■								30
Minimize positive drug tests (Performance enhancing)	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■			■			■	■	■	■	■								■										■								29
Embrace and support diverse playing list	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	58
Club culture	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	58
Inspiration of playing group and staff	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■			■			■			■		■	■	■			■					■	■										■							28
Maximize club reputation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	58
Compliance with AFL rules and regulations	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	58
Optimize facilities													■															■																															2
Total	21	20	10	24	21	21	21	21	21	21	13	12	13	24	22	19	19	19	13	19	16	16	20	16	16	18	8	9	18	16	16	17	22	10	8	18	12	12	12	12	18	14	10	10	11	10	10	10	10	11	10	11	10	10	8	7	8	11	

TABLE 6 | SOCA showing the football department actors associated with the purpose related functions identified in the abstraction hierarchy.

Actor code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
Play matches																																																											30
Team selection																																																											14
Coaching																																																											10
Player development																																																											16
Match tactical planning																																																											8
Develop game style																																																											7
S and C training																																																											11
Technical training																																																											9
Tactical training																																																											9
Psychological training (mental health, welfare)																																																											19
Performance analysis																																																											15
Opposition performance analysis																																																											12
Periodization (S and C and tactical)																																																											9
Evaluation of training																																																											16
Management of facilities																																																											2
Development of game insights																																																											19
Injury prevention and rehabilitation																																																											21
Player monitoring (training and matches)																																																											15
Manage player mental health and wellbeing																																																											19
Manage player recovery																																																											17
Manage player diets																																																											9
Player education																																																											16
Manage player and staff contracting																																																											6
Formalized meetings																																																											17
Drug testing (illicit and performance enhancing)																																																											5
Player and staff identification																																																											13
Player and staff recruitment																																																											20
Personal development (staff and players)																																																											14
Develop leadership capacity																																																											14
Community engagement																																																											14
Develop culture																																																											30

(Continued)

TABLE 6 | Continued

Actor code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
Logistics and planning				■	■								■	■	■												■					■	■	■																									9
External stakeholder management	■			■	■	■	■	■	■	■			■	■																		■	■			■				■											■								15
Media engagement and management	■			■	■	■	■	■	■	■																						■	■																										10
Systems and software management																			■																										■	■	■	■	■		■								7
Reporting to the AFL													■	■						■			■						■			■	■			■					■													■					10
Risk analysis													■	■	■	■	■	■		■			■	■								■				■																							11
Research	■													■					■	■			■	■	■				■			■	■			■					■								■	■								■	15
Season reviews				■	■	■	■	■	■	■				■	■	■		■	■	■			■	■		■			■			■	■								■				■	■	■	■	■										25
Tactical messaging (match)																													■																														1
Match reviews	■			■	■	■	■	■	■	■				■	■	■			■													■	■												■	■	■	■	■										19
Total	19	4	2	28	26	23	23	20	20	23	4	0	8	26	19	12	9	12	9	15	5	4	15	9	5	12	2	1	13	4	3	20	28	3	0	8	1	1	5	3	18	3	1	3	10	8	8	7	10	4	5	2	3	2	1	1	4	6	

Within the purpose related functions the playing leadership group (Actor 2) perform the same tasks as the players (Actor 1) in addition to the additional functions shaded.

be appropriate, however, it is important to note that the AFL club in the current study has endured long periods without achieving this Functional Purpose. Within the study of dynamic system behavior, "seeking the wrong goal" is a common trap made by organizations (Meadows, 2008). If the goal of the system does not reflect the reality of the system, then the system may have problems achieving the intended result (Meadows, 2008). This is known as a stretch goal in organizational behavior research, and although stretch goals can benefit some organizations it appears to be an exception rather than the rule, particularly where achievable and measurable sub-goals are not in place (Sitkin et al., 2011). Stretch goals, compared to more easily achievable goals, increase variance in organizational performance, undermine goal commitment, can adversely impact worker health and wellbeing, and generate lower risk-adjusted performance (Gary et al., 2017). As such, it may be beneficial for the club to set appropriate achievable, attainable and measurable sub-goals which move the organization toward the longer term stretch goal. For example, if at the midpoint of the season the stretch goal of "win premiership" is seemingly out of reach, the overall Purpose can have less of an influence on the behavior of actors within the organization. This is particularly important given that all actors within football department were deemed to contribute to both Functional Purposes. However, if achievable sub-goals become the focus of the organization, progress remains attainable. Without appropriate sub-goals, the realization that the stretch goal will not be achieved mid-season may impact motivation and commitment to the goal. Although stretch goals are attractive to stakeholders, they often produce poor organizational performance (Sitkin et al., 2011; Gary et al., 2017). The use of stretch goals by elite sports organizations is thus only encouraged when appropriate sub-goals are specified and monitored.

The Values and Priority Measures level of the WDA includes the criteria that the football department uses to assess progress toward the Functional Purposes. Many of the measures identified can be used in a straightforward manner to assess progress including "Matches won," "Percentage differentials," "Player physical condition," "Training and match performances." However, the extent to which data is available to enable the football department to understand whether they are achieving some Values and Priorities is not clear. For example, it is questionable whether valid assessments exist for some of the identified Values and Priority Measures including "Club culture," "Player empowerment," and "Maximizing existing talent." This presents an opportunity for the club to be innovative and develop or adopt new approaches for measuring their progress toward the Functional Purposes. Moreover, the development of valid measures for such aspects of elite sports organization performance represents an important direction for future sports science research.

Many of the measures used within the football department were identified as "lag" indicators in that they are retrospective measures of past performance and outcomes (e.g., "Matches won," "Percentage," "Injuries," "Player improvement"). Within economic and financial modeling and more recently safety science there is an increasing focus on the use of *leading indicators* to help understand and optimize performance.

TABLE 7 | SOCA showing the football department actors associated with the object related processes identified in the abstraction hierarchy.

Actor code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
Outlines plan for match				X	X	X	X			X																							X								X																		7
Provides environment for match play and training																																																											0
Playing games	X			X	X	X	X			X		X	X	X	X	X			X	X	X	X	X	X	X	X	X		X			X	X								X	X			X	X	X	X	X			X	X			X	X		34
Game plan development	X			X	X	X	X			X																																																	6
Enables skill acquisition	X			X	X	X	X	X	X	X																							X													X	X	X									X		13
Strength and conditioning	X													X	X	X	X	X					X	X	X	X																		X														X	12
Enhances physical performance	X													X	X	X	X	X	X	X	X	X	X	X	X	X															X	X	X	X						X			X					X	21
Protects players	X			X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X															X	X	X	X						X		X	X					X	29
Treatment of injuries	X																			X	X	X	X	X	X																	X	X										X						10
Provides sustenance	X																	X								X																																X	4
Enables recovery	X													X	X	X	X	X		X	X	X	X	X	X	X															X	X								X			X					X	18
Assessment of concussion	X																			X	X	X	X	X	X																	X																	8
Identification	X																																																										1
Video feedback	X			X	X	X	X	X	X	X																																																	8
Captures game and training data				X	X	X	X	X	X	X				X	X																														X	X	X	X	X								X		15
Captures player movement																			X																										X														2
Assessment of player health and wellbeing	X			X	X	X	X	X	X	X				X	X	X	X	X		X	X	X	X	X	X	X			X	X	X	X	X									X								X			X						28
Communication	X		X	X																												X	X																										5
Branding	X			X																												X	X																										4
Data storage																			X																										X	X	X	X	X								X		7
Outlines drug testing rules and regulations													X							X												X																											3
Staffing				X										X																		X	X																										4
Communicates club strategy				X																												X	X			X																							4
Outlines standard operating procedures													X																			X																											2
Outlines behavioral expectations	X			X	X	X	X	X	X	X				X	X																	X	X								X																		13
Stipulates rights and responsibilities between parties				X									X	X						X												X	X																										6
Recognition of excellence		X		X	X	X	X	X	X	X			X	X	X																	X	X								X																		14
Outlines AFL processes and procedures													X	X						X												X	X	X																									6
Talent scouting																																					X	X	X															X	X				5
Total	16	1	0	15	10	10	10	7	7	10	0	1	6	12	9	6	5	6	5	10	7	7	8	8	8	7	1	0	2	1	1	12	12	1	0	1	1	1	1	0	7	7	3	3	4	4	4	4	3	4	0	2	6	1	1	1	4	5	

TABLE 8 | SOCA showing the football department actors associated with the hierarchy physical objects identified in the abstraction hierarchy.

Actor code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
Game plan	X			X	X	X	X	X	X	X																							X																										9
Basketball court	X			X	X	X	X	X	X	X				X	X	X	X	X																																X									14
Stadium	X			X	X	X	X	X	X	X			X	X	X	X	X			X	X		X	X		X	X		X			X	X								X	X			X	X	X	X	X			X	X			X			32
Training facility	X			X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X			X	X					X								X	X																	25
Second tier club								X	X			X						X							X					X																											X		7
Training equipment (balls, markers)				X	X	X	X	X	X	X			X														X																																9
Gym equipment	X													X	X	X	X	X					X	X	X																																	X	10
Recovery equipment	X													X	X	X	X	X																																									6
Medical equipment																				X	X	X	X	X	X																	X																	7
Treatment rooms	X																			X	X	X	X	X	X																	X											X						9
Cogstate/SCAT	X																			X	X	X																																					4
Nutritional aids	X																	X								X																																X	4
Training and playing kits	X												X														X																																3
Sports code software	X			X	X	X	X	X	X	X																													X						X	X	X	X	X								X		15
Hudl software	X			X	X	X	X	X	X	X																																			X	X	X	X	X										13
Emperical software	X			X	X	X	X	X	X	X				X	X																										X				X				X	X	X								15
Champion data				X	X	X	X	X	X	X																										X	X	X	X						X	X	X	X	X								X		17
GPS	X			X	X	X	X	X	X	X				X	X	X	X	X	X																														X									X	16
Visual coaching software	X													X	X	X	X	X																																								X	7
Gym aware	X													X	X	X	X	X																																								X	7
Valde														X	X	X	X	X																																								X	6
Communication equipment (match day)	X			X	X	X	X			X		X		X	X																		X																										10
Game plan presentations	X			X	X	X	X	X	X	X																							X																										9
Theatre and meeting rooms	X			X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X		X	X	X	X	X						47
Zoom	X			X	X	X	X	X	X	X			X	X	X	X	X	X		X			X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X		X	X	X	X							39
Keynote				X	X	X	X	X	X	X				X	X					X												X	X			X			X						X	X	X												17
Video data bases	X			X	X	X	X	X	X	X																										X	X	X	X						X	X	X								X		X		17
Mobile phone applications	X			X	X	X	X	X	X	X			X	X	X	X	X			X		X	X						X			X	X			X	X	X							X	X	X												25
Website and social media	X			X	X	X	X			X																			X			X																											8
Finances and budget			X											X																		X	X	X	X	X																							7
Strategy documents			X											X																		X	X																										4
WADA/ASADA documents	X																			X												X																											3
Operation documents													X															X				X																											3
Expectations framework	X			X	X	X	X	X	X	X				X	X																	X	X								X																		13
Player and staff contracts																																X				X															X			X					4
AFL policies													X																			X																											2
Gym	X													X	X	X	X	X					X	X	X																																	X	10
Awards	X			X	X	X	X	X	X	X																						X	X																										10
Total	27	0	2	20	20	20	20	19	19	20	2	2	9	19	17	13	13	13	3	10	6	5	9	8	7	4	5	3	5	3	2	14	13	3	3	8	5	5	6	2	6	5	0	0	10	9	9	4	8	4	4	3	3	1	1	1	4	7	

Within the physical objects the leadership group (Actor 2) uses the same physical objects as the players (Actor 1).

Leading indicators are pro-active measures that allow organizations to predict, for example, safety issues before they arise (Grabowski et al., 2007). An example of a leading indicator in the current WDA includes "Player physical conditioning" which can be a leading indicator for future injuries. It is our view that the development of additional leading indicators for players, the team, the club, and the overall league could have substantial benefit for the football club and elite sporting organizations. This also represents an area for further research, in particular the identification of specific leading indicators and associated measures in different sports contexts.

Despite only a small number of values and priorities relating to the player and football team's performance itself (e.g., "Win matches," "Percentage differential," "Team and player training and match performance"), many of the Purpose Related Functions and Object-Related Processes identified are focused on supporting these values. This is perhaps expected; however, it is worth noting that less support is ostensibly given to other values and priorities such as staff health and wellbeing, culture, and compliance. This suggests that many functions are geared toward winning football matches, with less functions undertaken in support of other values such as developing culture. This highlights a potential conflict between allocation of resources between winning and developing culture. A counterintuitive approach to improving performance may be to redirect resources to developing culture, which has been shown as one of the most prominent factors contributing to successful sporting organizations (Bell-Laroche et al., 2014; Johnson et al., 2014). As such, there may be opportunities to improve the attainment of the lessor supported values as well as those relating to the football team's performance.

The Purpose-Related Functions identified are largely consistent with those found in previous analyses of elite sporting organizations i.e., "Playing matches," "Training," "Performance analysis," among others (Hulme et al., 2019). An insight derived from this level and the SOCA is the high level of specialist sport science and wellbeing support roles currently used by the football department. This is recognized in previous research with suggestions that professional sports organizations have evolved to encompass an increasingly complex team of specialized experts tasked with a diverse range of responsibilities (Sotiriadou and De Bosscher, 2018; Drust, 2019; Fullagar et al., 2019; Malone et al., 2019). Specifically, the SOCA highlighted the large number of specialist sports science functions and personnel (staff and external consultants) that currently contribute to football department operations. Included are functions such as "Strength and conditioning training," "Tactical and technical training," "Psychological training," "Performance analysis," "Injury prevention and rehabilitation," "Player health and wellbeing," "Management of player diets," and "Player recovery." Whilst the intention is to enhance performance, the use of many specialist roles and functions may be viewed differently by coaches and specialists regarding the importance of different activities (Fullagar et al., 2019; Otte et al., 2020). For example, knowledge on tactical and technical expertise is valued by coaches compared to specialist support staff whom often have a vested interest in their own specific area of expertise (Fullagar et al., 2019). This potentially creates the risk of siloed approach whereby the various skill sets are not well integrated (Otte et al., 2020). Given that the coaches ultimately make the decisions regarding training and competition, there is a level of uncertainty around the appropriate utility and value of applied sport science in professional sporting environments (Fullagar et al., 2019). A recent conceptual framework aimed to functionally integrate specialized roles into a multidisciplinary "department of methodology" drawing on expertise of sub-disciplines (e.g., skill acquisition, strength and conditioning) has been proposed (Otte et al., 2020; Rothwell et al., 2020). The purpose is to coordinate activities via shared theory and concepts, communication of ideas, and collaborative design of practice, which may prevent the siloing of sub-disciplines in elite sporting departments (Otte et al., 2020; Rothwell et al., 2020). A further consideration is that the resources required for large teams of specialized support staff and technology (Malone et al., 2019), may not be available post COVID-19. This presents an opportunity to streamline operations by merging roles and enhancing organizational cohesion by moving to a more generalist model whereby general sports science support is provided across these functions by an appropriately skilled but reduced number of personnel (Robertson, 2020).

Another potential negative impact of the large number of specialized support staff employed in professional sport is the conceivable intrusiveness to the players, which is beyond that of most other professions (Drust, 2019). Previous research has shown that a typical English Premier League player has more than 30 individual contacts with performance staff during a normal week (Drust, 2019). Although individual contacts were not measured in this study, the current findings indicate that many of the functions are designed to support player performance, development, and health and wellbeing. Whilst this is important, it also has the potential unwanted consequence of players being overly micromanaged which may diminish autonomy, competence, and subsequently motivation (Ryan and Deci, 2000). For example, the WDA highlights potential conflicts between the micromanagement required for supporting performance, and the functions of "Player empowerment," "Player education," and "Develop leadership capacity" in the players. To realize this, the organizational structure should be one that supports the players as the focal point of the club (Kihl et al., 2007), by providing the tools and skills necessary for development. The current findings suggest that, whilst the players are the focal point, many functions appear to be focused on providing direct interventions rather than on empowering players. As indicated in the SOCA, the players do not perform the Functions "Performance analysis," "Opposition performance analysis," or "Training evaluation." Presumably, the players contribute to these functions informally during practice, however, formalizing the involvement of players in these processes may provide autonomy and empowerment.

An insight from the Object-Related Processes level that conflicts with the club's ambition, is that there are few processes which support the Purpose-Related Functions of "Develop leadership capacity" and "Player education." Further, the SOCA analysis indicates that the player leadership group currently only undertake four of the 40 functions in the WDA. In the WDA, "Developing leadership capacity" and "Education of players" are linked with several important values and priorities measures above, such as, "Attraction and retention of players," "Club culture," and "Player empowerment." Given the importance of these functions in creating a player led environment, it may be pertinent to explore further ways in which players can be empowered. For example, this may be achieved by enabling player representation in decision making processes and policies that affect the playing group (Thibault and Babiak, 2005; Kihl et al., 2007).

Insights from Physical Objects level of the model included a high degree of overlap in terms of objects and their functionality. For example, "Sports code," "Hudl," "Champion Data," "visual coaching software," "Strength and conditioning software" are linked to the one process of "Captures game and training data." While these are all popular tools in sport science and coaching, consideration of how they are being used in terms of the trade-off between cost and resources required for analysis and usability of outputs for coaches is required. This is particularly relevant in light of new financial restrictions introduced following COVID-19. Furthermore, caution is urged with regard to the use of multiple data collection tools and player assessment methods. It is important that the measures do not become a target for the players to pursue at the expense of motivation for training to perform in football matches. This issue has been captured within sports science through Goodhart's law and the accompanying phrase "when a measure becomes a target, it ceases to be a good measure" (Goodhart, 1984; Strathern, 1997). Assigning importance to metrics can have unintended consequence on behavior which encourages a shift away from the initial intention of improving performance simply to satisfy the metric. For example, the degree of emphasis placed on distance covered, velocity measures (GPS and Gym Aware), the numerous Champion Data metrics (successful possessions, tackles completed, etc.) may have the potential to shift the focus from football performance to its component parts. This form of reductionism is increasingly being recognized as an inappropriate approach for performance analysis and improvement in sport (Glazier, 2010; McLean et al., 2019b; Salmon and McLean, 2019).

The SOCA revealed that there are a high number of actors within the football department. It is out of the scope of this article to determine the appropriate number of actors within the system. However, examination of specific roles is required to determine whether it is feasible to reduce the number of actors whilst still achieving the functions and values and priorities specific in the abstraction hierarchy. A recommendation for other sports organizations is to use methods such as WDA and SOCA to identify opportunities to reorganize their operations in response to COVID-19.

Implications for Sports Organization Restructure Post COVID-19

The current analysis has highlighted potential areas for modification in the AFL club's football department, and sports performance departments in general. Whilst it is beyond the scope of the present article to discuss redesigns specific to the club in question, it is possible to prescribe a generic approach that sports organizations can use in response to COVID-19 and other high impact events. First and foremost, it is the authors opinion that redesign activities should be driven by core STS values and

TABLE 9 | Sociotechnical system design prompts.

Abstraction hierarchy level	Prompt
Functional purposes	- Are there multiple purposes specified for the system? Do these conflict? Could they potentially conflict? Under what circumstances? - What factors within the system most positively influence the purpose/s? - What factors within the system most negatively influence the purpose/s? - Are any purpose/s of the system not well supported?
Values and priority measures	- Are there conflicting values and priority measures within the system? - Are the value and priority measures currently measured? - Are the value and priority measures currently achieved? - Do different value and priority measures exist in similar systems? - Do the value and priority measures have the potential to encourage functioning that doesn't support the purpose/s? How?
Purpose-related functions	- Are there any unexpected or unusual functions? - Could any other functions support the purpose/s of the system? - What functions are well-supported by the object-related processes? - What functions are poorly supported by the object-related processes?
Object-related processes	- Are there any unexpected or unusual object-related processes? - Could any other object-related process support each of the functions? - Which object-related processes are well-supported by the physical objects? - Which object-related processes are poorly supported by the physical objects? -
Physical objects	Are there any unexpected or unusual physical objects? - Could any other physical objects support each of the object-related processes? - Which physical objects have the most influence/support the most object-related processes? - Which physical objects have the least influence? - Are any physical objects unreliable in their ability to support the object-related processes? What influence does this have on the system? - How are physical objects related to one another? Do they suffer common mode failures? - Do any objects have the potential to conflict with, or affect the functioning of another object?

principles (Clegg, 2000; Read et al., 2015). Read et al. (2015) outline five core STS design values that appear to be pertinent in the sports context:

1. Humans should be treated as assets rather than as unpredictable, error-prone, and the cause of problems in otherwise well-designed systems.
2. Technology should be used as a tool to assist humans, rather than being seen as an end in its own right (Clegg, 2000; Norros, 2014).
3. Designs should focus on promoting quality of life, rather than creating strict work requirements (e.g., lack of flexibility around working hours and breaks), poor work design (e.g., repetitive tasks, lack of task rotation) and unachievable expectations. Quality work should be challenging and incorporate variety, should include scope for decision-making and choice and facilitate ongoing learning, should incorporate social support and recognition, and should have social relevance to life outside work (Cherns, 1976, 1987).
4. Designs should respect individual differences in the needs and preferences of the various end-users. For example, some players may prefer high levels of autonomy and control, while others may not.
5. Designers should consider all stakeholders, including the impacts of choices they make on various stakeholders. In the present context, these stakeholders include end users, broader club personnel, the community, sponsors, and the AFL.

Based on conducting analyses similar to the one presented in this article, sports organizations could use the prompts presented in **Table 9** to identify areas where redesign is required (adapted from Read et al., 2016). Participatory design approaches should then be used in conjunction with the STS values to develop and refine design concepts.

LIMITATIONS

The current study contained potential limitations. First, a small number of SMEs were involved in the WDA-SOCA development. However, the SMEs had extensive experience at the current organization and more broadly in the AFL, as well as across several different AFL clubs. Further development and validation of the model and its contents could occur in-house with additional club stakeholders and players. Despite the inclusion of a diverse set of SMEs, potential bias needs to be considered given the financial implications brought about by COVID-19 and the pending restructure to resource allocation within the football department. Further, current players were not included as SMEs in the current study. Given the important role of players within the football department, player input may have provided additional insights specific to the playing group. A second limitation is that the abstraction hierarchy method does not include weightings for the nodes or connections between the nodes across the levels of abstraction. As a result, the relative strength of different nodes and links is not considered and nodes with low incoming or outgoing links could be misinterpreted as being less important or less supported than others (e.g., culture in the present analysis). Whilst this was considered in the present analysis, future research could explore the use of weights to determine the relative importance of values, functions, processes and objects.

CONCLUSION

This study applied methods from the CWA framework, WDA and WDA-SOCA, in a first-of-its-kind approach to model an AFL football department. The modeling enabled identification of potential modifications to the clubs' operations in general, and for streamlining of operations in the wake of COVID-19. The realization of conflicts within the system captured via the modeling will assist the club to redesign operations, and the analysis has important messages for elite sports organizations generally. Firstly, sporting organizations should pursue appropriate goals that reflect the actual state of the system. Secondly, the measures used to assess whether the goals of the system are being achieved need to be specific and measurable in order to obtain valid assessments. Thirdly, shifting to a generalist model that combines specialized roles and objects may increase organizational cohesion, increase system resilience, reduce overlap, and reduce operational costs. This study has extended the applications of systems modeling in sport and provided a practical guide that can be used as template to direct other sporting clubs aiming to redesign their operations. It is hoped that this article emphasizes the important role that sociotechnical systems theory methods can have on sports and sports research.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception, model building, analysis, and writing of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.588959/full#supplementary-material

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Percentiles and Principal Component Analysis of Physical Fitness From a Big Sample of Children and Adolescents Aged 6-18 Years: The DAFIS Project

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Assessing physical fitness has emerged as a proxy of the health status of children and adolescents and therefore as relevant from a public health point of view. DAFIS is a project included in Plan Galicia Saudable (Healthy Galicia Plan) of the regional government of Galicia (Spain). DAFIS consists of an on-line software devoted to record the results of a standard physical fitness protocol carried out as a part of the physical education curriculum. The aims of this study were: to obtain normative values of physical fitness of the Galician school population evaluated in the DAFIS project, and to identify a reduced number of components and tests able to capture a significant amount of the variability in the physical fitness of children and adolescents. From an initial sample of 27784 records, 15287 cases (7543 males, 7744 females) were considered after filtering. Generalized Additive Models for Location, Scale and Shape were used for obtaining percentile curves and tables for each sex. Furthermore, a principal components analysis was performed, selecting the number of components by applying the Kaiser's rule and selecting a subset of variables considering the correlation between each variable and the components. Percentile curves and normative values are reported for each test and sex. Physical fitness was better in boys than in girls throughout age groups, except for flexibility that was consistently higher in girls. Two main components were detected throughout age groups: the first one representing body composition and partially cardiorespiratory fitness and the second one muscular fitness. For boys and girls, waist to height ratio had the highest correlations with the first component in four out of six age groups. The highest correlation with the second component, was most frequently observed for the handgrip test both in boys and girls (four out of six age groups). This study provides evidence about the utility of school community actions like DAFIS aimed to track the health-related fitness of children and adolescents. The results suggest that fat mass distribution (i.e., waist to height ratio and waist circumference) and muscular performance (mainly handgrip) concentrate a high proportion physical fitness variance.

Keywords: health-related fitness, adolescents, children, cardiorespiratory fitness, anthropometry, muscular fitness, motor fitness, percentiles

INTRODUCTION

The relationship between physical fitness and health in children and youth has been consistently established (Ruiz et al., 2006b; Ortega et al., 2008b; Smith et al., 2014). Thus, assessing physical fitness has emerged as a proxy of the health status of children and adolescents and consequently as relevant from a public health point of view (Ortega et al., 2008b; Cadenas-Sanchez et al., 2016). In this regard, several research projects have been conducted to establish both normative values of school populations (Castro-Piñero et al., 2009; Ortega et al., 2011a; De Miguel-Etayo et al., 2014; Tomkinson et al., 2017; Cadenas-Sanchez et al., 2019; Kolimechkov et al., 2019) and cut-off points in the outputs of fitness tests that identify health risk profiles in children and youth (Ruiz et al., 2016; Castro-Piñero et al., 2019; Cristi-Montero et al., 2019; Lang et al., 2019). These approaches are usually based on cross-sectional designs that provide information associated to a determined time-point.

Nevertheless, assessing physical fitness is a standard practice in physical education classes and therefore the management and analysis of that information recorded in the school system may be valuable for obtaining more dynamic information of great interest from a public health point of view. In this regard, the regional government of Galicia (Spain) approved in 2011 an action plan called Plan Galicia Saudable (Healthy Galicia Plan: HGP[1]) that contains several actions aimed to promote active living habits in this region. One of these actions consisted of the design and implementation of an on-line software devoted to recording the results of a standardized physical fitness protocol carried out as a part of the physical education curriculum. The software, named DAFIS, provides several types of reports aimed to be used by teachers and families. DAFIS was recognized as an example of good practice by the Health World Organization in 2015 (World Health Organization Regional Office for Europe, 2018), and since its launch in 2012 until February 2020 more than 27000 records had been stored. The analysis of this information is relevant for, on the one hand, obtaining normative values of the physical fitness in this region of Spain, and on the other hand to evaluate the utility of DAFIS as a practice useful for the public health monitoring.

One of the limitations of the project is the lack of time available in physical education classes to complete the full test battery. In fact, only 48.3% of the records corresponded to students that were fully evaluated. Therefore, it would be interesting to identify those assessments with the potential to reflect a high amount of physical fitness variability in students of different ages. In this regard, principal component analysis (PCA) is a statistical technique that allows reducing the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables (Jolliffe, 2006b). Associated to the PCA, a selection of a subset of variables that preserve most of the variation in the data can be carried out (Jolliffe, 2006a). Thus, it would be interesting to perform a PCA on the data recorded by DAFIS in order to select a reduced number of tests as representative of the health-related fitness of children and adolescents, with a relatively small loss of information.

Therefore, the aims of this study were: (i) to obtain normative values of physical fitness of the Galician school population evaluated in the DAFIS project, and (ii) to identify a reduced number of components and tests able to capture a significant amount of the variability in the physical fitness of children and adolescents. The results of this study may provide relevant information for the development of actions aimed to track health-related fitness at the population level.

MATERIALS AND METHODS

Study Design

DAFIS tool (Assessment of physical fitness data[2]) was used to assess the physical fitness of Galician children and adolescents. Data collection took place from 2012 to 2020. Participants were evaluated during school physical education classes by physical education teachers who had received specific training on software management and the application of the physical fitness protocols. Only physical education teachers who had attended to a course in which were instructed about the use of the software and the physical fitness battery procedures were included in the project. The procedures were conducted in accordance with the Declaration of Helsinki. It must be pointed out that the present work did not require ethical committee approval, since the data correspond to an institutional project (Galician Regional Government). In this regard, DAFIS only store information from students whose parents or legal guardians have signed written informed consent. Finally,

[1] https://galiciasaudable.xunta.gal/

[2] https://dafis.xunta.es/

participants' names are digitally coded to avoid the release of personal information.

Participants

A total of 27784 cases were obtained from the DAFIS database. Raw data were filtered according the following exclusion criteria: (a) outside the age range of 6-18 years; (b) cases without at least one test recorded; (c) cases with data entry errors. From these filtered cases, only the first evaluation performed by each participant was selected. Finally, 15287 cases (7543 males, 7744 females) were included in the study for further analysis (**Figure 1**).

Anthropometric and Physical Fitness Assessment

DAFIS battery entails 4 anthropometric measurements (weight, height, waist, and hip circumference) and 6 physical fitness tests (handgrip strength, standing long jump, back saver sit and reach, 4×10 m shuttle run test, bent hang arm, 20 m shuttle run test).

Weight in kilograms and height in centimetres were measured with a digital scale (Omron BF511, Kyoto, Japan) and a portable stadiometer (Seco Corp, Model 213, Hamburg, Germany) respectively. Waist and hip circumference were measured in centimetres using a measuring tape. Additionally, body mass index, waist to hip ratio and waist to height ratio were calculated as follows: Body mass index = weight/height^2 (BMI; kg/m^2); Waist to hip ratio = waist circumference/hip circumference (WHR); Waist to height ratio = waist circumference/height (WHtR), respectively.

Physical fitness tests allowed to assess upper body and lower body muscular fitness (handgrip for maximal isometric upper body strength, bent hang arm for upper body muscular endurance and standing long jump for lower body explosive strength), flexibility (back saver sit and reach), speed-agility (4×10 m shuttle run test) and cardiorespiratory fitness (20 m shuttle run test). All these tests have been extensively used in schools and research projects with children and adolescents (Ruiz et al., 2006b) showing acceptable levels of criterion validity and reliability (Ortega et al., 2008a; Ruiz et al., 2009, 2011). A brief description of these tests is reported below:

(a) Handgrip strength test was measured in a standing position with an adjustable grip using a digital hand dynamometer (TKK5401 grip-D, Takei, Niigata, Japan). Participants were instructed to squeeze the dynamometer as much as possible with the right and left hands in turn. Two attempts for the right and the left hand were carried out and the maximum score for each one was considered. The sum of both scores was used for further analysis, recorded in kilograms (Ortega et al., 2005; Laurson et al., 2017). Individual hand span was calculated according to equations previously published (Ruiz et al., 2006a; España-Romero et al., 2008).

(b) Standing long jump test (SLJ) was measured as the distance between the take-off line to the nearest contact with the floor landing with both feet together. Participants started in a standing position behind the take-off line, placing feet parallel at a shoulder level with. Arm swinging was allowed. Two attempts were performed and the best score in centimetres was considered for analysis (Roriz De Oliveira et al., 2014).

(c) Back saver sit and reach test was measured with the participants seated in the floor in front of a standard box with a small bar over a scale. Participants, with one leg straight and the other bent at the knee, should slide the arms as far forward with the palms down bending the trunk. Two attempts for each limb were performed and the best score was selected. The average of both values in centimetres were calculated for further analysis (Ortega et al., 2008a; Chillón et al., 2010).

(d) 4×10 m shuttle run test (4×10 mSRT), consisted in running as fast as possible between two parallel lines drawn 10 m apart. Three sponges were placed behind the lines, which were picked up (first time) or exchange (second and third time). The stopwatch was started at the "Go" signal and stopped when the participant crosses the finish line with one foot. Two trials were conducted and the best of them was retained to the nearest 0.1 s (Ortega et al., 2008a).

(e) Bent hang arm test. The participants were instructed to hang from a bar, as time as possible, with the arms bent at 90 degrees, hands shoulder-width apart and the palms facing forward. They were assisted to reach the bar into the initial position and time was recorded to the nearest 0.1 s, until the chin falls below the horizontal bar (Castro-Piñero et al., 2009).

(f) 20 m shuttle run test (20 mSRT), consisted in running in a straight line between two parallel pivots placed 20 m apart, keeping an incremental pace emitted from a pre-recorded audio. The initial speed corresponded to 8.5 km h^{-1}, increasing by 0.5 km h^{-1} each minute (Leger et al., 1988). The test stopped when the participants failed to reach the pivot on two consecutive occasions. Each minute equals one stage, so the last completed stage was registered (Ortega et al., 2008a). Children younger than 10 years of age were excluded of performing this test.

Statistical Analysis

All analyses were separately performed. Generalized Additive Models for Location, Scale and Shape (GAMLSS) (Stasinopoulos and Rigby, 2007) were used for obtaining percentile curves of the anthropometric and physical fitness outcomes considering the decimal ages which were calculated as the difference between evaluation date and birth date. We used the *gamlss* function of the gamlss package (version 5.1–6) for the statistical software R (version 4.0.2). Three distributions were used for fitting the values: the Box–Cox power exponential (BCPE), the Box–Cox t (BCT) and the Box–Cox Cole and Green (BCCG). For the search of the optimum degrees of freedom and non-linear parameters, P-Spline smoothing function was used as recommended in the gamlss package reference manual[3]. The global goodness of fit of each model was analyzed considering the Akaike Information Criterion (AIC) selecting that with the lowest value. Complementary, the residuals were analyzed by QQ plots and

[3]https://cran.r-project.org/web/packages/gamlss/gamlss.pdf

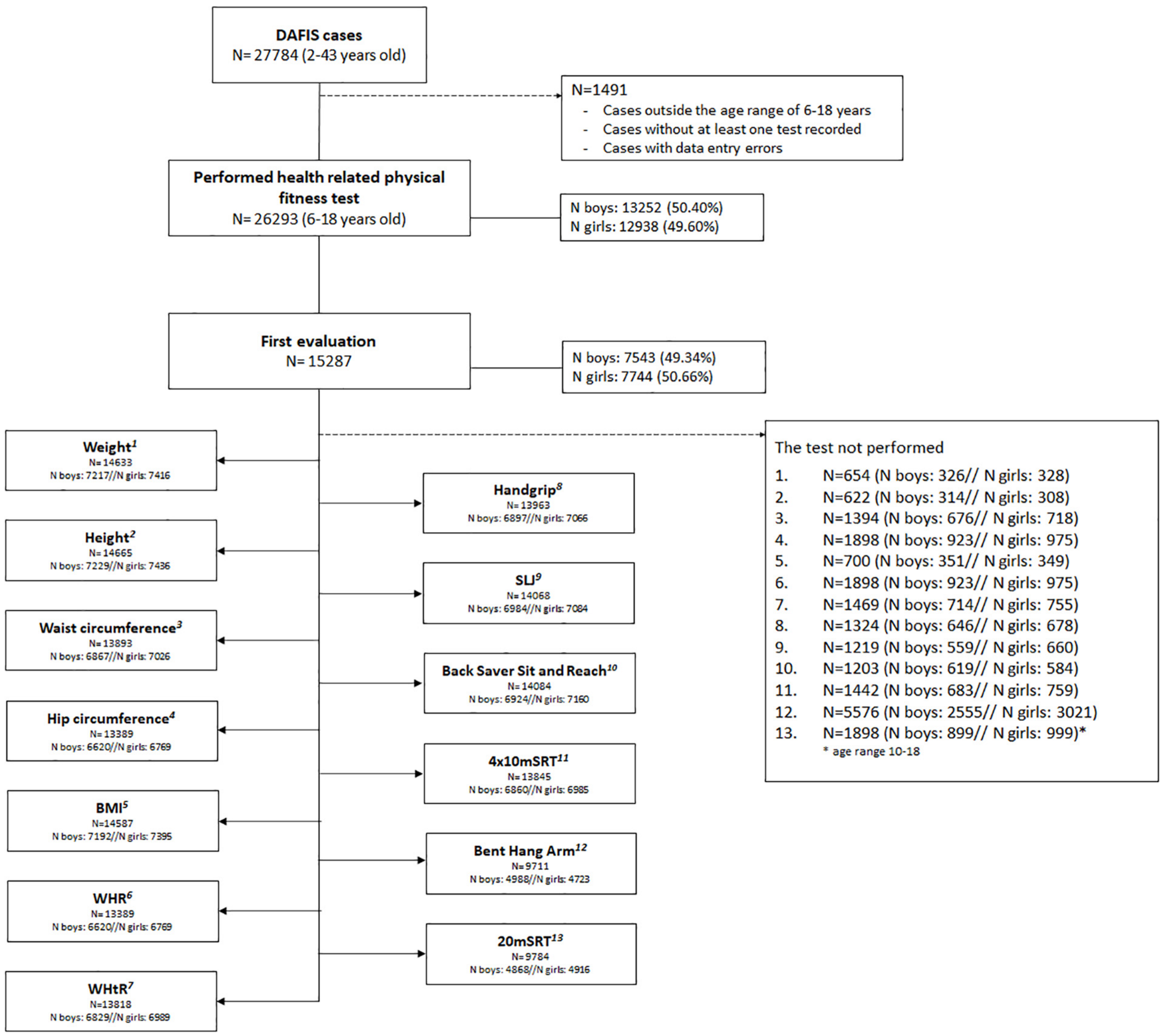

FIGURE 1 | Flowchart of the exclusion criteria. BMI, body mass index; WHR, waist to hip ratio; WHtR, waist to height ratio; SLJ, standing long jump; 4×10 mSRT: 4×10 m shuttle run test; 20 mSRT: 20 m shuttle run test.

the Q statistics for testing normality of the residuals within age groups (Stasinopoulos and Rigby, 2007). The model with the lowest AIC and therefore chosen for calculating percentile curves and values are listed in **Table 1**. Percentile values for each test were computed only considering data greater than zero.

A factorial Analysis of Variance (ANOVA) was performed to evaluate the effect of age, sex, and their interaction (age × sex) on the results of each variable. The effect size of each factor and interaction was estimated by calculating partial eta squared (η^2).

The PCA was carried out by using the function prcomp() of R (version 4.0.2). Six decimal age mixed intervals (i.e., right-open intervals) were considered: lower than 8; [8,10); [10,12); [12,14); [14,16) and [16,18). These age intervals approximately match education cycles in Spain. Ten variables were considered for PCAs: BMI, waist circumference, WHR, WHtR, handgrip, SLJ, back-saver sit and reach, 4x10mSRT, bent hang arm, 20mSRT. For the first and second age category, 20 mSRT was not included since this test was only performed for students over 10. The variables were standardized in order to equate their scale, and therefore PCs were obtained from correlation matrix instead variance-covariance matrix. The number of PCs was selected applying the Kaiser's rule, meaning that only PCs with eigenvalues (i.e., variance) exceeding 1 were retained (Jolliffe, 2006a). In other words, we only considered PCs that contained more information than one of the original standardised variables. Finally, in order to select the subset of variables that preserved a high proportion of the variance in the initial set, the correlation between each variable and the selected PCs was calculated, retaining from each PC that variable with the highest coefficient in absolute value (Jolliffe, 2006a). The PCA assumes that the original variables are correlated. Thus, this assumption was checked by obtaining the determinant of the correlation matrix (i.e.,

TABLE 1 | Distributions selected for fitting the values.

TEST	SEX	MODEL
Weight	Boys	BCPE
	Girls	BCPE
Height	Boys	BCPE
	Girls	BCT
Waist circumference	Boys	BCPE
	Girls	BCPE
Hip circumference	Boys	BCPE
	Girls	BCPE
BMI	Boys	BCPE
	Girls	BCPE
WHR	Boys	BCT
	Girls	BCT
WHTR	Boys	BCPE
	Girls	BCPE
Handgrip	Boys	BCPE
	Girls	BCT
SLJ	Boys	BCCG
	Girls	BCCG
Back saver sit and reach	Boys	BCPE
	Girls	BCPE
4x10mSRT	Boys	BCPE
	Girls	BCT
Bent hang arm	Boys	BCT
	Girls	BCT
20mSRT	Boys	BCPE
	Girls	BCPE

BCPE, Box–Cox power exponential distribution; BCT, Box–Cox t distribution; BCCG, Box–Cox Cole and Green distribution; BMI, body mass index; WHR, waist to hip ratio; WHtR, waist to height ratio; SLJ, standing long jump; 4×10 mSRT, 4×10 m shuttle run test; 20 mSRT, 20 m shuttle run test.

values close to 0 meaning correlation between variables) and by Bartlett's test of sphericity. The null hypothesis for Barlett's test is that the correlation matrix equals the identity matrix and therefore rejecting this hypothesis is interpreted as an evidence of multicollinearity between variables.

RESULTS

Estimated percentiles 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 95 (P5, P10, P20, P30, P40, P50, P60, P70, P80, P90, P95) are presented in **Table 2** for anthropometric and body composition variables and in **Table 3** for physical fitness ones. Percentile curves are depicted in **Figures 2–5** for boys and girls, respectively. For clarity, only P10, P25, P50, P75, and P90 are shown. The results of ANOVA are presented in **Table 4**.

The determinants of the correlation matrix were close to 0 in all the cases (from 0.001 to 0.029) and similarly, Bartlett's test was significant for all ages and sex groups ($p < 0.001$ in all the cases). The correlations between the initial set of variables and the PCs retained according to the Kaiser's rule are presented in **Table 5** for boys and girls. The highest correlation in absolute value between each PC and the variables, is highlighted in bold.

DISCUSSION

The main findings of this study were: (i) higher physical fitness was observed in boys in comparison with girls except for flexibility, (ii) PCA consistently detected two main PCs associated to body composition and neuromuscular performance respectively, and (iii) the variables to be selected in order to design a reduced version of the initial set of tests while a high proportion of the variance is preserved depend on the sex and age category.

Although we must be prudent when comparing our data with previous studies, given the methodological differences, the results obtained from the DAFIS project are similar to those previously reported for similar populations (Ortega et al., 2005, 2011a; Castro-Piñero et al., 2009; Marrodán Serrano et al., 2009). In this regard, applying the cut-off points identified by Cole et al. (2000) for BMI, the prevalence of overweight and obesity were 34.88% and 35.82% in boys and girls respectively, which is coincident with data previously reported for Galician children and adolescents (Pérez-Ríos et al., 2018) and slightly lower than Spanish scholars (Sánchez-Cruz et al., 2013; García-Solano et al., 2020). Nevertheless, BMI results can be complemented by the analysis of cut-off points suggested for adiposity indicators. In this regard, WHtR has been suggested as a measurement of adiposity and fat distribution that allows to normalize the waist circumference to a body size measurement that is not influenced by adiposity (Nevill et al., 2017).Thus, a ratio equals or higher than 0.5 is considered as indicative of excess of adiposity (Maffetone et al., 2017; Nevill et al., 2017). In this regard, a novelty of our study is to report percentile curves for this ratio, that reflects a prevalence of excessive adiposity in the sample of around 25.79%. Regarding physical fitness, P50 values observed in the current study are consistent with those previously reported for Spanish (Castro-Piñero et al., 2009; Marrodán Serrano et al., 2009) and European (Ortega et al., 2011a; De Miguel-Etayo et al., 2014) samples. Results of ANOVA reflected main effect of sex, showing that physical fitness was higher in boys than in girls except for flexibility, being this result concordant with data previously published (De Miguel-Etayo et al., 2014; Roriz De Oliveira et al., 2014; Santos et al., 2014). On the other hand, a significant sex × age interactions were detected for all the physical fitness data, suggesting a sex-specific development of physical fitness with age. However, we must be careful with this interpretation given the cross-sectional design used in our study. Overall, the results suggest that the data stored by DAFIS are robust, which may support its simultaneous use as a didactic resource for Physical Education teachers and an effective tool for tracking health related fitness at the population level.

One limitation of the physical fitness tests is the lack of robust cut-off points for identifying risk profiles. Nevertheless, a recent review (Ruiz et al., 2016) has suggested reference values of 20 mSRT performance for detecting cardiovascular risk profiles. Results of the 20 mSRT showed that only 19.33% (27.70% of boys and 11.03% of girls) performed under the cut points associated with a healthy cardiorespiratory fitness level. Considering BMI categories, the prevalence of low cardiorespiratory fitness in overweight and obese subjects was 43.6% and 15.21% in boys

TABLE 2 | Estimated percentiles for anthropometric and body composition variables.

	Boys											Girls										
Percentiles																						
Age	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Weight (kg)																						
6	17.40	18.33	19.54	20.47	21.29	22.09	22.97	24.03	25.51	28.09	30.88	17.62	18.31	19.30	20.17	21.04	21.97	22.99	24.16	25.61	27.78	29.74
7	19.75	20.82	22.26	23.40	24.46	25.53	26.69	28.10	29.98	33.17	36.47	19.40	20.32	21.66	22.82	23.98	25.22	26.59	28.16	30.14	33.13	35.86
8	22.01	23.23	24.90	26.29	27.62	28.99	30.52	32.31	34.68	38.54	42.39	21.54	22.71	24.40	25.87	27.32	28.86	30.56	32.51	34.96	38.66	42.02
9	24.66	26.05	28.02	29.70	31.34	33.08	35.01	37.27	40.19	44.82	49.28	24.05	25.48	27.52	29.25	30.96	32.76	34.72	36.97	39.76	43.95	47.73
10	26.91	28.49	30.75	32.71	34.64	36.70	38.99	41.65	45.05	50.33	55.29	26.34	28.04	30.45	32.48	34.45	36.52	38.76	41.32	44.50	49.25	53.51
11	29.08	30.89	33.49	35.72	37.92	40.26	42.85	45.85	49.65	55.48	60.88	28.81	30.90	33.84	36.30	38.67	41.13	43.79	46.82	50.58	56.19	61.22
12	32.26	34.39	37.41	39.98	42.49	45.12	48.03	51.37	55.61	62.10	68.11	32.27	34.73	38.14	40.97	43.67	46.45	49.45	52.86	57.09	63.42	69.09
13	36.42	38.91	42.39	45.28	48.06	50.94	54.08	57.72	62.33	69.47	76.13	36.99	39.51	42.99	45.85	48.57	51.36	54.38	57.82	62.14	68.68	74.64
14	40.98	43.75	47.54	50.62	53.52	56.48	59.70	63.43	68.22	75.72	82.82	41.53	43.90	47.18	49.86	52.42	55.05	57.92	61.24	65.48	72.09	78.33
15	45.32	48.26	52.22	55.37	58.28	61.20	64.36	68.06	72.86	80.51	87.89	44.20	46.44	49.53	52.06	54.46	56.93	59.64	62.81	66.93	73.52	79.94
16	49.02	52.09	56.14	59.30	62.16	64.99	68.04	71.64	76.37	84.07	91.64	45.47	47.67	50.67	53.13	55.45	57.84	60.46	63.56	67.64	74.28	80.90
17	52.50	55.67	59.79	62.94	65.74	68.47	71.40	74.89	79.54	87.25	94.97	45.64	47.83	50.83	53.28	55.59	57.96	60.58	63.71	67.88	74.84	81.99
18	56.13	59.41	63.59	66.72	69.47	72.10	74.91	78.29	82.87	90.56	98.41	45.12	47.33	50.35	52.81	55.13	57.51	60.16	63.36	67.70	75.14	83.04
Height (cm)																						
6	108.64	110.82	124.36	114.92	116.24	129.04	118.58	119.87	121.44	123.72	125.69	107.86	109.54	111.61	113.12	114.44	115.68	116.93	118.29	119.90	122.17	124.08
7	114.21	116.35	130.02	120.54	121.94	134.95	124.48	125.87	127.56	130.01	132.10	113.54	115.39	117.66	119.33	120.77	122.13	123.50	124.99	126.76	129.24	131.33
8	119.68	121.82	134.66	126.15	127.65	139.89	130.43	131.96	133.80	136.45	138.72	118.95	120.93	123.37	125.15	126.70	128.15	129.62	131.21	133.09	135.74	137.96
9	125.35	127.45	138.91	131.87	133.46	144.58	136.46	138.11	140.09	142.92	145.33	124.33	126.44	129.03	130.92	132.55	134.09	135.65	137.33	139.31	142.10	144.44
10	129.91	132.03	144.31	136.60	138.29	150.59	141.52	143.29	145.41	148.41	150.96	129.44	131.69	134.44	136.46	138.19	139.83	141.48	143.26	145.36	148.31	150.78
11	133.91	136.13	150.69	140.99	142.82	157.56	146.36	148.29	150.58	153.80	156.51	134.93	137.30	140.22	142.34	144.17	145.89	147.63	149.50	151.70	154.80	157.38
12	138.82	141.25	157.46	146.61	148.64	164.18	152.57	154.70	157.21	160.69	163.59	140.68	143.11	146.09	148.26	150.12	151.87	153.64	155.54	157.78	160.91	163.53
13	144.58	147.29	163.30	153.22	155.44	169.44	159.69	161.97	164.62	168.25	171.23	145.54	147.93	150.85	152.97	154.79	156.50	158.21	160.06	162.24	165.28	167.82
14	151.23	154.03	166.68	159.97	162.14	172.50	166.22	168.38	170.88	174.28	177.06	148.88	151.18	153.96	155.98	157.71	159.33	160.96	162.71	164.77	167.64	170.04
15	157.31	160.04	168.67	165.63	167.61	174.37	171.27	173.21	175.47	178.58	181.13	150.68	152.92	155.62	157.56	159.22	160.78	162.34	164.02	165.99	168.76	171.07
16	160.68	163.45	171.46	168.93	170.80	177.07	174.20	176.03	178.20	181.25	183.80	151.54	153.83	156.55	158.48	160.12	161.65	163.18	164.83	166.78	169.54	171.89
17	108.64	110.82	124.36	114.92	116.24	129.04	118.58	119.87	121.44	123.72	125.69	150.98	153.58	156.48	158.46	160.12	161.65	163.18	164.84	166.84	169.78	172.41
18	114.21	116.35	130.02	120.54	121.94	134.95	124.48	125.87	127.56	130.01	132.10	147.38	151.31	155.01	157.25	159.02	160.61	162.20	163.97	166.22	169.93	173.90

(Continued)

TABLE 2 | Continued

	Boys											Girls										
Percentiles																						
Age	**P_5**	**P_{10}**	**P_{20}**	**P_{30}**	**P_{40}**	**P_{50}**	**P_{60}**	**P_{70}**	**P_{80}**	**P_{90}**	**P_{95}**	**P_5**	**P_{10}**	**P_{20}**	**P_{30}**	**P_{40}**	**P_{50}**	**P_{60}**	**P_{70}**	**P_{80}**	**P_{90}**	**P_{95}**
Waist circumference (cm)																						
6	50.72	51.52	52.70	53.76	54.84	56.02	57.36	58.95	61.00	64.29	67.58	50.20	50.91	52.03	53.10	54.25	55.53	56.98	58.67	60.75	63.75	66.36
7	51.95	52.91	54.33	55.61	56.94	58.39	60.04	61.98	64.46	68.36	72.16	51.34	52.25	53.66	54.99	56.41	57.98	59.77	61.84	64.38	68.10	71.37
8	52.85	54.00	55.73	57.30	58.93	60.71	62.73	65.08	68.05	72.60	76.87	52.17	53.31	55.06	56.68	58.38	60.25	62.35	64.76	67.71	71.98	75.71
9	53.59	54.97	57.04	58.91	60.85	62.96	65.34	68.08	71.48	76.56	81.15	53.06	54.44	56.52	58.41	60.35	62.46	64.80	67.46	70.69	75.31	79.31
10	54.60	56.20	58.59	60.72	62.89	65.25	67.87	70.86	74.53	79.91	84.66	53.98	55.57	57.93	60.02	62.14	64.42	66.92	69.75	73.17	78.08	82.32
11	55.86	57.68	60.34	62.68	65.03	67.55	70.32	73.48	77.35	83.05	88.09	54.91	56.69	59.27	61.52	63.77	66.17	68.80	71.76	75.37	80.61	85.19
12	57.28	59.32	62.22	64.71	67.17	69.78	72.64	75.92	79.99	86.13	91.72	56.14	58.04	60.77	63.11	65.42	67.87	70.54	73.57	77.30	82.81	87.74
13	58.97	61.14	64.18	66.73	69.20	71.79	74.62	77.90	82.06	88.53	94.64	57.60	59.56	62.33	64.67	66.95	69.34	71.95	74.94	78.67	84.32	89.49
14	60.94	63.13	66.15	68.63	70.99	73.43	76.11	79.24	83.28	89.75	96.06	58.71	60.68	63.43	65.72	67.92	70.21	72.71	75.60	79.27	84.96	90.33
15	62.79	64.95	67.87	70.24	72.46	74.74	77.23	80.16	84.02	90.35	96.71	59.20	61.19	63.91	66.13	68.24	70.42	72.78	75.54	79.08	84.71	90.14
16	64.37	66.50	69.35	71.63	73.76	75.91	78.27	81.08	84.83	91.09	97.56	59.61	61.62	64.33	66.50	68.53	70.58	72.82	75.44	78.87	84.40	89.86
17	65.95	68.05	70.85	73.07	75.13	77.20	79.47	82.19	85.87	92.12	98.72	60.27	62.30	65.00	67.13	69.08	71.04	73.17	75.69	79.03	84.57	90.19
18	67.64	69.72	72.47	74.63	76.62	78.61	80.79	83.42	87.02	93.22	99.90	61.02	63.09	65.80	67.90	69.80	71.67	73.71	76.15	79.45	85.06	90.94
Hip circumference (cm)																						
6	59.67	60.32	61.34	62.32	63.36	64.53	65.87	67.44	69.41	72.37	75.08	59.65	60.32	61.36	62.34	63.38	64.53	65.82	67.31	69.13	71.77	74.08
7	61.18	62.07	63.42	64.67	65.98	67.43	69.06	70.94	73.26	76.69	79.77	61.30	62.23	63.63	64.93	66.27	67.74	69.38	71.26	73.57	76.91	79.85
8	62.44	63.65	65.46	67.06	68.70	70.45	72.39	74.59	77.26	81.11	84.47	62.67	63.93	65.79	67.43	69.10	70.89	72.85	75.05	77.70	81.49	84.75
9	63.75	65.36	67.65	69.61	71.55	73.59	75.78	78.23	81.18	85.38	88.98	63.99	65.65	68.01	70.01	71.97	74.01	76.20	78.61	81.47	85.47	88.83
10	65.47	67.44	70.16	72.40	74.54	76.73	79.06	81.62	84.69	89.07	92.80	65.32	67.43	70.31	72.67	74.89	77.14	79.50	82.06	85.06	89.23	92.69
11	67.44	69.75	72.82	75.27	77.53	79.80	82.18	84.79	87.93	92.43	96.30	67.20	69.76	73.13	75.80	78.24	80.66	83.17	85.88	89.07	93.53	97.24
12	69.64	72.21	75.56	78.15	80.49	82.79	85.20	87.86	91.11	95.86	100.00	70.09	72.89	76.53	79.35	81.89	84.37	86.95	89.77	93.16	98.00	102.14
13	72.18	74.93	78.44	81.09	83.44	85.72	88.09	90.75	94.06	99.00	103.42	73.67	76.51	80.14	82.91	85.37	87.76	90.25	93.03	96.43	101.46	105.89
14	75.06	77.88	81.41	84.03	86.31	88.48	90.75	93.33	96.59	101.58	106.17	76.97	79.80	83.37	86.04	88.38	90.63	92.97	95.63	98.96	104.03	108.63
15	77.79	80.64	84.17	86.74	88.94	91.01	93.16	95.66	98.88	103.95	108.72	79.34	82.18	85.71	88.29	90.52	92.62	94.81	97.34	100.56	105.58	110.26
16	80.17	83.08	86.62	89.16	91.30	93.28	95.34	97.78	100.97	106.13	111.11	80.70	83.59	87.12	89.65	91.80	93.79	95.86	98.29	101.45	106.47	111.27
17	82.57	85.48	88.97	91.44	93.49	95.35	97.30	99.64	102.77	107.95	113.09	81.52	84.46	87.99	90.48	92.55	94.44	96.41	98.75	101.87	106.95	111.92
18	85.03	87.89	91.30	93.66	95.60	97.34	99.16	101.38	104.41	109.55	114.81	82.18	85.15	88.67	91.11	93.10	94.88	96.74	99.00	102.06	107.19	112.35

(Continued)

TABLE 2 | Continued

	Boys											Girls										
Percentiles																						
Age	**P_5**	**P_{10}**	**P_{20}**	**P_{30}**	**P_{40}**	**P_{50}**	**P_{60}**	**P_{70}**	**P_{80}**	**P_{90}**	**P_{95}**	**P_5**	**P_{10}**	**P_{20}**	**P_{30}**	**P_{40}**	**P_{50}**	**P_{60}**	**P_{70}**	**P_{80}**	**P_{90}**	**P_{95}**
BMI																						
6	13.96	14.38	14.96	15.44	15.89	16.37	16.90	17.54	18.38	19.78	21.25	13.96	14.38	14.96	15.44	15.89	16.37	16.90	17.54	18.38	19.78	21.25
7	14.19	14.64	15.28	15.83	16.36	16.93	17.57	18.32	19.30	20.90	22.50	14.19	14.64	15.28	15.83	16.36	16.93	17.57	18.32	19.30	20.90	22.50
8	14.39	14.88	15.58	16.20	16.82	17.49	18.24	19.12	20.25	22.02	23.74	14.39	14.88	15.58	16.20	16.82	17.49	18.24	19.12	20.25	22.02	23.74
9	14.60	15.13	15.90	16.59	17.29	18.05	18.90	19.89	21.15	23.08	24.89	14.60	15.13	15.90	16.59	17.29	18.05	18.90	19.89	21.15	23.08	24.89
10	14.85	15.42	16.26	17.01	17.78	18.61	19.54	20.62	21.97	24.03	25.92	14.85	15.42	16.26	17.01	17.78	18.61	19.54	20.62	21.97	24.03	25.92
11	15.16	15.78	16.68	17.48	18.29	19.17	20.15	21.28	22.70	24.85	26.83	15.16	15.78	16.68	17.48	18.29	19.17	20.15	21.28	22.70	24.85	26.83
12	15.54	16.20	17.15	17.99	18.83	19.73	20.73	21.89	23.36	25.60	27.70	15.54	16.20	17.15	17.99	18.83	19.73	20.73	21.89	23.36	25.60	27.70
13	15.98	16.68	17.67	18.53	19.38	20.28	21.29	22.46	23.95	26.28	28.50	15.98	16.68	17.67	18.53	19.38	20.28	21.29	22.46	23.95	26.28	28.50
14	16.49	17.21	18.24	19.10	19.95	20.84	21.83	22.99	24.49	26.86	29.15	16.49	17.21	18.24	19.10	19.95	20.84	21.83	22.99	24.49	26.86	29.15
15	17.04	17.78	18.82	19.69	20.52	21.40	22.37	23.51	24.99	27.37	29.71	17.04	17.78	18.82	19.69	20.52	21.40	22.37	23.51	24.99	27.37	29.71
16	17.59	18.35	19.40	20.27	21.10	21.96	22.91	24.03	25.50	27.89	30.26	17.59	18.35	19.40	20.27	21.10	21.96	22.91	24.03	25.50	27.89	30.26
17	18.12	18.90	19.97	20.85	21.67	22.52	23.45	24.55	26.01	28.41	30.83	18.12	18.90	19.97	20.85	21.67	22.52	23.45	24.55	26.01	28.41	30.83
18	18.65	19.45	20.55	21.42	22.24	23.08	23.99	25.08	26.53	28.94	31.40	18.65	19.45	20.55	21.42	22.24	23.08	23.99	25.08	26.53	28.94	31.40
WHR																						
6	0.81	0.83	0.85	0.86	0.87	0.88	0.89	0.90	0.92	0.95	0.97	0.80	0.81	0.83	0.85	0.86	0.87	0.88	0.90	0.92	0.94	0.97
7	0.80	0.82	0.84	0.85	0.86	0.88	0.89	0.90	0.92	0.95	0.97	0.79	0.80	0.82	0.84	0.85	0.86	0.88	0.89	0.91	0.94	0.97
8	0.79	0.81	0.83	0.84	0.85	0.87	0.88	0.90	0.91	0.95	0.98	0.77	0.79	0.81	0.83	0.84	0.85	0.87	0.88	0.90	0.93	0.96
9	0.78	0.79	0.82	0.83	0.84	0.86	0.87	0.89	0.91	0.94	0.98	0.76	0.78	0.81	0.82	0.84	0.85	0.86	0.88	0.90	0.94	0.97
10	0.77	0.78	0.81	0.82	0.84	0.85	0.87	0.88	0.91	0.94	0.98	0.75	0.77	0.79	0.81	0.83	0.84	0.86	0.87	0.90	0.93	0.97
11	0.76	0.78	0.80	0.82	0.83	0.85	0.86	0.88	0.91	0.94	0.98	0.73	0.75	0.77	0.79	0.81	0.82	0.84	0.86	0.88	0.92	0.95
12	0.75	0.77	0.80	0.81	0.83	0.85	0.86	0.88	0.91	0.95	0.99	0.71	0.73	0.76	0.77	0.79	0.81	0.82	0.84	0.87	0.91	0.94
13	0.75	0.77	0.79	0.81	0.83	0.84	0.86	0.88	0.90	0.94	0.98	0.70	0.72	0.74	0.76	0.78	0.80	0.81	0.83	0.86	0.90	0.93
14	0.74	0.76	0.78	0.80	0.82	0.83	0.85	0.87	0.89	0.93	0.97	0.69	0.71	0.73	0.75	0.76	0.78	0.80	0.82	0.84	0.88	0.91
15	0.73	0.75	0.77	0.79	0.81	0.82	0.84	0.86	0.88	0.92	0.95	0.67	0.69	0.71	0.73	0.75	0.76	0.78	0.79	0.82	0.85	0.89
16	0.73	0.75	0.77	0.78	0.80	0.81	0.83	0.85	0.87	0.90	0.94	0.67	0.69	0.71	0.72	0.74	0.75	0.77	0.79	0.81	0.84	0.87
17	0.73	0.75	0.77	0.78	0.80	0.81	0.83	0.85	0.87	0.90	0.94	0.67	0.69	0.71	0.73	0.74	0.75	0.77	0.79	0.81	0.84	0.87
18	0.74	0.76	0.78	0.79	0.81	0.82	0.84	0.85	0.87	0.91	0.94	0.68	0.70	0.72	0.74	0.75	0.76	0.78	0.80	0.82	0.85	0.88

(Continued)

TABLE 2 | Continued

	Boys											Girls										
Percentiles																						
Age	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
WHtR																						
6	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.54	0.56	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.52	0.54	0.56
7	0.42	0.43	0.45	0.46	0.47	0.48	0.49	0.50	0.52	0.54	0.57	0.42	0.43	0.44	0.45	0.47	0.48	0.49	0.50	0.52	0.55	0.57
8	0.41	0.42	0.44	0.45	0.46	0.47	0.49	0.50	0.52	0.55	0.58	0.41	0.42	0.44	0.45	0.46	0.47	0.49	0.50	0.52	0.55	0.57
9	0.40	0.41	0.43	0.44	0.46	0.47	0.48	0.50	0.52	0.56	0.59	0.40	0.41	0.43	0.44	0.45	0.47	0.48	0.50	0.52	0.55	0.57
10	0.40	0.41	0.42	0.44	0.45	0.47	0.48	0.50	0.53	0.56	0.59	0.39	0.40	0.42	0.43	0.45	0.46	0.48	0.49	0.51	0.55	0.57
11	0.39	0.40	0.42	0.44	0.45	0.47	0.48	0.50	0.53	0.56	0.59	0.38	0.39	0.41	0.43	0.44	0.45	0.47	0.49	0.51	0.54	0.57
12	0.39	0.40	0.42	0.43	0.45	0.46	0.48	0.50	0.53	0.56	0.60	0.37	0.39	0.41	0.42	0.43	0.45	0.46	0.48	0.51	0.54	0.57
13	0.38	0.39	0.41	0.43	0.44	0.46	0.47	0.49	0.52	0.56	0.59	0.37	0.38	0.40	0.42	0.43	0.44	0.46	0.48	0.50	0.53	0.57
14	0.38	0.39	0.41	0.42	0.43	0.45	0.47	0.48	0.51	0.55	0.58	0.37	0.38	0.40	0.41	0.43	0.44	0.46	0.47	0.50	0.53	0.56
15	0.37	0.39	0.40	0.42	0.43	0.44	0.46	0.47	0.50	0.53	0.57	0.37	0.38	0.40	0.41	0.42	0.44	0.45	0.47	0.49	0.53	0.56
16	0.38	0.39	0.40	0.42	0.43	0.44	0.45	0.47	0.49	0.53	0.56	0.37	0.38	0.40	0.41	0.42	0.44	0.45	0.47	0.49	0.52	0.56
17	0.38	0.39	0.41	0.42	0.43	0.44	0.46	0.47	0.49	0.53	0.56	0.37	0.38	0.40	0.41	0.43	0.44	0.45	0.47	0.49	0.52	0.56
18	0.39	0.40	0.41	0.42	0.44	0.45	0.46	0.48	0.50	0.53	0.57	0.37	0.39	0.40	0.42	0.43	0.44	0.45	0.47	0.49	0.53	0.56

BMI, body mass index; WHR, waist to hip ratio; WHtR, waist to height ratio.

TABLE 3 | Estimated percentiles for the physical fitness tests.

	Boys											Girls										
Percentiles																						
Age	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Handgrip (kg)																						
6	12.45	13.09	14.07	14.97	15.90	16.89	17.94	19.08	20.35	21.97	23.17	11.21	12.07	13.21	14.11	14.93	15.75	16.62	17.63	18.90	20.87	22.71
7	13.71	14.69	16.07	17.22	18.33	19.46	20.65	21.95	23.45	25.49	27.16	12.64	13.66	15.00	16.04	16.98	17.90	18.88	19.99	21.37	23.48	25.39
8	15.39	16.79	18.62	20.03	21.29	22.52	23.80	25.21	26.91	29.37	31.49	14.70	15.96	17.58	18.82	19.93	21.01	22.14	23.41	24.97	27.32	29.42
9	17.94	19.68	21.86	23.50	24.92	26.29	27.69	29.24	31.14	33.92	36.34	17.25	18.80	20.77	22.26	23.58	24.86	26.19	27.66	29.48	32.17	34.56
10	20.45	22.39	24.83	26.66	28.25	29.77	31.34	33.07	35.19	38.27	40.95	19.31	21.11	23.38	25.08	26.58	28.03	29.53	31.20	33.23	36.24	38.91
11	22.66	24.87	27.65	29.70	31.49	33.19	34.94	36.90	39.33	42.94	46.13	22.18	24.33	27.02	29.02	30.78	32.48	34.23	36.16	38.53	42.03	45.14
12	25.57	28.22	31.56	34.04	36.20	38.25	40.38	42.80	45.85	50.48	54.67	25.98	28.55	31.72	34.07	36.13	38.10	40.13	42.38	45.12	49.17	52.78
13	29.77	32.96	37.09	40.22	43.01	45.72	48.54	51.74	55.74	61.76	67.17	29.25	32.07	35.53	38.06	40.27	42.37	44.54	46.93	49.84	54.14	57.98
14	35.01	38.82	43.80	47.65	51.11	54.50	58.03	61.97	66.78	73.84	80.02	32.30	35.27	38.85	41.45	43.70	45.83	48.02	50.43	53.36	57.70	61.59
15	41.52	46.16	51.93	56.18	59.84	63.31	66.87	70.85	75.77	83.05	89.47	34.35	37.38	40.99	43.57	45.79	47.90	50.04	52.40	55.27	59.53	63.38
16	48.20	53.50	59.66	63.89	67.33	70.41	73.54	77.12	81.67	88.62	94.92	35.01	38.06	41.62	44.16	46.32	48.36	50.43	52.71	55.50	59.65	63.43
17	54.11	59.31	65.51	69.90	73.59	77.00	80.43	84.20	88.76	95.36	101.03	35.41	38.57	42.20	44.74	46.90	48.93	51.00	53.27	56.05	60.23	64.09
18	59.94	64.50	70.54	75.30	79.66	83.92	88.20	92.59	97.42	103.58	108.27	34.90	38.18	41.90	44.46	46.63	48.65	50.71	52.98	55.77	60.00	63.97
SLJ (cm)																						
6	69.16	76.89	85.77	91.91	97.00	101.65	106.20	110.96	116.41	123.77	129.70	66.93	73.02	80.27	85.41	89.76	93.79	97.78	102.02	106.94	113.69	119.20
7	75.24	83.01	92.09	98.44	103.75	108.62	113.41	118.46	124.27	132.17	138.57	72.54	78.79	86.30	91.68	96.26	100.52	104.76	109.29	114.57	121.85	127.83
8	81.59	89.44	98.73	105.29	110.82	115.92	120.97	126.32	132.50	140.96	147.85	78.55	84.98	92.78	98.41	103.23	107.73	112.25	117.07	122.73	130.59	137.08
9	88.33	96.33	105.89	112.71	118.48	123.83	129.15	134.80	141.38	150.41	157.81	85.44	92.11	100.28	106.22	111.33	116.13	120.96	126.15	132.26	140.79	147.89
10	94.91	103.14	113.02	120.10	126.11	131.71	137.29	143.23	150.15	159.70	167.55	92.42	99.38	107.94	114.22	119.65	124.77	129.94	135.52	142.12	151.39	159.14
11	101.02	109.54	119.79	127.13	133.38	139.20	145.01	151.19	158.40	168.36	176.55	98.56	105.79	114.74	121.34	127.07	132.50	137.99	143.95	151.03	161.01	169.40
12	107.56	116.53	127.28	134.98	141.51	147.59	153.64	160.08	167.58	177.92	186.41	103.43	110.90	120.20	127.08	133.07	138.76	144.55	150.84	158.32	168.93	177.89
13	115.86	125.53	137.06	145.26	152.20	158.64	165.02	171.81	179.69	190.51	199.36	106.64	114.29	123.85	130.94	137.14	143.03	149.03	155.57	163.37	174.45	183.82
14	124.97	135.55	148.04	156.86	164.28	171.12	177.89	185.04	193.31	204.61	213.81	108.58	116.38	126.14	133.40	139.74	145.79	151.95	158.66	166.68	178.10	187.78
15	133.66	145.25	158.77	168.21	176.10	183.34	190.45	197.93	206.54	218.22	227.66	109.71	117.61	127.51	134.88	141.33	147.48	153.76	160.60	168.78	180.44	190.33
16	140.46	153.04	167.49	177.46	185.72	193.25	200.60	208.30	217.09	228.94	238.45	109.96	117.91	127.89	135.33	141.84	148.05	154.38	161.30	169.58	181.37	191.40
17	145.10	158.63	173.90	184.29	192.81	200.52	208.00	215.78	224.61	236.43	245.85	109.41	117.37	127.38	134.83	141.36	147.60	153.96	160.91	169.23	181.10	191.19
18	148.70	163.17	179.18	189.92	198.65	206.48	214.04	221.84	230.65	242.34	251.60	108.37	116.32	126.31	133.76	140.28	146.52	152.89	159.85	168.18	180.07	190.19

(Continued)

TABLE 3 | Continued

Percentiles	Boys											Girls										
Age	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Back saver sit and reach (cm)																						
6	15.60	17.99	20.74	22.67	24.28	25.76	27.18	28.62	30.18	32.16	33.67	18.38	20.82	23.64	25.60	27.25	28.75	30.21	31.69	33.33	35.44	37.08
7	14.37	16.79	19.58	21.52	23.15	24.64	26.08	27.55	29.17	31.26	32.88	16.98	19.42	22.25	24.22	25.88	27.40	28.87	30.37	32.04	34.22	35.92
8	13.20	15.60	18.38	20.32	21.94	23.43	24.87	26.36	28.03	30.22	31.95	16.09	18.60	21.51	23.55	25.26	26.83	28.36	29.93	31.69	34.00	35.81
9	12.50	14.87	17.65	19.60	21.24	22.76	24.24	25.79	27.54	29.89	31.77	15.60	18.20	21.23	23.37	25.16	26.81	28.42	30.10	31.98	34.48	36.46
10	12.07	14.41	17.21	19.20	20.89	22.45	24.00	25.63	27.51	30.05	32.10	15.06	17.68	20.76	22.95	24.79	26.49	28.17	29.91	31.90	34.56	36.69
11	11.48	13.80	16.61	18.63	20.35	21.96	23.56	25.26	27.22	29.90	32.08	14.80	17.45	20.61	22.85	24.75	26.52	28.26	30.09	32.20	35.05	37.35
12	10.83	13.15	15.98	18.03	19.79	21.45	23.10	24.85	26.87	29.64	31.91	15.06	17.81	21.10	23.44	25.43	27.28	29.11	31.05	33.30	36.37	38.87
13	10.28	12.66	15.57	17.68	19.51	21.22	22.92	24.73	26.82	29.66	31.98	15.45	18.34	21.78	24.22	26.28	28.19	30.08	32.10	34.43	37.64	40.26
14	10.16	12.74	15.88	18.17	20.13	21.96	23.79	25.71	27.91	30.90	33.30	16.14	19.27	22.95	25.53	27.69	29.67	31.63	33.72	36.14	39.46	42.18
15	10.53	13.37	16.83	19.33	21.48	23.49	25.48	27.56	29.94	33.13	35.68	16.71	20.05	23.92	26.60	28.81	30.83	32.82	34.93	37.38	40.74	43.49
16	11.07	14.06	17.71	20.36	22.64	24.78	26.90	29.12	31.64	35.02	37.73	17.00	20.42	24.34	27.01	29.21	31.20	33.16	35.23	37.63	40.94	43.64
17	11.58	14.56	18.23	20.93	23.27	25.48	27.68	29.98	32.61	36.13	38.94	16.82	20.23	24.07	26.68	28.80	30.71	32.58	34.56	36.87	40.05	42.65
18	12.09	15.01	18.66	21.38	23.76	26.03	28.29	30.67	33.38	37.03	39.96	16.32	19.66	23.39	25.88	27.91	29.72	31.48	33.36	35.54	38.55	41.02
4x10mSRT (s)																						
6	13.86	14.29	14.87	15.33	15.77	16.20	16.68	17.25	18.00	19.24	20.51	14.31	14.74	15.32	15.77	16.19	16.62	17.07	17.60	18.28	19.35	20.39
7	13.06	13.47	14.01	14.44	14.85	15.25	15.69	16.21	16.90	18.05	19.21	13.73	14.15	14.70	15.13	15.53	15.93	16.35	16.84	17.47	18.46	19.41
8	12.49	12.88	13.40	13.81	14.19	14.57	14.98	15.47	16.11	17.18	18.25	13.22	13.62	14.15	14.55	14.92	15.29	15.68	16.14	16.71	17.61	18.47
9	12.16	12.54	13.05	13.44	13.81	14.17	14.56	15.03	15.64	16.64	17.66	12.72	13.13	13.64	14.03	14.38	14.73	15.09	15.51	16.05	16.90	17.74
10	11.83	12.21	12.70	13.08	13.43	13.78	14.15	14.59	15.17	16.12	17.06	12.22	12.64	13.16	13.53	13.87	14.19	14.53	14.93	15.44	16.27	17.11
11	11.47	11.83	12.31	12.68	13.02	13.35	13.70	14.12	14.66	15.55	16.43	11.85	12.24	12.72	13.07	13.38	13.68	14.00	14.36	14.82	15.56	16.30
12	11.02	11.37	11.83	12.19	12.51	12.82	13.15	13.54	14.05	14.88	15.69	11.49	11.87	12.32	12.66	12.96	13.26	13.57	13.91	14.36	15.05	15.71
13	10.54	10.88	11.32	11.65	11.95	12.24	12.55	12.92	13.40	14.17	14.94	11.16	11.54	12.01	12.37	12.68	12.98	13.30	13.66	14.11	14.82	15.50
14	10.20	10.53	10.95	11.27	11.55	11.83	12.12	12.47	12.92	13.67	14.40	10.97	11.36	11.85	12.21	12.54	12.85	13.18	13.56	14.03	14.76	15.46
15	9.90	10.22	10.62	10.92	11.19	11.45	11.73	12.06	12.50	13.21	13.93	10.89	11.28	11.77	12.14	12.47	12.79	13.12	13.50	13.98	14.70	15.37
16	9.74	10.04	10.42	10.71	10.97	11.22	11.49	11.81	12.23	12.94	13.66	10.84	11.24	11.73	12.11	12.44	12.77	13.11	13.49	13.96	14.68	15.33
17	9.62	9.91	10.28	10.56	10.81	11.05	11.31	11.62	12.04	12.74	13.45	10.79	11.20	11.72	12.12	12.47	12.81	13.16	13.56	14.05	14.79	15.47
18	9.50	9.78	10.14	10.41	10.65	10.89	11.14	11.44	11.84	12.53	13.25	10.73	11.17	11.72	12.14	12.52	12.88	13.26	13.68	14.21	14.99	15.70

(Continued)

TABLE 3 | Continued

	Boys											Girls										
Percentiles																						
Age	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Bent hang arm (s)																						
6	0.62	0.98	1.63	2.29	3.01	3.85	4.86	6.19	8.10	11.53	15.19	0.62	0.93	1.49	2.06	2.68	3.40	4.29	5.46	7.17	10.30	13.73
7	0.63	1.01	1.71	2.43	3.24	4.18	5.33	6.86	9.08	13.14	17.54	0.66	1.00	1.60	2.22	2.90	3.70	4.69	6.00	7.94	11.52	15.47
8	0.73	1.20	2.08	3.01	4.04	5.26	6.77	8.77	11.70	17.08	22.93	0.69	1.05	1.71	2.37	3.12	4.00	5.10	6.56	8.73	12.80	17.34
9	0.80	1.32	2.31	3.35	4.53	5.93	7.68	10.00	13.45	19.83	26.84	0.73	1.11	1.81	2.53	3.34	4.30	5.51	7.13	9.56	14.15	19.35
10	0.85	1.40	2.45	3.55	4.81	6.31	8.19	10.70	14.45	21.44	29.21	0.76	1.17	1.91	2.68	3.56	4.60	5.92	7.71	10.41	15.59	21.51
11	1.00	1.63	2.82	4.08	5.51	7.23	9.38	12.26	16.58	24.68	33.73	0.79	1.22	2.00	2.83	3.77	4.90	6.35	8.31	11.31	17.11	23.85
12	1.02	1.69	2.96	4.30	5.83	7.63	9.87	12.85	17.26	25.40	34.33	0.82	1.27	2.09	2.97	3.98	5.21	6.77	8.92	12.23	18.74	26.39
13	1.20	2.00	3.52	5.12	6.92	9.03	11.64	15.09	20.14	29.36	39.33	0.85	1.31	2.18	3.11	4.19	5.51	7.20	9.55	13.20	20.47	29.14
14	1.32	2.54	4.90	7.33	9.99	13.03	16.65	21.24	27.65	38.62	49.70	0.88	1.36	2.27	3.25	4.40	5.81	7.64	10.20	14.21	22.32	32.14
15	1.67	3.76	7.87	11.89	15.93	20.18	24.83	30.22	37.02	47.25	56.34	0.91	1.40	2.35	3.38	4.60	6.11	8.08	10.86	15.27	24.30	35.41
16	2.93	5.86	11.20	16.11	20.85	25.66	30.75	36.45	43.41	53.45	62.02	0.93	1.44	2.43	3.51	4.80	6.41	8.53	11.54	16.38	26.43	39.00
17	3.23	6.40	12.10	17.29	22.29	27.33	32.65	38.61	45.85	56.28	65.18	0.95	1.48	2.50	3.64	5.00	6.71	8.98	12.25	17.54	28.72	42.96
18	3.37	6.71	12.69	18.11	23.32	28.57	34.13	40.34	47.92	58.86	68.21	0.97	1.51	2.57	3.76	5.19	7.01	9.44	12.97	18.76	31.20	47.32
20mSRT (stages)																						
10	0.91	1.13	1.53	1.97	2.49	3.09	3.81	4.64	5.63	6.93	7.92	0.94	1.08	1.37	1.74	2.18	2.74	3.42	4.26	5.28	6.55	7.37
11	0.99	1.31	1.85	2.41	3.03	3.73	4.52	5.39	6.40	7.68	8.64	1.03	1.21	1.55	1.93	2.39	2.93	3.57	4.33	5.23	6.39	7.23
12	1.17	1.60	2.29	2.95	3.64	4.37	5.16	6.00	6.94	8.12	9.00	1.19	1.44	1.85	2.24	2.65	3.12	3.65	4.25	4.98	6.01	6.86
13	1.14	1.73	2.64	3.44	4.22	5.03	5.86	6.74	7.70	8.91	9.81	1.16	1.47	1.95	2.38	2.83	3.31	3.85	4.46	5.22	6.33	7.30
14	1.39	2.14	3.20	4.08	4.90	5.71	6.52	7.35	8.27	9.42	10.30	1.30	1.63	2.13	2.58	3.03	3.50	4.03	4.61	5.31	6.31	7.14
15	1.51	2.40	3.69	4.71	5.63	6.51	7.38	8.27	9.25	10.51	11.48	1.38	1.76	2.31	2.78	3.23	3.70	4.19	4.75	5.42	6.39	7.21
16	2.06	3.08	4.44	5.46	6.34	7.16	7.95	8.77	9.68	10.86	11.79	1.35	1.83	2.47	2.98	3.44	3.89	4.36	4.90	5.58	6.62	7.55
17	2.75	3.86	5.25	6.22	7.03	7.75	8.46	9.18	10.01	11.11	11.98	1.35	1.84	2.52	3.07	3.58	4.08	4.61	5.19	5.89	6.91	7.77
18	2.92	4.18	5.84	7.03	8.01	8.90	9.78	10.70	11.77	13.22	14.39	1.07	1.54	2.26	2.92	3.58	4.27	5.00	5.76	6.61	7.67	8.46

SLJ, standing long jump; 4×10 mSRT, 4×10 m shuttle run test; 20 mSRT, 20 m shuttle run test.

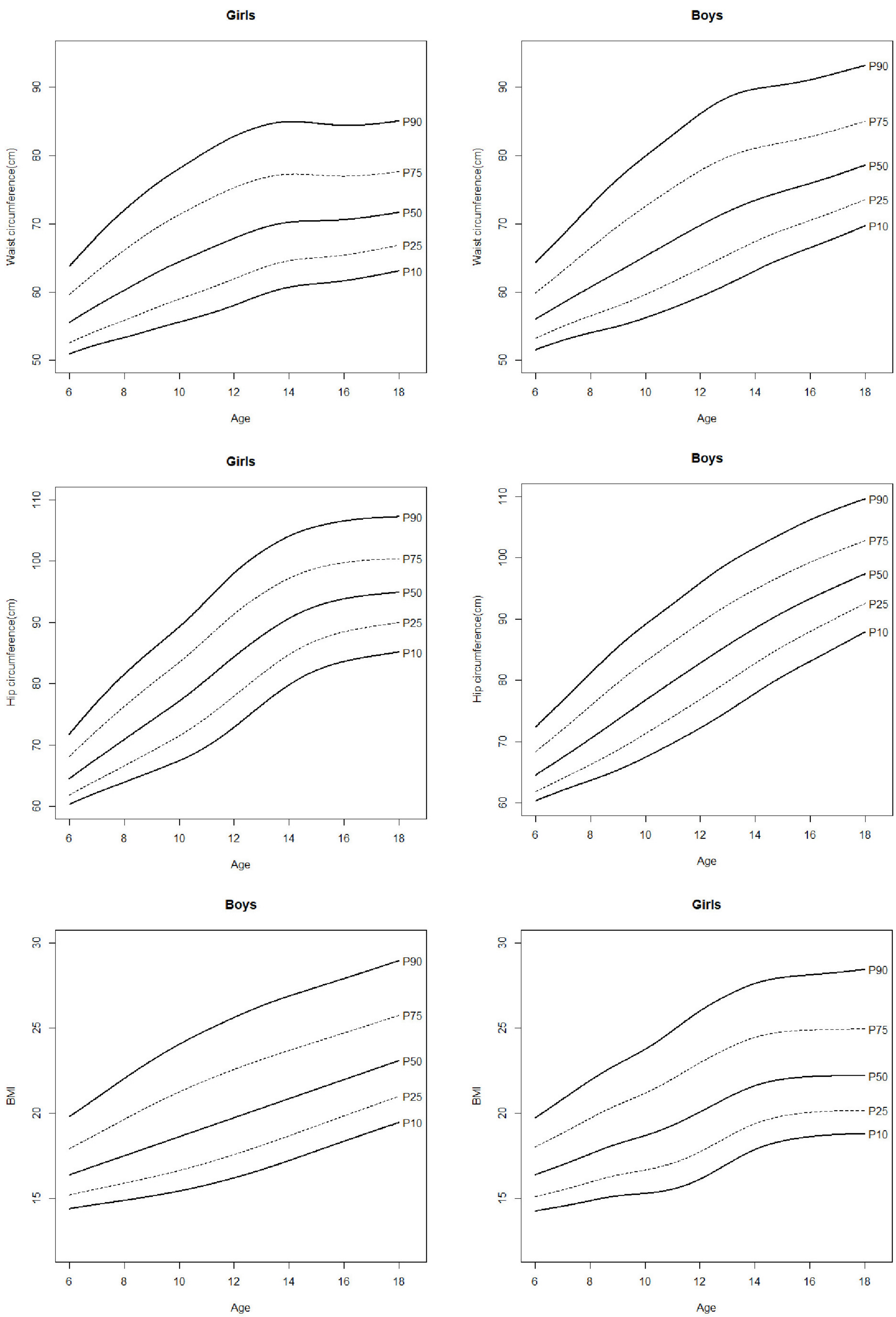

FIGURE 2 | Percentile curves for waist circumference, hip circumference, and body mass index (BMI).

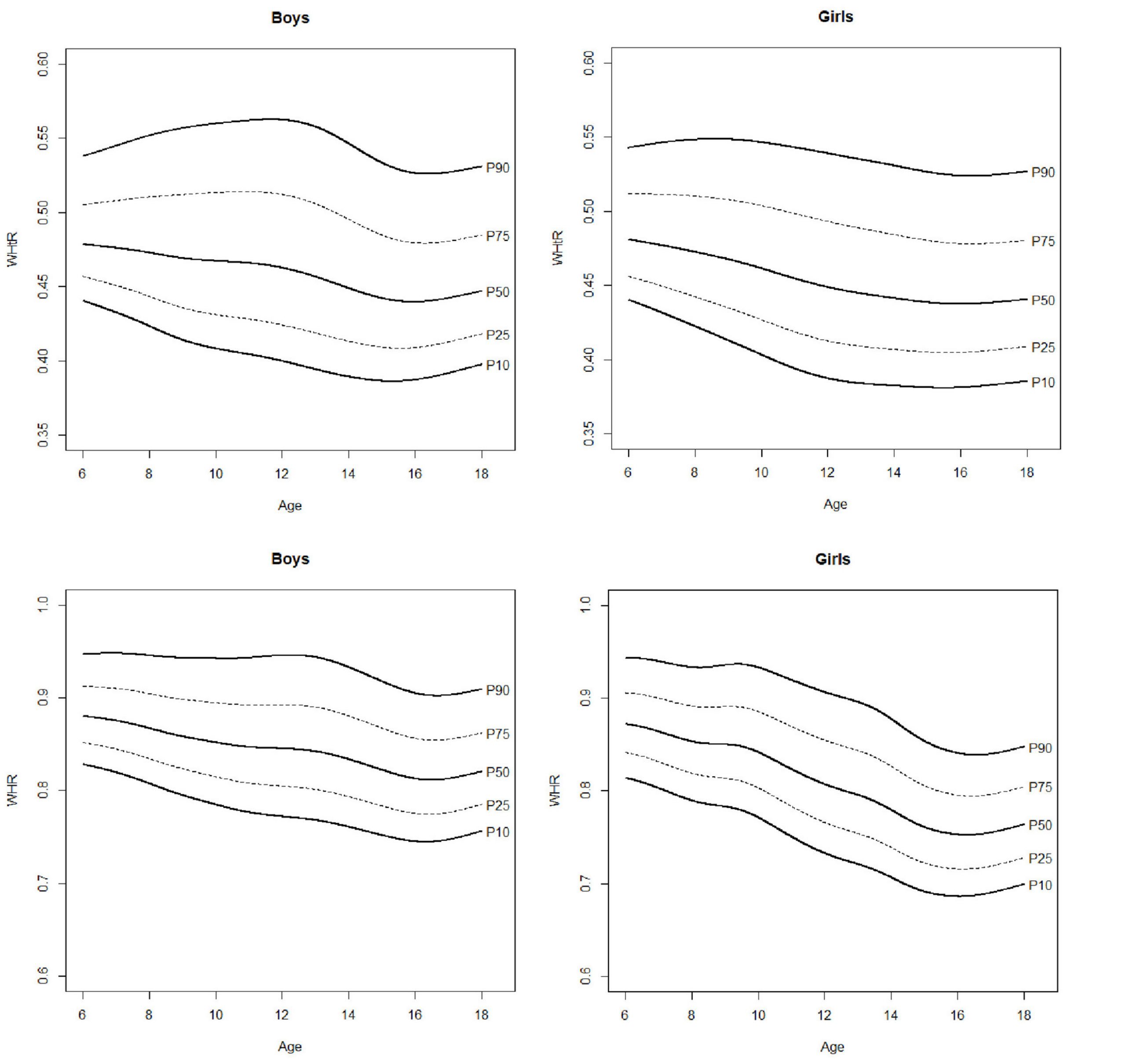

FIGURE 3 | Percentile curves for waist to hip ratio (WHR) and waist to height ratio (WHtR).

and girls respectively in comparison with 18.6% and 8.59% in normal-weight boys and girls. Similarly, the prevalence of low cardiorespiratory fitness between participants with WHtR equals or higher than 0.5 was 48.6% and 16.9% in boys and girls respectively, but only of 19.1% and 9.3% in boys and girls with WHtR lower than 0.5. Therefore, these results suggest a relatively high prevalence of low cardiorespiratory fitness between children with unhealthy body composition, especially in the case of boys, supporting the influence of fat mass on the development of cardiorespiratory fitness recently reported (Joensuu et al., 2020). The analysis of this tendency is out of the scope of the current paper but should be addressed in future studies.

Similarly, the relationship between muscular fitness and health of children and adolescents has been consistently reported (Ortega et al., 2008b, 2012; Ruiz et al., 2009) but studies focused on identifying cut-off points for this component of the health related fitness are scarce. In this regard, the usefulness of muscular fitness evaluated by handgrip and SLJ for detecting risk of metabolic syndrome has been recently explored (Castro-Piñero et al., 2019). In this study, average relative (i.e., normalized to body mass) grip strength of both hands and SLJ cut points to detect an elevated cardiometabolic risk profile were identified for boys and girls between 13 and 17 years. Our results of handgrip test showed that 48.93% (48.03% of boys and 49.82% of girls) of

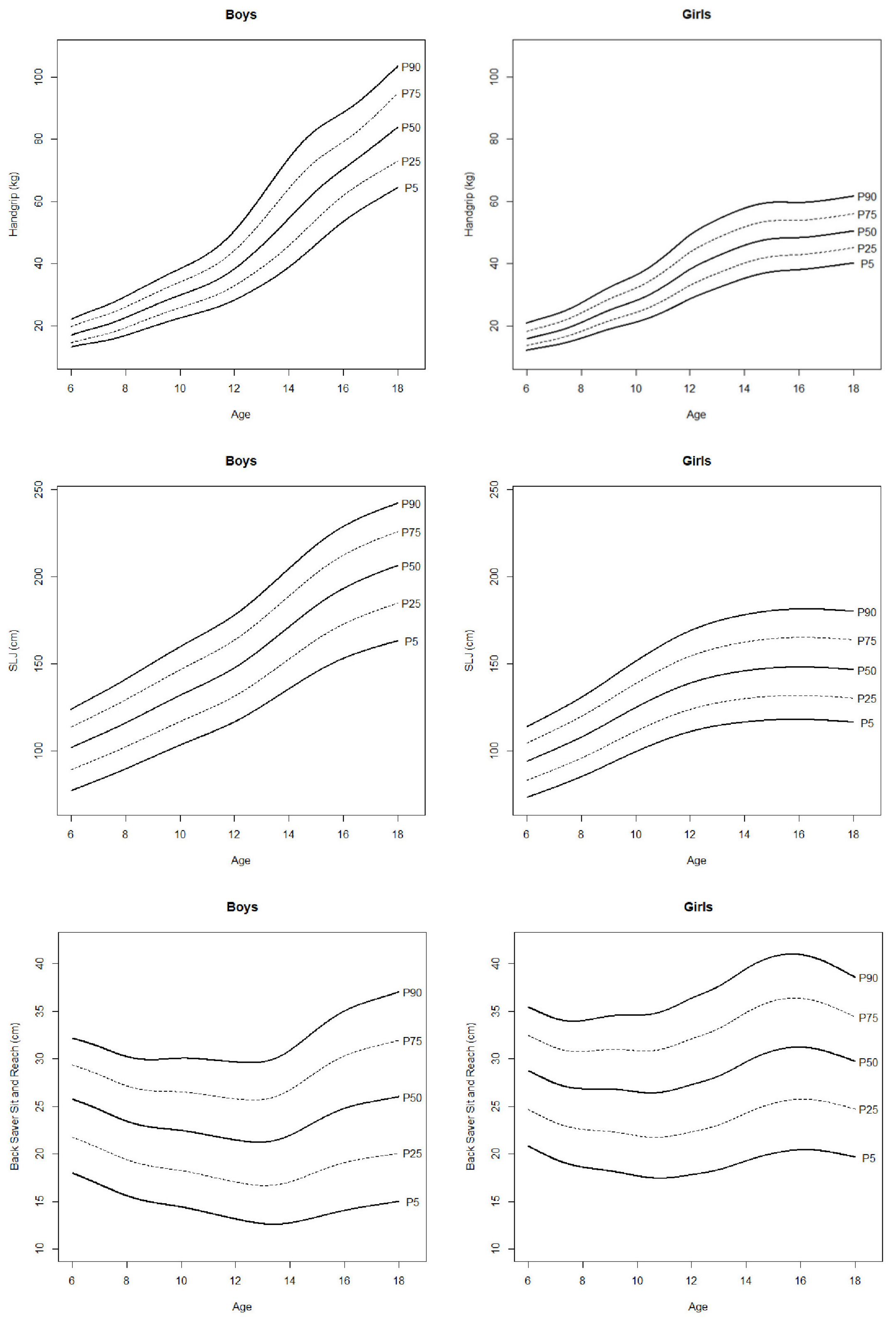

FIGURE 4 | Percentile curves for handgrip, standing long jump, and back saver sit and reach.

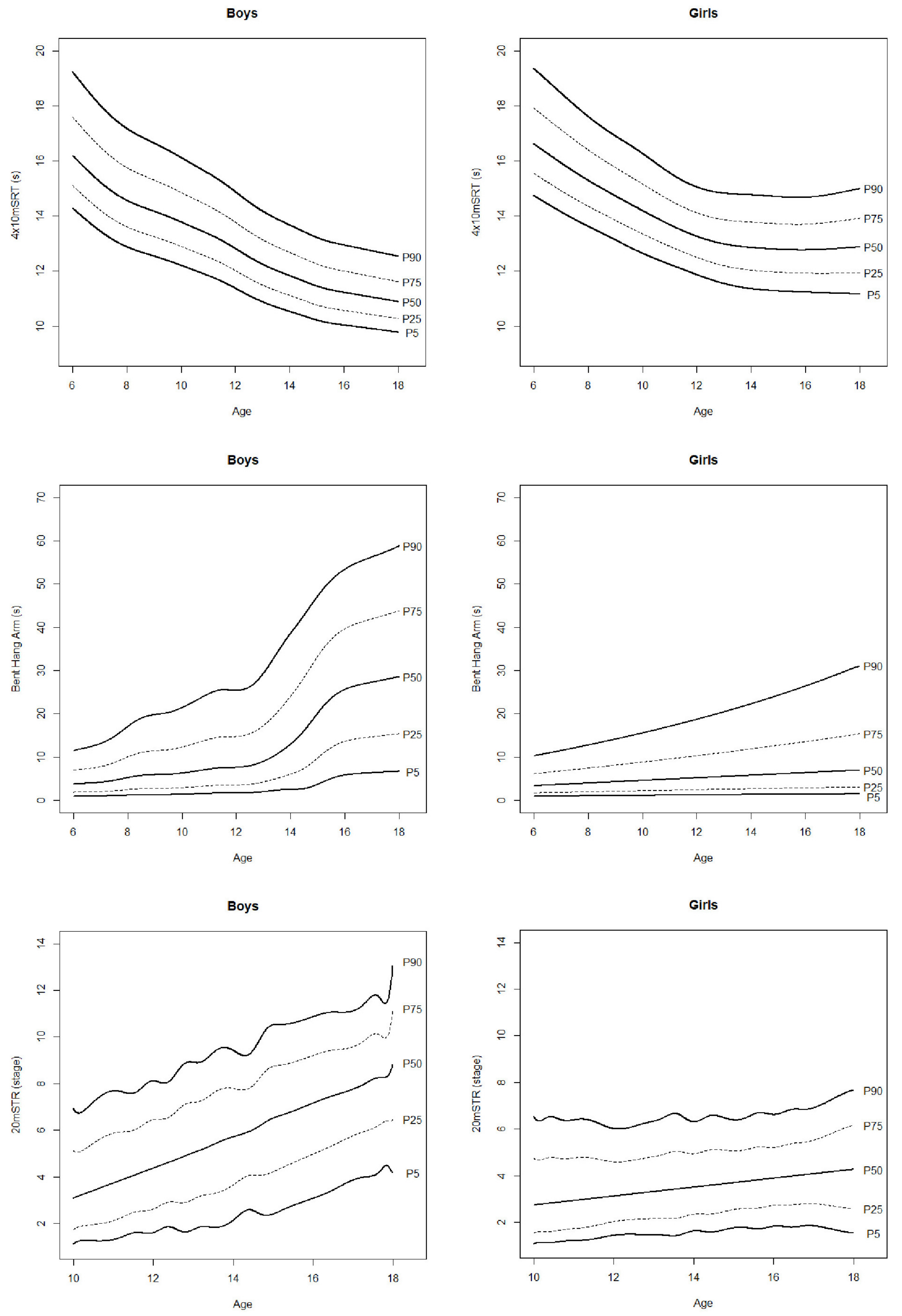

FIGURE 5 | Percentile curves of 4x10m shuttle run test (4×10 mSRT), bent hang arm and 20 m shuttle run test (20 mSRT).

TABLE 4 | ANOVA results for the anthropometric and physical fitness test.

Test	Sex	Age group						ANOVA P-value (η^2)		
		<8	[8,10)	[10,12)	[12,14)	[14,16)	[16,18)	Sex	Age	S×A
Weight	Boys	26.57 ± 5.75	34.82 ± 8.49	42.13 ± 10.13	52.65 ± 12.89	63.20 ± 13.76	69.45 ± 13.32	<0.001 (0.011)	<0.001 (0.583)	<0.001(0.019)
	Girls	26.01 ± 5.59	34.36 ± 7.87	42.84 ± 10.83	52.42 ± 11.87	58.63 ± 11.42	60.24 ± 12.14			
Height	Boys	123.29 ± 6.95	135.21 ± 6.95	145.09 ± 7.56	157.06 ± 8.90	169.13 ± 7.57	173.80 ± 7.21	<0.001 (0.058)	<0.001 (0.808)	<0.001 (0.078)
	Girls	121.95 ± 6.85	134.60 ± 6.85	146.14 ± 7.90	155.91 ± 7.06	160.64 ± 6.18	161.77 ± 6.62			
Waist Circumference	Boys	59.77 ± 6.76	64.68 ± 8.99	69.04 ± 10.04	73.48 ± 11.51	76.66 ± 10.74	78.62 ± 10.51	<0.001 (0.018)	<0.001 (0.226)	<0.001 (0.009)
	Girls	59.10 ± 6.58	64.25 ± 8.58	67.48 ± 9.49	70.72 ± 10.18	71.85 ± 9.72	72.47 ± 9.61			
Hip Circumference	Boys	68.51 ± 6.11	74.86 ± 8.19	80.53 ± 8.76	86.28 ± 9.82	92.06 ± 9.69	95.60 ± 9.30	<0.001 (0.001)	<0.001 (0.473)	0.001 (0.002)
	Girls	68.71 ± 6.28	75.21 ± 7.95	81.38 ± 9.59	88.04 ± 9.99	93.34 ± 9.38	95.12 ± 9.67			
BMI	Boys	17.33 ± 2.74	18.85 ± 3.38	19.81 ± 3.61	21.15 ± 4.09	21.99 ± 4.11	22.93 ± 3.96	0.015 (<0.001)	<0.001 (0.191)	0.004 (0.001)
	Girls	17.32 ± 2.60	18.77 ± 3.19	19.82 ± 3.79	21.42 ± 4.03	22.67 ± 4.07	22.99 ± 4.33			
WHR	Boys	0.88 ± 0.05	0.87 ± 0.06	0.86 ± 0.07	0.85 ± 0.07	0.83 ± 0.07	0.82 ± 0.07	<0.001 (0.061)	<0.001 (0.138)	<0.001 (0.021)
	Girls	0.87 ± 0.06	0.86 ± 0.06	0.83 ± 0.07	0.80 ± 0.07	0.77 ± 0.07	0.76 ± 0.06			
WHtR	Boys	0.48 ± 0.05	0.48 ± 0.06	0.47 ± 0.06	0.47 ± 0.07	0.45 ± 0.06	0.45 ± 0.06	<0.001 (0.003)	<0.001 (0.038)	<0.001 (0.002)
	Girls	0.48 ± 0.05	0.48 ± 0.06	0.46 ± 0.06	0.45 ± 0.06	0.45 ± 0.06	0.45 ± 0.06			
Handgrip	Boys	19.87 ± 4.48	26.65 ± 5.95	34.11 ± 7.86	45.99 ± 12.30	64.21 ± 15.20	74.16 ± 15.01	<0.001 (0.145)	<0.001 (0.684)	<0.001 (0.184)
	Girls	18.43 ± 4.27	25.26 ± 5.61	33.39 ± 7.97	42.34 ± 9.01	47.95 ± 8.79	49.32 ± 9.06			
SLJ	Boys	107.81 ± 19.41	123.88 ± 21.35	139.91 ± 23.37	157.23 ± 26.95	182.10 ± 29.29	197.10 ± 29.87	<0.001 (0.135)	<0.001 (0.452)	<0.001 (0.078)
	Girls	100.09 ± 17.70	117.06 ± 19.47	133.46 ± 22.40	142.93 ± 23.21	148.23 ± 24.82	148.61 ± 24.78			
Back Saver Sit and Reach	Boys	24.21 ± 5.68	22.53 ± 5.99	22.07 ± 6.16	21.39 ± 6.37	23.56 ± 7.60	25.50 ± 7.89	<0.001 (0.110)	<0.001 (0.034)	<0.001 (0.011)
	Girls	27.21 ± 5.77	26.53 ± 6.45	26.42 ± 7.00	28.11 ± 7.39	30.51 ± 8.09	30.74 ± 7.73			
4x10mSRT	Boys	15.60 ± 2.05	14.46 ± 1.83	13.51 ± 1.53	12.50 ± 1.43	11.68 ± 1.31	11.26 ± 1.84	<0.001 (0.059)	<0.001 (0.386)	<0.001 (0.018)
	Girls	16.19 ± 1.85	14.89 ± 1.63	13.85 ± 1.54	13.14 ± 1.35	12.94 ± 1.38	12.91 ± 1.42			
Bent Hang Arm	Boys	6.06 ± 5.81	8.75 ± 8.65	11.09 ± 10.81	13.41 ± 13.41	23.44 ± 17.60	28.40 ± 19.05	<0.001 (0.071)	<0.001 (0.130)	<0.001 (0.015)
	Girls	5.26 ± 5.10	6.57 ± 7.06	7.40 ± 8.09	9.22 ± 10.20	10.29 ± 11.84	11.78 ± 13.25			
20mSRT	Boys			4.26 ± 2.34	5.28 ± 2.62	6.58 ± 2.89	7.21 ± 3.00	<0.001 (0.148)	<0.001 (0.075)	<0.001 (0.030)
	Girls			3.35 ± 1.88	3.77 ± 1.90	3.88 ± 1.90	4.16 ± 1.98			

BMI, body mass index; WHR, waist to hip ratio; WHtR, waist to height ratio; SLJ, standing long jump; 4×10 mSRT, 4×10 m shuttle run test; 20 mSRT, 20 m shuttle run test; η2, partial eta square; S×A: sex × age interaction.

TABLE 5 | Correlation between the initial set of variables obtained in boys and girls, and the principal components retained according to the Kaiser's rule.

		Boys			Girls		
Age group	**Test**	**PC1**	**PC2**	**PC3**	**PC1**	**PC2**	**PC3**
a<8	BMI	0.828	−0.170	0.194	0.822	−0.146	0.269
	Waist	**0.916**	−0.253	0.048	**0.931**	−0.196	0.062
	WHR	0.587	−0.207	−0.554	0.593	−0.177	**−0.620**
	WHtR	0.900	−0.205	−0.210	0.920	−0.048	−0.217
	Handgrip	0.229	−0.623	**0.579**	0.185	−0.641	0.358
	SLJ	−0.333	−0.643	0.152	−0.265	−0.702	0.062
	Back saver	0.271	−0.430	−0.549	−0.146	−0.499	−0.380
	4x10mSRT	0.323	**0.672**	0.065	0.127	**0.707**	0.023
	Bent Hang Arm	−0.489	−0.560	−0.118	−0.534	−0.413	−0.275
[8,10)	BMI	−0.820	0.353		0.837	0.197	−0.313
	Waist	−0.916	0.312		**0.928**	0.270	0.061
	WHR	−0.616	0.005		0.610	0.125	**0.656**
	WHtR	**−0.928**	0.167		0.922	0.127	0.222
	Handgrip	−0.095	**0.776**		0.219	**0.698**	−0.550
	SLJ	0.515	0.597		−0.428	0.639	0.033
	Back saver	0.259	0.349		−0.255	0.418	0.237
	4x10mSRT	0.411	−0.556		0.257	−0.682	0.077
	Bent Hang Arm	0.574	0.316		−0.509	0.404	0.362
[10, 12)	BMI	0.749	−0.459	0.146	−0.761	0.435	−0.324
	Waist	**0.811**	−0.500	−0.017	−0.857	0.449	0.111
	WHR	0.515	−0.318	−0.334	−0.500	0.075	**0.751**
	WHtR	0.144	−0.073	**−0.852**	**−0.874**	0.285	0.260
	Handgrip	0.005	**−0.773**	0.273	−0.109	**0.751**	−0.402
	SLJ	−0.624	−0.501	−0.018	0.569	0.615	0.105
	Back saver	−0.376	−0.184	0.165	0.212	0.297	−0.354
	4x10mSRT	0.577	0.464	0.141	−0.458	−0.573	−0.169
	Bent Hang Arm	−0.654	−0.150	−0.060	0.595	0.238	0.277
	20m SRT	−0.696	−0.260	−0.183	0.586	0.456	0.307
[12, 14)	BMI	−0.782	0.417		−0.772	0.325	−0.347
	Waist	−0.850	0.463		−0.896	0.353	0.111
	WHR	−0.621	0.248		−0.563	0.218	**0.672**
	WHtR	**−0.907**	0.282		**−0.910**	0.253	0.200
	Handgrip	−0.024	**0.763**		−0.194	0.600	0.514
	SLJ	0.599	0.550		0.453	**0.629**	0.082
	Back saver	0.100	0.371		0.158	0.439	−0.422
	10m SRT	−0.554	−0.536		−0.388	−0.616	−0.205
	Bent Hang Arm	0.605	0.377		0.541	0.374	0.196
	20m SRT	0.639	0.400		0.527	0.456	0.260
[14, 16)	BMI	−0.773	0.418		0.778	−0.317	0.275
	Waist	−0.876	0.416		0.889	−0.379	−0.082
	WHR	−0.617	0.201		0.605	−0.347	−0.499
	WHtR	**−0.916**	0.280		**0.02**	−0.344	−0.063
	Handgrip	−0.090	**0.758**		0.029	**−0.630**	0.225
	SLJ	0.535	0.627		−0.490	−0.620	0.016
	Back saver	0.203	0.430		−0.166	−0.375	**0.714**
	4x10mSRT	−0.472	−0.582		0.498	0.587	0.103
	Bent Hang Arm	0.606	0.388		−0.591	−0.293	−0.227
	20m SRT	0.504	0.404		−0.537	−0.540	−0.284
[16, 18)	BMI	−0.823	0.245	−0.141	−0.822	0.217	0.068
	Waist	−0.908	0.335	0.078	−0.889	0.371	0.068

(Continued)

TABLE 5 | Continued

		Boys			Girls		
Age group	**Test**	**PC1**	**PC2**	**PC3**	**PC1**	**PC2**	**PC3**
	WHR	−0.608	0.427	0.288	−0.591	0.408	0.277
	WHtR	**−0.923**	0.268	0.053	**−0.910**	0.294	0.023
	Handgrip	−0.099	0.602	−0.265	−0.050	**0.669**	−0.099
	SLJ	0.538	0.599	−0.125	0.412	0.662	−0.058
	Back saver	0.167	0.287	−0.783	0.160	0.251	**−0.858**
	4x10mSRT	−0.446	**−0.612**	−0.262	−0.520	−0.601	−0.034
	Bent Hang Arm	0.666	0.289	0.064	0.570	0.229	0.317
	20m SRT	0.549	0.435	0.347	0.508	0.580	0.190

Blank cells mean that a third principal component was not retained for that age group. The highest correlation in absolute value between each PC and the variables, is highlighted in bold. PC1, first principal component; PC2, Second principal component; PC3, third principal component. BMI, body mass index; WHR, waist to hip ratio; WHtR, waist to height ratio; SLJ, standing long jump; 4×10 mSRT, 4×10 m shuttle run test; 20 mSRT, 20 m shuttle run test.

the sample between 13 and 17 years was under the cut points associated with cardiometabolic risk profile. Regarding SLJ, this percentage was 17.47% (20.02% of boys and 14.93% of girls). Additionally, the prevalence of low muscular fitness for handgrip test in overweight and obese subjects was 74.2% and 79.3% in boys and girls respectively in comparison with 36.0 % and 35.8% in normal-weight boys and girls. On the other hand, for SLJ these percentages were 35.6% and 24.3% in overweight and obese boys and girls respectively, in comparison with the 12.9% and 10.3% in normal-weight boys and girls, respectively. Moreover, the prevalence of low muscular fitness for handgrip test between participants with WHtR equals or higher than 0.5 was 81.4% and 85.0% in boys and girls respectively but only of 38.5% of boys and 41.6% of girls with WHtR lower than 0.5. Concerning SLJ, this prevalence in boys and girls with WHtR equals or higher than 0.5 was 42.1% and 31.2% respectively. In contrast, only 13.9% of boys and 11.5% of girls with WHtR lower than 0.5 presented results for SLJ under the cut points associated with cardiometabolic risk profile. These results suggest a higher prevalence of low muscular fitness between children with both excess of body mass and a high WHtR, reinforcing the negative influence an unhealthy body composition on muscular fitness (Castro-Piñero et al., 2009).

The connection between cardiorespiratory fitness and body composition is also supported by the PCA in which the first component (i.e., the one that retains most of the variation presented in the pool of original variables) was mainly associated to body composition variables (**Table 5**), meanwhile the correlation between 20 mSRT and the retained PCs were consistently higher for this first component, except for girls within 14-16 and 16-18 age groups in which 20mSRT showed similar correlations with the first (PC1) and second (PC2) PCs. Therefore, PC1 mainly represented body composition and indirectly cardiorespiratory fitness. The variables with the highest absolute correlation with PC2 were representative of the muscular component or a combination of the motor component and the muscular performance (i.e., 10 mSRT). Therefore, this second PC can be interpreted as representative of neuromuscular performance. The variable with the highest correlation in absolute value for these two main components varied throughout age groups and sex. For boys, WHtR ratio had the highest correlations with PC1 in four out of six age groups, followed by waist circumference (2 out of 6 groups). Similarly, in girls the variables with the highest correlation with PC1 were WHtR (4 out of 6 groups) and waist circumference (2 out of 6 groups). Regarding PC2, the highest correlation was most frequently observed for the handgrip test (4 out of 6 groups both in boys and girls). Finally, for most of the age groups, a third PC was retained although its interpretation is less consistent between sexes and age categories. Considering all these results we suggest that a short version of a battery to evaluate health-related fitness in children and adolescents should at least contain an evaluation of the body composition, a muscular component measurement and complementarily, a cardiorespiratory fitness assessment given its association with health and its weight in the PC1 detected in the current study. These considerations may be useful for Physical Education teachers that frequently deal with limitations in material resources and time, which have been exacerbated by the current pandemic conditions.

This study is not without limitations. Firstly, a non-probabilistic sampling was performed which could be at least partially compensated by a big sample size. Secondly, these data have been obtained in a specific region of Spain. Nevertheless, it must be pointed out that the normative values that were obtained, are similar to those previously published for both Spanish and European population. On the other hand, we must highlight some strengths of the project: (i) it reflects results for a wide range of ages, (ii) the data have been obtained from an "ecological environment" of Physical Education classes, (iii) the battery included physical fitness tests with acceptable levels of criterion validity and reliability (Ortega et al., 2008a; Ruiz et al., 2009, 2011).

In conclusion, this study provides evidence about the utility of school community actions like DAFIS aimed to track the health-related fitness of children and adolescents. On the other hand, our results suggest that fat mass distribution (i.e., waist to height ratio and waist circumference) and muscular performance (mainly handgrip) concentrate the highest proportion of variance. Therefore, a reduced battery should include these measurements complemented with the cardiorespiratory fitness assessment.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

EI-S did the conceptualization. EI-S, JRL-L, IC, JR-D, and MR-DC did the methodology. EI-S, MR-A, and JR-V did the formal analysis, writing – original draft, and visualization. EI-S, MR-A, JR-V, JRL-L, IC, JR-D, MR-DC, MAG-G, EC-F, and XD-C did the writing – review and editing. All authors contributed to the article and approved the submitted version.

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Towards a More Efficient Training Process in High-Level Female Volleyball From a Match Analysis Intervention Program Based on the Constraint-Led Approach: The Voice of the Players

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The aim of the research was to know the perception of high-level volleyball players of the changes produced (in relation to the previous season) in the efficiency of the training process, after a match analysis intervention program based on the Constraint-led Approach (CLA). The sample consisted of 11 players from a women's volleyball team. The protocol of the intervention program consisted of providing objective, contextualised and systematic information to the coach (adapted to his needs) that would allow understanding the different real game contexts. We used semi-structured interviews to assess players' perceptions. The athletes perceived changes in training, both in their preparation and development, specifically in greater involvement and organisation in preparing the training; in an increase in the specificity and suitability of training tasks according to individual needs; in the representativeness of the restrictions of the game; in a more tactical approach; in the variability of task and in the accountability to achieve the objective proposed. In addition, in the preparation and development for competition, the players detected more game planning; a deeper analysis of the opponents; an objective selection of the most relevant data, an increase in the depth of match analysis and the inclusion of the weekly meeting with the use of video compared to the previous season. These results expose the benefits of coaches incorporate programmes to obtain objective information about the game in their training process.

Keywords: athletes' perceptions, teaching-learning process, training, match analysis, volleyball

INTRODUCTION

Performance analysis in sport can be done from different points of view (biomechanical, physiological, psychological, etc.) (Trecroci et al., 2018; Araújo et al., 2019; Formenti et al., 2019), among which we highlight performance analysis through match analysis as a fundamental tool to obtain information for the process of preparing for team sports (Butterworth et al., 2013; Filetti et al., 2017). As such, it has been introduced into the work routines of many teams

(Palao and Hernández-Hernández, 2014). This information includes objective data that enables coaches to interpret the real context in which they are attempting to improve performance (Hughes and Bartlett, 2008). Match analysis has evolved over time. Initially, these analyses were conducted with the aim to obtain a general overview of competitions, but more recently they have been used to evaluate different aspects of the game and to be able to obtain the keys that guide our athletes to success. As a result, they have become more meticulous in their attention to the various game and situational variables (Fernández-Echeverria et al., 2017). Due to recent technological advances, there are now multiple statistical programmes that facilitate the analysis of the competition (Palao and Hernández-Hernández, 2014).

While some sport teams have pre-established key performance indicators, which are constantly evaluated through match analysis (Wright et al., 2013), it is necessary that these indicators can be modified according to the needs of the coach, depending on the match or the phase of a competition (Fernández-Echeverria et al., 2017). Therefore, if match analyses are not performed by the coach, and are instead conducted by an assistant coach or scout, it is important (a) for communication with the coach, (b) to identify the main features of the game (Wright et al., 2013); and (c) to select the important information for the team at each moment (Sarmento et al., 2015; Gesbert et al., 2016).

Several studies have shown that coaches consider match analysis to be important, easy to use, and useful for establishing objectives and planning the teaching-learning process of sport (Groom et al., 2011; Wright et al., 2012, 2014; Lago-Peñas and Gómez-López, 2014; Lupo and Tessitore, 2016; Kraak et al., 2018), evaluating results (Palao and Hernández-Hernández, 2014), and influencing the style and tactics of a game (Painczyk et al., 2017; Martin et al., 2018). This is because the information obtained from match analysis can help coaches to determine the key elements to develop in training (Wright et al., 2012; Renshaw et al., 2019; Loo et al., 2020). Understanding these key elements allows coaches to design more ecological and representative tasks (Renshaw et al., 2010; Chow, 2013; Woods et al., 2019) that give athletes a greater ability to adapt (Orth et al., 2019; Ramos et al., 2020a) to new circumstances and meet their needs (Greenwood et al., 2012). This adaptation process of the athlete to the environment has generated great interest in the scientific community, from which a theoretical perspective emerges, the Constraint-led Approach (CLA). The CLA understands that the athlete is in constant interaction with different conditioning factors that affect the appearance of behaviours creative and adaptive game-related (Davids et al., 2006). For this reason, CLA focuses on the manipulation of constraints during sports performance with the aim of facilitating the action-perception coupling of our athletes (Renshaw et al., 2016).

The information obtained from match analysis is not only used by coaches to plan the teaching-learning process or to design tasks of sport training. It is also transmitted to athletes (Wright et al., 2016). Currently, because it is vital to involve players in the pursuit of sports performance (Bampouras et al., 2012; Middlemas et al., 2018), high-level sports teams typically incorporate meetings into their training schedules in order to present information to their players (Groom and Cushion, 2004; Mesquita et al., 2005).

Players can be presented with information of various different forms, which can refer to personal or team performances, and can include statistical data and/or video clips (Cushion et al., 2006; O'Donoghue, 2006; Groom et al., 2011; Fernández-Echeverria et al., 2017). Moreover, this information can refer to the team itself and to rival teams (Painczyk et al., 2017). Analyses relevant to the team itself can provide information about the positive aspects of performance, in order to reinforce them, and the negative aspects of performance, to work and reduce them in training (O'Donoghue, 2006; Jenkins et al., 2007; Francis and Jones, 2014). Other analyses offer information on the strengths and weaknesses of rivals (Sarmento et al., 2015). This for the preparation of future matches is very useful (Groom and Cushion, 2004; Kraak et al., 2018).

Although several past studies showed the importance and usefulness of match analysis for sports coaches (Butterworth et al., 2012; Painczyk et al., 2017; Kraak et al., 2018), it remains unclear how the information obtained via match analysis, based on the Constraint-led Approach, can influence the teaching-learning process, specifically in the preparation and development of training and competition. One approach to addressing this research question is to ask athletes. Indeed, very few studies have been concerned with understanding the Athletes' opinions of the use of match analysis and its usefulness for training (Francis and Jones, 2014; Wright et al., 2016) and the changes this can provoke. Consequently, the objective of the study was to know the perception of high-level volleyball players of the changes produced (in relation to the previous season) in the efficiency of the training process after a match analysis intervention program, based on the Constraint-led Approach. The hypothesis of this study is that "high-level volleyball players will perceive changes in the efficiency of the training process (in the preparation and development of training and competition) after a match analysis intervention program, based on the Constraint-led Approach."

MATERIALS AND METHODS

Sample

Players from a women's volleyball team ($N = 11$) who competed at a high level formed the study sample. The age of the players was between 18 and 32 years old ($M = 26.09$, $SD = 4.45$). All the players had basic previous experience in performance analysis, which allowed the application of the program without any problem. The team were trained 5 days a week, specifically 9 h a week on the court and with a weekly competition game (Saturdays).

All participants were guaranteed confidentiality and anonymity throughout the process. The investigation was carried out under the recommendations of the Declaration of Helsinki. The participants were informed of the study and signed a consent form. It was in accordance with Spanish guidelines for scientific research in human beings.

Protocol for the Match-Analysis Intervention Programme Based on Constraint-Led Approach

The protocol of the intervention programme consisted of the provision of objective, contextualised and systematic information. Specifically, the information given to the coach (adapted to his needs), pertaining to the competitive performances of the players of the study team and their opponents, was obtained via match analysis (Fernandez-Echeverria et al., 2019).

The programme was applied by the study's principal investigator who was also the assistant coach. This role in the team was suitable for applying the intervention programme due to the trust between the head coach and the assistant coach. In addition, we emphasise that the reports were completed based on the coach's needs (Wright et al., 2013). For the intervention programme, the assistant coach made scout reports (relating to the performances of the study team and their opponent) for each match and provided them to the coach. This occurred for each game during the period of a full competitive season. The season lasted 6 months. This season was composed of two phases of 3 months each (first and second matches).

The intervention programme consisted of several phases for each game. During phase one, or the diagnosis and game analysis phase, data was collected by video recording the match from the back of the court (this guarantees an optimal line of sight) and this was later used to conduct a match analysis (study of the own team and the rival). During phase two, or the elaboration and provision of information phase based on the pedagogical principles of the CLA, the information obtained from the match analysis was collated in two scout reports (one related to the performance of the study team and the other relating to the performance of the opponent). These two reports were then presented at different times: the report related to the study team was delivered to the coach at the beginning of the week, and the opponent report was delivered midweek.

To facilitate the coach's understanding of the data, the reports contain only the most important data (Hughes and Franks, 2004). The reports concerning performance of the study team focused on several types of contextualised information: (a) Specific game situations of different phases of the game (KI attack phase and K2 defence phase) (Beal, 1989) that required correction or improvement. Specifically, the objective of the attack phase is to build an attack to obtain the point (setting, reception, attack, and attack coverage) and the objective of the defence phase is to defend the attack to build a counterattack that allows to obtain the point (includes serve, block, defence, setting, counterattack, and counterattack coverage). (b) Individualised technical-tactical information for each player, including the positive aspects to highlight and the negative aspects that need to be reduced or corrected (O'Donoghue, 2006; Jenkins et al., 2007). The information presented to the coach concerning the study team was obtained by analysing multiple variables (game and situational variables) relevant to both the team and its individual players (see **Table 1**).

TABLE 1 | Aspects of the game considered for own team reports.

Game variables:	***Situational variables:***
• **Serve:** serve type, serve zone, serve efficacy, etc. (Fernandez-Echeverria et al., 2015) • **Recepción:** recepción zone, reception type, reception efficacy, etc. (Afonso et al., 2012) • **Set:** setting technique, set's area, tempo of a set, setting efficacy, etc. (González-Silva et al., 2016) • **Attack:** attack type, attack tempo, attack efficacy, etc. (Castro et al., 2011) • **Coverage:** coverage zone, coverage efficacy, etc. (Hileno and Buscà, 2016) • **Block:** block type, block eficacy, etc. (Marcelino et al., 2009)	• **Set** (García-Hermoso et al., 2013) • **Rotation** (Đurković et al., 2008) • **Game Complex (K1/K2)** (Castro and Mesquita, 2010) • **opposition quality** (Marcelino et al., 2012) • **Score** (Marcelino et al., 2011) • **Match period** (Marcelino et al., 2012)

TABLE 2 | Aspects of the game considered for the opponent team reports.

Characteristics of the game system (Mesquita et al., 2013):	**Characteristics of the players** (Quiroga et al., 2010):
• Reception • Attack • Defence (1st and 2nd line) • Coverage	• The strongest and weakest players at reception and their characteristics • The strongest and weakest players at attack and their characteristics • The strongest and weakest players at blocking and their characteristics • The strongest and weakest players at defence and their characteristics
Game tendencies for rotations (Đurković et al., 2008): • Serve • Distribution of attack • Direction of attack	**Rival game model** (Fernández del Valle et al., 2009): • Technical-tactical intentions of the opponent in the final moments of set and match • Initial rotations in serve possession and in reception
Other relevant information (Campos et al., 2014): Player substitution, coach characteristics, court characteristics, nature of public, etc.	

The opponent reports focused on contextualised information about the characteristics of the opponent's game system, players, game tendencies, and game model. In addition, these reports took into account other types of information including the possible player changes during the course of the game, the characteristics of the coach, the characteristics of the court, the public, etc. (see **Table 2**). Because understanding the weaknesses and strengths of an opponent can help guide a team's strategic plan (Groom and Cushion, 2004), the above information was collected to help the study team prepare for future encounters with their opponents.

Finally, in phase three, or the phase of providing information to players, the report was delivered to the coach, and the coach then transmitted the information to the team through reports

TABLE 3 | Weekly summary of activities providing information.

Weekdays	Days of training sessions and match	Activities
Monday	Training session	Post-match meeting with the full team (before the training session). Providing information to players about the team's performance and video clips (post-match report).
Tuesday	Training session	Analysis and study of the opponent's game (next match) carried out by the scout. Delivery of the pre-match scout report to the coach
Wednesday	Day of rest	
Thursday	Training session	Pre-match meeting with the full team. Providing information to players of the opponent's study and video clips (pre-match report).
Friday	Training session	
Saturday	Match day	Video recording of the match/statistics.
Sunday	Day of rest	Analysis and study on the performance of the team itself carried out by the scout. Delivery of the post-match scout report to the coach.

TABLE 4 | Features of the intervention programme.

Preparation and development of training	Increases the involvement of the coach in the training process
	Increases tactical work
	Increases contextualisation of training tasks
	Increases the specificity of training tasks
	Increases variability of training tasks
	Involves and increases responsibility of players for achieving the proposed objectives
Preparation and development for competition	Increases the clarity of transmitted information
	Increases the depth and specificity of game analysis of the team and their opponents
	Makes the game analysis of the team and their opponents more systematic
	Inclusions of the weekly meeting with the use of video clips to complement game analysis of the team and their opponents.

and video clips (see **Table 3**). Video clips related to the positive and negative game actions performed by the players, as well as the opponent's game in the attack and defence phases. Information was presented to players in two separate meetings each week. Specifically, at a post-match meeting held on Monday and a pre-match meeting held on Thursday (Middlemas et al., 2018). The purpose of the post-match meeting was to analyze the scout reports related to the team itself and to visualise, using video clips, the negative and positive aspects of their game. The aim of the pre-match meeting was to evaluate the scout reports related to the opponent team and to visualise, using video clips, different game situations of the opponent in the defence phase (K2) and attack phase (K1). All pre-match and post-match meetings were held with the full team, before starting the training session. The same pattern has been followed in the transmission of information with small changes throughout the season according to the needs of the team and the coach. In addition, in both meetings, an emphasis was given to transmitting information to players clearly and to focus on the most relevant aspects.

In addition, the intervention programme (based on delivering objective, contextualised, and systematic information tailored to the needs of a high-level volleyball coach) influences a number of features of the preparation and development of training and for competition (see **Table 4**).

Data Collection and Instrument

Data was collected using a semi-structured interview technique. This technique was applied with the aim to understand players' perceptions of the changes produced in the teaching-learning process of hight level sport. Eleven players who were part of the team during the intervention season and season prior (season in which not the match analysis of the own team and the rival provided to the coach was carried out based on Constraint-led Approach) to it were interviewed so that they could answer comparative questions. This was due to the fact that one of the players was not part of the team last season and could not answer the questions aimed at comparing the two seasons. Consequently, 11 of the 12 players who were part of the team were interviewed at the end of the competitive season involving the intervention programme. This specific moment was chosen so that the athletes could make a full assessment of any changes across the season, in relation to the prior seasons, after the intervention programme. The interview consisted of the questions presented: Do you perceive any change or modification in the preparation and development of training with respect to the previous season? If yes, indicate what these are. Do you perceive any change or modification in the preparation and development for competition with respect to the previous season? If yes, indicate what these are.

The interviews were recorded with a digital recorder (Olympus VN-712PC) in a quiet room in the pavilion where the team trained. The average duration of each of the interviews with the players of the team was 12.32 min. The contents of the interviews were transcribed verbatim in order to obtain an accurate and complete record of the data collected. During the development of the interviews, the main researcher acted as an active listener (Smith and Sparkes, 2005).

Data Analysis

For data analysis, we carried out a thematic analysis following the process suggested by Charmaz (2014). Concretely, various phases were carried out. The first phase was based on a repeated reading of the transcripts was carried out and an open data coding. All this, with the aim of segmenting the data and listing a series of subcategories and categories. The second phase was based on axial coding to subsequently philtre the subcategories and categories of the first phase (**Table 4**) (guided by specialists in qualitative research and volleyball). The third phase was based

TABLE 5 | Descriptive analysis of the changes and modifications perceived by players in the preparation and development of training.

Categories	Subcategories	Frequency	Percentage	Players
Changes in the coach		6	54.54%	2/4/5/6/7/10
	Greater involvement of the coach in training preparation (work to be done written on paper and use of blackboard or notebook)	6	54.54%	2/4/5/6/7/10
Changes to the training tasks		7	63.63%	1/3/4/5/6/7/9
	Increase in tactical work (individual and collective)	3	27.27%	1/4/7
	Training tasks more contextualised (simulation of rival game)	4	36.36%	1/4/5/7
	Increased specificity of training tasks (tasks specific to roles and tasks designed to develop game situations that require improvement)	6	54.54%	1/4/5/6/7/9
	Greater variability of tasks (tasks with distinct variants and alternatives of action)	1	9,09%	3
	Introduction of control mechanisms so that athletes are responsible for completing the task–*accountability* (use of scoring in tasks)	2	18.18%	4/5
Total		9	81,81%	1/2/3/4/5/6/7/9/10

on selective coding. Specifically, the researchers selected two main dimensions (preparation and development of training, and preparation and development for competition) and then related all the other subcategories and categories with them (Charmaz, 2006, 2014). To contextualise the results, a review of the current literature was carried (Holt and Dunn, 2004). Finally, we focus on refining the relationships between the categories (report between the first author and co-authors).

Trustworthiness

To optimise the credibility of the research, we carried out several steps suggested by the literature (Biddle et al., 2001). First, the principal investigator (interviewer) carried out a training period supervised by an investigator with experience in qualitative analysis and in semi-structured interviews (Patton, 1990). Second, several meetings were held by a group of specialists in qualitative methodology and volleyball (three volleyball specialists with a level III coaching qualification) to establish the category system (Meyer and Wenger, 1998). In addition, the players were asked to review the transcript of the interviews for verification, which will allow adding, deleting or reworking any information that they consider did not accurately reflect the information previously provided (Corbin and Strauss, 2015). All these steps are necessary for the credibility of the data in qualitative research (Silverman, 2000).

RESULTS

The results indicated that the athletes perceived that their coach was more efficient, than the previous season, in the preparation and development of training and competition from the use of Match analysis information based on CLA.

Specially, the players perceived changes in training preparation and development, compared to the previous season: (1) in greater involvement and organisation in preparing the training; (2) in an increase in the specificity of training tasks; (3) in an increase in the suitability of training tasks according to individual training needs; (4) in the representativeness of the restrictions of the game in the training task (by the use of a more tactical approach); (5) in a more variability of tasks; (6) in the accountability to achieve the objective proposed by the coach and complete the tasks.

In addition, the players perceived in the preparation and development for competition: (1) changes in the match analysis of opponents (with a more specific, deep and clear match analysis that provides great information to analyze and that helps athletes decide what to do during the game); (2) changes in the match analysis of own team (with an objective selection of the most relevant data, in a clear and concise way, a greater depth of analysis due to the incorporation of positive and negative aspects and the inclusion of a weekly meeting with the use of video compared to the previous season).

Preparation and Development of Training Compared to the Previous Season

Our results show that 81.81% of the team's athletes perceived changes in the preparation and development of training compared to the previous season. Specifically, 54.54% of the athletes referred to changes in the coach and 63.63% referred to changes in the training tasks (see **Table 5**).

The results indicated that the coach was more involved and more organised in training preparation because of the intervention according to the players' perception (54.54%). The perception of players was that in the previous season training sessions were less prepared. In contrast, players indicated that the intervention programme changed the coach: the coach had prepared written training sessions and supported his explanations of exercises using a notebook and a blackboard.

We have observed more preparation in all senses, at all levels... the training tasks were much more prepared than in previous years. (Player 5)
I realised that the coach has prepared the training much more, was all the time with notes or the blackboard. This year, it was noticed that the coach was studying a lot, he always knew what he wanted to train and he had everything in his head. However, last year in training they improvised more, I was not as prepared as this year. (Player 6)

Concerning the perceived changes to training tasks, our results show that most of the players referenced an increase in the specificity of training tasks (54.54%). The players indicated that the coach had increased the use of tasks that were specific to game roles during the intervention season and had incorporated new materials, such as a precision hoop to help develop the pass of the setters.

In addition, this year we have done a minimum of two specific tasks per week for setters. Lately, with the precision hoop, which is very important because the previous year we did not. Carrying out specific training came in handy because accuracy is very important. (Player 5)

Moreover, there is an increase in the suitability of training tasks according to individual training needs. Specifically, there was an inclusion of tasks to work on specific game situations or aspects that the players needed to improve.

This year we trained very specifically, for example it was suggested that we were going to play against a specific team and they trained certain balls from a player specific to that team... (Player 7)

Another of the perceived changes was an increase in the representativeness of the game restrictions in training tasks that simulated the rival's game. This caused an increase in the contextualisation of the training tasks (36.36%).

...we trained simulating the game of the other teams, in some parts of the training, as we tried to do the same thing that the rivals did against those we were going to face. I think that has been very good for us. (Player 1)

In addition, our results indicate a more tactical approach through an increase of tasks focused on tactical work (27.27%), including tasks to develop individual and team tactics.

This year we have trained very tactically. (Player 7)
Perhaps we have trained more tactically to improve certain things individually. This is very good because we have improved many aspects of the game. (Player 1)

There was also a perceived increase in the control mechanisms used to encourage athletes to be responsable and accountable for reaching the goal proposed by the coach and completing tasks (18.18%). These included giving extra points if a goal was achieved or by subtracting points for any errors committed. In the previous season, the coach gave no importance to these issues.

Perhaps in this second part we have gotten more games with points, where the goal was to get them and if you made a mistake you subtracted. For example, if you missed the serve, they took more points. This came in handy because you put a little more pressure on the training, and you demand more than when it does not matter if you miss 10 serves or one. This will make you do better in matches... it's very good. (Player 5)
This year we have learned to think more, for example last year maybe you just started playing without thinking about so many questions and this year... everything had a goal. (Player 4)

Finally, the results show an increase in the variability of tasks compared to the previous season (9.09%), through a modification of the constraints that promote work under different game situations.

This year we have trained more different things compared to the previous year, we have trained with a greater variability of exercises. (Player 3)

Preparation and Development for Competition Compared to the Previous Season

Our results show that 100% of the team's athletes perceived changes in the preparation and development for competition compared to the previous season. Specifically, 90.9% of the athletes referred to changes in the match analysis of opponents and 81.81% related to changes in the match analysis of the study team (see **Table 6**).

Concerning the changes perceived in the analysis of opponents, our results indicate that the players perceived deeper analysis of opponents (81.81%) to give players more information to analyze and decide what to do during the game. This is due to a detailed analysis of the player and match characteristics. Concretely, information is provided on the strongest and weakest players in the various game actions (reception, attack, blocking, and defence) and their characteristics.

This year an in-depth analysis was made, focusing more on the players individually. However, before comments were made only if one stood out, and now with the statistical analysis you get many details, I think it is better. In addition, this is how the week is set according to the team that we are going to face, depending on its characteristics. I think it has developed much better than last year. (Player 3)

In addition, players indicated a greater specificity of analysis of the opponents' game (72.72%). Specifically, the players indicate a more detailed analysis that considered situational aspects such as game rotations. We highlight that service information, attack distribution, and attack direction were presented at each game rotation.

Totally, last year was very different from this one, we made it more specific, last year we watched videos and talked about people in a general way, but now with the theme of rotations, we analyze each player, in each rotation, and so we know more about them. (Player 11)

TABLE 6 | Descriptive analysis of the changes perceived by the players in the preparation and development for competition.

Categories	Subcategories	Frequency	Percentage	Players
Analysis of opponents		10	90.9%	1/2/3/4/5/6/7/8/10/11
	Increase the clarity of the transmitted information (objective selection of the most relevant data in a clear and concise form)	4	36.36%	1/6/10/11
	Increase the depth of match analysis (detailed analysis of players and the game)	9	81.81%	2/3/4/5/6/7/8/10/11
	Increase the specificity of match analysis (analysis according to different situational variables)	8	72.72%	3/4/5/6/7/8/10/11
Analysis of own team		9	81.81%	1/2/3/4/5/7/8/9/11
	Game analysis is more systematic (weekly meeting and analysis)	3	27.27%	1/3/11
	Increased depth of match analysis (inclusion of positive and negative aspects of the game)	7	63.63%	1/2/3/4/5/9/11
	Incorporation of the weekly meeting with the use of video clips (phases of play and plays cut into clips)	5	45.45%	2/4/7/8/9
Total		11	100%	1/2/3/4/5/6/7/8/9/10/11

Last year there were no reports, there was nothing specific. Now they give you the reports and indicate specific aspects of the opponent such as this player attacks in this way… (Payer 5)

The players also highlighted that with this programme there was an increase in the clarity of information transmitted to them (36.36%). Specifically, the players perceived that they were shown an objective selection of the most relevant data, in a clear and concise manner, while in the previous season they observed game videos that were too long and thus caused a loss of attention.

Yes, this year there have been many changes, the reinforcement of all the data that you gave us when it comes to studying the players. Now everything is much more clear than other years. (Player 1)
For example, now we see a team serve and its reception in all rotations and this is much better than last year. Before, the coach showed us a whole set and it was too long to watch. The girls started talking about other things like the player's hair, we were not focused on what we had to look at. However, this year is more clear, if you put each rotation, it is clearer, because half an hour of video is a lot. This has also changed from last year to this one. (Player 6)

Concerning the evaluation of the team's own game, most of the players referred to a greater depth of analysis due to the incorporation of positive and negative aspects (63.63%) in pre-match meetings, which were not held in the previous season.

In the evaluation of the game, the comments on the errors and successes is good. Last year we did not do it, we commented a little, but we did not have a meeting to discuss the mistakes and the successes. (Player 3)

The players also highlighted the incorporation of video to complement the analysis of their teams' game in the intervention season (45.45%). They emphasised the inclusion of detailed images of different aspects of the game that helped players to be aware of the positive aspects to be maintain and the negative aspects to be corrected or improved.

Last year we used videos, for example to see the next team, but to see us we did not use anything. This is a big change because we have improved a lot in the analysis of our own team, both in terms of the use of statistics and in the videos you showed us, to be aware of the failures and improvements. (Player 4)
Last year there was also an assessment of the game and the coach spoke to us. However, this year we have videos of different moments of the game and this, the images, count a lot, with this we see many of the aspects of the game that we do wrong. (Player 8)

The inclusion of a weekly meeting was definitely important to give the players the opportunity to reflect and make a systematic analysis of the team's own game compared to the previous season (27.27%).

Last year we analysed the games we had had a little bit after, we did not meet every Monday, as we do this year… the meetings were very important to assess what we had done well or failed in the game. (Player 1)

DISCUSSION

The aim of the research was to know the perception of high-level volleyball players of the changes produced (in relation to the previous season) in the efficiency of the training process, after a match analysis intervention program, based on the CLA.

The results of the study indicated that after the application of the intervention programme, athletes perceived changes in training and competition both in preparation and development. In relation to perceived changes in the preparation and development of training, the players perceive that the coach is more involved and organised in the preparation of the training. The players referred to a greater involvement of the coach in the preparation of training as evident by the use of prepared written work plans, the absence of a need to improvise due to lack of preparation, and continually using notes or the blackboard to support explanations of tasks. In the season prior to the intervention, training session were reported to be less prepared. Studies that evaluate players' perceptions of the possible changes in training that can result from using match analysis are scarce. Nonetheless, our findings align with those that demonstrate match analysis facilitates an understanding of the weaknesses and strengths of a team and its rivals, and that they help coaches to prepare training and to establish objectives (Silva et al., 2011; Wright et al., 2012; Sarmento et al., 2015). Further, it is likely that when coaches are clear about their goals and the means to achieve them they may be more motivated and thus present a greater engagement in daily work.

Another of the changes perceived by the athletes regarding the preparation and development of training was in the design of training tasks. Specifically, the players detected an increase in the specificity of training tasks (increased use of tasks specific to game roles and development of specific game situations), in the suitability of the training tasks according to the individual training needs, in the representativeness of the restrictions of the game in the training tasks, in the more tactical approach through a increase of tasks focused on tactical work, in the variability of tasks (increased use of tasks with different variants and alternatives of action) and in the accountability to achieve the objective proposed by the coach and complete the tasks, compared to the season prior to the intervention.

It is possible that these changes were due to objective knowledge, obtained from match analysis, being transmitted to the coach and thus enabling them to understand the key aspects of the game to work (O'Donoghue, 2006; Laird and Waters, 2008; Wright et al., 2012; Loo et al., 2020). Concretely, with such information it is possible to identify the constraints that must be manipulated in the design of tasks in order to create representative work environments (Renshaw et al., 2010; Chow, 2013), which meet the needs of athletes (Greenwood et al., 2012) and that guide the exploration of effective solutions in challenging environments (Roberts et al., 2019) with the aim of improving their performance (Hanin et al., 2016). In this sense, there are several studies that recently expose the importance of this ecological perspective for coaches in the advancement of training design (Ramos et al., 2020b; Woods et al., 2021).

The obtained tactical information about the team's opponents, as well as the information about the performance of the team itself, will increase the coach's knowledge of the game (Nash and Collins, 2006). This helps the coach to adjust their game model, determine the tasks with which to work during the week (Silva et al., 2011; Lago-Peñas and Gómez-López, 2014; Lupo and Tessitore, 2016), and to increase the possible variants of each exercise (Da Matta, 2015), all of which were referred to by the athletes interviewed in the current study.

In addition, objective information concerning a team and their opponents helps the coach to understand real-game scenarios, which in turn will allow them to design training tasks that simulate those contexts (Da Matta, 2015; Sarmento et al., 2015). As such, training tasks will be more representative of the game (Pinder et al., 2011, Vickery and Nichol, 2020) and allowing players to make decisions and solve problems that arrive during the competition (Davids et al., 2008). Moreover, in the pursuit of performance and the achievement of objectives, the accountability of tasks will be increased, that is, the way in which the coach ensures that athletes are responsible for completing the task and reaching the proposed objectives (Silverman et al., 1995).

Concerning the players' perceptions of changes in the preparation and development for competition, our results showed changes to the quality of game analyses. This applied to the analyses of the study team and their opponents. In particular, the players detected more game planning, a deeper (the strongest and weakest players in the various game actions and their characteristics) and specificity (service information, attack distribution and attack direction were presented at each game rotation) analysis of the opponents to give them more information to analyze and decide. In addition, an objective selection of the most relevant data was detected, in a clear and concise way, a greater depth of analysis due to the incorporation of positive and negative aspects and the inclusion of the weekly meeting with the use of video. All of this was important to give players a chance to reflect and make a more systematic analysis of the team's game compared to the previous season.

There are numerous studies demonstrating the importance of performing an analysis of opponents (Wright et al., 2012, 2013; Palao and Hernández-Hernández, 2014). Although research focused on players' perceptions of this topic is scarce, some studies have shown that prior knowledge of a rival helps athletes to be more prepared for competition and increases the chance of winning future encounters (Francis and Jones, 2014). An analysis of an opponent's game allows coaches to define the game strategies needed to overcome the opponent, helps define their strengths and weaknesses, guides the design of training tasks, and helps determine the best strategic plan (Silva et al., 2011). Although the relevance given by coaches to the information extracted from match analysis has been highlighted (Wright et al., 2012; Palao and Hernández-Hernández, 2014), it is also necessary that this information is transmitted efficiently and systematically to players (Wright et al., 2012; Fernández-Echeverria et al., 2017). It is, therefore, necessary to implement the use of match analysis in sports teams and to analyze the most efficient mechanisms for transmitting this information considering athletes' opinions.

Another factor indicated by the players was their perception that the game analysis of their team had changed. Specifically, players indicated that after the intervention programme there was an increase in the depth of the analysis (due to focus on both negative and positive aspects of performance) and the inclusion of the weekly meeting with the use of video (emphasising the inclusion of detailed images of aspects of the game that help the players to be aware of their failures and their successes). In addition, the players perceived that their game analysis was more systematic due to the inclusion of a weekly meeting in the training process for analysing team performance.

In a similar vein, several studies have shown the importance of analysing the performance of one's own team in addition to the performance of rivals. For example, a study by Silva et al. (2011) has shown that game analysis of a team helps; (a) consolidate their way of playing, (b) identify the weaknesses and strengths of the team and individual players, (c) correct individual and team errors, and (d) design training tasks according to the needs of the team. It is, therefore, necessary that analyses of a team are conducted systematically and focused on an evaluation of positive aspects, in order to reinforce them, and negative aspects, in order to correct in training (O'Donoghue, 2006; Jenkins et al., 2007). A study by Francis and Jones (2014) highlights the importance given to match analysis by players as a means to understanding the aspects of the game that they have to change, in line with more current studies such as that of Woods et al. (2019). Moreover, the transmission of visual feedback to players can be enhanced if game analyses of a team are accompanied by images or videos (Groom et al., 2011; Nelson et al., 2011; Booroff et al., 2016). Such visualisations present different aspects of the game that athletes are often unable to remember (Groom and Cushion, 2004) and are considered important by players due to their need to evaluate and reflect on performance (Wright et al., 2016).

CONCLUSIONS

In the present study, the athletes reported that they thought match analysis intervention program, based on the Constraint-led Approach caused positive changes in training and competition, both in preparation and development. Specifically, athletes perceived a greater participation and organisation in training preparation, more representative and contextualised task design, more tactical work, more mechanisms that allow to control that the athletes assume the responsibility for completing tasks (accountability), and increased specificity and variability of tasks. Additionally, the players reported improvement to the game analysis of opponents (with deeper and more specific analysis and increased clarity of transmitted analysis), and of their own team (with an increase of systematic analysis focused on both positive and negative factors and the inclusion of the weekly meeting with the use of video). Therefore, as recommendations for practise, we expose the importance of coaches incorporate programmes to obtain objective information about the game via match analysis, taking into account the ecology of the game. These programmes must be developed according to the needs of the team, with detailed analysis of both the team itself and their opponents. This information will allow coaches to identify the most relevant elements of the game and facilitate a representative design of tasks according to the reality of the team. In relation to the limitations of the research of our study, we expose that it has been carried out in a single high-level women's volleyball team, so we suggest to researchers that this type of field research work continue in the future in various sports teams of different gender, category, and sports modality.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Extremadura. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CF-E, IM, and MM: conceptualisation and methodology. CF-E, IM, JG-S, and MM: formal analysis. CF-E and MM: investigation and conceived and designed the research. IM, JG-S, and MM: supervision and reviewed and discussed the results. CF-E: writing—review and editing, drafted the manuscript, and prepared figures. MM and IM: revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
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Differences in the Psychological Profiles of Elite and Non-elite Athletes

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One of the main goals of sport psychology is to identify those psychological factors that are relevant for sport performance as well as possibilities of their development. The aim of the study was to determine whether the set of specific psychological characteristics [generalized self-efficacy, time perspective, emotional intelligence (EI), general achievement motivation, and personality dimensions] makes the distinction between athletes based on their (non)-participation in the senior national team, that is, their belonging to the subsample of elite or non-elite athletes depending on this criterion. According to the group centroids it can be said that elite athletes are characterized by a positive high score in self-efficacy, emotionality, present fatalistic time perspective, past positive time perspective, and openness to experience. They are also characterized by low past negative time perspective, emotional competence, and future time perspective. Non-elite athletes have the opposite traits. The results have been discussed in the context of their application in the process of talent selection and development in sport as well as the development of life skills in athletes.

Keywords: sport, self-efficacy, time perspective, emotional intelligence, achievement motivation, personality dimensions

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INTRODUCTION

Researchers and practitioners in the field of sport psychology have always been interested in the psychological factors that affect sport performance. Some studies have shown that it is possible to predict future success in sport, based on specific psychological factors, relatively successfully even in an early stage of sports engagement (Van Yperen, 2009), and that psychological factors are crucial and should be developed from an early sports age (MacNamara et al., 2010). In this regard, the Talent Identification and Development System (TIDS) has been designed, which consists of four steps including Talent Detection (refers to those who have not been involved in sports yet), Talent Identification (early talent detection in athletes), Talent Development (providing the most favorable conditions for the achievement of assumed potentials), and Talent Selection (standard form of sport selection) (Reilly et al., 2000; Till and Baker, 2020). Talent Transfer, which implies guiding athletes toward the sports in which they can realize the maximum of their potentials, has been included later in the process (MacNamara and Collins, 2015). As emphasized by some critical publications (Johnston and Baker, 2019), the decision-making process regarding talent in sport is sometimes not so objective, which results in some talented children "dropping out". As for the complexity and challenges related to the TIDS, Till and Baker (2020) recommended that talent development should be applied to a wider sports population (as much as possible), since this would be more ethical as well as more useful in terms of the improvement of both health and performance.

The psychological variables considered in the context of sport performance in this study included: self-efficacy, time perspective, emotional intelligence (EI), general achievement motivation, and personality dimensions (emotionality, extraversion, agreeableness, conscientiousness, openness to experience, and honesty-humility). The choice of mentioned variables does not derive from a special, coherent model, but is made based on the criteria of the possibility for development and relationships with successful functioning inside and outside the sports context. So, in addition to previous studies which have indicated their relationship with sport performance (excluding time perspectives), there were two more reasons to include these variables in the study. The first reason for selecting these variables was a possibility of their improvement (except for some of the personality dimensions), which is relevant for potential talent development programs in sport. The second reason was a definite correlation between these variables and the functioning of persons outside the context of sports. Although psychologists, during a sports career, are primarily focused on improving athletes' performances, what happens to athletes after the end of their sports careers and transition to other ones should not be neglected (Taylor and Lavallee, 2009).

According to the standard definition, EI consists of four attributes: (1) ability to perceive, assess, and express emotions quickly, (2) ability to recognize and generate the feelings that facilitate thinking, (3) ability to understand emotions and knowledge about emotions, (4) ability to manage emotions in order to improve emotional and intellectual development (Salovey and Mayer, 1990). Although everybody mostly agrees with the above definition, there is also a dilemma regarding its operationalization in measurement—whether it should be considered as an ability or a personality trait. Observing and measuring EI as an ability means to measure it as done in the case of standard tests used for measuring IQ, i.e., by the application of achievement tests which involve correct and incorrect answers (Petrides, 2011) such as MEIS (Mayer et al., 1999) and MSCEIT (Mayer et al., 2002) tests. Should it be considered as a trait, the operationalization is performed using self-assessment questionnaires and it is often called a trait of emotional self-efficacy (Petrides, 2011). There are many EI self-assessment questionnaires (e.g., EQ-i—Bar-On, 1997; SEIS—Schutte et al., 1998; TEIQue—Petrides and Furnham, 2001; ECI—Boyatzis et al., 1999; UEK-45—Takšić, 2002).

A high level of EI is associated with using psychological techniques such as self-talk, imaginary, and activation more frequently, both in training and competitions (Lane et al., 2009). Having studied running, which requires a great endurance (282 km in 6 days), Lane and Wilson (2011) found that the athletes with a higher level of emotional intelligence trait experienced pleasant emotions more often in relation to unpleasant ones. The trait of EI correlated with a number of points and a number of matches played in professional ice-hockey (Perlini and Halverson, 2006), satisfaction with sport performance (Laborde et al., 2014), and frequency and duration of practicing both individual and team sports (Laborde et al., 2017). Also, when it comes to the studies on EI as an ability, the obtained results have suggested that it is a significant predictor of sport performance in cricket (Crombie et al., 2009). To a certain extent, EI can predict life skills (Bastian et al., 2005), and it is associated with performance in the workplace as well (O'Boyle et al., 2011; Joseph et al., 2015). The studies have shown that EI can be developed under various conditions (Bagshaw, 2000; Slaski and Cartwright, 2005), including sport (Campo et al., 2016).

A time perspective means that a person is dominantly focused on thinking about their past, present, or future and it has a dynamic impact on the person's experience, motivation, opinion, and other forms of behavior, i.e., it represents a personal attitude toward time (Zimbardo and Boyd, 1999). Zimbardo and Boyd (1999, 2008) stated that the past, present, and future time perspectives may include the following operationally defined perspectives: past-negative, past-positive, present-hedonistic, present-fatalistic, future. The recent approaches to the study of time perspectives (Stolarski et al., 2018) have suggested two additional dimensions (Future-Negative and Present-Eudaimonic), as well as a dual perception of time perspectives—considered as a trait or a state.

Future-positive time perspective is in a positive correlation with physical activity in adolescents (Henson et al., 2006). Some authors (Zentsova and Leonov, 2013) found past-positive time perspective to be dominant in professional athletes, and, therefore, recommended that coaches and sport psychologists should put their efforts to change such a situation and influence the development of future time perspective in athletes. As they assumed, this would contribute to the athletes not being satisfied with already achieved results, which could help coaches to set goals more adequately. Some studies have indicated that time perspectives can be changed by interventions (Oyanadel et al., 2014). Balanced Time Perspective can be developed and is important for adaptations in human functioning (Stolarski et al., 2020). Stolarski et al. (2019) provided a complex model of possible effects of time perspectives on sport performance, which needs an empirical validation.

Bandura (1999) defined self-efficacy as an individual's assessment of his or her own capacities to organize and execute specific actions necessary to achieve desired goals. Self-efficacy reflects a person's confidence in their own ability to exert complete control over the outcomes of the previously set goals, in spite of events, difficulties, or obstacles that could interfere with goal achievement (Bandura, 1986). Self-efficacy has been recognized as a significant factor in the context of sport (Feltz et al., 2008). Some authors have considered self-efficacy as an important attribute relevant for understanding variations in sport competition anxiety (Wittig et al., 1987). A high level of perceived self-efficacy reduces the chances of an athlete participating in self-handicapping behavior, i.e., finding a reason for poor performance in advance (Kuczka and Treasure, 2005), and it is, therefore, recommended that coaches work on enhancing self-efficacy. The perceived self-adequacy related to physical activity can affect running results in children (Cairney et al., 2008). General self-efficacy is a significant factor which can moderate an impact and interpretation of the relationship between personality traits and perceived stress (Ebstrup et al., 2011). The meta-analysis of 45 studies has found that the average correlation between self-efficacy and sport performance is 0.38 (Moritz et al., 2000). Most studies apply specific scales for the assessment of self-efficacy (Feltz and Lirgg, 2001). Self-efficacy can be developed in athletes successfully through various interventions (Zagórska and Guszkowska, 2014). Generalized self-efficacy represents a protective factor in stressful life transitions (Jerusalem and Mittag, 1995) and it is one of the best predictors of performance in the workplace (Judge and Bono, 2001).

Athletes' motivation is one of the most important topics considered in sport psychology (Aktop and Erman, 2006) and achievement motivation is one of the most researched fields from the aspect of various theoretical approaches (Ong, 2019). Achievement motives in athletes are different in regard to gender, type of sport, and level of competition (Van de Pol and Kavussanu, 2012; Ong, 2019). The research suggests that a proper development of achievement motivation can prevent a premature drop-out in sport (Gardner et al., 2017), as well as that achievement motivation is associated with moral reasoning in athletes (Tod and Hodge, 2001). In this paper, we have taken the stand stating that a real value of the achievement motivation measurement is not reflected in predicting success in competitions but in predicting long-term types of motivation (Cox, 1998). Achievement motivation is in correlation with entrepreneurial career and performance (Collins et al., 2004).

The five-factor model of personality (McCrae and John, 1992; McCrae and Costa, 2008), which includes the following dimensions: extraversion, neuroticism, openness, agreeableness, and conscientiousness, represents the dominant model applied in personality research. The HEXACO model of basic personality structure (Lee and Ashton, 2008) was created by testing the "Big five" model when, in further lexical studies, it turned out necessary to examine the six-factor structure or the structure of latent dimensions underlying the personality descriptors in different languages. The sixth factor of personality has been confirmed in the majority of operationalizations of this model and it is called "honesty/humility" (Ashton et al., 2004). Numerous studies have confirmed that specific dimensions of personality are differently expressed in athletes of different levels of competition (e.g., Garland and Barry, 1990; Allen et al., 2011). Also, it seems absolutely justified to put forward the question concerning how participation in sports and competitions can affect the development of personality (Allen et al., 2013), regardless of its strong genetic basis. Personality development is significant since, in a non-sport context, personality traits are associated with a number of important psychological and behavioral factors such as coping with stress (Connor-Smith and Flachsbart, 2007), successful task performance (Oh et al., 2011), unhealthy life habits such as smoking and alcohol abuse (Malouff et al., 2006, 2007).

The aim of this study was to determine whether the set of specific psychological characteristics (generalized self-efficacy, time perspective, EI, general achievement motivation, and personality dimensions) makes the distinction between athletes based on their (non)-participation in the senior national team, that is, their belonging to the subsample of elite or non-elite athletes depending on this criterion.

MATERIALS AND METHODS

Participants

The sample of this study included 230 athletes (22.35 ± 4.16 years) from the Republic of Serbia (140 males and 90 females). The criterion according to which the sample was divided was their participation in the Serbian senior national teams. The national team members (who all have significant experience at an international level as well) included 94 athletes from the sample, while the remaining part of the sample (136 athletes) included the athletes participating in national competitions, training more than five times a week, but have never been invited to join a senior national team and have no international experience. The inclusion criteria in the research also was that athletes train for more than 7 years. The sample of the athletes who are not the members of national teams was proportionate to the sample of the athletes who appear in the national teams, according to gender and type of sport. Such a division was made to clearly distinguish between the elite athletes and the athletes who cannot be classified as the elite ones. The entire Serbian senior national teams (male basketball national team, male volleyball national team, female volleyball national team, female football national team), as well as individual members of the male and female judo national teams and members of water polo and handball national teams, participated in this study. All participants were completing a paper and pencil questionnaires.

Instruments

The *Zimbardo Time Perspective Inventory* (Zimbardo and Boyd, 1999), or more precisely the Serbian version of this instrument (ZTPI, Kostić and Nedeljković, 2013) comprising 52 items was used to examine time perspectives. The dimensions are the same as in the original questionnaire: *past-negative (8 items), present-hedonistic (16 items), future (11 items), past-positive (13 items)*, and *present-fatalistic (4 items)*. The reliability of the whole questionnaire obtained in this study by calculating the Cronbach alpha is 0.868.

The instrument used to assess self-efficacy was the *General Self-Efficacy Scale* (GSE, Schwarzer and Jerusalem, 1995) which consists of 10 items, and respondents provide answers showing the extent to which the given statements are true in relation to themselves, using a five-point Likert-type scale. The reliability of the questionnaire obtained in this study by calculating the Cronbach alpha is 0.827.

The instrument used to determine a level of achievement motivation was *MOP2002* (Franceško et al., 2002) which consists of 55 items formulated as statements, and the respondents assessed a degree of agreement using a five-point scale. This scale includes the following four factors of the first order: Persistence in achieving goals (15 items), Competing with others (19 items), Goal achievement as a source of satisfaction (13 items), and Orientation toward planning (8 items). Since the specified factors were not independent and significantly correlated with the overall score, only the total score was used in the study. The reliability of the questionnaire obtained in this study by calculating the Cronbach alpha is 0.905.

The instrument used to determine personality traits was *HEXACO-PI-R* (Lee and Ashton, 2018) which consists of 100 items in total. The dimensions represented were as follows: *Honesty*, *Emotionality*, *Extraversion*, *Agreeableness*, *Conscientiousness,* and *Openness*. The Serbian version showed good metric characteristics (Mededović et al., 2019). The reliability of the questionnaire obtained in this study by calculating the Cronbach alpha is 0.866.

The emotional competence questionnaire (Takšić, 2002) consists of 45 statements where respondents give their answers by choosing one of the numbers given on a five-point scale. The answers represent the respondents' assessment of the development of their own abilities regarding emotional competence. In addition to the overall score, the scores using the subscales of *Ability to perceive and understand emotions, Ability to express and identify emotions*, and *Ability to manage and regulate emotions* were also obtained. Only the overall score was used in the study. The reliability of the questionnaire obtained in this study by calculating the Cronbach alpha is 0.909.

Data Analysis

In the data analysis, descriptive measures, mean differences, and discriminant analysis were used.

RESULTS

The basic research question was whether a set of psychological factors including time perspectives, self-efficacy, basic personality traits, general achievement motive, and EI made a distinction between the athletes according to their participation in the national teams. Since univariate tests do not take into account the relationship among variables, a discriminant function analysis was also performed on the 14 variables. The values of group centroids (mean discriminant scores for each group) for the national team members and the non-member athletes were 0.599 and −0.414, respectively. The discriminant function obtained for the 14 factors, Wilks $\lambda = 0.800$, Chi-square $(14) = 49.312$, $p < 0.001$. Refer to **Table 1** for the entry order of the 14 variables and their corresponding standardized discriminant function coefficients.

The obtained canonical discriminant function is: Discriminant score = 0.981 * self-efficacy + 0.594 * emotionality + 0.247 * present fatalistic time perspective + 0.132 * past positive time perspective + 0.130 * openness to experience – 0.693 * past negative time perspective – 0.380 * emotional competence – 0.250 * future time perspective.

According to the group centroids it can be said that the members of the national teams are characterized by a positive high score in self-efficacy, emotionality, present fatalistic time perspective, past positive time perspective, and openness to experience. They are also characterized by low past negative time perspective, emotional competence, and future time perspective.

DISCUSSION

The obtained results have shown that self-efficacy is the most important factor which made a distinction between the athletes who are members of the national teams and those who are non-members, i.e., successful and less successful athletes. General self-efficacy is one's confidence in the ability to overcome demanding situations and one's belief that success depends on our own actions (Schwarzer and Jerusalem, 1995). Taking into account that the sources of self-efficacy in sport (past performance accomplishments, social/verbal persuasion, vicarious experience/modeling, and interpretation of physical/emotional states) are the same as in other fields of human functioning (Samson and Solmon, 2011), it is easy to assume why such big differences occurred in the perceived self-efficacy—more successful athletes had a greater number of and more significant results, therefore, they were certainly more convinced of their own capabilities related to sport achievements via the media and their sports environment. One of the methods to enhance self-efficacy in the sport context is to practice self-talk (Hatzigeorgiadis et al., 2008). However, the obtained results gain in significance, taking into account that generalized self-efficacy, and not the sport-specific one, was examined in this study, which was not the case in most studies which dealt with the relationship between self-efficacy and sport performance (Feltz and Lirgg, 2001). This practically means that more successful athletes are confident about their abilities not only when it comes to sports venues but also in general. Since a high level of self-efficacy is associated with life transitions and work-related performance, it may be assumed that they are more prepared for a more successful career transition following the termination of their active sport participation. Thus, the findings obtained in this study suggest that the development of general self-efficacy should be included in the talent development programs in sport as well as that sport performance would be thereby improved and life skills developed.

Personality dimensions defined by the HEXACO Model (Ashton et al., 2014) are another psychological factor which distinguishes between the elite and non-elite athletes, as suggested by the results of this study. More successful athletes are characterized by higher levels of emotionality and openness to experience. Emotionality comprises subordinating aspects: Fearfulness, Anxiety, Dependence, and Sentimentality, and high scores on this scale are achieved by the persons who fear of physical dangers of injuries, they feel anxiety as a response to life stresses and the need for emotional support by other people, have empathy and sentimentality for others (Ashton et al., 2014). Logically, body and its readiness to perform is a basic precondition of success in sport and elite athletes are aware of the fact that injuries make the desired sport results more distant so they feel fear of injuries. High scores related to the need for emotional support by other people, empathy and sentimentality may be described by the fact that a vast

TABLE 1 | Means, standard deviations, *t*-tests, standardized discriminant function coefficients, and correlations between discriminant scores and variable raw scores for national team members and non-members.

	National team	Mean	*SD*	$F_{(1, 228)}$	Stand. Can. Disc. Fun. Coeff.	Corr. Disc. Var. Raw
Past negative TP	Yes	2.04	0.721	7.699**	−0.693	−0.368
	No	2.33	0.847			
Present hedonistic TP	Yes	3.58	0.566	2.661	0.022	0.216
	No	3.47	0.443			
Past positive TP	Yes	3.22	0.692	0.008	0.132	0.012
	No	3.21	0.621			
Future TP	Yes	3.54	0.515	1.043	−0.250	0.135
	No	3.47	0.527			
Present fatalistic TP	Yes	2.38	0.715	0.000	0.247	0.001
	No	2.38	0.833			
Self-efficacy	Yes	34.78	3.558	28.698**	0.981	0.710
	No	31.99	4.101			
Honesty-Humility	Yes	53.41	9.407	0.140	−0.089	0.050
	No	52.96	8.707			
Emotionality	Yes	49.14	7.386	2.452	0.594	0.207
	No	47.69	6.615			
Extraversion	Yes	59.61	7.569	3.370	0.036	0.243
	No	57.67	8.089			
Agreeableness	Yes	47.42	7.591	0.522	0.062	−0.096
	No	48.08	6.272			
Conscientiousness	Yes	59.13	8.821	2.664	−0.031	0.216
	No	57.33	7.841			
Openness to experience	Yes	54.53	9.753	2.401	0.130	0.205
	No	52.65	8.501			
General motive of achievement	Yes	212.48	20.964	3.871*	0.055	0.261
	No	207.29	18.755			
Emotional competence	Yes	172.97	18.816	2.512	−0.380	0.210
	No	169.19	17.031			

*$p < 0.05$; **$p < 0.01$.*

majority of the respondents included in this study are engaged in team sports and mutual support and understanding are often crucial for successful team play. Both elite and non-elite athletes show a higher level of anxiety in relation to general population (Matsumoto et al., 2000), and a great percentage of athletes achieve the best results in the state of intensified anxiety (Hanin, 2007). Higher scores related to the dimension of openness to experience may indicate the creativity in performance and an athlete's responsiveness to coaches' various tactical and training suggestions. It should be noted that these interpretations of the obtained findings are speculative to a great extent, since the facets comprising the domains were excluded from the statistical processing in this study. In regard to the role of global personality dimensions in sport, the seemingly reasonable perspective obtained by the analysis of the so-far research should also be noted, stating that personality dimensions mediate the relationships between the factors which are specifically relevant for sport performance but do not predict success directly (Allen et al., 2013).

By examining the differences between the members of national teams (elite athletes) and those who are non-members (non-elite athletes) in regard to time perspectives, it has been found that the elite athletes are characterized by high present fatalistic and past positive time perspectives, and past negative and future time perspectives are less expressed in these athletes. Unfortunately, the number of studies that investigate time perspectives in a sports context is neglectable, so the discussion can be based on logical analysis and assumed models of the connection between playing sports and the perception of time perspectives. It was expected that the time perspectives of the elite and non-elite athletes were different since they arise out of personal and social experience (Zimbardo and Boyd, 2008), and their engagement in sports is certainly significant experience for both groups of the athletes examined. The assumed model of the effects of time perspectives on sports engagement (Stolarski et al., 2019) suggested that past positive time perspective would have positive effects, either directly or indirectly, and past negative time perspective would have adverse effects on sport performance. The results obtained in this study have supported this assumption. However, the results which are inconsistent with the assumed model were also obtained in this research. Present fatalistic time perspective has shown to be more present in the elite athletes and it was expected to have negative effects on a motivation-engagement-performance chain (Stolarski et al., 2019). The obtained data is unexpected when we take into account that people with fatalistic understanding of the present have, amongst other things, reduced personal efficiency, external locus of control and planning, which should be accompanied by effort and work. It is very difficult to connect such a description with elite athletes since they go through various cycles of carefully planned preparations during which clearly determined goals are realized. It may be possible to assume that elite athletes are satisfied with what they have achieved and do not make plans, while non-elite athletes are convinced that they can still significantly increase their performance through training. One of explanations for expression of the fatalistic present in top athletes can be found in the lack of autonomy during sports development. Lack of autonomy refers to the exclusion (although sometimes with the best intentions) of athletes from decision-making process and is associated with occurrence of overtraining in young athletes (Winsley and Matos, 2011). A lower future time perspective of the elite athletes was most difficult to explain since its significant positive impact on sport results was assumed, especially through motivation (Zentsova and Leonov, 2013; Stolarski et al., 2019). Nevertheless, a real effect of future time perspective in a sport context can be considered in different ways. For example, Stolarski et al. (2019) stated that a high future positive time perspective could be proven a factor which would prevent young athletes' drop-out, and present fatalistic time perspective would have opposite effects. This may be true given the findings of the research indicating a dominant future perspective in less successful athletes and a higher present fatalistic time perspective found in more successful athletes. Both groups of athletes remained involved in sports and the reasons for their staying in sports may be found in the future time perspective of those belonging to the group of less successful athletes—they plan and set goals and put efforts in their realization, therefore, they can delay current pleasures in anticipation of achieving a greater satisfaction in future. The reason for a long-term participation in sports in elite athletes can be probably found in their realistic sports achievements which are high in both the present and the past. Regardless of the slightly unexpected results, we hope that this study, being among the first ones of its kind, would serve as the background for further, more complex, empirical research on the theory of time perspectives in the field of competitive sports.

The results of the study have shown that the presence of a general achievement motive did not make a difference in the athletes' psychological profiles in regard to performance, and the finding stating that emotional competence (emotional intelligence trait) was more expressed in the less successful athletes was surprising, since it is contrary to the results of some previous studies (Perlini and Halverson, 2006; Laborde et al., 2014).

The aim of the study was to determine whether the set of specific psychological characteristics (generalized self-efficacy, time perspective, EI, general achievement motivation, and personality dimensions) makes the distinction between athletes based on their (non)-participation in the senior national team, that is, their belonging to the subsample of elite or non-elite athletes depending on this criterion. The study was conducted on a highly selected sample of the elite athletes (most of whom have a medal won at the Olympics or World or European Championships) and a parallel sample of the less successful athletes. The study was conducted by the application of the questionnaires which were used in the previous studies and demonstrated excellent metric characteristics in the culture the examined athletes belong to. The results have shown that the elite athletes, compared to those who are less successful, have high scores in self-efficacy, emotionality, present fatalistic time perspective, past positive time perspective, and openness to experience. They are also characterized by low past negative time perspective, emotional competence, and future time perspective.

LIMITATIONS AND FUTURE LINES OF RESEARCH

There are also some limitations regarding the results of this study. The first limitation is related to the fact that the study was conducted in one culture which relativizes the generalization and extrapolation of the obtained findings. Another limitation refers to heterogeneity of the sample in terms of gender, type of sport, and not controlling the length of sports experience (it was only important that they train for more than 7 years). The division into sub-samples obtained by crossing criteria of sex and sports performance would lead to far too small sub-samples for carrying out valid conclusions based on statistical analysis. However, we believe that such heterogeneous samples also served to establish a general distinction between elite and non-elite athletes, and laid foundations for further research on larger samples. This is also justified by the fact that data obtained in this study actually aim to suggest an improvement in the long-term development of young athletes regardless of their gender, although it is certain that gender differences would contribute to clearer recommendations for sports practitioners. The third limitation could be associated with the application of instruments which are not sport-specific, but intended for general population. Regardless of the fact that the application of sport-specific instruments would (probably) demonstrate clearer differences between the subsamples there are two reasons for opting for this instrument. The first being a lack of sport-specific questionnaires developed for all the studied variables (personality dimensions, time perspectives). Secondly, we intended to draw attention to the fact that specific psychological traits can be developed with double benefit—to improve sport performance but also to develop life skills. In future studies, the focus should be on researching time perspectives in sports, i.e., their connection with motivational processes, stress, and overtraining, especially in young athletes. We believe that the talent development programs in young athletes have to take into account the humanistic approach to work, regardless of the extreme competitiveness and, sometimes, even cruelty of today's sport.

Talents should definitely be developed, however, during this process, the care should be taken of the children who do not manage to become top athletes for various reasons, as well as of athletes after the termination of their active sports careers.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Committee of the University of Novi Sad (Ref. No. 46-06-02/2020-1). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PM, JN, ŽB, and MF wrote the article. PM, JN, ŽB, MF, IM, AB, and PD designed the study, analyzed the data, discussed the results, and reviewed and approved the article. All authors contributed to the article and approved the submitted version.

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Improving on Half-Lightweight Male Judokas' High Performance by the Application of the Analytic Network Process

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Judo is a multifactorial sport where many variables or key performance indicators (KPIs) such as force-velocity profile, bioenergetic capacity, technical and tactical skills, and cognitive and emotional competence play a role and influence the final result. While there have been many academic studies of these variables, usually in isolation, none have examined KPIs holistically or analyzed their impact on strategic performance. The main objective of the present study, therefore, is to apply a novel and easily replicable methodology to identify and prioritize the main KPIs affecting performance in professional judo. Such a methodology was applied to the High-Performance Judo Centre of Valencia, using a multi-criteria decision aid technique: the analytic network process (ANP). The ANP is used to identify and quantify cause and effect relationships not only between KPIs but also between KPIs and performance objectives. Further, the ANP offers effective results when there is a lack of historical KPI data, because it is based on experts' opinions and judgments. A judo expert group (JEG) comprising elite judo coaches and half-lightweight (under 66 kg) male judokas applied the methodology to discriminate between the characteristics required when aiming to reach high-level strategic objectives (such as participating in the Olympic Games or winning a medal in a Grand Slam/Gran Prix). The JEG, which consisted of five elite judokas, national and international champions, and three Olympic coaches—including a former European champion and silver medalist in a world championship—provided high added value to the study. The main findings were that the KPIs that made the most difference were mostly psychological, specifically motivation, stress, and team cohesion. Of these, motivation was by far the most important KPI for success in our case study, so judokas should make sure that they analyze it properly. Motivation is usually intrinsic to the competitor and should be maintained at a high level, not only during tournaments but also during daily training and lifestyle activities. Physical and other specific forms of training, as well as lifestyle KPIs, are very important for the elite competitor but are not sufficient to reach high-level objectives. The most important of these KPIs were Kumi-Kata (grip work), dual career, focus and concentration level, scouting, nutrition, and basic technique. Power and strength were the most important physical KPIs. In general, these are essential for meeting strategic objectives, but they do not make the crucial difference. This suggests that professional psychological support should be provided in daily training and that international team composition and internships should be fostered.

Keywords: performance improvements, judo, psychology skills, analytic network process, key performance indicators

INTRODUCTION

There are currently many indicators to measure, control, and monitor sport performance. The recent incorporation and application of new data analysis techniques to professional sport (i.e., using big data or artificial intelligence) allow access to a more holistic analysis of the information extracted from real-world sports (Gu et al., 2019). This information is employed to enhance the decision-making process in the context of sports performance improvement, which should lead to goal achievement. Conversely, the coaching staff (i.e., coaches, sports psychologists, sports physicians, and so on) dispose of an overwhelming quantity of data that could help to establish what variables are key and which ones directly impact performance. Frequently, once the key performance indicators (KPIs) have been identified, problems arise when trying to identify which of these KPIs are directly linked to an athlete's ability to reach their strategic objectives. Such strategic objectives can be defined as the main goals that the athlete aims to achieve in the medium–long term (i.e., to obtain classification for the Olympic Games) and that therefore condition their efforts and planning. The strategic objectives should be few in number and realistically achievable to avoid frustration and wrongly defined preparation planning (Kaplan and Norton, 1992).

Competition in elite combat sports, such as boxing, tae-kwon-do, wrestling, and judo, requires complex technical skills with high strength and conditioning demands (Miarka et al., 2016). The athletes have to make correct decisions in a very short period of time, when multiple choices are available (Franchini et al., 2019). Furthermore, anxiety control and emotional intelligence are necessary not only on the day of competition but also in the preparation period, when athletes have to manage their weight and deal with a stressful training program (Merino Fernández et al., 2020). Previous studies have to some extent identified the variables that can be considered as KPIs for judo performance; these including weight management (Escobar-Molina et al., 2016; Thomson et al., 2017; Gallot et al., 2019), level of strength (Ache Dias et al., 2012; Franchini et al., 2019), technical and tactical skills (Weigelt et al., 2011; Bocioaca, 2014; Miarka et al., 2020), level and direction of motivation (Gillet et al., 2010; Boughattas et al., 2017; Oliveira et al., 2018), nutrition (Artioli et al., 2019), capacity for focus and attention (Yahija, 2010; Jacini et al., 2012; Mihailescu and Sava, 2013; Toh et al., 2018; Campos Faro et al., 2020), sleep habits (Chtourou et al., 2018; Knowles et al., 2018; Vlahoyiannis et al., in press), speed (Almansba et al., 2008), and level of conditioning capacity (aerobic and anaerobic; Detanico et al., 2012; Franchini et al., 2014, 2016; Hesari et al., 2014; Anthierens et al., 2016).

Recently, our research group (Uriarte Marcos et al., 2019) studied the KPIs for judo and sought to classify them into four clusters: general physical training, specific training tasks, lifestyle, and psychology skills. To the best of our knowledge, no scientific study has identified and prioritized the relative importance of KPIs in achieving strategic objectives in judo. The expected main benefits from prioritizing judo KPIs to achieve the athlete's strategic objectives include improvements in the design of training programs, identification of strengths and weakness of the athletes, saving and aligning efforts among technical staff working with judokas, and better organization at all levels. This should lead to higher performance. It is possible to find within the scientific literature studies that have dealt with linking judo KPIs with performance. Some authors have investigated the impact of weight loss on performance (Artioli et al., 2010; Fortes et al., 2017), while others have analyzed how the time of day influences explosive performance and psychological variables in elite judokas (Chtourou et al., 2018). The relationship between technical-tactical behaviors (Miarka et al., 2017) and physical capacities (Kons et al., 2018) has also been a focus of attention. Notwithstanding, the design of previous studies has limited researchers' capacity to explain the complexity of success in judo competition. They have invariably selected one or various KPIs and related them to outcomes in specific and unspecific test performances; this type of experimental design cannot eliminate the noise produced by strange variables when interpreting causality in performance outcomes. Employing an integrated approach, even at the risk of precision, could shed light on understanding the key skills needed for success in a complex multifaceted judo competition. Identifying the importance of particular KPIs might assist in the achievement of high-level strategic objectives. Experts' criteria have been used as a tool for detecting key performance indicators in sport (Sanchez et al., 2019). However, it has to be borne in mind that this technique involves a certain degree of subjectivity, so it is necessary to apply methods that manage this, for example multi-criteria decision aid (MCDA) techniques. In particular, the analytic network process (ANP; Saaty, 1996) captures the valuation of decision makers in a systematic and organized way and provides clear quantitative results. In addition, the original valuations can be easily modified if necessary, and at the same time, the results can be amended. Furthermore, the ANP has proven its effectiveness in identifying and quantifying the influence of heterogeneous KPIs on performance in similar research in other disciplines (Souza Farias et al., 2019; Andrade Arteaga et al., 2020).

Therefore, the main aims of the present study are as follows: (a) to identify and to prioritize the main KPIs that can help to build on the high performance of professional judokas; (b) to establish the link between judo KPIs and the achievement of strategic objectives; and (c) to make recommendations to improve performance based on the findings.

MATERIALS AND METHODS

Participants

Five half-lightweight (under 66-kg category) male judokas and their coaches met the inclusion criteria for the judo expert group (JEG). They were recruited from the High-Performance Judo Centre of Valencia during a training camp. The inclusion criteria were that they should be elite judo athletes in the under 66-kg category with international presence and should have similar ambitious strategic objectives such as participation in the Olympic Games, international ranking improvement, or winning a Grand Prix/Slam. They were members of the national teams of Spain, Italy, USA, France, the Dominican Republic, and Puerto Rico and represented their countries as athletes and national coaches in international championships. Their personal data and assessments were coded during the research process to ensure that all information was anonymous and protected.

Procedure

The methodology used to prioritize the KPIs for professional judokas to reach strategic objectives is presented in **Figure 1**.

Step 1: Identify Main Judo KPI

The objective of this step was to identify the main judo KPI using the process employed in the scientific literature and the experience of the JEG. The JEG first used the classification carried out by Uriarte Marcos et al. (2019), as this work not only identified the most important KPIs for elite judo athletes but also classified them into four clusters (physical training, specific training, psychology, and lifestyle). They then decided by consensus which KPI from the literature should be kept for the purposes of the research and which others to add. The KPIs were selected according to their capacity to impact the judo athlete's high performance.

Step 2: Define Judo Strategic Objectives

In this step, the JEG defined the strategic objectives for the judokas (with the researchers' assistance). The members were asked to write down freely the five medium-term (i.e., the next 2–3 years) strategic objectives they regarded as the most important. These were then analyzed, and it was agreed to keep four of them based on their frequency of appearance in the survey and on their alignment.

Step 3: Application of the ANP: Prioritization of KPIs According to the Strategic Objectives

In this step, the KPIs were prioritized according to their importance in achieving the strategic objectives by applying the analytic network process (ANP; Saaty, 1996). The main steps of the ANP, and how the JEG developed them, are presented next.

Step 3.1: Definition of the Dependence Matrix

This involved the JEG identifying any potential relationships between each pair of variables and forming a one–zero matrix called the dependence matrix, which indicates the presence of a meaningful relationship between the two (Saaty, 1996).

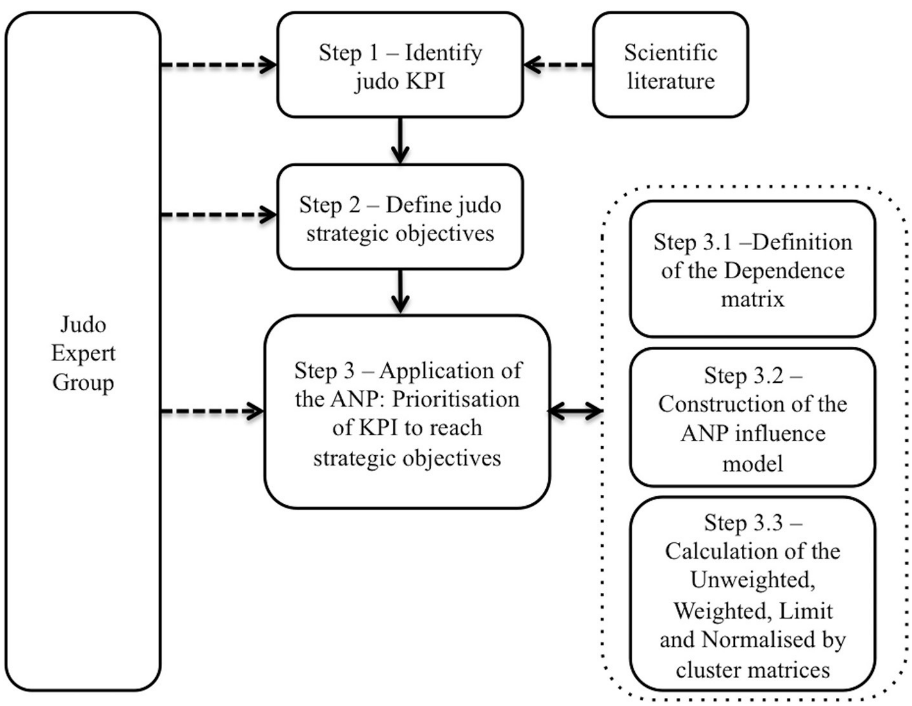

FIGURE 1 | Methodology.

Additionally, the variables were grouped in different clusters according to their common characteristics; e.g., the physical training KPI constituted the "physical training cluster."

Step 3.2: Construction of the ANP Influence Model

The results of the dependence matrix were used to build the ANP influence model, which is a graphical representation of the matrix, where the relationships established between both clusters and elements are introduced.

Step 3.3: Construction of the Unweighted, Weighted, Limit, and Normalized-by-Cluster Matrices

Different matrices were worked out to determine the influence of the different elements of the ANP model (i.e., the KPIs and strategic objectives). The JEG began by completing a pair-wise questionnaire for all the existing relationships defined in the dependence matrix and modeled in the ANP influence model. They then compared two elements according to their influence on a third and quantified the influence using Saaty's Fundamental Scale (see **Table 1**).

For example, the question "Which element has a greater influence on the 'Olympic Games classification' strategic objective: 'Technical and tactical skills' or 'Relative strength'?" had to be scored as a 5 if the judo expert valued that the KPI "Technical and tactical skills" was substantially more important that the KPI "Relative strength" in achieving the strategic objective of "Olympic Games classification."

Once the pair-wise comparisons were made, the first matrix computed was the unweighted matrix, followed by the weighted matrix. The latter made it possible to extract directly the cause and effect relationships between each pair of elements of the network and to identify the KPIs that strongly affected the strategic objectives. The matrix was then raised to as many powers as were necessary to obtain the limit matrix, in which all of the columns would amount to 100%. The limit matrix offered the global relative weight of each variable and, in the present study, provided the basis for the prioritization not only of the KPIs but also the strategic objectives. Finally, the normalized matrix was computed; this showed the relative importance of each variable within its cluster.

Derived from these matrices, it is possible to conduct different analyses. Then, in this research, three analyses are carried out:

TABLE 1 | Saaty's Fundamental Scale (Saaty, 1996).

Intensity of importance	Definition
1	Equal importance/preference
2	Weak
3	Moderate importance/preference
4	Moderate plus
5	Strong importance/preference
6	Strong plus
7	Very strong or demonstrated importance/preference
8	Very, very strong
9	Extreme importance/preference

1) Cause–effect analysis. This analysis is made from the results of the unweighted matrix and it identifies the main direct cause–effect relationships between each pair of variables. Then, it aims to determine the most important cause KPIs that are influencing not only to other KPIs but also to the strategic objectives. In general, these KPIs that are producing a high intensity and direct effect on the strategic objectives should be fostered, as the main aim of the judokas is to reach such objectives. Additionally, this analysis also studies the cause–effect relationships between the strategic objectives, being then able to classify and align such objectives. Finally, it is also possible to study the indirect cause–effect relationships that would identify the KPIs that are strongly influencing to other KPIs, which at the same time strongly influence to the strategic objectives.
2) ABC analysis. This analysis is based on the results of the limit matrix and categorizes the study variables as follows:
    - Class A includes the variables that account for ∼65–70% of the total value of the limit matrix. These are the most important variables of the network from a global point of view;
    - Class B includes the variables that account for ∼20% of the total value of the limit matrix. The importance of the B class variables is medium;
    - Class C includes the variables that account for ∼10–15% of the total value of the limit matrix. The importance of the C class variables is low.
3) Cluster analysis. This analysis is based on the normalized-by-cluster matrix and identifies, for each of the defined clusters, the most important variables, ranking them and offering a cluster-based vision for decision-makers.

All comparisons and posterior matrices outcomes were processed using the software Superdecisions V2.10 (www.superdecisions.com, Pittsburg, USA).

RESULTS

Step 1: Identifying KPIs for Judo

The JEG retained all 15 KPIs classified into the four clusters defined previously (Uriarte Marcos et al., 2019) and modified some of them. They also added other KPIs that they felt had an important impact on the high performance of male half-lightweight judokas in reaching their high-level strategic objectives. There were a total of 26 KPIs in all. **Table 2** summarizes both the KPIs and clusters used in the study and the original ones defined by Uriarte Marcos et al. (2019).

Step 2: Define Judo Strategic Objectives

The JEG drew up a list of nine strategic objectives, from which the following four were retained for the research:

- To qualify for the Olympic Games;
- To win a medal in either a Grand Prix or a Grand Slam;
- To make a significant improvement in international ranking;
- To become (or remain) national champion.

TABLE 2 | Selection of the judo KPI and clusters.

Cluster	KPI from Uriarte Marcos et al. (2019)	KPI for research
Physical training	Coordination	
	Strength	Maximum strength Relative strength
	Speed	
	Heart rate	Cardiac frequency—basal Cardiac recovery
	Aerobic and anaerobic fitness	Aerobic resistance Anaerobic resistance
	Flexibility	
	Power	
Specific training	Technical and tactical preparation	Basic tactic Basic technique Specific tactic Specific technique
	Age	
	Weight	
	Kumi-Kata	
	Scouting	
Psychology	Focus and concentration level	
	Stress	
	Motivation	
	Activation level	Activation level
	Team cohesion	
Lifestyle	Nutrition	
	Dual career	
	Sleep	8/8/8

Step 3: Application of the ANP: Prioritization of KPIs to Reach the Strategic Objectives

Step 3.1: Definition of the Dependence Matrix

Table 3 shows the definition of the dependence matrix.

Step 3.2: Construction of the ANP Influence Model

We designed the ANP influence model (**Figure 2**), which contains all the variables, clusters, and their relationships as defined in the dependence matrix.

Step 3.3: Construction of the Unweighted, Weighted, Limit, and Normalized-by-Cluster Matrices

The first activity was to state the influence between each pair of variables and to reach a third using Saaty's Fundamental Scale. The unweighted matrix and the weighted matrix (**Table 4**) were thus obtained.

Cause–Effect Analysis

Using the weighted matrix, it was possible to identify which KPI directly influenced the strategic objectives the most, as well as the relationships between the latter. The variables in the rows represent the cause and the variables in the columns the effects (**Table 4**). This leads to the construction of **Figure 3**, which shows that three KPIs—motivation, stress, and team cohesion—directly and meaningfully affected the strategic objectives (O_1, O_2, O_3, and O_4). Some of the effects were of greater intensity (continuous arrows) than others (discontinuous arrows). They are described as follows:

- Motivation strongly influences O_1 (OG qualification), O_2 (GP/GS medal), and O_3 (international ranking improvement);
- Stress strongly influences O_4 (national champion) and moderately influences O_1, O_2, and O_3;
- Team cohesion has a moderate influence on O_1, O_2, and O_3.

When considering the strategic objectives, it is also possible to find the following:

- There is a dual and strong relationship between the priority objectives; reaching O_1 will help one to reach O_2 and vice versa;
- There is a strong relationship between O_2 and O_3 (i.e., winning a medal will lead to an improvement in international ranking) and a moderate relationship between O_3 and O_2 (i.e., an improvement in international ranking will not necessarily lead to winning a medal);
- There is a moderate relationship between O_2 and O_1 (i.e., an improvement in international ranking is aligned with becoming a national champion);
- There is a strong relationship between O_1 and O_4 (i.e., participating in the Olympic Games helps the competitor to become a national champion).

ABC Analysis

The limit matrix is shown in **Table 5**, along with an ABC analysis that categorizes the study variables as specified previously in the paper.

The A class KPIs were motivation, stress management, team cohesion, and dual career. The last three belonged to the psychology cluster and the last one to the lifestyle cluster. The motivation KPI was by far the most important variable in the network, with a weight of 20%, followed by stress management, with a weight of 8.6%. Both belonged to the psychology cluster, and the reason for their importance might be their connection with the high-level strategic objectives defined in the present study. The definition and accomplishment of a dual career was also an important KPI and positively affected the motivation level of the judoka (**Table 4**).

The B class contained KPIs from the clusters of lifestyle, psychology, and specific training and none from the physical training cluster. The highest ranked KPI in the B class was 8/8/8 (8-h training, 8-h sleep, and 8-h rest per day), followed closely by focus and concentration level. This was aligned with the nutrition KPI, which was directly linked with the weight of the athlete and the severity of the discipline required for rapid weight loss in preparation for competitions. With regard to specific training, the Kumi-Kata KPI was the most important in the B class, followed by scouting and basic technique.

TABLE 3 | Dependence matrix.

		AR	ANR	CF	CR	MaxS	RelS	Sp	Pw	Coor	Flex
DEPENDENCE MATRIX (1/3)											
Physical training	Aerobic resistance (AR)	0	1	1	1	0	0	0	0	1	0
	Anaerobic resistance (ANR)	1	0	1	1	0	0	1	1	1	0
	Cardiac frequency—basal (CF)	1	1	0	1	0	0	0	0	0	0
	Cardiac recovery (CR)	1	1	1	0	0	0	1	1	0	0
	Maximum strength (MaxS)	0	0	0	0	0	1	0	1	0	0
	Relative strength (RelS)	0	0	0	0	1	0	0	1	0	0
	Speed (Sp)	1	1	0	0	0	0	0	1	0	0
	Power (Pw)	1	1	0	0	1	1	1	0	0	0
	Coordination (Coor)	0	0	0	0	1	1	1	1	0	0
	Flexibility (Flex)	0	0	0	0	0	0	0	0	1	0
Specific training	Basic technique (BT)	0	0	0	0	1	1	0	0	1	1
	Specific technique (ST)	0	0	0	0	1	1	0	0	1	1
	Basic tactic (BTac)	0	0	0	0	0	0	0	0	0	0
	Specific tactic (Stac)	0	0	0	0	0	0	0	0	0	0
	Kumi-Kata (KK)	0	0	0	0	1	1	1	1	1	0
	Scouting (SC)	0	0	0	0	0	0	0	0	0	0
	Weight (Wei)	1	1	1	1	1	1	1	1	1	0
	Age	1	1	1	1	1	1	1	1	1	1
Lifestyle	Nutrition (Nut)	1	1	1	1	1	1	1	1	1	0
	Dual career (Dual)	0	0	0	0	0	0	0	0	0	0
	8/8/8	1	1	1	1	1	1	1	1	0	0
Psychology	Motivation (Mot)	1	1	1	1	1	1	1	1	1	1
	Stress (Stress)	1	1	1	1	1	1	1	1	1	0
	Activation level (Act)	0	0	1	0	1	1	1	1	1	0
	Focus and concentration level (Foc)	0	0	0	0	1	1	1	1	1	0
	Team cohesion (Cohe)	0	0	0	0	0	0	0	0	0	0
Objectives	National champion (N. Champ)	0	0	0	0	0	0	0	0	0	0
	International ranking improvement (IRI)	0	0	0	0	0	0	0	0	0	0
	GP/GS medal	0	0	0	0	0	0	0	0	0	0
	OG classification	0	0	0	0	0	0	0	0	0	0

		Specific training								Lifestyle		
		BT	**ST**	**Btac**	**Stac**	**KK**	**SC**	**Wei**	**Age**	**Nut**	**Dual**	**8/8/8**
DEPENDENCE MATRIX (2/3)												
Physical training	Aerobic resistance (AR)	0	1	0	1	1	0	1	0	0	0	0
	Anaerobic resistance (ANR)	0	1	0	1	1	0	1	0	0	0	0
	Cardiac frequency—basal (CF)	0	0	0	0	0	0	0	0	0	0	0
	Cardiac recovery (CR)	0	1	0	1	0	0	0	0	0	0	0
	Maximum strength (MaxS)	1	1	0	1	1	0	1	0	0	0	0
	Relative strength (RelS)	1	1	0	1	1	0	0	0	0	0	0
	Speed (Sp)	1	1	0	1	1	0	0	0	0	0	0
	Power (Pw)	1	1	0	1	1	0	0	0	0	0	0
	Coordination (Coor)	1	1	1	1	1	0	0	0	0	0	0
	Flexibility (Flex)	1	1	0	0	0	0	0	0	0	0	0
Specific training	Basic technique (BT)	0	1	1	1	1	1	0	0	0	0	0
	Specific technique (ST)	1	0	1	1	1	1	0	0	0	0	0
	Basic tactic (BTac)	1	1	0	1	1	1	0	0	0	0	0
	Specific tactic (Stac)	1	1	1	0	1	1	0	0	0	0	0
	Kumi-Kata (KK)	1	1	1	1	0	1	0	0	0	0	0

(Continued)

TABLE 3 | Continued

		Specific training								Lifestyle		
		BT	**ST**	**Btac**	**Stac**	**KK**	**SC**	**Wei**	**Age**	**Nut**	**Dual**	**8/8/8**
	Scouting (SC)	1	1	1	1	1	0	0	0	0	0	0
	Weight (Wei)	1	1	1	1	1	1	0	0	1	1	1
	Age	1	1	1	1	1	1	1	0	1	1	1
Lifestyle	Nutrition (Nut)	1	1	1	1	1	0	1	0	0	1	1
	Dual career (Dual)	0	0	0	0	0	1	1	0	1	0	1
	8/8/8	1	1	1	1	1	1	1	0	1	1	0
Psychology	Motivation (Mot)	1	1	1	1	1	1	1	0	1	1	1
	Stress (Stress)	1	1	1	1	1	1	1	0	1	1	1
	Activation level (Act)	1	1	1	1	1	1	1	0	1	1	1
	Focus and concentration level (Foc)	1	1	1	1	1	1	1	0	1	1	1
	Team cohesion (Cohe)	1	1	1	1	1	1	1	0	1	1	1
Objectives	National champion (N. Champ)	0	0	0	0	0	0	0	0	0	0	0
	International ranking improvement (IRI)	0	0	0	0	0	0	0	0	0	0	0
	GP/GS medal	0	0	0	0	0	0	0	0	0	0	0
	OG classification	0	0	0	0	0	0	0	0	0	0	0

		Psychology					Objectives			
		Mot	**Stress**	**Act**	**Foc**	**Cohe**	**N champ**	**IRI**	**Medal**	**OG**
DEPENDENCE MATRIX (3/3)										
Physical training	Aerobic resistance (AR)	1	1	0	0	0	1	1	1	1
	Anaerobic resistance (ANR)	1	1	0	0	0	1	1	1	1
	Cardiac frequency—basal (CF)	0	0	0	0	0	1	1	1	1
	Cardiac recovery (CR)	1	1	0	1	0	1	1	1	1
	Maximum strength (MaxS)	1	1	0	0	0	1	1	1	1
	Relative strength (RelS)	1	1	0	0	0	1	1	1	1
	Speed (Sp)	1	1	0	0	0	1	1	1	1
	Power (Pw)	1	1	0	0	0	1	1	1	1
	Coordination (Coor)	1	1	0	0	0	1	1	1	1
	Flexibility (Flex)	1	1	0	0	0	1	1	1	1
Specific training	Basic technique (BT)	1	1	0	0	0	1	1	1	1
	Specific technique (ST)	1	1	0	0	0	1	1	1	1
	Basic tactic (BTac)	1	1	0	1	0	1	1	1	1
	Specific tactic (Stac)	1	1	0	1	0	1	1	1	1
	Kumi-Kata (KK)	1	1	0	1	0	1	1	1	1
	Scouting (SC)	1	1	0	1	0	1	1	1	1
	Weight (Wei)	1	1	1	1	1	1	1	1	1
	Age	1	1	1	1	1	1	1	1	1
Lifestyle	Nutrition (Nut)	1	1	1	1	0	1	1	1	1
	Dual career (Dual)	1	1	0	0	1	1	1	1	1
	8/8/8	1	1	0	0	1	1	1	1	1
Psychology	Motivation (Mot)	0	1	1	1	1	1	1	1	1
	Stress (Stress)	1	0	1	1	1	1	1	1	1
	Activation level (Act)	1	1	0	1	1	1	1	1	1
	Focus and concentration level (Foc)	1	1	1	0	1	1	1	1	1
	Team cohesion (Cohe)	1	1	1	1	0	1	1	1	1
Objectives	National champion (N. Champ)	0	0	0	0	0	0	0	0	1
	International ranking improvement (IRI)	0	0	0	0	0	0	0	0	0
	GP/GS medal	0	0	0	0	0	0	1	0	1
	OG classification	0	0	0	0	0	1	0	1	0

The JEG decided whether the relationship between each pair of variables was either significant (one) or not (zero). This Table has been divided, due to space limitations, into three parts.

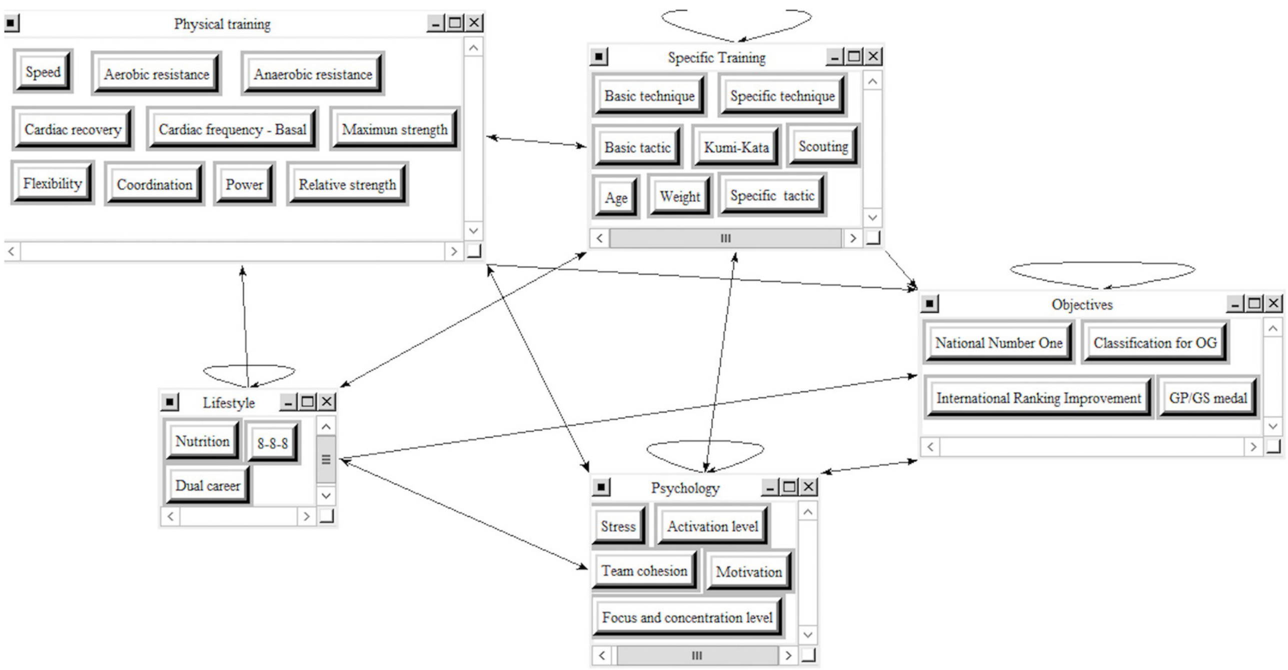

FIGURE 2 | ANP influence model in Superdecisions TM.

Finally, the C class included all of the KPIs with less global importance in the network: one in the psychology cluster, five in the specific training cluster, and all 10 in the physical training cluster.

From a global perspective (**Table 6**), three strategic objectives were in class A: qualification for the Olympic Games (10.3% of total importance), winning a Grand Prix or Grand Slam medal (8.9% of total importance), and an improvement in international ranking (with 4.4% of total importance). The final strategic objective (to become or remain a national number one) was a B-class objective (2.7% of total importance). Therefore, qualifying for the Olympic Games was by far the most important strategic objective of the judokas in the study, followed by winning either a Grand Slam or Grand Prix.

To calculate the relative importance of each element of a cluster, the normalized-by-cluster matrix was obtained (**Table 6**).

In the psychology cluster, motivation was the most important KPI, with more than 50% relative importance, followed by stress, team cohesion, focus and concentration level, and activation level. The specific training cluster contained three leading KPIs—Kumi-Kata, scouting, and basic technique—while the other KPIs had equivalent importance, with the exception of age, which had nearly zero importance. In the physical training cluster, the most important KPIs were maximum strength, power, and relative strength, each of which had more than 10% relative importance. The other KPIs in the cluster amounted to $< 10\%$ importance, with flexibility the least important. Finally, within the lifestyle cluster, dual career accounted for more than 40% relative importance, followed by 8/8/8 and nutrition.

DISCUSSION

We found that male half-lightweight judokas (under 66-kg category) aiming to participate in the Olympic Games, to win a medal in either a Grand Slam or Grand Prix, and to improve their international ranking had great motivation skills, stress management capacity, and an ability to strengthen their team's cohesion. These results were consistent with the superiority of personality traits and psychological skills of Olympic-level athletes reported in a systematic review of articles (published from 1984 to 2017) that dealt with the talent-related characteristics of outstanding athletes (Issurin, 2017). Some authors stated that coaches cited psychological training as a determining factor in judo competition success (Lane, 2007; Santos et al., 2015; Zurita-Ortega et al., 2017).

Motivation was by far the most important KPI of success in the present study. This is not surprising, since the link between motivation and sport performance in judo competition has been reported previously (Gillet et al., 2010). In particular, Gillet et al. (2010) indicated that judokas who displayed self-determined situational motivation toward competition performed better during the subsequent event. Moreover, such motivation was related with contextual self-determined motivation, and this in turn was significantly and positively related with autonomy-supportive coaching. This kind of coaching style is therefore warranted if high-level strategic objectives are to be achieved. It has also been found that mindfulness, rather than passion, is the main factor enhancing intrinsic motivation in athletes (Amemiya and Sakairi, 2019). Exercises to maintain and improve

TABLE 4 | Weighted matrix.

		Lifestyle			Objectives			
		8/8/8	**Dual**	**Nut**	**OG**	**Medal**	**IRI**	**N champ**
WEIGHTED MATRIX (1/4)								
Lifestyle	8/8/08	0.00	0.24	0.24	0.00	0.00	0.00	0.00
	Dual career (Dual)	0.22	0.00	0.08	0.00	0.00	0.00	0.00
	Nutrition (Nut)	0.11	0.12	0.00	0.00	0.00	0.00	0.00
Objectives	OG classification	0.06	0.07	0.07	0.00	0.22	0.00	0.22
	GP/GS medal	0.04	0.04	0.03	0.29	0.00	0.33	0.00
	International ranking improvement (IRI)	0.03	0.03	0.02	0.00	0.11	0.00	0.11
	National champion (N. Champ)	0.02	0.02	0.02	0.04	0.00	0.00	0.00
Physical training	Aerobic resistance (AR)	0.02	0.00	0.02	0.00	0.00	0.00	0.00
	Anaerobic resistance (ANR)	0.02	0.00	0.02	0.00	0.00	0.00	0.00
	Cardiac frequency—basal (CF)	0.01	0.00	0.01	0.00	0.00	0.00	0.00
	Cardiac recovery (CR)	0.02	0.00	0.01	0.00	0.00	0.00	0.00
	Coordination (Coor)	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	Flexibility (Flex)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Maximum strength (MaxS)	0.01	0.00	0.01	0.00	0.00	0.00	0.00
	Power (Pw)	0.01	0.00	0.01	0.00	0.00	0.00	0.00
	Relative strength (RelS)	0.01	0.00	0.01	0.00	0.00	0.00	0.00
	Speed (Sp)	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Psychology	Activation level (Act)	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	Focus and concentration level (Foc)	0.12	0.00	0.02	0.00	0.00	0.00	0.00
	Motivation (Mot)	0.07	0.15	0.15	0.36	0.36	0.36	0.00
	Stress (Stress)	0.04	0.08	0.04	0.20	0.20	0.20	0.67
	Team cohesion (Cohe)	0.02	0.04	0.03	0.11	0.11	0.11	0.00
Specific training	Age	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	Basic technique (BT)	0.03	0.00	0.01	0.00	0.00	0.00	0.00
	Basic tactic (BTac)	0.04	0.00	0.01	0.00	0.00	0.00	0.00
	Kumi-Kata (KK)	0.05	0.00	0.01	0.00	0.00	0.00	0.00
	Scouting (SC)	0.03	0.07	0.00	0.00	0.00	0.00	0.00
	Specific technique (ST)	0.02	0.00	0.01	0.00	0.00	0.00	0.00
	Specific tactic (Stac)	0.02	0.00	0.01	0.00	0.00	0.00	0.00
	Weight (Wei)	0.00	0.14	0.11	0.00	0.00	0.00	0.00

		Physical training									
		AR	**ANR**	**CF**	**CR**	**Coor**	**Flex**	**MaxS**	**Pw**	**RelS**	**Sp**
WEIGHTED MATRIX (2/4)											
Lifestyle	8/8/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dual career (Dual)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Nutrition (Nut)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Objectives	OG classification	0.12	0.14	0.16	0.11	0.11	0.11	0.11	0.14	0.11	0.11
	GP/GS medal	0.07	0.06	0.11	0.08	0.08	0.08	0.08	0.09	0.08	0.08
	International ranking improvement (IRI)	0.05	0.05	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	National champion (N. Champ)	0.03	0.03	0.06	0.04	0.04	0.04	0.04	0.00	0.04	0.04
Physical training	Aerobic resistance (AR)	0.00	0.06	0.38	0.12	0.00	0.00	0.00	0.02	0.00	0.03
	Anaerobic resistance (ANR)	0.06	0.00	0.07	0.05	0.00	0.00	0.00	0.03	0.00	0.27
	Cardiac frequency—basal (CF)	0.19	0.04	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00
	Cardiac recovery (CR)	0.11	0.03	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Coordination (Coor)	0.02	0.05	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00
	Flexibility (Flex)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Maximum strength (MaxS)	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.17	0.26	0.00

(Continued)

TABLE 4 | Continued

		Physical training									
		AR	ANR	CF	CR	Coor	Flex	MaxS	Pw	RelS	Sp
	Power (Pw)	0.00	0.11	0.00	0.03	0.10	0.00	0.26	0.00	0.13	0.09
	Relative strength (RelS)	0.00	0.00	0.00	0.00	0.06	0.00	0.13	0.13	0.00	0.00
	Speed (Sp)	0.00	0.10	0.00	0.03	0.18	0.00	0.00	0.04	0.00	0.00
Psychology	Activation level (Act)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Focus and concentration level (Foc)	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
	Motivation (Mot)	0.17	0.15	0.00	0.03	0.17	0.17	0.16	0.16	0.16	0.15
	Stress (Stress)	0.02	0.05	0.00	0.11	0.02	0.02	0.04	0.03	0.03	0.05
	Team cohesion (Cohe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Specific training	Age	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Basic technique (BT)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.02
	Basic tactic (BTac)	0.00	0.00	0.00	0.00	0.05	0.09	0.02	0.05	0.03	0.04
	Kumi-Kata (KK)	0.04	0.05	0.00	0.00	0.02	0.00	0.06	0.00	0.07	0.05
	Scouting (SC)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Specific technique (ST)	0.01	0.02	0.00	0.05	0.02	0.00	0.01	0.02	0.02	0.01
	Specific tactic (Stac)	0.01	0.02	0.00	0.09	0.04	0.05	0.01	0.05	0.02	0.02
	Weight (Wei)	0.07	0.04	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00

		Psychology				
		Act	Foc	Mot	Stress	Cohe
WEIGHTED MATRIX (3/4)						
Lifestyle	8/8/8	0.05	0.10	0.05	0.05	0.03
	Dual career (Dual)	0.03	0.05	0.10	0.10	0.11
	Nutrition (Nut)	0.10	0.03	0.03	0.03	0.06
Objectives	OG classification	0.09	0.09	0.09	0.18	0.10
	GP/GS medal	0.07	0.07	0.07	0.02	0.07
	International ranking improvement (IRI)	0.05	0.05	0.05	0.01	0.05
	National champion (N. Champ)	0.03	0.03	0.03	0.03	0.04
Physical training	Aerobic resistance (AR)	0.00	0.00	0.01	0.01	0.00
	Anaerobic resistance (ANR)	0.00	0.00	0.01	0.01	0.00
	Cardiac frequency—basal (CF)	0.02	0.03	0.00	0.00	0.00
	Cardiac recovery (CR)	0.00	0.00	0.00	0.01	0.00
	Coordination (Coor)	0.02	0.01	0.01	0.01	0.00
	Flexibility (Flex)	0.00	0.00	0.00	0.00	0.00
	Maximum strength (MaxS)	0.02	0.01	0.02	0.02	0.00
	Power (Pw)	0.01	0.02	0.02	0.02	0.00
	Relative strength (RelS)	0.01	0.02	0.02	0.02	0.00
	Speed (Sp)	0.02	0.01	0.01	0.01	0.00
Psychology	Activation level (Act)	0.00	0.07	0.04	0.04	0.05
	Focus and concentration level (Foc)	0.17	0.00	0.06	0.10	0.07
	Motivation (Mot)	0.09	0.14	0.21	0.15	0.16
	Stress (Stress)	0.05	0.09	0.00	0.00	0.10
	Team cohesion (Cohe)	0.03	0.04	0.03	0.06	0.00
Specific training	Age	0.00	0.00	0.00	0.00	0.00
	Basic technique (BT)	0.01	0.01	0.02	0.01	0.02
	Basic tactic (BTac)	0.03	0.02	0.03	0.02	0.03
	Kumi-Kata (KK)	0.02	0.03	0.03	0.03	0.04
	Scouting (SC)	0.04	0.02	0.01	0.02	0.01
	Specific technique (ST)	0.02	0.01	0.01	0.01	0.01
	Specific tactic (Stac)	0.01	0.02	0.02	0.01	0.02
	Weight (Wei)	0.01	0.01	0.01	0.04	0.01

(Continued)

TABLE 4 | Continued

		Specific training							
		Age	**BT**	**Btac**	**KK**	**SC**	**ST**	**Stac**	**Wei**
WEIGHTED MATRIX (4/4)									
Lifestyle	8/8/8	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Dual career (Dual)	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Nutrition (Nut)	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Objectives	OG classification	0.06	0.12	0.10	0.10	0.12	0.12	0.10	0.09
	GP/GS medal	0.06	0.08	0.07	0.07	0.08	0.08	0.07	0.06
	International ranking improvement (IRI)	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.05
	National champion (N. Champ)	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.03
Physical training	Aerobic resistance (AR)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04
	Anaerobic resistance (ANR)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03
	Cardiac frequency—basal (CF)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Cardiac recovery (CR)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	Coordination (Coor)	0.01	0.00	0.07	0.01	0.00	0.00	0.07	0.01
	Flexibility (Flex)	0.01	0.00	0.04	0.00	0.00	0.00	0.04	0.00
	Maximum strength (MaxS)	0.01	0.00	0.02	0.03	0.00	0.00	0.01	0.01
	Power (Pw)	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.01
	Relative strength (RelS)	0.01	0.00	0.03	0.05	0.00	0.00	0.02	0.01
	Speed (Sp)	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.01
Psychology	Activation level (Act)	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Focus and concentration level (Foc)	0.03	0.05	0.00	0.04	0.04	0.05	0.00	0.03
	Motivation (Mot)	0.03	0.14	0.17	0.13	0.17	0.15	0.15	0.07
	Stress (Stress)	0.03	0.03	0.02	0.02	0.00	0.02	0.04	0.02
	Team cohesion (Cohe)	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Specific training	Age	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Basic technique (BT)	0.05	0.00	0.05	0.07	0.08	0.08	0.03	0.03
	Basic tactic (BTac)	0.05	0.06	0.00	0.05	0.04	0.03	0.12	0.07
	Kumi-Kata (KK)	0.05	0.17	0.02	0.00	0.18	0.19	0.05	0.17
	Scouting (SC)	0.05	0.12	0.18	0.15	0.00	0.13	0.17	0.02
	Specific technique (ST)	0.05	0.08	0.04	0.09	0.11	0.00	0.02	0.04
	Specific tactic (Stac)	0.05	0.04	0.11	0.04	0.06	0.05	0.00	0.05
	Weight (Wei)	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00

This Table has been divided, due to space limitations, into four parts.

mindfulness should, therefore, be added to regular training tasks to ensure a positive effect on motivation.

Stress management was one of the class A KPIs. Psychological skills encompass a number of practical tools that enable athletes to manage competitive stress and self-regulation. These are fundamental in reaching reach peak performance, both preparation- and participation-wise (Issurin, 2017). Judokas would benefit for being in an environment that challenges their comfort zone, where psychological assistance in dealing with stress is offered and where there are opportunities to train with high-level competitors. Therefore, in combat sports and judo, the organization of international training camps where there are chances to fight with different fight styles with outstanding judokas is habitual. Additionally, focus and concentration level has been ranked highly as a determinant KPI for high-level success. Thus, coaches should design situational tasks such as simulated competitions to challenge the attention of judokas. This would help them to work on their focus and concentration. Furthermore, coaches could also assess the attention capacity of judokas and their progress using some of the specific tools and methods developed for this precise purpose (Mihailescu and Sava, 2013). In addition, the JEG considered that the dual career KPI, a component of the lifestyle cluster, could provide both a backup and a way of keeping the mind busy. This can complement the judo training. The dual career KPI most influenced motivation (9.8%), and thus, it is important to define a coherent plan that avoids conflicts of identity but does not interfere with the judoka's results (Kavoura and Ryba, 2020).

The specific training cluster was ranked in both B and C classes, which indicates that it discriminated less between high-level and outstanding athletes than psychological factors. Judo is a complex sport in coordinative terms; athletes spend many years mastering techniques to throw their opponents, control

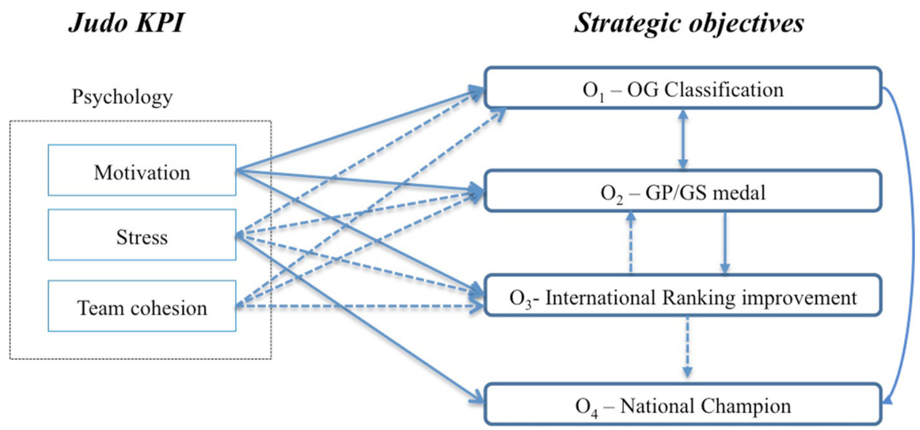

FIGURE 3 | Impact of KPI on the strategic objectives.

them in groundwork, and/or dominate them sufficiently to force the referee to impose a sanction on them. Therefore, when a certain level of performance is reached, judokas are assumed to be of high technical-tactical quality. This may have been the reason why specific training was not regarded as particularly decisive in achieving the more ambitious strategic objectives. The emphasis on stress management (as indicated by the JEG) enables outstanding athletes to produce greater technical-tactical performances in stressful competitive situations. Negative factors such as fear, anxiety, and insufficient self-regulation may have strong detrimental effects on preparations for the big event and/or on the day itself. Within the specific training cluster, the Kumi-Kata KPI was ranked highest by the JEG. Judokas invest approximately half of the total combat time, pauses not included, on Kumi-Kata (Marcon et al., 2010). It is seen as the *condition sine qua non*, because throwing techniques are not possible without proficiency in this area; judokas employ it to dominate the combat and to encourage the referees to sanction the opponent. This is why Barreto et al. (2019) proposed that coaches should introduce training tasks to improve the approaching moment in Kumi-Kata.

Finally, the JEG considered power and strength the most important KPIs within the physical cluster. This was in keeping with a great deal of other research on performance in judo (Franchini et al., 2014, 2019). Physical capacities were valued as essential in achieving high-level strategic objectives, but the JEG did not indicate that KPIs were discriminant indicators between the most successful judokas and those who do not reach the highest level in judo competitions. These results contrast with a recent investigation by Kons et al. (2020), where neuromuscular and judo-specific test differentiated the judo ranking position. However, the level of the strategic objectives studied by Kons et al. (2020) was lower (i.e., regional ranking) than the strategic objectives analyzed by the JEG in the present instance. The possibility that specific judo tests can discriminate between performance levels in young judokas—and could therefore be used as a tool to detect sport talent—has attracted some interest (Lidor et al., 2005). Lidor et al. (2005) monitored the fitness of 10 young male judokas over 2 years, but the outcomes did not reveal any predictive potential of the athletic ranking of the participants after a follow-up program was completed. As the authors indicated, this may have been due to the relatively low sensitivity of the general and specific test batteries used to detect differences between the highly specific judo skills.

The main strengths of the research are as follows: (i) the novel data analysis with the application of the ANP; (ii) the identification and prioritization of KPIs and strategic objectives for improving judokas' performance; (iii) the international and intercultural elite judo expert group formed; and (iv) the application of the methodology to an international high-performance judo center. On the other hand, the main limitations are as follows: (i) the results from applying the methodology are limited to the male under 66-kg judo category and (ii) then, there are no other studies available yet for comparing the obtained results with either female counterparts with similar weight (under 52 kg) or heavyweight judo athletes.

Our results demonstrate the importance of psychological KPIs in reaching the defined strategic objectives for high-level male half-lightweight judo athletes. Future studies should investigate whether these KPIs apply to female counterparts of similar weight or heavyweight judo athletes.

CONCLUSIONS

The present study has outlined an easily replicable methodology by which to identify and prioritize the main KPIs affecting performance in elite-level judo. Then, regarding the two main objectives of the research, (1) to identify and to prioritize the main KPIs that can help to build on the high performance of professional judokas and (2) to establish the link between judo KPIs and the achievement of strategic objectives, the results of applying this methodology at the High-Performance Judo

TABLE 5 | Limit matrix and ABC analysis.

Cluster	Variable	Limit	Cumulative percentage	Class
Psychology	Motivation	0.20158	20%	A
Objectives	Classification for OG	0.10362	31%	A
Objectives	GP/GS medal	0.08958	39%	A
Psychology	Stress	0.08664	48%	A
Lifestyle	Dual career	0.04588	53%	A
Objectives	International ranking improvement	0.04434	57%	A
Psychology	Team cohesion	0.04235	61%	A
Lifestyle	8/8/8	0.03878	65%	B
Psychology	Focus and concentration level	0.03721	69%	B
Specific training	Kumi-Kata	0.03262	72%	B
Objectives	National number one	0.02762	75%	B
Specific training	Scouting	0.02622	78%	B
Lifestyle	Nutrition	0.02487	80%	B
Specific training	Basic technique	0.02043	82%	B
Psychology	Activation level	0.01704	84%	C
Specific training	Specific technique	0.01699	86%	C
Specific training	Basic tactic	0.01672	87%	C
Physical training	Maximum strength	0.01653	89%	C
Specific training	Weight	0.01647	91%	C
Specific training	Specific tactic	0.01645	92%	C
Physical training	Power	0.01606	94%	C
Physical training	Relative strength	0.01477	95%	C
Physical training	Aerobic resistance	0.00942	96%	C
Physical training	Anaerobic resistance	0.00872	97%	C
Physical training	Speed	0.00809	98%	C
Physical training	Coordination	0.00708	99%	C
Physical training	Cardiac frequency—basal	0.0065	99%	C
Physical training	Cardiac recovery	0.00552	100%	C
Physical training	Flexibility	0.00154	100%	C
Specific training	Age	0.00036	100%	C

Centre of Valencia showed that, for the male under 66-kg category, the most important KPIs (out of the 26 identified) in reaching certain strategic objectives (i.e., participating in the Olympic Games or winning a medal in either a Grand Prix or a Grand Slam) were related to the psychological cluster. Motivation was by far the most important KPI, followed by stress and team cohesion. Regarding the third objective of the paper, to make recommendations to improve performance based on the findings, it is recommended that judokas should receive professional psychological support during daily training sessions, and coaching staff should foster international team gathering and sports internships. Other important KPIs were Kumi-Kata, dual career, focus and concentration level, scouting, nutrition, and basic technique. Finally, power and strength were the most important physical KPIs; however, while they were considered to be essential for high-level competitors, they did not make the difference between outstanding and high-level judokas. The JEG (which comprised five elite judokas, national and international champions, and three trainers, including a former European champion and a world championship silver medalist) added high value to the study.

TABLE 6 | Normalized-by-cluster matrix.

Cluster	KPI	Normalized by cluster
Lifestyle	8/8/8	0.35404
	Dual career (Dual)	0.41893
	Nutrition (Nut)	0.22702
Physical training	Aerobic resistance (AR)	0.09993
	Anaerobic resistance (ANR)	0.09251
	Cardiac frequency—basal (CF)	0.06895
	Cardiac recovery (CR)	0.05857
	Coordination (Coor)	0.07517
	Flexibility (Flex)	0.01638
	Maximum strength (MaxS)	0.17542
	Power (Pw)	0.17039
	Relative strength (RelS)	0.15677
	Speed (Sp)	0.0859
Psychology	Activation level (Act)	0.04429
	Focus and concentration level (Foc)	0.0967
	Motivation (Mot)	0.52381
	Stress (Stress)	0.22515
	Team cohesion (Cohe)	0.11004
Specific training	Age	0.00244
	Basic technique (BT)	0.11431
	Basic tactic (BTac)	0.13968
	Kumi-Kata (KK)	0.22303
	Scouting (SC)	0.17927
	Specific technique (ST)	0.11245
	Specific tactic (Stac)	0.11619
	Weight (Wei)	0.11262

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethics Committee of the Universitat

Politècnica de Valéncia. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SU, RR-R, and J-JA-S made the definition of the methodology and conducted the analysis of results. SU, RR-R, J-JA-S, EC, and MU conducted the application of the methodology and wrote the manuscript. SM, RR-R, J-JA-S, and EC made the discussion. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.621454/full#supplementary-material

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How Does Happiness Influence the Loyalty of Karate Athletes? A Model of Structural Equations From the Constructs: Consumer Satisfaction, Engagement, and Meaningful

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Federations are concerned about attracting new sportsmen and sportswomen and increasing the number of members. The purpose of this research was to describe karate federations' strategies for attracting and retaining members through happiness. The analysis was carried out by designing a structural equation modeling (SEM), which allowed to analyze the main variables that influenced the happiness of the karate athlete and consequently to study their effect on people's loyalty to sports federations. In particular, Partial least squares SEM was applied in an overall model when it was possible to understand the happiness role in relation with other traditional relevant variables on loyalty. The data were obtained through primary sources employing a survey sent to the autonomous federations in the discipline of karate, obtaining a sample of 682 federated members in Spain. The results of the model revealed that consumer satisfaction, engagement, and meaningful influence on consumer happiness, but engagement was the most important and relevant variable for affecting this variable. Finally, consumer satisfaction and consumer happiness influence loyalty, and consumer satisfaction was the most important variable, but consumer happiness showed a real alternative for improving loyalty in karate sports federations. Then, one of the implications of this work was that it helped to explain how the federations can be managed to achieve loyal consumers together with a more considerable increase in the number of federated members.

Keywords: happiness, loyalty, consumer satisfaction, commitment, quality, engagement, meaningful, SEM

INTRODUCTION

Consumer loyalty is a strategic variable that ensures the survival of entities in the long term and has therefore been extensively researched in the literature from the point of view of psychology, marketing, and management (Dwyer et al., 1987; Dick and Basu, 1994; Sheth, 1996). It is generally accepted that consumer satisfaction has a positive influence on loyalty (Taylor, 1998; Bennet and Rundle-Thiele, 2004; Schultz, 2005; Sondoh et al., 2007). However, sports federations perceive that, despite high consumer satisfaction, the number of federated members remains stable over the years. Nowadays, they are concerned about attracting new sportsmen and sportswomen and increasing the number of members. This makes it necessary to introduce new variables in the management model of sports federations, which will have a positive influence on the loyalty of the federate and will make it possible to attract new sportsmen and sportswomen.

More loyalty studies need to be conducted to better understand this concept (Sondoh et al., 2007; Cuesta-Valiño et al., 2020) to understand that there are more variables that can be considered as the background of loyalty, in the context of karate sports federations. Therefore, one of the novelties of this study is the consideration of the consumer satisfaction variables, engagement, and meaningful as determinants of loyalty, as well as the happiness construct, which in turn is a mediator.

Research on happiness is common in the fields of psychology, education, organizational behavior, religion, tourism, and hospitality (Fu and Wang, 2020). One of the novelties of this study is the consideration of the happiness variable as an antecedent to loyalty applied to sport, specifically in the discipline of karate.

In Spanish sport, the federations function as mixed organizations, being of a public and private nature. In other words, they are private non-profit organizations, but they perform functions typical of other public services. Specifically, among the main functions of the karate federations are the promotion and encouragement of high-level and high-performance sport by Spanish karate athletes at the international level (Loranca-Valle et al., 2019).

Despite the growing interest of the general population in physical activity and sport, there has not been a proportional increase in the number of federated karate sportsmen and sportswomen in recent years (Wemmer and Koenigstorfer, 2016). For their part, for-profit sports organizations have made a very strong entry into the market and are attracting more and more sportsmen and sportswomen, to the detriment of non-profit sports organizations (Kotler, 1971; Smith and Stewart, 2010; Liu et al., 2018). Thus, the contributions of this article provide insights into the analysis of loyalty strategies that work best in the context of karate sport. In this way, the members of the Boards of Directors of the karate federations can improve their market share, gaining the loyalty of current sportsmen and sportswomen, and gaining new members.

Thus, the main objective of this research is to propose an SEM model that explains the relationships between consumer satisfaction, engagement, and meaningful and happiness as a background to loyalty. Such a model has important implications both for the contribution to literature and for the practice of loyalty marketing strategies of the federated karate athlete.

Figure 1 shows the model developed with each of the constructs, its dimensions, and the hypotheses to be contrasted.

Satisfaction is the most emotional antecedent to loyalty and consumer intent (Rauyruen and Miller, 2007). Satisfaction is related to the satisfaction of the consumer's needs, and when these needs are repeatedly satisfied, it is possible to lead the client to feel an emotional bond between the entity and the consumer (Stauss and Neuhaus, 1997). Therefore, satisfaction in the services provided by an entity is formed in a cumulative way with all the exchanges (Maxham and Netemeyer, 2002).

Some authors (Oliver, 1997; Szymanski and Henard, 2001) explain satisfaction as a perception of consumer response to consumption, with levels of compliance being insufficient or excessive with respect to expectations and actual implementation (Fornell, 1992; Andreassen, 2000). Other authors consider other variables such as consumption experience (Cadotte et al., 1987; Anderson et al., 1994; Sirdeshmukh et al., 2018), consumption of the ideal product or service (Tse and Wilton, 1988); equity theory (Oliver and Swan, 1989), and desires (Spreng and Olshavsky, 1993).

Perceptions derived from the experience of consumption form the basis of consumer satisfaction, and in turn, this leads to consumer happiness (Dagger and Sweeney, 2006; Anderson and Mansi, 2009; Sweeney et al., 2015; Gong and Yi, 2018). Han et al. (2019) add that satisfaction has a positive influence on consumer happiness and retention.

In the literature on consumer behavior, several authors argue that the experience of consuming a good or service translated into levels of satisfaction has a positive influence on the consumer's happiness with that consumption (Nicolao et al., 2009; Howell and Guevarra, 2013; Gilovich et al., 2015; Theodorakis et al., 2019).

Satisfaction is reflected in global feelings from the material, and experiential consumption derived from the purchase (Yoshida and James, 2010; Theodorakis et al., 2019). Thus, consumer satisfaction is reflected in the degree of a positive feeling of a client toward a service provider (Cronin et al., 2000; Deng et al., 2010).

Therefore, the following hypothesis is formulated:

H1. Consumer satisfaction positively influences happiness.

Engagement refers to feeling more secure and committed to the entity (Massimini and DelleFave, 2000; Deng et al., 2010). Engagement is also the result of immediate experience (Hom Cary, 2004; Duckworth et al., 2005). Consumers can engage when they go through active and passive experiences (Schmitt, 2012). Multiple points of contact with consumers can be created, such as events and direct interactions, which enhance the direct experience. On the other hand, the experience can be passive through traditional mass media and even make use of online media to foster brand immersion (Schmitt, 2012).

Engagement can be seen as the motivation that drives a party to trust a particular entity (Moorman et al., 1993) or as the psychological attachment to the organization (Gruen et al., 2000). The commitment implies the conviction on both sides that maintaining the relationship will be more beneficial than ending it (Theyskens et al., 1996). All definitions of engagement agree that there is a psychological component (bonding, liaison, promise, or commitment) and a motivational component (maintaining the relationship, repeat purchases, staying in the organization, Meyer and Allen, 1991; Jones et al., 2010). Consumers expressed confidence in service providers to avoid unfair and opportunistic exchanges (Gefen et al., 2003).

Commitment is a very important ingredient for the success of a business relationship (Morgan and Hunt, 1994), and it is

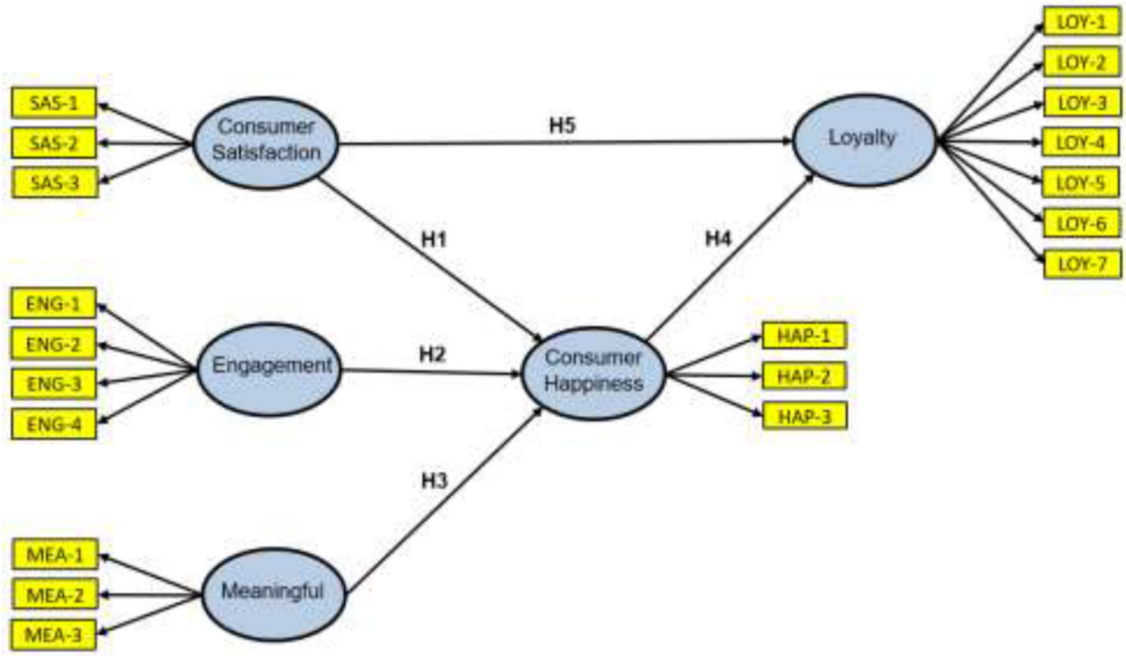

FIGURE 1 | Conceptual model and hypothesis.

also a key variable in marketing (Garbarino and Johnson, 1999). Commitment is closely related to reciprocity, loyalty, and the rejection of alternatives. All these variables are related to the meaning of the relationship (Gundlach et al., 1995). It is the first step in building trust in the relationship and influencing the development of social norms that regulate future exchanges (Williamson, 2007).

Many authors agree that trust is one of the basic ingredients for successful relationships (Dwyer et al., 1987; Moorman et al., 1993; Berry, 1995). Trust in an organization is based on consumer assurance of the quality and integrity of the service offered (Moorman et al., 1993; Morgan and Hunt, 1994; Garbarino and Johnson, 1999; Hennig-Thurau et al., 2001). Trust is the belief of one party that the actions of the other party will necessarily meet its needs (Anderson and Weitz, 1989). In the relationship between consumers and organizations, the psychological benefits of safety and confidence are more important than the special treatment or social benefits derived from that relationship (Gwinner et al., 1998). Trust is a participation in a process, which has been well-planned, whereas affection for the institution is spontaneous, more immediate, and less reasoned (Chaudhuri and Holbrook, 2001). Trust, as engagement, can have both affective and cognitive dimensions (Johnson and Grayson, 2005).

Some authors explain happiness as the positive psychological state derived from a good, pleasant, and satisfying experience (Jang et al., 2017; Loranca-Valle et al., 2019). Therefore, the following hypothesis is formulated:

H2. Engagement positively influences happiness.

There is currently a great deal of research on the economics of happiness that empirically demonstrates that money alone does not bring higher levels of subjective well-being or happiness to human beings in the era of the digital society (Powdthavee, 2010; Ravina-Ripoll et al., 2020). If this issue is examined from the perspectives of positive psychology and happiness management, it shows us, among other things, that people's happiness is conditioned by a wide range of heterogeneous factors, including health, sexual behavior, resilience, stress, or quality of life (Blanchflower and Oswald, 2004; Leite et al., 2020; Tandler et al., 2020). It is generally accepted that happiness is found, on the one hand, in the individual satisfaction that is enjoyed in the long term when our achievements and purposes are fulfilled—eudemonism—and, on the other hand, in the pleasure of carrying out rewarding activities in the short and medium term—hedonism (Huta and Waterman, 2014). Based on this philosophical and psychological adage, an important volume of scientific work emerges focused on exploring that the meaningful originates when people gravitate their individual efforts in undertaking social activities or actions that contribute to the common good and therefore to the collective happiness of the citizens (Duckworth et al., 2005; O'Donovan and Sheikh, 2014; Núñez-Barriopedro et al., 2020). In line with this research, the literature shows that meaningful, at the microindividual level, should be associated not only with negative, depressive, and unhealthy experiences, but also with positive and optimistic emotions. As is known, both elements are excellent drivers for enjoying a healthy, joyful life full of subjective well-being, i.e., good living (Li et al., 2020). This has a strongly subjective, individual, and relational component (Kok et al., 2015). If this issue is approached from the lens of religion, the predominant vectors for living a truly meaningful life will be the love of neighbor, generosity, and altruism (Nielsen, 2014). However, a review of the literature suggests the existence of limited attempts to analyze this link (meaningful–happiness) within the world of sport (Netz et al., 2008; Jang et al., 2020). Many studies have shown that meaningfully contributes holistically to good physical health and psychological well-being, especially in difficult everyday circumstances (Taylor et al., 2000; Crawford, 2006).

Along with this cognitive purpose, it cannot be overlooked that over the last decades, a significant number of academic productions have empirically shown that the happiness of human beings lies entirely in cultivating a meaningful life (Sirgy and Wu, 2009; Baumeister et al., 2013; Bartsch and Oliver, 2017). The questionnaire developed by Morgan and Farsides (2009) on the Measurement of Meaningful Living, as well as the survey designed by Steger et al. (2006) on the Meaning of Life, has undoubtedly contributed to this assumption. Both psychometric scales are characterized by assessing, among other things, whether my life is exciting or whether I am satisfied with my life project.

This growing interest leads us to propose the following hypothesis of analysis:

H3. Meaningful positively influences happiness.

Many studies have identified that happiness has a significant effect on loyalty (Shin, 2008; Khan and Hussain, 2013; Kim et al., 2015; Vittersø et al., 2017; Wu et al., 2017; Cuesta-Valiño et al., 2019).

The importance of making consumers happy not only involves cultivating happiness as a state but also in the favored consumption behavior that results from that state (Higgins, 1997; Fredrickson, 2001).

Also, consumers tend to repeat pleasant and happiness-fostering experiences and avoid unpleasant ones (Higgins, 1997). In this way, positive emotions have the capacity to expand the consumer's momentary thinking and facilitate the construction of lasting physical, intellectual, social, and psychological patterns of purchasing behavior (Fredrickson, 2006).

In addition, authors (Van Boven and Gilovich, 2003) explain that purchase happiness is the sum of material consumption and the experience of such consumption, which affects the consumer's choice to consume the product again and therefore has a positive influence on loyalty.

Likewise, happiness has been defined as the positive psychological state derived from a pleasant and satisfactory experience (Lyubomirsky et al., 2005a; Ahuvia, 2008). Happiness can be seen from two perspectives, one referring to a specific moment and the other to an imperishable duration in time (Ravina-Ripoll et al., 2020). The first results from a particular positive situation or experience, whereas the second is a general positive psychological state that is cumulative over time (Lyubomirsky et al., 2005b).

Loyalty comprises all those behaviors that involve the consumption of a good or service of the same entity repeatedly, both now and in the future (Gong and Yi, 2018; Septianto et al., 2019; Gómez-Suárez and Veloso, 2020), despite the influences of competitive marketing strategies (Septianto et al., 2019).

Loyalty consists of two concepts that combine to give the variable the greatest explanatory power. These two concepts are behavioral aspects or purchase intentions and attitudinal loyalty (Cossío-Silva et al., 2016). Behavioral loyalty has been identified as the willingness of customers to buy back the product or services and to maintain a relationship with the supplier or service provider (Jones et al., 2010). Attitudinal loyalty, however, is the level of consumer commitment to a product/brand and their promotional attitude toward the supplier of goods or services (Dick and Basu, 1994; Chaudhuri and Holbrook, 2001).

As a consequence of loyalty, there are authors who explain the resistance to change (Pritchard et al., 1999; Bansal et al., 2004; Bodet, 2012) and word-of-mouth (Parasuraman et al., 1988; Dick and Basu, 1994; Kim and Trail, 2011; Yaseen et al., 2011).

According to numerous studies, happiness and loyalty are positively related (Cuesta-Valiño et al., 2019). Customer satisfaction does not imply happiness, but in order to lead the customer to loyalty, we must seek his/her happiness (Khan and Hussain, 2013; Cuesta-Valiño et al., 2020) instead of focusing on his/her satisfaction, which is what has been pursued for the last 50 years (Easterlin, 2001).

Therefore, the following hypothesis can be made:

H4. Happiness positively influences loyalty.

Consumer loyalty to a brand is manifested in the fact that there is a commitment to future repurchase behavior of a product or service and is not affected by the marketing influences of competitors (Oliver, 1999). This definition emphasizes the two fundamental aspects of loyalty described in the literature relating to behavior and attitude (Oliver, 1999).

The behavioral component of loyalty is linked to the repurchase of a product or the degree of repeat purchase by an individual with respect to a brand, without analyzing the reasons why it occurs (Chaudhuri and Holbrook, 2001). However, the authors consider that knowing the cause of repurchase is essential to be able to talk about loyalty (Bloemer and Kasper, 1995).

In contrast, the attitudinal approach to loyalty refers to a certain degree of commitment to the brand (Chaudhuri and Holbrook, 2001) and advocates that, to measure true consumer loyalty, one must collect preferences or intentions for future behavior (Bloemer and Kasper, 1995). Even Reichheld (2003) has argued that it is possible for several service companies to properly assess loyalty using only one measure: the willingness to recommend. This feeling corresponds to a positive attitude toward the company (Dick and Basu, 1994; Barroso Castro and Martin Armario, 1999) generated by an internal evaluation process (Bloemer and Kasper, 1995), which is reflected in recommending the product or brand to others (Selnes, 1993) and in other cognitive aspects (Lee and Zeiss, 1980), such as tolerance to pay a higher price for the product (Martin et al., 2009) or being the brand that would be chosen first from a range of alternatives (Ostrowski et al., 1993). Researchers have also argued for the third dimension of service loyalty—the cognitive element (Bloemer and Kasper, 1995; Oliver, 1999)—where loyalty is based on a conscious assessment of brand attributes or the reward and benefits associated with sponsorship (Lee and Cunningham, 2001), leading the consumer to consider this service provider in relation to others (Dwyer et al., 1987).

TABLE 1 | Constructs, items, factor loading, reliability, and validity.

Factor loadings		References
Consumer satisfaction (SAS) RVM: Cronbach α: 0.84, AVE: 0.76, composite reliability: 0.90		
I think I did the right thing when I subscribed to this federation service.	0.79	Maxham and Netemeyer, 2002; Deng et al., 2010
As a whole, I am satisfied with the federation.	0.92	
I am satisfied with the overall service that my federation provided to me.	0.88	
Engagement (ENG) RVM: Cronbach α: 0.90, AVE: 0.77, composite reliability: 0.93		
I do feel "emotionally attached" to my federation.	0.86	Meyer and Allen, 1991; Hennig-Thurau et al., 2001; Gefen et al., 2003
I was proud to be able to participate in my federation.	0.88	
Based on my experience, I know the federation service provider cares about customers.	0.89	
Based on my experience, I know the federation service provider is honest.	0.89	
Meaningful (MEA) RVM: Cronbach α: 0.70, AVE: 0.63, composite reliability: 0.83		
I do feel like "part of the family" at my federation.	0.85	Meyer and Allen, 1991
I have friends who belong to my federation.	0.80	
I do feel a strong sense of belonging with my federation.	0.72	
Consumer happiness (HAP) RVM: Cronbach α: 0.83, AVE: 0.82, composite reliability: 0.93		
Participating in the activities of my federation makes me happy.	0.93	Dagger and Sweeney, 2006; Sweeney et al., 2015; Gong and Yi, 2018; Han et al., 2019
The members are happy when they participate in the activities of my federation.	0.92	
The fee I paid for participating in my federation activities was worth.	0.88	
Loyalty (LOY) RVM: Cronbach α: 0.94, AVE: 0.72, composite reliability: 0.95		
The relationship will remain intact well into the future.	0.82	Miller and Boster, 1988; Holmes and Rempel, 1989; Rauyruen and Miller, 2007; Fu and Wang, 2020
I will recommend others to use the federation service.	0.90	
Even if friends recommended another service, my preference for the federation service would not change.	0.81	
I am motivated to maintain the relationship into the future.	0.86	
Even there are other options to federate, I will still federate in my federation.	0.90	
I will continue to participate in activities of my federation.	0.81	
I will continue my activities in my federation before any other federation.	0.84	

RVM, reliability and validity measures.

It is widely accepted in the literature that loyalty is based on satisfaction, which acts as a background to it (Dick and Basu, 1994), helping to increase sales (Lewis, 2004). Thus, it is recognized that consumers with high levels of satisfaction also tend to be more loyal (Fornell, 1992; Bloemer and Kasper, 1995; Oliver, 1997; Chang and Tu, 2005; Li and Green, 2011). Therefore, a satisfied consumer is more likely to buy back a product (Selnes, 1993; Oliver, 1997; Baker and Crompton, 2000; McDougall and Levesque, 2000; Caruana, 2002; Olsen and Johnson, 2003; Yoon and Uysal, 2005; Mao, 2010) and become a prescriber of the product, engaging in positive word-of-mouth communication with other consumers (Andreassen, 2000; Homburg and Giering, 2001; Olsen and Johnson, 2003).

Therefore, the following hypothesis is formulated:

H5. Consumer satisfaction has a positive influence on loyalty.

METHODS

Survey Design

The data to test these hypotheses were collected from a cross-sectional descriptive study. This research used primary data from a survey answered by a sample of members of karate federations in Spain from March 2019 to March 2020. The questionnaire analyzes the constructs of the proposed model with the different items. The primary selection of the different items of the five constructs was based on a review of the literature. Previously, the items had been carefully chosen, and before sending out the survey, preceding qualitative research was carried out through a focus group, which included three professors who are experts in psychology and consumer behavior, three managers who work in karate federations, and three members of karate federations.

As a result of this qualitative research, the final questionnaire was achieved, consisting of five constructors with a total of 20 items: three for consumer satisfaction (Maxham and Netemeyer, 2002; Deng et al., 2010), four for engagement (Meyer and Allen, 1991; Hennig-Thurau et al., 2001; Gefen et al., 2003), three for meaningful (Meyer and Allen, 1991), three for consumer happiness (Dagger and Sweeney, 2006; Sweeney et al., 2015; Gong and Yi, 2018; Han et al., 2019), and seven items for loyalty (Miller and Boster, 1988; Holmes and Rempel, 1989; Rauyruen and Miller, 2007; Fu and Wang, 2020). The scale used for these 20 items was a five-point Likert-type response format, in which respondents could value the items from 1 ("strongly disagree") to 5 ("strongly agree") (**Table 1**).

A pretest of the questionnaire was carried out in February 2019 on a representative sample of members of karate federations. Some errors were then corrected, and all questions were validated. When the questionnaire had been refined, it was launched online through a discretionary non-probabilistic sampling by quotas, with the objective of completing the distribution of genders as similar as possible to that of the population who are members of karate federations in Spain, which have a total of 75,406 members. The questionnaire was distributed through the main social networks in March 2019 and through karate federation websites from March 2019 to March 2020. The result was that 714 members answered the survey, but 32 surveys were not filled in correctly, so the total number of valid questionnaires was 682, implying a sampling error of 3.81% (with a 95.5% confidence interval and $p = q = 0.5$).

Sample Size and Composition

A descriptive statistic for the sample is presented below. The total sample size was 682 individuals who represent members of karate federations in Spain. The composition of the sample was 71% male and 28% female. By age group, 19% are younger than 16 years, 27% are 16–29 years old, 20% are 30–44 years old, 32% are 45–64 years old, and 2% are older than 64 years. By years of membership, 3% have <1 year, 16% have 1–5 years, 23% have 6–10 years, 25% have 11–20 years, and 32% have more than 20 years. And finally, from the point of view of Black Belt grade, the most numerous groups are members with Black Belt 1st and 2nd Dan (42%), members with less than Black Belt (29%), and members with Black Belt 3rd and 4th Dan (21%), and only 8% are members with the highest Black Belt grades (**Table 2**).

TABLE 2 | Sample composition.

Gender	Total of 682	%
Male	484	71.0
Female	194	28.4
Non-responded	4	0.6
Age (y)	**Total of 682**	**%**
<16	130	19.1
16–29	181	26.5
30–44	135	19.8
45–64	218	32.0
More than 64	16	2.3
Non-responded	2	0.3
Years of membership	**Total of 682**	**%**
<1	22	3.2
1–5	109	16.0
6–10	158	23.2
11–20	172	25.2
More than 20	219	32.1
Non-responded	2	0.3
Black Belt grade	**Total of 682**	**%**
Less than Black Belt	195	28.6
Black Belt 1st and 2nd Dan	283	41.5
Black Belt 3rd and 4th Dan	146	21.4
Black Belt 5th and 6th Dan	38	5.6
More than Black Belt 7th Dan	19	2.8
Non-responded	1	0.1

RESULTS

Measurement Model: Reliability and Validity

Partial least squares structural equation modeling (PLS-SEM) is an opportunity to advance the development and testing of theory in sport organization management. SEM has become a mainstream method in many fields of business research, and PLS-SEM provides a flexible method in terms of data requirements, model complexity, and relationship specification. PLS-SEM does not require normally distributed data (Hair et al., 2017) and is therefore the more appropriate method of SEM for many social science studies, where data are often non-normally distributed. Also, as the primary purpose in theory development is to find relationships, their directions, and strengths, as well as observable measures, PLS-SEM is appropriate.

Analyzing the proposed model, there are five different latent constructs, and each of the scales consists reflective items. The main reason that this option was selected can be held on that the effects when items are removed do not affect the content validity and the items are correlated. In the following paragraphs, it will be assessed factor loading, reliability, discriminant validity assessment, and the other measures included in the study to determine the model fit. In order to assess factor loading or indicator reliability, it is examined how each item relates to the latent constructs. Then, the outer loadings of the reflective constructs are well above the threshold value of 0.707, from which it is possible to obtain the indicator reliability. In this study, all of the 20 items reach this level of acceptable reliability because their loadings exceed 0.72 and load more highly on their own construct than on others. These results provide strong support for the reliability of the reflective measures (**Table 1**).

In order to measure reliability, Cronbach α is commonly used, but it has been criticized for its lower bound value, which underestimates the true reliability (Peterson and Kim, 2013). In Smart PLS 3.3.2 (Ringle et al., 2015), composite reliability (CR) is available to measure reliability because some items will be more important for your construct than others, which implies different outer loadings on the construct. These different outer loadings are taken into account when you determine the CR of your construct. Nunnally and Bernstein (1994) suggest 0.70 as a benchmark for a Cronbach α reasonable reliability, and the CR is suggested 0.80 as "stricter" reliability applicable in basic research. In this case, all constructs exceed the limit values recommended for both measures.

The discriminant validity assessment has the goal to ensure that a reflective construct has the strongest relationships with its own indicators (Hair et al., 2017). Discriminant validity assessment has become a generally accepted prerequisite for analyzing relationships between latent variables (Hair et al., 2017). Traditionally, the Fornell and Larcker (1981) criterion is used, but Henseler et al. (2014b) propose an alternative approach because the heterotrait–monotrait ratio of correlations (HTMT)

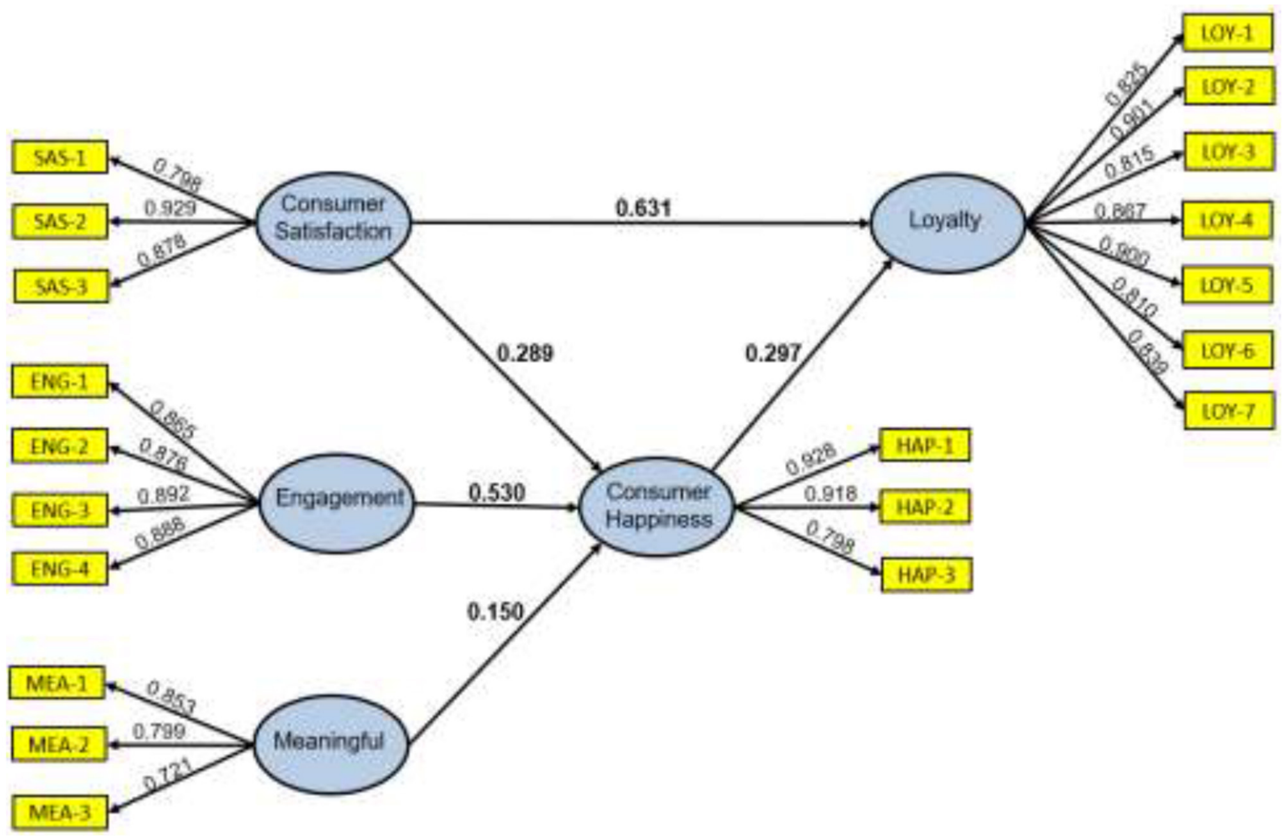

FIGURE 2 | Conceptual model results.

detect the lack of discriminant validity in common research situations. If the HTMT value is below 0.90, discriminant validity has been established between two reflective constructs. All the HTMT coefficients in the study have a value below 0.9, and the square root of AVE is greater than the correlation between the constructs (Fornell and Larcker, 1981). This last result is referred to the Fornell–Larcker criterion, suggesting that each construct relates more strongly to its own measures than to measures of other constructs.

Structural Model: Goodness-of-Fit Statistics

Absolute fit indices indicate how well a model fits the sample data (McDonald and Ho, 2002). Standardized root mean square residual (SRMR) was introduced by Henseler et al. (2014a) as a goodness-of-fit measure for PLS-SEM. Standardized SRMR is defined as the average magnitude of the discrepancies between observed and expected correlations as an absolute measure of (model) fit criterion. Hu and Bentler (1998) considered that a value <0.10 is a good fit, but a value <0.08 (in a more conservative version) is more recommended. In this model, SRMR is 0.055, suggesting a good fitting model. A large amount of variance is also explained in consumer happiness and loyalty, with R^2 values of 0.77 and 0.78, respectively. The Stone–Geisser (Q2) results for the same variables are 0.63 and 0.56, respectively, where values larger than zero indicate a good model's predictive relevance. Predictive validity is included as the last step of confirmatory composite analysis (CCA), which is a systematic methodological process for confirming measurement models in PLS-SEM. The statistical objective of CCA and confirmatory factor analysis (CFA) is confirmation of measurement theory. To achieve measurement confirmation objectives in developing or adapting multi-item measures, researchers could use either CFA or CCA (Hair et al., 2020). These steps with reflective measurement models are significant loadings, indicator reliability, CR, AVE, discriminant validity, nomological validity, and predictive validity. All these elements have been presented previously. Also, the consistent PLS algorithm that performs a correction of reflective constructs' correlations can be used to ensure that the results were consistent with a factor model. The results are very similar, and it was not necessary to apply this algorithm.

Results of SEM

The conceptual model results (**Figure 2**) show how consumer happiness is related to each of its antecedents. With a coefficient of 0.53, the results suggest that engagement influences consumer happiness in an important and positive way. This situation is followed by consumer satisfaction and meaningful antecedents that are also influencing positively but in a less relevant way. Even so, it can be said that meaningful has a weak influence (with

TABLE 3 | Summary of hypothesis verification.

Hypothesis	Content	Verification
H1	Consumer satisfaction has a positive influence on happiness.	Supported
H2	The engagement has a positive influence on happiness.	Supported
H3	Meaningful has a positive influence on happiness.	Supported
H4	Happiness has a positive influence on loyalty.	Supported
H5	Consumer satisfaction has a positive influence on loyalty.	Supported

TABLE 4 | Total effects.

	Consumer happiness	Loyalty
Consumer satisfaction	0.289*	0.717*
Engagement	0.530*	0.158*
Consumer happiness		0.297*
Meaningful	0.150*	0.044*

**Significant path coefficients (at $p < 0.01$).*

value coefficients of 0.29 and 0.15, respectively). Therefore, the hypotheses H1, H2, and H3 are not rejected (**Table 3**).

For the hypothesis attempting to discover the relationship between consumer happiness and loyalty, it is very clear that the relationship is relevant and positive (0.30). The relation between consumer satisfaction and loyalty is strong and positive, with a high coefficient (0.63). Then, H4 and H5 are not rejected.

Finally, it is relevant to analyze the results of the total effects on consumer happiness and loyalty. Before, the direct effects were commented on in the hypothesis, but it is also noteworthy to know how indirect effects are influencing the total effects of engagement and meaningful on loyalty (**Table 4**).

DISCUSSION

The present study arises with the purpose of deepening the knowledge about the variables that can positively influence loyalty and specifically how happiness can generate loyalty considering each of its dimensions (Aksoy et al., 2015; Zhong and Moon, 2020) in addition to the satisfaction. For this purpose, a structural equation model (SEM) has been developed, composed of exogenous variables of positive values that aim to explain the happiness dimensionality inferentially, from the perception of consumer satisfaction, engagement, and meaningfulness. The literature shows that these three parameters are significantly associated with people's happiness, understood as a continuous state of pleasure and significance (Ltifi and Gharbi, 2015; Lera-López et al., 2020; Oishi et al., 2020). The empirical results achieved by this research are in line with our theoretical model, despite the fact that there are currently few economic and multidisciplinary studies that analyze the subject matter of our work in the field of sport and particularly in the area of karate (Loranca-Valle et al., 2019).

Reichheld (2003) and Jones et al. (2010) warn that without an understanding of the nature and extent of loyalty, service organizations may be measuring misguided elements of consumer behavior or attitudes when designing loyalty programs. While it is true that the consumer may purchase the same product by chance, lack of alternatives (Chaudhuri and Holbrook, 2001), convenience (Bloemer and Kasper, 1995), or price does not lead to true loyalty. Therefore, the contributions of this work on the dimensions that truly influence loyalty are Happiness, Satisfaction, Engagement, understood as trust, meaningful, or the pleasant life of the consumer to want to maintain the relationship or purchase the same brand and the meaning is fundamental for an efficient allocation of resources in consumer loyalty programmes.

Likewise, one of the findings of this study is that the happiness variable plays a very important role in the loyalty parameter of sportsmen and sportswomen (Gladden and Funk, 2001) in a study environment that has not been explored until now. This suggests that loyalty to this sport is associated with the happiness of its practitioners whenever high levels of engagement are experienced (0.526), which should be accompanied by moderate levels of meaningful (0.150) and consumer satisfaction (0.293). This interpretation is also consistent with previous studies, such as the work of Baena-Arroyo et al. (2020), who empirically demonstrate that the happiness or satisfaction of people who practice sports is strongly conditioned by the quality of the services offered by sports organizations. In this sense, the study by Mirehie and Gibson (2020) should also be noted. This study shows that women who practice skiing and snowboarding enjoy a high level of psychosocial well-being, as the practice of this leisure activity provides them with high doses of positive emotions, commitment, and meaning.

In line with this, our quantitative results reveal that happiness needs to be given greater consideration in its association with loyalty in the context of sport. This gap constitutes a great opportunity to put on the academic agenda that happiness is understood as a strategic differential factor that motivates people to be loyal to practice a sport assiduously under the lens of consumer satisfaction, engagement, and meaningful. This is extremely important as the continuous practice of physical exercise contributes to holistically improve people's health and psychological well-being, factors that cushion stress, depression, vascular diseases, etc. (Ronkainen et al., 2020).

Regarding the practical implications of our work, on the one hand, public institutions can encourage the regular practice of sport to citizens through happiness, as emotional health, self-esteem, cognitive performance, commitment, confidence, socialization, etc. (Jiménez-Marín et al., 2020). On the other hand, it is recommended that sports federations implement Certification Happiness Management in the future as an instrument that certifies that, within these organizations, the collective well-being of all their human capital and stakeholders is cultivated under the guiding principles of the collaborative economy, philosophy, corporate social responsibility, and positive psychology. In this way, sports companies can carry out strategic actions aimed at building positive emotions and satisfactory experiences that help to engage their potential consumers. In light of the above, we believe that a very promising scenario is opening up in the post–COVID-19 era, as well as many opportunities for entities that actively develop this type of culture, marketing, and business management based on the virtuous circle of corporate happiness (Ravina-Ripoll et al., 2020).

Among the limitations of this study is that a transversal study has been designed so that in future research, longitudinal studies can be carried out based on panel data to evaluate the impact of the variables evaluated in the model presented in this work. The geographical area studied was Spain, where karate members from all the Autonomous Communities formed part of the sample for this study. However, in future work, the sample could be extended to other countries. Another limitation is the application of the study to the discipline of karate so that, in future research work, the proposed model can be applied to other sporting disciplines.

Finally, future research on happiness management in the sports context should be focused on exploring whether the individual happiness provided by the daily practice of sport is significantly correlated with other psychological dimensions or with quantitative indicators of subjective well-being. In this way, we will be able to obtain, on the one hand, empirical evidence of new constructs associated with happiness in the environment of sports participation, both an active and passive nature. On the other hand, we can analyze, in a multidisciplinary and cross-cultural way, how daily physical exercise is linked to a meaningful and healthy life, etc., and therefore full of happiness in the broad sense of the word. Hence, the interest in promoting new works can empirically confirm the subject of this research from our structural equation model, bearing in mind that the practice of sport is an important determinant of people's happiness, which is also affected by other socioeconomic and psychological elements.

CONCLUSION

This study shows how the consumer happiness of the karate federation members could be a good strategy for developing loyalty in this non-profit sports organization. In an overall model, consumer satisfaction is still a well-established variable for influencing loyalty, but consumer happiness plays a mediator role with consumer satisfaction, and it is able to increase loyal members if federations principally work on engagement activities. It would therefore be interesting for karate sports federations to use this information when developing new strategies for improving loyalty.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

EN-B, PC-V, PG-R, and RR-R: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, and supervision. EN-B and PG-R: software. PC-V: funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Training in Rhythmic Gymnastics During the Pandemic

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The pandemic caused by the COVID 19 Virus creates an unprecedented situation of global confinement altering the development of competition and sports training at all levels of participation and in all sports, including rhythmic gymnastics (RG). To avoid possible effects of physical, technical and psychological detraining, coaches looked for home training alternatives. The objectives of the study were to know how rhythmic gymnastics training developed during the lockdown period (the conditions, type of training, performance monitoring means, and determinants of gymnasts' participation) and to provide recommendations for a possible future lockdown. Three hundred and two RG coaches from twenty-six different countries throughout the five continents and four professional levels took part in the study: national team (28), international (26), national (172) and regional (75). The data collection tool was a questionnaire consisting of 39 closed questions structured in three dimensions: identification data of the coaches, training data during confinement and gymnast participation data. The independent variable was the gymnasts' performance levels and the dependent variables organized in four categories: the technical media used to conduct and monitor the training sessions, the type of training done, the mechanisms for monitoring training performance and the aspects that determined participation. Most coaches kept their gymnasts training during confinement, although 76.5% confirm abandonment of any of their gymnasts. The main means used were real-time video conferencing, although at the lower practice levels the media stand out in deferred time. The contents of the training were mainly body technique, physical preparation and body difficulties. For performance monitoring, challenges, physical, and technical tests were predominant. The determinants for the development of training in the confinement vary depending on the level of the gymnasts, connectivity and electronic resources at the highest level, and the availability of spaces and social distancing at lower levels. For future lockdowns, it is necessary to review the content of the trainings, as well as the performance evaluation and the means necessary for it.

Keywords: COVID-19, confinement, coaches, training, gymnasts, rhythmic gymnastics

INTRODUCTION

In December 2019, a severe acute respiratory syndrome outbreak caused by the Coronavirus 2 (SARSCoV-2 or COVID-19) occurred. The virus spread rapidly across the globe causing a pandemic without precedent and forcing governments to impose a global lockdown, giving rise to an extreme situation never seen before.

The world of sport, and of course also rhythmic gymnastics (RG), has been affected by the effects of pandemic and confinement in an unprecedented way, through the suspension of all kinds of sporting events, such as national competitions, international tournaments and macro events like the Olympic Games (JJOO). For its part, the situation of isolation has resulted in a number of direct consequences for the practice of sport: absence of organized training and competition, lack of physical communication between athletes and coaches, inability to move freely, lack of adequate exposure to sunlight, and inadequate training conditions (Jukic et al., 2020). Furthermore, Edwards and Thornton (2020) point out that this pandemic scenario may have triggered or worsened pre-existing psychiatric illnesses, such as anxiety, obsessive compulsive disorder (OCD), depression, insomnia and isolation. To this situation of affecting the well-being and self-esteem of athletes, coaches have had to face dilemmas such as controlling the performance of athletes, injuries and other information related to training (Evans et al., 2020). All this has limited the effectiveness of training methods, especially in sports of high technical and physical component, as is the case of RG.

RG is a sports specialty of great technical demand and high number of difficulties of extreme coordination and aesthetic complexity (Vernetta et al., 2017). Competition exercises involve mastery of five manual apparatus (rope, hoop, ball, clubs, and ribbon) in combination with body elements involving various components for high performance: physical, technical, tactical and psychological factors (Douda et al., 2007; Di Cagno et al., 2009). Practiced at individual or group (five gymnasts) modality, it is an artistic and aesthetic sport performed to the music with a particular training process: very young athletes, early specialization, high volume of training, high number of repetitions and great psychological stress (Bobo-Arce and Méndez-Rial, 2013; Debien et al., 2019).

We can distinguish different levels of competition (Rodríguez and Gómez-Landero, 2017) depending on the ages and the level of performance, from the highest (national team), to the lowest (regional level). But all require a specific training ranging from the work of body and apparatus technique, ballet or the integration of physical preparation and specific psychological preparation of sport (Law et al., 2007; Batista et al., 2018).

During the lockdown, training had to adapt to this unique situation in order to maintain the physical and technical condition of athletes. Given that physiological adaptation is a reversible process and that most of the aspects that determine it are lost during an extended period of inactivity, it is likely that during confinement there could have been a loss of up to 10% fitness for each week of total inactivity (Varandas et al., 2017; Eirale et al., 2020). Authors, such as Jukic et al. (2020) refer to changes after 8 weeks of detraining in flexibility, a fundamental quality in RG. In this same line, lack of training can also lead to the onset or worsening of pathologies, as well as a weight gain (Eirale et al., 2020; Sarto et al., 2020). Other authors mention a return to initial values in some capacities such as aerobic performance or strength in a 2 to 4-week period (Mujika and Padilla, 2001; Sousa et al., 2019). Tran et al. (2017) found a reduction in the sensorimotor capacity of athletes, which could be an important consideration when technical and/or skillful actions are required, as in the case of gymnastics. For their part, Edwards and Thornton (2020) point out that it is common for athletes to encounter transitional phases during their careers, although always foreseeable and under control. However, when the interruption is against their will, the consequences are comparable to those associated with an injury or can bring forward retirement from sport altogether, forcing the sportsperson to embark on a new path they had never planned for.

There are several studies on the impact of COVID-19 on athletes (Toresdahl and Asif, 2020) or on the conditions necessary for the resumption of training (Herrero-Gonzalez et al., 2020). However, the impact that confinement has had on training has received little attention and few research describes what has been done during this stage at home (Eirale et al., 2020; Herrera-Valenzuela et al., 2020; Jukic et al., 2020; Latella and Haff, 2020). In particular, none found in RG or similar artistic sports.

The concept of detraining as a total or partial loss of training adaptations and their application to a confinement situation and their prevention are totally novel phenomena (Girardi et al., 2020). Since health authorities have warned of future waves of COVID-19 and the possibility of encountering similar scenarios, it seems appropriate to know the conditions and difficulties in which rhythmic gymnastics training has developed during the confinement period. In this way, similar future situations can be oriented and planned, trying to minimize the effects that may have occurred on the loss of adaptation on gymnasts.

Therefore, the study aims to know how rhythmic gymnastics training has developed during the lockdown period (the conditions, type of training, performance monitoring means, and determinants of gymnasts' participation) and to provide recommendations for a possible future lockdown.

MATERIALS AND METHODS

Data Collection Tool

The data collection instrument was a questionnaire drawn up specifically for the occasion. It consists of 39 closed questions, structured in three dimensions. (i) Identifying data of the coach: country, federation, professional level, years of coaching experience and level of gymnasts they train. (ii) Training data during confinement: sports period in which confinement occurs, duration of the same, means or instruments used to direct training, training content, volume (days and hours per week), mechanisms of control and monitoring of gymnasts. (iii) Participation of gymnasts: monitoring of trainings, aspects that conditioned participation.

Discussion groups were set up with rhythmic gymnastics methodological and training experts to draw up the questionnaire and oversee its validation process. The profile of the experts corresponded to university professors with more than 20 years of experience in sports performance and to members of the International Gymnastics Federation's (FIG) Scientific and Academic Commission, which is in charge of official gymnastics training and development programs at global level.

In the process of preparing the questionnaire, there were consultation rounds among the experts to obtain a consensual thinking of the group and to make a first draft of the questionnaire (Reguant-Álvarez and Torrado-Fonseca, 2016). From here, the discrepancies between the experts went through analysis and discussion, and a final report was prepared to achieve stability and consensus among the views of the group. In this way, the drafting process completed with the writing of the final questionnaire.

To ensure methodological and content validity, the questionnaire was resubmitted to expert judgment that gave their report on it and advised on possible modifications. The final version was the questionnaire presented below in the format used (online) and in three languages:

Spanish: https://docs.google.com/forms/d/1Qe2-kp4uc2-2ug8WO3LB0shaKVtgcDoXA7BsX5sR_OE/edit?usp=sharing

English: https://docs.google.com/forms/d/1oOhN_mNkG-jHddTIaVuDChb0334CGj0eWIVmxytF80/edit?usp=sharing

Russian: https://docs.google.com/forms/d/1JJO8GzrJwHn76jVdI82npOk5DDteViIEMvLrJMF4oJU/edit?usp=sharing

The internal consistency index for questionnaire questions was Cronbach Alpha coefficient obtaining values of $\alpha > 0.65$.

Procedure

Distribution was via email sending it to 150 FIG-affiliated Gymnastics Federations and Unions. Prior to the completion of the questionnaire, all participants received information of the purpose of the study, the anonymity of the answers and the processing of the data. They accessed it after giving their informed consent. Data collection lasted from July to November 2020, being that the time allowed for the completion of the questionnaire. The study developed in line with the ethical patterns of Sports Sciences (Harriss and Atkinson, 2015) and overseen by the Director of the FIG Academy.

Sample

The sample comprised 302 RG coaches (age: 35.7 ± 121 years), from 26 countries across the five continents. Their professional level was national team 5%, international 16.6%, national 55.6%, and regional 22.8%. Considering the sports level of the gymnasts they coach, national teams 8.6%, international 8.6%, national 56.63%, and regional 26.5%. Most of the coaches in the study have more than 10 years of experience (59.3%), 24.5% experience between 5 and 10 years and 16.2% have been training for less than 5 years.

Variables and Statistical Analysis

The independent variable studied has been the level of sport performance of the gymnasts: national team, international, national and regional.

TABLE 1 | General characteristics of training during confinement.

Training volume	**Mean**	**SD**
Days of confinement	107.5	± 49.4
Training days per week	3.8	±1.3
Training hours per day	2.6	± 1.3
Training period in which lock down happened	**N**	**%**
Competitive	214	70.9
Pre-competitive	64	21.2
Pre-season	11	3.6
Resting	2	0.7
Gymnasts following training		
Less than 50%	67	22.2
More than 50%	175	56.6
All	64	21.2
Any gymnasts leaving the sport?		
Yes	223	76.5
No	71	23.5

SD, standard deviation; N, frequency of answers.

The dependent variables studied have been set into four categories. Technical means used to direct and control trainings: real-time, deferred, others. Type of training carried out: physical preparation, ballet, body technical work, apparatus technical work, body difficulties, apparatus difficulties, parts of the competition exercise, psychological preparation and others. Training control mechanisms: weight, diet, physical tests, technical tests, challenges, others; Determining aspects of participation: connectivity, spaces and material, overload and injury, demotion and distance, loss of targets, others.

Within each dependent category, the variable others was included to give the coaches the opportunity to mark other possible less common options considered in their trainings, even though the specific content was not collected since it was a closed questionnaire distributed worldwide.

Statistical analysis was performed using SPSS version 25.0 for Windows (SPSS Inc., IBM, Armonk, NY, United States). Descriptive statistics used for variable description and study contextualization: means, standard deviations, frequencies, and percentages. The chi-squared test was used to identify the differences between gymnast performance levels and Cramer V to assess the degree of association between variables. The level of statistical significance was set at $p < 0.05$.

RESULTS

The results show that the average number of days of confinement was 107.5 ± 49.4, more than 3 months. During this time, gymnasts trained at home an average of 3.8 ± 1.3 days a week and 2.6 ± 1.3 hours per day. For most gymnasts, the confinement period coincided with the competitive period (70.9%) or pre-competitive (21.2%). Most coaches continued to do their training during the confinement period with more than 50% of their gymnasts (see **Table 1**), although a large majority, 76.5% refer to abandonment of some gymnasts during confinement.

Results on the percentages of gymnast dropping out the sport during confinement (see **Table 2**) indicate that increased significantly in the groups of lower-level gymnasts (regional and national).

The media used to conduct and monitor training sessions during the confinement period are in **Table 3**.

Regardless of the gymnasts' levels, all the coaches used real-time video conferencing to enable themselves to conduct training sessions. Video, email and phone calls were used as complementary resources to the former, although in the case of the lower-level gymnasts the latter played a significant role (χ^2 = 8,441; $p < 0.05$; moderate).

The different training content developed during the confinement period is shown in **Table 4**. Body technique was the most frequently used content during all of the training sessions, with no significant differences found in terms of the gymnasts' performance levels (χ^2 = 1.758; $p > 0.05$). Physical fitness and body difficulties were the other two content elements also common to all of the gymnasts, although they played a more significant role the higher the performance level. In the case of the international and national-team gymnasts, both ballet and technical apparatus work featured prominently in training sessions. Performing parts of competition exercises was the content element least developed by the gymnasts. Psychological training also represented a small percentage of the overall training content, increasing significantly the higher the gymnasts' level (χ^2 = 15.127; $p > 0.02$).

Table 5 shows the main evaluation and performance control means used by the coaches. Challenges come above all the others, followed by the technical and physical tests. In the case of the latter, the technical tests were carried out to a largely by the international gymnasts and the national team gymnasts. Weight featured more prominently as the gymnasts level of performance increased, and statistically significant differences were found in this respect (χ^2 = 26.465; $p < 0.05$; moderate).

The aspects that determined training development during confinement varied significantly in terms of the gymnasts' levels (see **Table 6**). In the case of the international gymnasts and national teams electronic resources and connectivity were key, while for the gymnasts at regional and national levels

TABLE 2 | Coaches answers on gymnasts dropping out the sport during confinement.

	Regional *n* = 75		National *n* = 172		International *n* = 26		Nat. Team *n* = 28		χ^2	p	V Cramer
	N	%	N	%	N	%	N	%			
Yes	79	79.0	155	81.2	10	37.0	10	33.3	49.918	0.000	0.379
No	21	21.0	36	18.8	17	63.0	20	6.7			

N, frequency of answers; n, sample size.

TABLE 3 | Media used during training.

	Regional *n* = 75		National *n* = 172		International *n* = 26		Nat. Team *n* = 28		χ^2	p	V Cramer
	N	%	N	%	N	%	N	%			
In real time	75	100.0	172	100.0	26	100.0	28	100.0	–	–	–
Deferred	52	69.3	118	68.6	12	46.2	14	50.0	8.441	0.038	0.167
Others	6	8.0	28	16.3	9	34.6	10	35,7	16.493	0.001	0.234

N, frequency of answers; n, sample size.

TABLE 4 | Type of training done.

	Regional *n* = 75		National *n* = 172		International *n* = 26		Nat. Team *n* = 28		χ^2	p	V Cramer
	N	%	N	%	N	%	N	%			
Physical	64	85.3	166	95.5	26	100.0	26	92.9	12.955	0.005	0.207
Ballet	36	48.0	123	71.5	24	92.3	27	96.4	32.705	0.000	0.330
Body tech*	73	97.3	16	95.3	25	96.2	28	100.0	1.758	0.624	0.076
Apparatus tech*	43	57.3	133	77.3	22	84.6	27	96.4	20.971	0.000	0.264
Body diff**	61	81.3	165	95.9	24	92.3	26	92.9	14.687	0.002	0.221
Apparatus diff**	32	42.7	118	68.6	20	76.9	14	50.0	18.993	0.000	0.251
Parts exercise	25	33.3	85	49.7	13	50.0	7	25.0	10.187	0.017	0.184
Psychological	24	32.0	83	48.3	19	73.1	16	57.1	15.127	0.002	0.224
Others	19	25.3	48	27.9	12	46.2	7	25.0	4.536	0.209	0.123

N, frequency of answers; n, sample size; (technique; ** difficulties).*

TABLE 5 | Evaluation and monitoring means.

	Regional $n = 75$		National $n = 172$		International $n = 26$		Nat. Team $n = 28$		χ^2	p	V Cramer
	N	%	N	%	N	%	N	%			
Weight	2	2.7	19	11.8	8	32.0	9	34.6	26.465	0.000	0.300
Food intake diet	6	8.0	32	18.9	6	25.0	3	11.5	6.490	0.090	0.149
Physical tests	32	42.7	57	33.3	14	56.0	13	48.1	6.723	0.081	0.150
Technical tests	29	38.7	72	41.9	14	53.8	13	46.4	2.026	0.577	0.082
Challenges	59	78.7	143	83.1	21	80.8	22	78.6	0.868	0.833	0.054
Others	12	16.0	37	21.5	8	30.8	17	60.7	24.107	0.000	0.283

N, frequency of answers; n, sample size.

TABLE 6 | Determinants of gymnasts' participation.

	Regional $n = 75$		National $n = 172$		International $n = 26$		Nat. Team $n = 28$		χ^2	p	V Cramer
	N	%	N	%	N	%	N	%			
Electronic sources/connectivity	46	61.3	107	63.3	21	80.8	22	84.6	7.832	0.050	0.173
Spaces and materials	61	81.3	143	83.1	120	76.9	13	46.4	19.802	0.000	0.256
Overload and injuries	12	16.0	41	23.8	10	38.5	8	28.6	5.979	0.113	0.141
Demotivation and distancing	65	86.7	140	81.9	15	60.0	10	35.7	37.189	0.000	0.353
Loss of sports goals	54	72.0	143	83.1	17	65.4	19	67.9	8.095	0.044	0.164
Others	24	32.0	49	28.5	8	30.8	12	42.9	2.386	0.496	0.089

N, frequency of answers; n, sample size.

availability of spaces and materials as well as the lack of motivation caused by social distancing from their teammates were fundamental.

It is notable that during this period, overloads and injuries did not play a decisive role in the participation of any of the gymnasts.

DISCUSSION

The aims of this study were to know how rhythmic gymnastics training developed during the lockdown period (the conditions, type of training, performance monitoring means, and determinants of gymnasts' participation) and to provide recommendations in the event of a future lockdown. Most of the scientific literature on COVID-19 in sport tackled the direct impact of the pandemic on social, health and organizational aspects or on strategies for the return to training and competition. However, the training done in confinement, what the conditions were and what the consequences of this period were with regard to rhythmic gymnastics have scarcely been looked at.

The results indicate that for most gymnasts the confinement period coincided with the time of the main competitions, which logically could not take place. Most continued to train with a high volume of training in both days and hours, which could be due to the high levels of both coaches and gymnasts. The majority belong to national teams with fundamentally international participation at the highest level, world championships and Olympic Games. The results described by Bowes et al. (2020) on the impact of the pandemic on elite women's sport go along these lines. They point out that 100% of those surveyed continued doing their sporting activity and received the support of the coaching staff via online training sessions, this being the tool most used by coaches with their gymnasts in our study.

In relation to the duration of training sessions, Eirale et al. (2020) recommend no more than 60 min per day, both for developing strength and endurance. Ranasinghe et al. (2020) indicate that after an hour, during periods of vigorous training or competition, there is a reduction in the number of immune cells circulating in peripheral blood, therefore they recommend having gradual training strategies with no excessive doses during and after confinement. The rhythmic gymnasts in our study amply exceed the average of this number of minutes.

Of the few studies on training content, Jukic et al. (2020) stress the difficulty involved in monitoring the training load, especially with regard to intensity and volume, as well as prescribing the type of exercise precisely. The RG coaches in our study were capable of developing specific exercises such as ballet or body and apparatus technique, whose loads were difficult to monitor, as they mainly oversaw weight and diet. Eirale et al. (2020) emphasize that excessively intense training can weaken the immune system, thus increasing the risk of catching COVID-19. Hence, the scant use of monitoring mechanisms in the sample may give rise to this undesired situation. Hagen et al. (2020) recommend using welfare questionnaires and remote monitoring tools (mobile apps, GPS, temperature, heart rate monitoring, etc.) to evaluate the state of physical performance and strategically plan for their return to sporting activity when training, as well as competition, is resumed under normal conditions.

Physical fitness was the content most used with the rhythmic gymnasts in the study. Several authors point out that during confinement they worked on strength, overall fitness, endurance training and sports skills (Jukic et al., 2020; Latella and Haff, 2020; Melim et al., 2020). On the other hand, Herrera-Valenzuela et al. (2020) in a study carried out on combat athletes, recommend high-intensity interval training (HIIT) and sport-specific muscular strengthening. Along these lines, Melim et al. (2020) describe HIIT as the most suitable for footballers. Also worthy of highlighting is the importance the RG coaches in the sample place on body and apparatus technique skills, coinciding with the recommendations made by several authors with regard to coaching sport-specific technical skills (Jukic et al., 2020; Ranasinghe et al., 2020). However, other key technical contents of the sport, like apparatus difficulties (many of them performed to high throws into the air of the apparatus) and parts of the competitive exercise (complex connections of body and apparatus movements done at a floor area of 13 × 13 m) were scarcely included.

The psychological preparation of the gymnasts in the study was a training content with little consideration at all levels of performance, but the national teams, when the majority of authors refer to the lockdown as an ideal moment for this kind of training (Bowes et al., 2020; Latella and Haff, 2020; Ranasinghe et al., 2020). Studies in the prolonged abstinence from physical training and its psychological effects in athletes, forced to abstain due to injury, show that they are more likely to develop problems such as depression, anxiety, loss of self-esteem and mood swings (Melim et al., 2020). At different levels of performance and before the times of COVID pandemic, the RG psychological studies dealt mostly with anxiety, attentional and pre-attentional processes, self-consciousness, behavior analysis and personality traits of rhythmic gymnast (Bobo-Arce and Méndez-Rial, 2013). Cénat et al. (2021) in a systematic review of the psychological effects of the pandemic, with more than 190,000 participants, found that depression, anxiety and stress were between five and three times more frequent than commonly reported by the World Health Organization (2017). Effects that have not been analyzed yet in RG gymnasts across the world and at different levels of performance. Future studies should approach the consequences of the global lockdown to determine the specific effects on gymnasts and to explore if the sport practiced contributed to reduce or increase them.

A study carried out with Italian athletes (Di Fronso et al., 2020) found a significant increase in perceived stress and dysfunctional psycho-biosocial states in comparison with pre-confinement situations, greater in women than in men, and greater in novice than in elite athletes. Esteves et al. (2020) describe similar results for professional footballers, pointing out that high performance male athletes have lower levels of anxiety. It appears to be desirable, to include in gymnasts' training sessions specific psychological programs directed to female athletes at non-professional level, as recommended by the UN in order to prevent the pandemic from influencing gender and social inequality (United Nations, 2020). Iancheva et al. (2020) find also differences between men and women in sports specialties and refer to differences in psychological intervention. Furthermore, these authors found different ways of perceiving the consequences of the pandemic in accordance with nationality, which makes it easier to understand some of the results obtained in this study.

Even though psychological training has not been a priority for the coaches during this first world lockdown, it is remarkable that challenges were the main monitoring mechanism used. Considering that challenges could represent a motivation for gymnast to keep on training gymnastics skills under difficult circumstances, it is to some extent contradictory the results obtained in the two categories: training content and monitoring means.

With regard to the difficulties sportspeople found in continuing their training routines during the confinement, Bowes et al. (2020) point out that 94% told of problems that affected their training regimes, and 74% of them indicated mainly that they were unable to train in suitable, specialist facilities, or use specialist equipment. A high percentage of coaches in this study indicate that they had some gymnast who left due to the difficult circumstances of confinement. The results also show significant differences according to the levels of performance. For the elite gymnasts extrinsic factors, such as poor connectivity or lack of facilities and materials are the main reasons behind problems in training. For the lower level gymnasts, intrinsic factors including the lack of contact with other gymnasts and the loss of sport goals were determinant.

It is notable that for all performance levels in the study overloads and injuries did not play a decisive role, even though the difficulty of implementing an injury recovery plan with the scant resources available for professional and physical assistance in the home is considered as a limitation (Girardi et al., 2020).

There is no data found in previous studies on athletes abandoning training during the lockdown. Rhythmic Gymnastics is taken up from a very early age, therefore gymnasts will be psychologically immature and their predisposition to doing sport maybe modified by such a long period of confinement. For youth sports, Breslin et al. (2020) recommend guidance and working in three priority areas: mental health and dealing with uncertainty, maintaining social connections, and motivation and setting goals. The results also indicate that giving up is more frequent the lower a gymnast's level, which might suggest that being less involved in sport can lead to more people giving it up altogether. Similarly, the type of rhythmic gymnastics most participants do at lower performance levels is in groups (five gymnasts together), and this was unfeasible during confinement. While extrinsic conditions for training in a lockdown situation could improve through sport policies and investment, intrinsic factors should be deal through specific psychological training of the gymnasts.

Bearing in mind the study's limitations (sample size, the distribution of training loads and the type of gymnastics modality, that is individual or group performance), and the scientific evidence with respect to training during the period of confinement, we would propose the following recommendations for RG in case of subsequent home confinements:

- To plan the training load (intensity and volume), considering the different content possible beyond fitness training and body and apparatus technique. It would be necessary to include other main components of the sport that the gymnasts can practice at home, like choreographic preparation based on ballet, expression and musical rhythm, and mental preparation, using concentration and visualization techniques.
- To establish the duration of training sessions at home in accordance with gymnasts' ages and performance levels, avoiding prolonged sessions of over an hour when the training content is of high intensity.
- To program the calendar and mechanisms needed for monitoring gymnasts' evolution in all dimensions of performance: physical, technical and psychological.
- To provide the gymnasts with the resources necessary for them to develop their training sessions and control their performance progressions at home.
- To draw up specific psychological support programs to give guidance and help gymnasts to maintain their motivation and goals in the sport.

CONCLUSION

During the period of confinement brought about by the COVID-19 RG training was widely monitored by the coaches in the sample as well as by the gymnasts themselves, although a high percentage of coaches admit that some of their gymnasts gave up the sport altogether. The technological resources used enabled coaches and gymnasts to be in contact and to prescribe and follow training sessions online. This did not occur to the same extent in the monitoring of training, which was scant and somewhat vague.

The training content most used was general and sport-specific physical fitness as well as body and apparatus technique. The average duration of training sessions was much higher than that recommended in other studies on athletes' health and well-being. For its part, psychological preparation was not undertaken enough during the lockdown period, contrary to the recommendations found in literature and which should be corrected in the event of future confinements by establishing specific protocols.

The difficulties revealed with regard to the continuation of training, such as connectivity problems and lack of facilities and materials, should be resolved at some stage in the future.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

MB-A and ES-P contributed to the study conception and design. MB-A and HF controlled the validation process and data collection. MF-V performed the data analysis. MB-A, ES-P, and MF-V wrote, reviewed, and edited the manuscript. All authors contributed to the article and approved the submitted version.

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Age at Nomination Among Soccer Players Nominated for Major International Individual Awards: A Better Proxy for the Age of Peak Individual Soccer Performance?

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Individual soccer performance is notoriously difficult to measure due to the many contributing sub-variables and the variety of contexts within which skills must be utilised. Furthermore, performance differs across rather specialised playing positions. In research, soccer performance is often measured using combinations of, or even single, sub-variables. All too often these variables have not been validated against actual performance. Another approach is the use of proxies. In sports research, the age of athletes when winning championship medals has been used as a proxy for determining their age of peak performance. In soccer, studies have used the average age of players in top European leagues or in the Champions League to determine the age of individual peak performance. Such approaches have methodological shortcomings and may underestimate the peak. We explore the use of a new proxy, the age at nomination for major individual awards, to determine the average age at peak individual soccer performance. A total of 1,981 players nominated for major awards from 1956 to 2019 were included, and a subset of 653 retired players was extracted, thus including players' complete careers. Players' average ages at nomination, at their first nomination, and at their last ever nomination were calculated, and differences across playing positions were calculated together with changes over time in the average age at peak. Based on our proxy, the age of individual peak soccer performance occurs around 27–28 years, varying across playing positions from 26 to 31 years. A player's first peak, on average, seems to coincide with known peaks of physiological variables; their last-ever peak occurs long after physiological performance has started to decline, indicating that the decline can be compensated for by other variables. The peak age is higher than previously reported for soccer; however, it is similar to those in other team ball sports. The average age at peak performance has increased over time, especially in the last decade. Our approach of using proxies for unearthing information about hidden features of otherwise immeasurable complex performance appears to be viable, and such proxies may be used to validate sub-variables that measure complex behaviour.

Keywords: football, performance, elite, team sport, optimal, career

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INTRODUCTION

In soccer, team performance is measured in the simplest way: the number of scored goals minus the number of conceded goals (IFAB, 2020). Accumulated performance over time is measured by the total points earned in winning or drawing matches (usually three points and one point, respectively) in a league in one season (see, for example, Premier League, 2020). Individual soccer performance is more difficult to measure and is not formally assessed since *who* scores the goals does not affect the result. However, an abundance of statistics is kept on individual players to rank their performances relative to one another (e.g., Whoscored.com, Transfermarkt.com, fbref.com). Furthermore, teams keep accounts of players' performances using a variety of sub-variables that contribute to individual soccer performance and, ultimately, to team performance.

A goal being scored or conceded is often due to a chain of events, during which each involved player contributes to the result to varying degrees and in different ways. Sometimes a player's involvement can be decisive and easily measured, such as in scoring a goal, assisting a goal, saving a penalty, or keeping a clean sheet in the case of the goalkeeper. Most often, however, each player's contribution to each goal (whether scored or conceded) is more subtle and cannot be readily measured.

Individual soccer performance is dependent on a variety of physiological factors such as running speed, endurance, muscle strength (see Slimani and Nikolaidis, 2017), and agility (Young and Farrow, 2006). Soccer players also must possess a number of different ball skills (see Wilson et al., 2020). For example, a player must be able to pass the ball over a variety of distances, with different requirements of force and accuracy, within a changing environment that includes opposing players who are actively trying to intercept the passes or retain the ball. The player must master shooting, controlling the ball with many different body parts, dribbling, heading, and more, with each different action involving a quite different, yet specific, skillset. Furthermore, all these skills need to be adapted to situations involving a varying number of teammates as well as players from the opposing team. Such decisions need to be timed well, and decisions often need to be taken in a matter of milliseconds (Roca et al., 2020) or the opportunity may be missed, and the player(s) will need to start searching for other opportunities. Thus, players need rather advanced perceptual (Oppici et al., 2017; McGuckian et al., 2018) and decision-making skills (Romeas et al., 2016).

To make the measurement process even more complicated, the players on each team do not necessarily possess the same mix of skills, especially due to their playing different positions on the field: a team is composed of highly specialised players with different specialities (Di Salvo et al., 2007; Ade et al., 2016; Vigh-Larsen et al., 2018). For example, defenders more often intercept, clear, and cross the ball, whereas midfielders perform more dribbles and tackle more often, as do fullbacks (Taylor et al., 2004). Goalkeepers have a completely different skillset, including catching shots, making saves or blocking shots (including dives), defending crosses, deflecting or punching the ball, as well as quick distribution of the ball by hand and by foot (Ziv and Lidor, 2011). Furthermore, there are different physical demands across playing positions. Midfielders run longer distances and at higher intensities compared with central defenders and forwards in particular (Altavilla et al., 2018). Also, wide defenders (fullbacks) spend more time performing high-intensity work compared with central defenders (Di Salvo et al., 2007; Lago-Peñas et al., 2009). These different requirements seem to influence the average age of players in different positions on the field, with defensive players (defenders and especially goalkeepers) being older than midfielders and forwards (Bloomfield et al., 2005; For a more thorough description of the complexity of the game, see McHale et al., 2012).

Within a host of domains like arts, culture, and science, peak performances seem to vary somewhat randomly within an individual's career (Liu et al., 2018). In sports, however, where physical attributes play a greater role, careers are less random. Albeit variable, athletes' careers are, in essence, biphasic, consisting of a period of growth and development followed by a period of decline (Guillaume et al., 2011; Berthelot et al., 2012). Consequently, soccer players, for whom physical capacity in part determines performance, will inevitably experience a decrease in performance with age due to physiological decline. Exactly when this decline will occur, and by how much, is uncertain since it can be compensated for by superior ball skills, perceptual skills, and tactical skills, but it is possible to speculate based on the known peaks for various physiological variables and their decline with age.

Mean peak performance among elite sprint specialists is achieved at 25–26 years of age (Haugen et al., 2018). For soccer players, sprint times improve from 12 years of age until adulthood (Baumgart et al., 2018), and they begin declining after the age of 28 (Haugen et al., 2020). Sprint performance is also strongly related to jumping performance among soccer players (Emmonds et al., 2019) due to the strong power requirements in both tasks (Methenitis et al., 2016). Specialists in power production, such as elite athletes in Olympic weightlifting, demonstrate their peak performance at 26 years of age (Huebner and Perperoglou, 2019), which corresponds well with peak performance in vertical jumping and sprint performance among soccer players.

The age at peak endurance performance among specialised athletes generally increases with duration of the event, and performance in endurance events of long duration may peak as late as the mid- to late-30s (Longo et al., 2016). In soccer, endurance among top-level Czech Republic players (measured as maximal oxygen uptake) was similar for players aged 17–30 years, while it was significantly lower for players aged 30–39 years (Botek et al., 2016). Tønnessen et al. (2013) reported that players younger than 18 years old had higher VO^2_{max} values than players aged 23–26 years. However, soccer endurance is also dependent on playing position. Tønnessen et al. (2013), for example, reported midfielders to have higher maximal oxygen uptakes than defenders, forwards, and goalkeepers.

The findings reported above, which are based on measurements of isolated physiological capacities such as power generation and endurance, seem to correspond well with the findings of

Sal de Rellán-Guerra et al. (2019), which are based on real soccer match performance. These authors reported that professional soccer players above 30 years of age ran significantly shorter distances and completed fewer fast runs and sprints during matches compared with players below 30 years of age. Interestingly, the same authors reported that players' ability to make successful passes improved after they turned 30 years old. These effects were observed in all positional roles except wide midfielders (Sal de Rellán-Guerra et al., 2019). Furthermore, Wilson et al. (2017) showed that the best players in matches were those with superior technical (ball) skills rather than athletic traits such as speed, agility, strength, and stamina. Superior ball skills might help explain why some players can maintain a high performance level in soccer well beyond the age at which physiological capacities have peaked.

A vast number of tests aim at measuring soccer skill performance (Ali, 2011). Several studies have identified correlations between field test and match performance. For example, Rampinini et al. (2007) identified a correlation between an incremental running field test and high-speed running in matches. Still, it is possible that high-speed running does not correlate with success for the team. Hoppe et al. (2015) correlated match running performance with success in the German Bundesliga and found that match running performance is not the only skill needed to achieve success for teams; technical and tactical skills as well as ball possession are also important. However, Ré et al. (2014) found that, in general, for young players, the measures of technical skills obtained outside of games did not correlate with performance in games. Carling (2013) also cast doubt on the importance of physical performance for team success. Also, a team's playing formation seems to impact on high intensity running activity and technical aspects of performance (Bradley et al., 2011). Furthermore, playing style affects match outcome (Castellano and Pic, 2019), and match status affects style of play (Fernandez-Navarro et al., 2018), illustrating the importance of contextual variables when evaluating soccer performance. Together, these examples illustrate that soccer performance is complex, and it is futile to reduce its measurement to single variables that can be tested and then summed up. Rather, what might be needed is a global view that sees the contributing aspects in soccer as inseparable elements of a single set that, according to non-linear complexity, are mutually determined (see Di Domenico et al., 2019).

In individual sports, athletes' career trajectories can be studied by monitoring the development of raw results or by recording more global performance indicators. An individual athlete's peak performance, and thereby their age at peak performance, can be calculated as the age at their best ever performance during their careers (Haugen et al., 2018). However, in studies that attempt to determine at what average age athletes across different sports reach their career peaks (often called athletes' peak age), it has been common to consider peak performances such as winning world championships, Olympic medals, and the like (see Allen and Hopkins, 2015; Longo et al., 2016).

In soccer, for obvious reasons, tallying up world championships or similar achievements will not suffice as a measure of individual performance. Soccer is a team sport, and all players of a squad are crowned world champions regardless of their individual contributions (if any). Additionally, the world championship is held every 4 years; thus, a player will have perhaps five or six attempts, at most, to achieve this honour during their career. Becoming a world champion, however, is also dependent on being part of a team that is good enough to win the championship, which means being born in a country that can produce an entire squad of top players. Only eight countries have ever won the FIFA World Cup, and only a handful more have ever reached the final (Britannica, 2020). Furthermore, the timing has to be such that the particular crop of players constituting a squad is not coincident with another, even better, squad.[1]

When attempting to measure "unmeasurable" complex behaviours by selecting sub-variables (sometimes even a single variable), it is a good idea to find some overall proxy against which to validate those measures; this is common practice, especially if any sub-variable (or combination of such) is used for predicting or drawing conclusions about overall complex behaviour. McHale et al. (2012), for example, in an attempt to formulate a soccer player performance rating system, envisaged a hypothetical English National team chosen from the highest ranked players in each position, based on their index scores, and compared the hypothetical team against the actual English team appearing in the first game of the 2010 World Cup. Similarly, McIntosh et al. (2019) validated objective performance indicators by comparing them with subjective ratings of player performance in Australian Rules football.

By validating against such proxies, it is (often implicitly) assumed that the proxy represents the overall complex behaviour in a valid manner, without such assumptions being tested. However, the proxies are intuitively regarded as good measures of the behaviour, which is arguably the case in the mentioned cases of peak sports performance being determined by the winning of world championships and the like.

Our approach was rather the opposite. In the present study, our departure point was a proxy that we believed to be a better representation of the overall complex behaviour that constitutes individual soccer performance. Based on our proxy, we determined age at peak individual soccer performance, and then we compared it with the age at peak performance as reported in other studies. Furthermore, we attempted to validate this against results from studies reporting age at peak performance based on a number of sub-variables that contribute to overall soccer performance. Last, we compared our determined age at peak individual soccer performance with age at peak performance identified in studies involving various other sports.

Previous studies have attempted to determine the peak age of soccer players using different proxies, such as the average

[1]Many of the best players of all time, according to the website FourFourTwo (2020), were not part of teams that won the World Cup, including Eusebio, Lev Yashin, Paolo Maldini, Zico, Franco Baresi, George Best, Marco van Basten, Michel Platini, Ferenc Puskas, Alfredo Di Stefano, Johan Cruyff, Lionel Messi, and Cristiano Ronaldo (although a few of these have won the UEFA European Championship), to mention but a few household names. Additionally, some will remember the team that is often described as the best team to never win the WC, Brazil of 1982, boasting players such as Zico, Socrates, Junior, and Eder.

age of players at the highest level – notably in the big European leagues (Dendir, 2016) or in the Champions League (Kalén et al., 2019) – or the amount of playing time at the particular level (Dendir, 2016). Other possible proxies for individual performance could be the monetary value of a player (as on Transfermarkt.com) or various rating systems based on the accumulation of counts and ratings of match-related actions, of which Whoscored.com would seem to be the leader (see more details below).

Kalén et al. (2019) argued that the age of peak performance for soccer players was 26.5 years, having increased from 24.9 years in the 1992–1993 season, based on the average age of players in the squads of clubs participating in the UEFA Champions League. Utilising a model that included the average age of the players at the highest club level (the top four leagues in Europe: the Italian Serie A, the German Bundesliga, La Liga in Spain, and the English Premier League), the average playing time in that sample, and those players' average ratings from Whoscored.com, Dendir (2016) found that soccer players peak at 25–27 years of age, varying with playing position; he stated that his calculated peak age was probably lower and with a narrower age band than in previous reports that suggested peaks in the mid-to-late 20s, which might be due in part to the fact that the sample did not include goalkeepers. Furthermore, as we will discuss, both the above studies included players who were still active at the time; thus, their actual age at peak performance was not yet known.

However, being part of a squad at a high level (as were players in Dendir, 2016 and in Kalén et al., 2019) does not necessarily indicate high performance at that same level. Thus, the average age of such a sample would not be an indication of the peak age of that sample; it would simply indicate the average age. In fact, the average squad age in the top four European leagues is similar to the average squad age in any European league. The average age of European soccer players is currently 26 years. The average squad ages across European leagues vary from 24.3 (Slovakia) to 28 years (Turkey), with ages in the top five leagues varying from 25.6 (France) to 26.9 years (Italy; Poli et al., 2019), probably reflecting midpoints of average-length careers.

WhoScored (2020) ratings, as indicated above, are promising as indicators of individual soccer performance, but they have notable methodological shortcomings. The ratings are somewhat condensed around the average (which Who Scored defines as six points). Most importantly, however, ratings are relative to playing level, reflecting performances relative to teammates and opposing players at that same level. Thus, they cannot be meaningfully compared across levels of performance. For example, the average score for the top 50 players in the German Bundesliga in the 2019–2020 season was 7.2 points, quite similar to 7.1 points in the Zweite Bundesliga (the second-highest-rated German league; the league Bundesliga teams are relegated to or promoted from). This fact might not constitute a problem when comparing players across similar levels, such as the top five leagues (which WhoScored does). However, it introduces problems when, for example, comparing a player with himself across a career when that career includes playing at different performance levels.[2] Knowing that the best players in the lower leagues will migrate to the top five leagues and that many top players in fact started their careers in lower-ranked leagues, a significant share of players would not be comparable to themselves over time in terms of performance if one relies on WhoScored ratings, and for some, it would not even be possible to find complete records.

Furthermore, the WhoScored rating system dates back only some 10 years; thus, performances predating this can neither be compared within nor across players. Adding the effect of a (assumedly) continuously updated algorithm, one could argue that ratings are not comparable over time, at least not over longer periods.

In the present study, as mentioned, we introduce the ages at nomination of major player of the year award recipients as a performance proxy, with the argument that this variable, in fact, is the closest one can come in soccer, being a team sport, to counting championship medals within individual sports (see Allen and Hopkins, 2015; Longo et al., 2016).

The most renowned player of the year awards are the Ballon d'Or, the FIFA Player of the Year award, and the combined FIFA Ballon d'Or and the UEFA Player of the year awards. The Ballon d'Or is "one of the oldest and generally regarded as the most prestigious individual award for football players, and it has been awarded since 1956" (Ballon d'Or, 2020). "Doing well in the Ballon d'Or election is an invaluable stamp of approval that authenticates and personalizes achievement and confers power and status to those players who place near the top" (Anderson et al., 2020, p. 94). There are no exact performance measures that qualify players for the awards. The Ballon d'Or prize organiser, France Football, provides a shortlist of 30 players. From that list, international journalists and the coaches and captains of the national teams under FIFA's jurisdiction are eligible to vote for five players they deem to have performed the best in the previous calendar year (Ballon d'Or, 2020). The jury evaluates the players according to several subjective criteria, including on-field performance as well as a player behaviour on and off the field. Voters are instructed to consider a player's individual and team performances during the previous 12 months, including championships won, skill and fair play on the field, career accomplishments, and, interestingly, a player's appeal (Anderson et al., 2020).

Coupe et al. (2018) investigated biases and strategic behaviour related to performance evaluations in jury voting for the FIFA Ballon d'Or award. They found that national biases are substantial,

[2]For illustration, the European Golden Shoe is awarded by European Sports Media (ESM) to the player scoring the most goals in a European league each season (European Sports Media, 2020). In order to fairly compare performances across leagues, from 1996 onwards a points system has been applied in which goals scored in the top five leagues are multiplied by a factor of 2, whereas goals scored in leagues ranked 6th through 21st are multiplied by 1.5. Any goals scored in any of the remaining leagues are multiplied by 1.0 (European Sports Media, 2020). Thus, a player would need to score twice as many goals in a lower-ranked league compared to the top five in order to win the Golden Shoe. In the 2019–2020 season, Erling Braut Haaland of Borussia Dortmund accumulated a total of 50 goal points from 29 goals, 16 for Red Bull Salzburg (multiplied by 1.5) and 13 goals for Dortmund (multiplied by 2). In the same season, Lionel Messi accumulated 50 goal points for his 25 goals for Barcelona.

with jury members disproportionately voting for candidates from their own countries, national teams, continents, and leagues. However, the impact of such biases on the total number of votes a candidate receives is fairly limited and hence is likely to affect the outcome of the Ballon d'Or only on rare occasions (Coupe et al., 2018). Regarding strategic voting, jury candidates are actually more, rather than less, likely to vote for their main competitor (Coupe et al., 2018). Coupe et al. (2018) investigated jury voting for the nominated players, but, to the best of our knowledge, no studies have looked into the nomination process itself.

Nominations for player-of-the-year awards seem to be based entirely on subjective evaluations by soccer experts in, for example, France Football for Ballon d'Or. Laurence (2011) argued that when measured by the WhoScored rating, six players other than those shortlisted for FIFA Ballon d'Or should have been included, and five others should have been excluded. Regardless of such inconsistencies, the Ballon d'Or and the other major awards are widely recognised, and there is no doubt that being nominated for one of them indicates a career peak for a player.

The purpose of the present study was to

1. Determine the age at individual peak performance for soccer players using our proxy.
2. Discuss how the peak age changes with operationalisation of the dependent (proxy) variable.
3. Discuss our proxy relative to other (proxy) variables used in previously published studies.
4. Discuss the age at peak performance based on our proxy variable relative to peak performance based on contributing (sub-)variables.

MATERIALS AND METHODS

Player Sample and Procedure

The present data comprised the soccer players nominated for awards each year from 1956 to 2019, and they provided us with the opportunity to record each player's (often multiple) career peaks in a manner similar to that used in studies determining age at peak performance in other sports (Allen and Hopkins, 2015; Longo et al., 2016). From these peaks, each player's age at peak performance was determined according to several different operationalisations of the peak (see below). Furthermore, a detailed timeline of players' average ages at nomination was established from the first-ever Ballon d'Or in 1956 up to and including major awards for 2019.

Different operationalisations of the proxy are interesting and relevant for different reasons. The *age at player's first nomination* is relevant in a developmental context because it provides information on how early in a career it is possible to perform at the very top level of international soccer (viz the 10,000-h/10-year rule; Ericsson and Lehmann, 1996). The *average age at nomination for awards* indicates the typical age at which players perform at their best, and it can be compared with similar ages in other sports. Last, the *last time a player was nominated for an award* indicates the age up to which top players, on average, can expect to maintain their highest performance level, which may be of importance in contract negotiations and when trading players (see Dendir, 2016).

All players nominated (not merely those receiving awards) for the various player of the year awards during the period 1956–2019 were included (N = 1,981). Nomination lists for player-of-the-year awards, including nominees for positional awards, were collected for Ballon d'Or (Rec.Sport.Soccer Statistics Foundation, 2020a), FIFA World Player of the Year (Rec.Sport. Soccer Statistics Foundation, 2020b) and The Best Fifa Men's Player (Wikipedia, 2020). The main data source was the annual football award, Ballon d'Or, presented by France Football and awarded during the periods 1956–2009 (N = 1,571) and 2016–2019 (N = 123). Additionally, nominations were collected from the merged FIFA and Ballon d'Or for 2010–2015 (N = 125), the UEFA Men's Player of the Year from 2011 to 2019 (N = 138), the FIFA World Player of the Year from 1991 to 2009 (N = 19), and the Best FIFA Men's Player from 2017 to 2019 (N = 5).

When a player was nominated for several awards in the same season, only one of them was counted for that season. This total sample of nominated players was used to identify each player's age at nomination, and this was used to calculate the *average age at nomination, average age of a player's first nomination*, and *average age at a player's last-ever nomination*.

From this total sample of nominated players, a subsample was extracted to identify each player's career peaks. Players who had not yet finished their careers were excluded, resulting in a retired player subsample (n = 685). The latter sample consisted of 661 nominations for Ballon d'Or, six nominations for Ballon d'Or/FIFA, eight nominations for the Best FIFA Men's Player, and eight nominations for the UEFA Men's Player of the Year.

In addition, from the player-of-the-year data, players' positions on the pitch were recorded as registered in the nomination for the award (when applicable) and further verified at Transfermarkt.com. Positions were further re-categorised into four general positions: goalkeeper, defender, midfielder, and forward.

Players' ages were recorded (as in Dendir, 2016) as of January 15, approximately the mid-season mark for a typical league measured on a continuous scale. For instance, a player born on October 26, 1984 was 28.2 years of age in the 2012–13 season.

Some players had been nominated more than once. In these cases, both the player's average age over several nominations (a single player can represent multiple cases) and the player's age at first or last-ever nomination (each player is represented only once) was calculated. In order to create a timeline of the average ages of the nominated players, we calculated their average ages for each year from 1956 to 2019.

Sources: Major Individual Soccer Awards

From its inception in 1956 until 2006, the winner of the Ballon d'Or award was chosen by football journalists only. Since 2007, coaches and captains of national teams have been eligible to vote. Originally, it was an award for players from Europe, but in 1995 the Ballon d'Or was expanded to include all players of any origin who had been active in European clubs and, subsequently, the award became global in 2007.

The FIFA World Player of the Year award was presented annually by FIFA from 1991 to 2009. The award was merged with the Ballon d'Or from 2010 to 2015 and re-established as the FIFA Best Men's Player of the Year award in 2016. Coaches and captains of international teams, as well as international media representatives, decide the nominations for this award.

The UEFA Club Footballer of the Year was presented annually by UEFA from the 1997–98 season to the 2010–11 season, when it was replaced by the UEFA Best Player in Europe award, originally established to revive the Ballon d'Or, which had merged with the FIFA World Player of the Year in 2010. The recipients of the UEFA Men's Player of the Year award are selected from among players in the European leagues. In the beginning, this award was decided by 53 sports journalists (later expanded to 55) representing each of the UEFA national associations. We have not succeeded in retrieving shortlists of all nominees, only listings of winners of the positional awards during the period 1997–2010.

Ethics

The present study was based on publicly available, non-sensitive data from the above-mentioned websites. Thus, ethics approval was not required per applicable institutional and national guidelines and regulations.

Statistical Analysis

Kolmogorov-Smirnov tests (KS), histograms, and Q-Q plots were applied to examine normality assumptions of the variables' statistical distributions, and they indicated a normal distribution (KS test = 0.015, $p > 0.20$). Distribution of nominations across playing positions was examined with Chi-square tests (χ^2) against an even distribution. Potential position-related differences in age at nomination were examined by one-way ANOVAs with partial eta squared (η^2_p) as the indicator of effect size, interpreted as small effect: 0.01, medium effect: 0.06, and large effect: 0.14 (Cohen, 1988; Richardson, 2011). Position-related differences were further examined with Bonferroni-corrected *post hoc* analysis with Cohens d applied as a measure of effect size, in which 0.2, 0.5, and 0.8 were considered small, moderate, and large, respectively (Cohen, 1988; Lakens, 2013). Pearson product-moment correlations were used to examine the relation between year of nomination and average age of nomination at various timepoints. Predictive Analytics Software (PASW, IBM, United States; previously SPSS) version 27.0.0.0 was used for all statistical procedures, with $p < 0.05$ as the statistical significance criterion.

RESULTS

Total Sample of Nominated Players

In the overall sample of 1,981 nominations, 9.2% were goalkeepers; 15.2% were defenders; 32.2% were midfielders, and 43.5% were forwards. The distribution of nominations across positions differed significantly from an even distribution ($\chi^2 \geq 176$, $p < 0.001$), with defenders being underrepresented relative to the number of defending positions and attackers being somewhat overrepresented. The age at nomination was normally distributed for the total sample of nominations (see **Figure 1**; the mean age of players in the total sample was 26.75 years, with a SD of 3.66 years).

Age at Nomination

The mean age at nomination, as can be seen in **Table 1**, varied across playing positions. An initial one-way ANOVA indicated significant differences {F [1,3] = 65.77, η^2_p = 0.09 [95% CI (0.07; 0.12)], $p < 0.001$} across playing positions. Further *post hoc* analysis with Bonferroni correction indeed confirmed that age at nomination was significantly different between all positions {$d \geq 0.50$ [95% CI (0.31; 0.69)], $p < 0.001$} except between midfielders and forwards {$d = 0.14$ [95% CI (0.04; 0.24)], $p = 0.071$}.

Age at First Nomination

The mean age at first nomination (**Table 1**) also varied across playing positions. An initial one-way ANOVA indicated significant differences {F [1,3] = 24.34, η^2_p = 0.08 [95% CI (0.05; 0.12)], $p < 0.001$}. Further *post hoc* analysis with Bonferroni correction confirmed that age at nomination was significantly different between all positions {$d \geq 0.46$ [95% CI (0.18; 0.74)], $p < 0.001$} except between midfielders and forwards {$d = 0.09$ [95% CI (−0.07; 0.25)], $p = 0.29$}.

Age at Last-Ever Nomination

One-way ANOVA indicated significant differences {F [1,3] = 19.73, η^2_p = 0.07 [95% CI (0.04; 0.10)], $p < 0.001$} between playing positions for mean age at last nomination (**Table 1**). *Post hoc* analysis with Bonferroni correction indicated that age at last nomination was significantly different between all positions {$d \geq 0.56$ [95% CI (0.28; 0.84)], $p < 0.001$} except between midfielders and forwards {$d = 0.05$ [95% CI (−0.11; 0.21)], $p = 0.55$}.

Age at Nomination Over the Period 1956–2019

As can be seen in **Figure 2**, the mean age at nomination for each year increased, culminating with a mean age at nomination of 28.4 years in 2018. From 1956 to about 1967, the average age at nomination dropped from about 27.5 to 24.5 years before increasing again to reach the initial 1956 values in 1973. During 1974–2014, a period of rather stable ages at nomination was followed by a considerable increase of 1.3 years from 2014 to 2018. Thus, a significant relationship was found between year of nomination and average age at nomination during the period 1956–2019 ($r = 0.41$, $p < 0.01$). For the most recent 2 decades (1999–2019), an even stronger statistical relationship was found between year of nomination and average age at nomination ($r = 0.63$, $p < 0.01$).

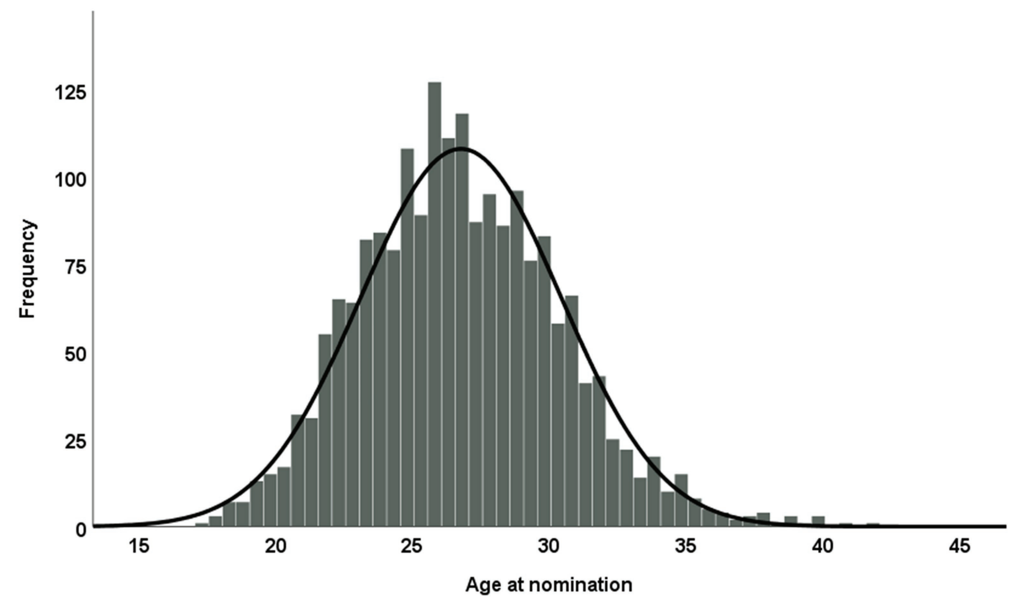

FIGURE 1 | Frequency of nominations at different ages for the total sample.

TABLE 1 | Age at nomination across playing positions for the total sample.

Position	*n* (% of total)	Average age	First nomination	Last nomination
		Mean (SD)	Mean (SD)	Mean (SD)
Goalkeepers	182 (9.19)	29.64 (4.01)	28.24 (3.60)	30.43 (4.21)
Defenders	301 (15.19)	27.82 (3.38)	26.70 (3.19)	28.36 (3.38)
Midfielders	637 (32.16)	26.46 (3.42)	25.30 (3.26)	27.39 (3.44)
Forwards	861 (43.46)	25.99 (3.47)	25.08 (3.48)	27.28 (3.45)
Total	1981 (100.00)	26.76 (3.66)	25.73 (3.51)	27.80 (3.63)

Subsample: Retired Players

The subsample of confirmed retired players ($n = 685$) consisted of 8.6% goalkeepers, 17.0% defenders, 32.6% midfielders, and 41.8% forwards. The number of nominations was normally distributed by age; the most frequent age at nomination was from 26 to 27 years (see **Figure 3**).

Age at Nomination for Retired Players

The mean age at nomination for retired players (**Table 2**) also varied across playing positions. An initial one-way ANOVA indicated significant differences {F [1,3] = 63.56, $\eta^2_p = 0.11$ [95% CI (0.08; 0.13)], $p < 0.001$} across playing positions. Further *post hoc* analysis with Bonferroni correction confirmed that age of nomination was significantly different between all positions {$d \geq 0.32$ [95% CI (0.17; 0.47)], $p < 0.001$} except between midfielders and forwards {$d = 0.15$ [95% CI (0.04; 0.27)], $p = 0.055$}.

Age at First Nomination for Retired Players

The mean age at the first year of nomination for retired players was 25.78, with SD at 3.68 (see **Table 2**). One-way ANOVA indicated a significant difference in age at first nomination across playing positions {F [1, 3] = 21.13, $\eta^2_p = 0.09$ [95% CI (0.05; 0.12)], $p < 0.001$}. *Post hoc* analysis indicated that age at nomination was significantly different between all positions {$d \geq 0.40$ [95% CI (0.17; 0.63)], $p < 0.005$} except between midfielders and forwards {$d = 0.08$ [95% CI (−0.10; 0.25)], $p = 0.40$}.

Age at Last-Ever Nomination for Retired Players

The mean age at last year of nomination for retired players was 27.94, with SD at 3.64 (**Table 2**). A one-way ANOVA indicated a significant difference in age at last nomination across playing positions [F [1, 3] = 19.59, $\eta^2_p = 0.08$ [95% CI (0.04; 0.12)], $p < 0.001$], and a *post hoc* analysis indicated that goalkeepers were significantly older at year of last nomination compared to players in other positions {$d \geq 0.71$ [95% CI (0.39; 1.03)], $p < 0.001$} and that defenders were significantly older compared to forwards {$d \geq 0.31$ [95% CI (0.10; 0.53)], $p < 0.01$}. No further position-related differences in age at last year of nomination for the retired players was found {$d \leq 0.22$ [95% CI (−0.003; 0.451)], $p > 0.05$}.

DISCUSSION

The average age at nomination for major individual awards was 26.8 years in the total sample. There was considerable variation across playing positions, with forwards and midfielders peaking earlier than defenders, 26 and 26.5 years vs. 27.8 years, respectively, and goalkeepers peaking particularly late, at 29.6 years. There were, however, interesting variations across the different operationalisations of the proxy.

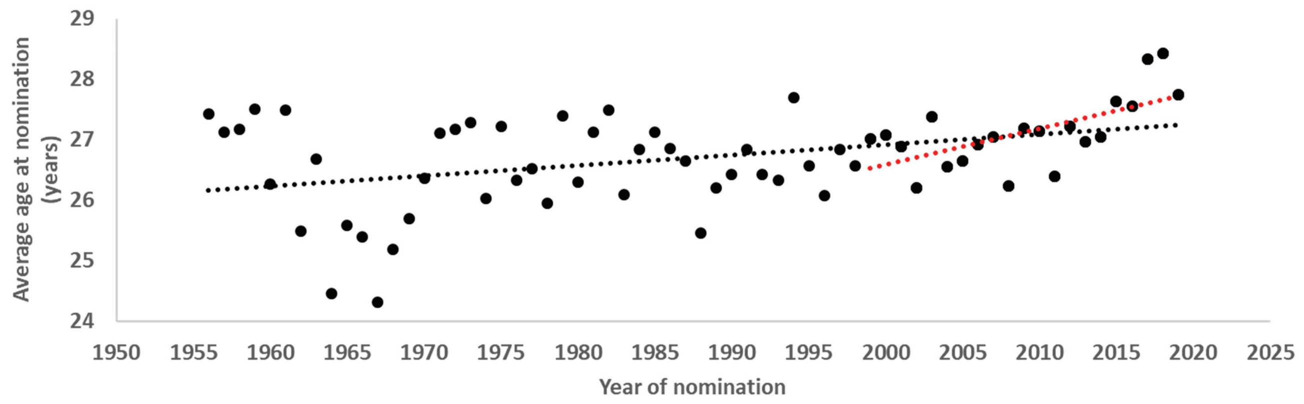

FIGURE 2 | Development of mean age at nomination from 1956 to 2019. Black dotted line indicates trendline for the entire period; red dotted line indicates development in the past two decades (1999–2019).

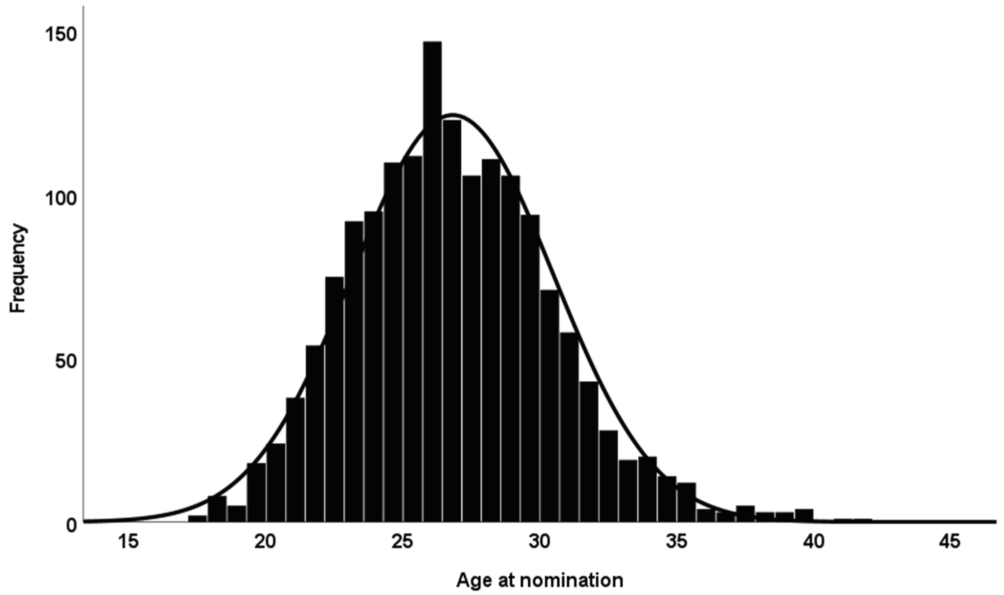

FIGURE 3 | Frequency of nominations at different ages for retired players' last nominations.

The average age at a player's first nomination for major individual awards was 25.7 years. For this variable as well, there were notable differences across playing positions. Forwards and midfielders were youngest when first nominated, at just above 25 years; defenders were closer to 27 years, whereas goalkeepers were oldest by some margin, receiving their first-ever nomination on average at 28 years of age.

It could be argued that the average age at player's first nomination indicates how long it takes to consistently perform among the very best in the game. This would occur some 7–8 years after entering that level for outfield players, and one extra year for goalkeepers. This first peak age is similar to those estimated by Dendir (2016) and Kalén et al. (2019), and it seems to correspond well with findings in top-performing groups from different walks of life, which formed the basis for the 10-year rule for developing expertise within a domain (Ericsson and Lehmann, 1996). In two oft-cited studies, Simonton (1991a) showed that composers of classical music produced their first successful composition some 9 years after composing their first piece of music. Similarly, scientists produced their best work some 10 years after they produced their first work (Simonton, 1991b). Of course, scientists' and composers' careers are not directly comparable to soccer players', whose careers are much shorter. However, the trend is compelling and has since been replicated for many other domains (see Ericsson and Lehmann, 1996).

The average age at nomination for players in our total sample (thus their average age at peak performance) is slightly below peak ages in other team-ball sports. The age at peak performance of athletes in field hockey, basketball, water polo, volleyball,

TABLE 2 | Age at nominations across playing positions for retired players.

Position	*n* (% of total)	Average age[1]	First nomination	Last nomination
		Mean (SD)	Mean (SD)	Mean (SD)
Goalkeepers	60 (8.8)	30.28 (3.99)	28.57 (3.46)	31.03 (4.29)
Defenders	113 (16.5)	27.65 (3.41)	26.71 (3.26)	28.41 (3.33)
Midfielders	223 (32.6)	26.55 (3.43)	25.39 (3.32)	27.65 (3.44)
Forwards	289 (42.2)	26.03 (3.43)	25.13 (3.44)	27.94 (3.64)
Total	685 (100.00)	26.81 (3.68)	25.78 (3.52)	27.91 (3.61)

[1]*All nominations (n = 1609).*

handball, and beach volleyball ranges from 27 to 30.5 years (Longo et al., 2016). These findings are supported by Brander et al. (2014), who reported the peak age of ice hockey players in the NHL to be 28 years (forwards 27.7 and defensemen 28.2). In line with this, Vaci et al. (2019) reported NBA basketball players to peak around 28–29 years of age. In our sample of retired players, the peak age is more similar to those sports, albeit it is in the nether regions of the age span. Also, the variations across playing positions are similar, with defensive players peaking a year or two later than those in attacking positions.

The average age at nomination has increased from 1956 to 2019, the increase being particularly strong in the last decade or so. This finding is similar to that of Kalén et al. (2019), who found that soccer players currently at the highest level are on average older compared to those who played some 25 years ago. In the present sample, the average age of nominated players increased by almost 3 years compared to the early 1960s. In fact, 2 out of the 3 years of increase occurred in the last decade, with the average age at nomination culminating in 2018–2019 at 28.4 years.

In the total sample, the average age at players' last nomination was 28 years, with similar variations across playing positions as described for the total sample. It can be argued that this constitutes the player's last career peak; thus, it indicates the point in time when a player's physical capacity is reduced enough that it is difficult to maintain the highest performance level, even when excelling in other variables such as technical, perceptual, or tactical skills. This inflection point was identified by Vaci et al. (2019) to occur on average at 27–28 years of age for basketball players. Our argument would be supported by the fact that defenders, playing in the position that includes the least and the slowest running, maintain their performance levels on average a year longer. Even more so, goalkeepers, having completely different physical requirements that include limited amounts of running, continue to be nominated on average 3 years longer compared to forwards and midfielders.

As discussed in the introduction of the present paper, calculating the average age of players participating at a certain level (in the present case, those who have been nominated for major individual awards) does not provide information on individual players' peaks. Thus, we cannot establish whether they actually peak at this age. Therefore, in order to examine individual players' actual peaks, the subsample of retired players was consulted.

Among retired players, the average age at nomination was higher. More specifically, it was 27.9 years, varying from 27.3 to 27.5 years, for forwards and midfielders, respectively, 28.6 years for defenders and up to 31 years for goalkeepers. This operationalisation (last-ever nomination) could be argued to be a more accurate measure of a player's age at peak performance, as each player's actual peak was known. In the total sample, however, similarly to Dendir (2016) and Kalén et al. (2019), the average represents players' average age of nomination thus far in their careers.

In fact, we had expected that the average age at nomination would be higher in the subsample of retired players. The fact that the average was similar to that of the total sample indicates that our suggested peak age may be somewhat underestimated. That the average peak age at nomination is similar in a sample of players including many who are still active compared to a sample of retired players suggests that ultimately the peak age will increase in the former sample. Judging by the increase in the average age at nominations for awards over time (depicted in **Figure 2**) of 2 years during the last decade, as well as the 1.6-year increase since 1992–1993 in the average age of players in the Champions League (Kalén et al., 2019), it is not unreasonable to speculate that the age of peak individual soccer performance for players at the highest possible level lies closer to 29 years and that players may, on average, continue to be nominated for best player awards long after they have turned 30, especially when they play in defensive positions. Thus, defenders may continue to perform at their highest levels well into their 30s, and goalkeepers, with their special and less physically demanding skillset, may sustain careers at the top level up to 40 years of age. The latter assumption is supported by the fact that goalkeepers in the present sample had their first peak at age 28 and their last when they were over 30 years old, which is within the overall trend of increasing age.

The age at peak soccer performance for an individual player would then occur some 10 years after the age at which they entered the top level, which for most players is just under 20. Thus, the 10-year rule (Ericsson and Lehmann, 1996) holds even for top-level soccer players. Their decline, however, is rather steep compared with those of experts within other domains, as soccer players on average experience their last peak a year or so after their average peak and only 2–3 years after their first peak, indicating a biphasic career trajectory. This would be due to physical decline (see Guillaume et al., 2011 and Berthelot et al., 2012) that can no longer be compensated for by superior skills. However, players' careers may last much longer, and even after they stop being nominated for awards, players continue to play at the highest level for several years.

When individual athletes win world championships or Olympic medals, it is recognised as a clear career peak (Allen and Hopkins, 2015; Longo et al., 2016), indicating an athlete's peak age in that sport. We would argue that being nominated for major individual awards constitutes a similar achievement among soccer players as well as, probably, athletes in other team sports, indicating that age at nomination for awards is a good proxy for peak performance of individual players.

WhoScored ratings, for reasons mentioned earlier, cannot be used for comparisons of individual players' performances across different performance levels. Still, if the goal is to distinguish between performances at the absolute top level, it would be reasonable to compare across the top five leagues. Out of 427 nominations for player of the year since 2005, only 16 (Ballon d'Or, 2020) were for players outside the Big Five.

As suggested above, soccer may value and emphasise attacking players over defenders. This might be due to the narrative of TV productions focusing mainly on goal scorers (Anderson et al., 2020). Although popularity and public voting has been included to a certain extent in the criteria for the awards, performance as judged by soccer experts has always been the main evaluation criterion. Furthermore, popularity and performance might be quite entangled. Yucesoy and Barabási (2016) showed, for example, how a predictive model comprising data on a tennis player's performance in tournaments can accurately predict the athlete's popularity, and it is argued that in most areas of human achievement, exceptional visibility may be rooted in detectable performance measures.

While nominations have, at least in the most recent years, been somewhat more balanced with respect to playing positions, still, in our total sample, players occupying attacking and midfield positions are overrepresented at around 70% of the nominated players. At the same time, their relative representation on the field, independent of the playing system (e.g., 4-3-3, 4-4-2) was around 55%.

Dendir (2016) found the peak age of soccer players to be from 25 to 27 years of age, depending on playing position, with forwards peaking earliest at 25, defenders last at 27, and midfielders somewhere from 25 to 27, depending on which model was used for calculation. From the work of Dendir (2016), it is reasonable to estimate that the peak age of outfield soccer players lies somewhere around 26 years. Goalkeepers were excluded from sample of Dendir (2016) due to their rather unique skillset, thus calculating a total average for soccer players was not possible. If we exclude goalkeepers from our sample of retired players, individual peak performance is 27.8 years. Thus, the reported peak age of sample of Dendir (2016) was considerably lower than in the present dataset, probably reflecting the fact that it takes somewhat longer to reach the absolute top level compared to having played in the Big Four leagues. Also, Kalén et al. (2019) reported an average peak age of 25.8 years for players in the Champions League, considerably lower than that of the present sample.

The age distribution in sample of players of Dendir (2016), hence the average age of players who had played a minimum of three games in one of the top four European leagues, was normal around the average of 26–27 years (indicating a bimodal career trend), as was the case for the average age at peak minutes played. However, the picture was more complex for the WhoScored ratings. Especially with defenders, these ratings were unrelated to the former two variables, and for forwards an additional peak was evident at around 37 years.

Kalén et al. (2019) reported an average age for players in the UEFA Champions League (more specifically, players who were members of squads on participating teams) of 26.5 years. Furthermore, they reported an increase of 1.6 years in the average age from the 1992 to 1993 season.

Our finding of differences in age at peak performance for different playing positions (similar to both Dendir, 2016 and Kalén et al., 2019) seems to be related to physical and technical requirements for the various playing positions. Also similar to the present results, Kalén et al. (2019) concluded that goalkeepers and centre backs peak later and may maintain their peak performance until about 31 years of age. Fitness profiling in soccer identifies attackers as the quickest players (Sporis et al., 2009). Specialised sprinters peak at 25–26 years of age (Haugen et al., 2018), and it seems that soccer players' sprint times can be maintained until 28 years of age (Haugen et al., 2020). The average age at nomination for forwards in our total sample was 26 years, coinciding with peak sprint times, and it was similarly around 26.5 years for midfielders. Also, the decline in sprint performance is rather coincident with age at last nomination in awards for midfielders and forwards. It should be kept in mind, however, that the possible underestimation of peak age indicates that while sprint times are important, many additional variables contribute to the mix that is soccer performance, not the least of which are ball and tactical skills (Sal de Rellán-Guerra et al., 2019); thus, players may continue to be nominated well after their peaks. The oldest nominated forward of all time was Stanley Matthews at 42 years in 1956. More recently, Zlatan Ibrahimović was nominated for the FIFA Best Player award at the age of 35.6 years in 2017 (and still, in 2020, he continues to score goals in the Italian Serie A).

As discussed in the introduction, endurance performance in specialised endurance athletes generally peaks later as the duration of the race increases, up to the late 30s in races of long duration (Longo et al., 2016). This also seems to be the age Botek et al. (2016) recognised as the inflection point of endurance performance, while Tønnessen et al. (2013) reported 18-year-old players to have higher maximal oxygen uptake than older players. Results regarding peak endurance capacity are somewhat equivocal, and as for sprint capacity, it seems that endurance sufficient to elicit nomination for player of the year awards can be maintained at a late age. Midfielders generally have the highest maximal oxygen uptake among players in all positions (Sporis et al., 2009; Tønnessen et al., 2013), and from our data, we identified an average age of peak performance for the total sample of midfielders to be 26.46 (27.53 for retired last nomination). Our estimated ages at peak performance relative to age variations in endurance capacity seem to reflect the findings on sprint performance, and they indicate that a decrease in endurance can be compensated for by improved performance regarding technical and tactical skills (Sal de Rellán-Guerra et al., 2019). The midfielder Lothar Matthäus was nominated for Ballon d'Or in 1999 at the age of 37.8 years, being to date the oldest nominated midfielder.

In summary, the age at last nomination in our sample of retired players corresponds well with peak sprint performance among both specialised athletes and soccer players, while for endurance, the literature on peak performance is equivocal. However, the age range of nominated players supports the findings of Sal de Rellán-Guerra et al. (2019) and Wilson et al. (2017) that although players may be past their peaks as to several physiological attributes, soccer performance can be maintained at a high level by compensating with other non-physiological skills that are less subject to decline after the age of 25.

We must again remind the reader that the results are based on data for the proxy *nomination for major international individual awards* and that these do not directly measure performance. Thus, we cannot directly establish age of peak performance. However, as we have argued, no other variable can directly measure individual soccer performance on an overall level. Furthermore, the results cannot necessarily be generalised to populations other than the absolute top players comprising the present sample.

We would argue that compared with proxies used in previous studies, our proxy is most similar to those most often used in studies on age of peak performance in individual sports, namely the age when winning world championships or Olympic medals. This would make ours a good proxy, and our average age a decent estimate of the age at peak individual soccer performance. Furthermore, and perhaps more importantly, our proxy, as well as other proxies, may be used to validate the myriad of variables measured in studies of soccer skills to enable comparisons or predictions of individual soccer performance.

In fact, we would argue that our approach using proxies to unearth information about hidden features of otherwise immeasurable complex performance, depending on a host of variables acting in concert, is viable. Furthermore, we would argue that such proxies may be used for validating single variables or combinations of limited numbers of variables that are touted as being explanatory of complex behavior.

CONCLUSION

Age at peak individual performance, when estimated based on our proxy, is higher compared with previous studies, which can partially be accounted for by differences between the various proxies and their operationalisations. As in previous studies, average age at peak performance varied considerably across the different operationalisations, thus supporting the notion that players have rather distinct skillsets across playing positions. Furthermore, the age is higher than peak ages for the many physiological variables that contribute to soccer performance, indicating that soccer skills are more important than physique. Players in defensive positions, goalkeepers in particular, were nominated for awards at more advanced ages compared with players in attacking positions.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

GO and AVP conceived the idea, and all three co-authors designed the study. GO collected the data together with AVP and analysed them together with HL. GO wrote the first draft of the manuscript. All three co-authors contributed substantially to the final version of the manuscript and approved it for publication.

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State Transition Modeling in Ultimate Frisbee: Adaptation of a Promising Method for Performance Analysis in Invasion Sports

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Although the body of literature in sport science is growing rapidly, certain sports have yet to benefit from this increased interest by the scientific community. One such sport is Ultimate Frisbee, officially known as Ultimate. Thus, the goal of this study was to describe the nature of the sport by identifying differences between winning and losing teams in elite-level competition. To do so, a customized observational system and a state transition model were developed and applied to 14 games from the 2017 American Ultimate Disc League season. The results reveal that, on average, 262.2 passes were completed by a team per game and 5.5 passes per possession. More than two-thirds of these passes were played from the mid zone (39.4 ± 6.57%) and the rear zone (35.2 ± 5.09%), nearest the team's own end zone. Winning and losing teams do not differ in these general patterns, but winning teams played significantly fewer backward passes from the front zone to the mid zone, nearest the opponent's end zone than losing teams (mean difference of −4.73%, $t_{(13)} = -4.980$, $p < 0.001$, $d = -1.16$). Furthermore, losing teams scored fewer points when they started on defense, called breakpoints (mean difference of −5.57, $t_{(13)} = -6.365$, $p < 0.001$, $d = 2.30$), and committed significantly more turnovers per game (mean difference of 5.64, $t_{(13)} = 5.85$, $p < 0.001$, $d = -1.18$). Overall, this study provides the first empirical description of Ultimate and identifies relevant performance indicators to discriminate between winning and losing teams. We hope this article sheds light on the unique, but so far overlooked sport of Ultimate, and offers performance analysts the basis for future studies using state transition modeling in Ultimate as well as other invasion sports.

Keywords: Ultimate, Ultimate Frisbee, disc sports, performance analysis, performance indicators, state transition modeling

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INTRODUCTION

Despite the growing interest in sport science, as seen by the increasing number of articles and journals on the topic over the past couple of decades (Lago, 2009), some lesser-known sports have been neglected. This could be due in part to the pressure felt by some researchers to publish only in top-tier journals where a sport's popularity could promise greater acclaim. One such sport is

Ultimate Frisbee, officially known as Ultimate, a fast-paced, limited contact invasion game played in teams and with a flying disc made of plastic. In a keyword search of "ultimate frisbee" on PubMed and Web of Science, the search results show that less than 20 articles have been published between 2005 and 2020. This is rather surprising, given the sport is played in 85 countries worldwide (World Flying Disc Federation, 2019) and has more than 2,000,000 participants in the United States alone (Sports and Fitness Industry Association, 2020).

So far, the few scientific articles about Ultimate have not focused on performance analysis. Thornton (2004) was one of the first to examine Ultimate as a "lifestyle" sport by exploring the sporting values that differentiate it from other more traditional sports. Subsequently, several more studies were published on the sociocultural aspects of the sport, including the sporting landscape (Griggs, 2009), player norms and practices (Robbins, 2004), and even sport-related drinking behavior (Crocket, 2016). In addition, despite some studies on the physical (Krustrup and Mohr, 2015; Madueno et al., 2017; Palmer et al., 2020) and physiological (Scanlan et al., 2015) demands of the sport, little attention has been given to performance analysis, yet its importance in sports is well-established (O'Donoghue, 2010; Maslovat and Franks, 2019).

Although biomechanical indicators are equally relevant for performance analysis in game sports, the interaction between two opposing teams requires the consideration of other indicators (Lames, 2006; Lames and McGarry, 2007; Garganta, 2009; Korte and Lames, 2018). This interactive behavior is described as a dynamic process, as the actions of either party are subject to change at any time during the match (Lames and McGarry, 2007). Thus, to understand and explain the specific behaviors in game sports, performance analysts must apply techniques that are able to represent or simulate this interaction. One such technique is state transition modeling. A state transition model is a level of modeling that requires not only some input, such as historical performance data, but also some knowledge of the sport's internal functioning to generate some output, such as future performance (Lames, 2020). This internal functioning is described by a sequence of states, which can be further categorized as starting states, transient states, and absorbing states (Wenninger and Lames, 2016). More importantly, these states must reflect a strictly defined game characteristic, because it is the transitions between these states that provide information about tactical behaviors (Pfeiffer et al., 2010). For example, Pfeiffer et al. (2010) applied state transition modeling to the tactical analysis of stroke techniques in table tennis and found that different strokes contribute to scoring rate, not through winners but by forcing more errors from the opponent. Wenninger and Lames (2016) present an example from table tennis where they derived scoring probabilities as a function of rally length using a customized state transition model. Although there have been reports of such models in invasion games (Hirotsu and Wright, 2003; Forbes and Clarke, 2006), where researchers were able to identify sufficient and appropriate states, none have attempted to apply the model as a spatial representation of the playing field.

The aim of this article is thus twofold. This will be the first study to provide empirical insights into the nature of the sport of Ultimate. In more detail, this study will investigate passing patterns and the spatial structure of possessions. To this end, our second aim was to adapt the existing method of state transition modeling to better suit Ultimate and other invasion sports. We sought to demonstrate the merit of including proper spatial representation of the playing field into state transition models for such sports. Overall, we hope this study will generate further interest in Ultimate within the sports science community, as this sport has been neglected so far.

MATERIALS AND METHODS

Data Collection

Sample

The sample entities consisted of 14 games from the 2017 American Ultimate Disc League (AUDL) season (**Table 1**). The AUDL is a men's semiprofessional Ultimate league and is only one of several elite-level competitions based out of North America. The sport is also played at the international level and is governed by the World Flying Disc Federation. Ten different teams across the four divisions (East, West, Midwest, and South) and games from both the regular season (weeks 1–17) and the postseason (Championship Weekend) were included. Regular season games were played in various cities across the United States and Canada, but all games from the 2017 Championship Weekend were hosted in Montreal, Canada (home and away team assignments in **Table 1** are arbitrary in the postseason). All post-game analyses were performed by a qualified investigator with more than 10 years of elite-level Ultimate experience, using video footage of the games which was made publicly available by AUDL and accessed from YouTube (American Ultimate Disc League, 2017).

Observational System

To investigate the nature of Ultimate, we chose a multimethod approach combining a series of complementary methods (Anguera et al., 2018). An observational system was designed to systematically annotate the states and state transitions from the state transition model to further analyze performance indicators in Ultimate. The observational system was created in Microsoft Excel (v16.16.23), and the same system was used for all 14 games. Each datasheet contained game identification information, timestamps for every pull, and the state transition model annotations for every possession during the game. These annotations include spatial information about each pass and the result of each possession. In case readers are unfamiliar with Ultimate, the remainder of this paragraph gives a brief introduction to the structure and rules of the sport. The objective of the game is similar to other invasion sports—to score more points than the opposing team while conceding fewer by passing the disc between teammates until it is caught inside the opponent's end zone. Players are not permitted to run with the disc and can only hold the disc for a limited number of seconds called "stalls." In the AUDL, players can hold the disc for seven stalls (American Ultimate Disc League, 2019). Each point begins with seven players from each team lined up horizontally in front

TABLE 1 | Sample entities from the 2017 AUDL season.

Week	Division	Home team	Away team
1	West	San Francisco FlameThrowers	San Jose Spiders
2	East	New York Empire	Toronto Rush
2	West	San Jose Spiders	San Francisco FlameThrowers
2	East	DC Breeze	Toronto Rush
4	West	San Francisco FlameThrowers	San Diego Growlers
7	West	San Francisco FlameThrowers	Seattle Cascades
8	West	San Francisco FlameThrowers	Vancouver Riptide
11	East	DC Breeze	Toronto Rush
16	West	San Francisco FlameThrowers	Seattle Cascades
17	East	Toronto Rush	New York Empire
Division Finals	East	Toronto Rush	DC Breeze
Semifinals	West/Midwest	San Francisco FlameThrowers	Madison Radicals
Semifinals	East/South	Toronto Rush	Dallas Roughnecks
Championship	East/West	Toronto Rush	San Francisco FlameThrowers

of their respective end zones. The game is divided into two halves; for the first point of each half, the teams are assigned to either offense or defense. In the AUDL, gameplay is further subdivided into quarters lasting 12 min each (American Ultimate Disc League, 2019). For all subsequent points, the team that scored the previous point starts the next point on defense. The team that starts on defense initiates the point by throwing the disc across the field to the team on offense; this is known as a "pull." Given that a team always starts on defense after scoring a point, in theory, the rules of Ultimate allow each team equal opportunity to score, as the team that was scored on will start the next point with possession of the disc. As a result, the offensive team's goal is to maintain possession of the disc and score a point. It is the defensive team's goal to steal possession of the disc by forcing a turnover with an interception or by an error of the opponent.

Data Processing

General Performance Indicators

From the observational system, nine performance indicators were identified (**Table 2**). These performance indicators address general match indicators, as well as technical and tactical behaviors in Ultimate. The general match indicators include points scored per game (PPG), breakpoints scored per game (BPG), and possession opportunity (PO%). Breakpoints are points that were scored by the team who pulled the disc. PO% refers to the number of times a team receives the pull and starts with possession of the disc. The technical indicators include total turnovers per game (TTPG), unforced turnovers per game (UTPG), and forced turnovers per game (FTPG). The tactical indicators include completed passes per game (CPG), average number of passes per possession (PPP), and turnover-to-point conversion efficiency (TTPCE%). TTPCE% represents a team's ability to score during the subsequent possession after a turnover is committed by the opponent.

State Transition Modeling

The concept of state transition modeling was adapted for the analysis of tactical passing behavior in Ultimate. This state transition model, illustrated in **Figure 1**, describes disc possession in Ultimate as a sequence of states characterized

TABLE 2 | Identified performance indicators.

Points scored per game (PPG)	A point is scored when a player on the offensive team catches the disc inside the opponent's end zone
Break points scored per game (BPG)	A break point refers to a point scored by the team who pulled the disc (i.e., started the point on defense)
Completed passes per game (CPG)	A completed pass is a successful exchange of disc possession between players of the same team. A successful exchange refers to full control of the disc (i.e., no fumbling)
Average number of passes per possession (PPP)	A possession is an uninterrupted period where a team maintains control of the disc through a sequence of completed passes
Total turnovers per game (TPG)	A turnover is a loss of disc possession.
Unforced turnovers per game (UTPG)	An unforced turnover is the loss of disc possession due to an error (e.g., disc is dropped, disc is thrown out of bounds)
Forced turnovers per game (FTPG)	A forced turnover is the loss of disc possession due to active defensive effort (e.g., interception, double team)
Turnover-to-point conversion efficiency (TTPCE%)	The turnover-to-point conversion efficiency is a team's ability to score immediately after a turnover by the opponent. The number of points scored after a turnover is divided by the total number of turnovers by the opponent, expressed as a percentage
Possession opportunity (PO%)	The possession opportunity is the number of times a team starts with the disc (i.e., the opponent pulls) divided by the total number of possessions in the game, expressed as a percentage

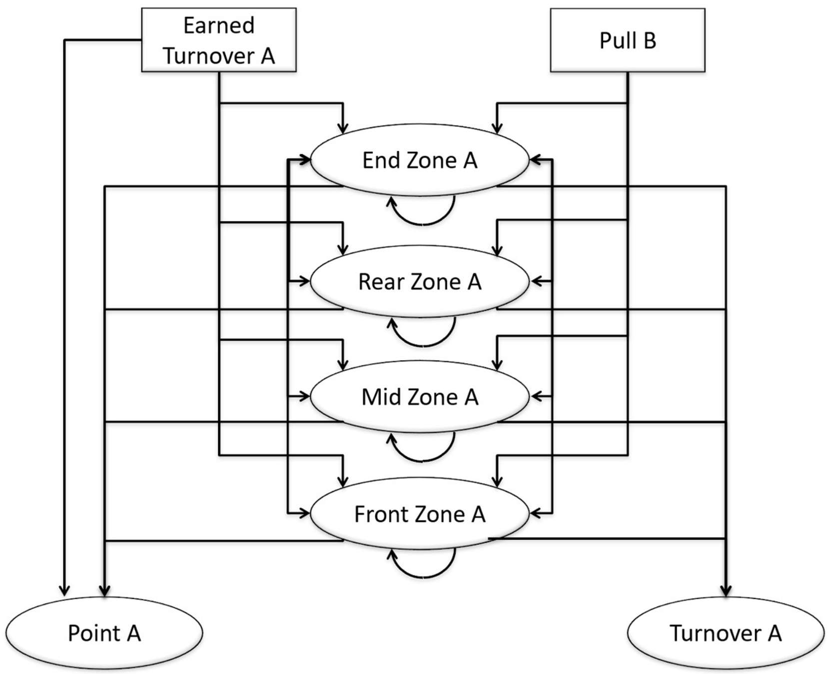

FIGURE 1 | State transition model for analysis of tactical behavior in Ultimate. Labels correspond to initial disc possession by Team A. The same model can be used for initial disc possession by Team B by switching the labels from B→A, A→B.

by field location. By including spatial representation of the playing field within the state transition model, we were able to properly apply the observational methodology and interpret the findings with consideration for game context (Barreira et al., 2020). The starting state in this model refers to any event that initiates a new possession, either a pull or an earned turnover. A turnover is earned when the opposing team commits a turnover, either forced or unforced, and play continues from where the turnover occurred. The playing field is divided into zones, which reflect the four discrete transient states (**Figure 2**); because the sample entities are taken from the AUDL, where games are often played on American football fields, the zones are defined using the yard lines: end zone (behind the 10-yard line), rear zone (between the 10- and 35-yard lines nearest the offensive team's end zone), mid zone (between the two 35-yard lines), and front zone (between the 35- and 10-yard lines nearest the defensive team's end zone). It is worth noting that the names of the transient states (zones) change depending on which team has possession of the disc, as the playing direction changes when disc possession changes (American Ultimate Disc League, 2019). The absorbing state is any event that terminates a possession, either a point or a turnover. In this context, all state transitions (except the pull transitions) occur every time the disc is passed.

Transitions between states can occur within the same zone, between adjacent zones, and across zones; however, transitions are impossible between pulls and points, pulls and turnovers, and earned turnovers and turnovers (**Figure 3**). In rare instances, it is

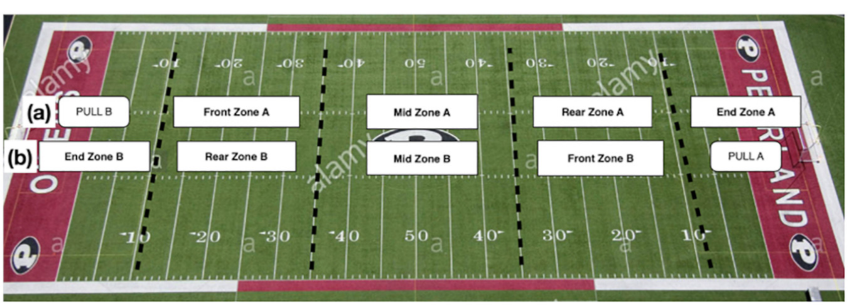

FIGURE 2 | Transient states in the state transition model for Ultimate. **(a)** When Team B pulls and Team A starts with possession of the disc. **(b)** When Team A pulls and Team B starts with the disc.

	End Zone A	Rear Zone A	Mid Zone A	Front Zone A	End Zone B	Rear Zone B	Mid Zone B	Front Zone B	Turnover A	Turnover B	Point A	Point B
Pull B	x	x	x	x								
Earned Turnover A	x	x	x	x							x	
End Zone A	x	x	x	x					x		x	
Rear Zone A	x	x	x	x					x		x	
Mid Zone A	x	x	x	x					x		x	
Front Zone A	x	x	x	x					x		x	
Pull A					x	x	x	x				
Earned Turnover B					x	x	x	x				x
End Zone B					x	x	x	x		x		x
Rear Zone B					x	x	x	x		x		x
Mid Zone B					x	x	x	x		x		x
Front Zone B					x	x	x	x		x		x

FIGURE 3 | State transition matrix for all the possible transition probabilities (x) between the starting states, transient states, and absorbing states.

possible in Ultimate to score directly from a turnover (transition between earned turnover and point)—this is called a "Callahan" and occurs when an interception is caught inside the defender's own end zone (American Ultimate Disc League, 2019). These transition probabilities are thus a function of the location on the field where the disc is held before being thrown. The turnover transitions represent where (i.e., in which zone) the turnover occurred. The earned turnover transitions indicate where a new possession begins. Similarly, the pull transitions refer to where the disc was caught or picked up by the receiving team.

Reliability

Whereas some of the states are objective, for example, if a point was scored, others are more subjective, such as the exact position (zone) where a pass was caught or thrown and whether a turnover was forced or unforced. For this reason, a second experienced investigator annotated half of one game from our sample, consisting of 371 observations, and we were thus able to measure inter-rater reliability. Cohen's kappa was calculated for all states, specifically for the classification of turnovers, and showed an agreement of 0.857 and 0.877. According to Landis and Koch (1977), these values demonstrate almost perfect inter-rater agreement.

Data Analysis

Descriptive statistics were calculated for all nine performance indicators (PPG, BPG, CPG, PPP, TTPG, UTPG, FTPG, TTPCE%, and PO%) from the observational system. The state transition model annotations generated 30 different state transition probabilities. These state transitions can be classified as four pull probabilities (end, rear, mid, and front zones), four earned turnover probabilities (end, rear, mid, and front zones), six passing probabilities (end to rear, rear to mid, mid to front, front to mid, mid to rear, and rear to end), eight turnover probabilities (end, rear, mid, and front zones for forced and unforced turnovers), and four scoring probabilities (end, rear, mid, and front zones). The passing probabilities were also used to report the distribution of attempted passes thrown from each of the four zones (end, rear, mid, and front zones). As such, the state transition probabilities provide meaningful performance indicators, for example, the quality and tactical efficiency of pulls, passes, and points.

Descriptive statistics are provided as means and standard deviations, as well as medians and interquartile ranges, as some variables did not show a normal distribution according to a Shapiro–Wilk test. A comparison was made between winners (n = 14) and losers (n = 14). For the normally distributed variables, paired sample t-tests were used. For variables where the assumption of a normal distribution was violated, we used its nonparametric counterpart, the Wilcoxon signed-rank test for paired samples. Cohen's d effect sizes were considered trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (>0.80) (Cohen, 1992). Statistical significance was set at $p < 0.05$ (two-tailed). All statistical analyses were performed using SPSS (v27.0.1.0). The plots were created in R (v4.0.2), utilizing the following packages *via* RStudio (v1.3.1056): ggplot2 (v3.2.2), gggap (v1.0.1), and ggpattern (v0.1.3).

RESULTS

Means and standard deviations of the nine performance indicators for all teams, winning teams, and losing teams are presented in **Figure 4**. Having an equal PO% of 50.00 ± 0.75%, teams scored an average of 24.64 ± 5.27 PPG. On average, teams recorded 262.25 ± 42.14 CPG and 5.50 ± 1.13 PPP. As for the average number of turnovers per game, teams committed 22.96 ± 5.49 TTPG, of which 12.11 ± 4.04 were UTPG and 10.86 ± 3.61 were FTPG. Teams converted an average of 48.11 ± 11.45% of their earned TTPCE%, resulting in 6.64 ± 3.70 BPG.

In the comparison between winning and losing teams, paired sample t-tests revealed significant differences in PPG (M = 5.43; SD = 3.65; $t_{(13)}$ = 5.561; p < 0.001; d = 1.19), BPG (M = 5.57; SD = 3.28; $t_{(13)}$ = 6.365; p < 0.001; d = 2.30), TTPG (M = −5.64; SD = 3.61; $t_{(13)}$ = −5.852; p < 0.001; d = −1.18), UTPG (M = −2.93; SD = 4.65; $t_{(13)}$ = −2.357; p = 0.035; d = −0.77), and FTPG (M = −2.71; SD = 3.95; $t_{(13)}$ = −2.571; p = 0.023; d = −0.80). Although the paired sample t-test did not report a significant difference in TTPCE% (M = 6.09%; SD = 12.44%; $t_{(13)}$ = 1.832; p = 0.090), a medium effect size was reported (d = 0.54). No significant difference was reported in PO% (M = 0.34%; SD = 1.49%; $t_{(13)}$ = 0.858; p = 0.406), and only a small effect size was observed (d = 0.46). The Wilcoxon signed-rank test did not reveal a significant difference in CPG (Z = −0.251; p = 0.802), and the effect size was trivial (d = −0.06).

Figure 5 summarizes the means and standard deviations of the forced and unforced turnover transition probabilities for all teams, winning teams, and losing teams. On average, forced turnovers were committed most frequently in the mid zone (4.09 ± 1.99%) and end zone (4.04 ± 5.14%), followed by the front zone (3.72 ± 2.49%) and rear zone (3.66 ± 2.18%). Unforced turnovers were committed most frequently in the front zone (5.63 ± 3.76%) and mid zone (4.68 ± 2.41%), followed by the end zone (4.02 ± 5.83%) and rear zone (3.58 ± 2.13%). When comparing winners and losers, the Wilcoxon signed-rank test reported a significant difference in forced turnovers in the mid zone (Z = −2.794; p = 0.005; d = −0.92). Although the paired sample t-test did not reveal a significant difference in unforced turnovers in the mid zone (M = −1.81%; SD = 3.30%; $t_{(13)}$ = −2.045; p = 0.062), there was a medium effect size (d = −0.79). The means and standard deviations of the earned turnover transition probabilities are illustrated in **Figure 6** for all teams, winning teams, and losing teams. On average, turnovers were earned most frequently in the end zone (33.11 ± 14.94%), followed by the rear zone (27.15 ± 9.83%) and mid zone (26.49 ± 9.75%) and finally the front zone (13.12 ± 8.57%). Between winning and losing teams, the paired sample t-test revealed a significant difference in earned turnovers in the rear zone (M = −7.29%; SD = 11.35%; $t_{(13)}$ = −2.403; p = 0.032; d = −0.79).

The means and standard deviations of the pull transition probabilities for all teams, winning teams, and losing teams are shown in **Figure 7**. On average, pulls were caught or landed most frequently in the rear zone (63.75 ± 19.25%), followed by the end zone (26.57 ± 21.71%), mid zone (9.39 ± 9.31%), and front zone (0.36 ± 1.34%). There were no significant differences in any of the pull probabilities between winners and losers,

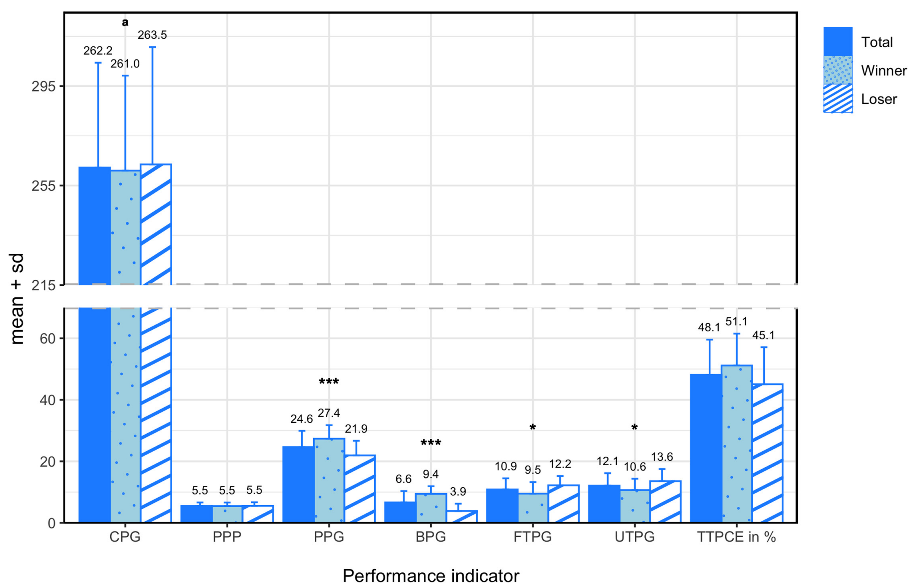

FIGURE 4 | Means and standard deviations of all performance indicators for all teams, winning teams, and losing teams. * denotes a significant difference between winning and losing teams at a significance level of 0.05 and *** at a significance level of 0.001. Variables compared using a non-parametric test are marked with an [a].

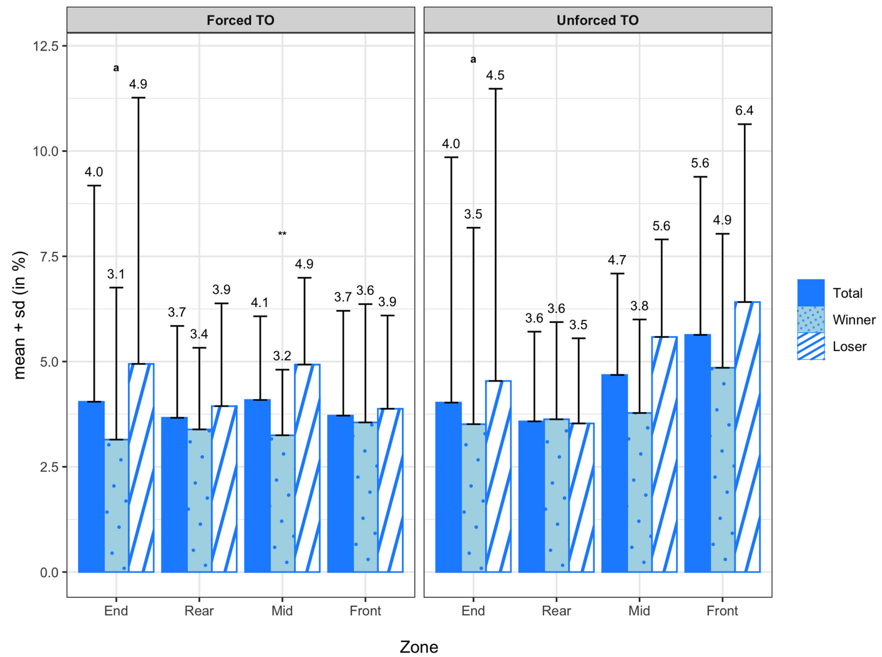

FIGURE 5 | Transition probabilities of forced (4a) and unforced (4b) turnovers by zone for all teams, winning teams, and losing teams. ** denotes a significant difference between winning and losing teams at a significance level of 0.01. Variables compared using a non-parametric test are marked with an [a].

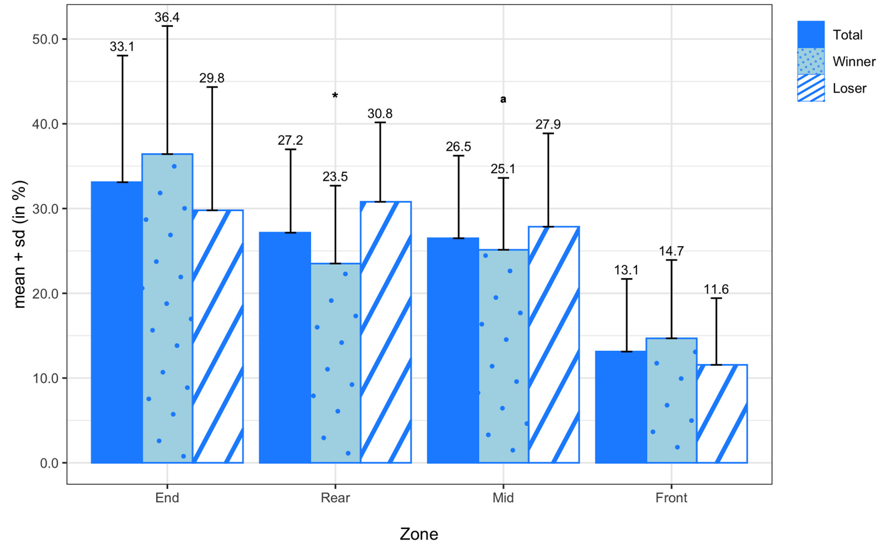

FIGURE 6 | Transition probabilities of earned turnovers by zone for all teams, winning teams, and losing teams. * denotes a significant difference between winning and losing teams at a significance level of 0.05. Variables compared using a non-parametric test are marked with an [a].

but there was a medium effect size in pulls in the end zone (d = 0.51). In **Figure 8**, the means and standard deviations of the scoring transition probabilities are reported for all teams, winning teams, and losing teams. On average, points were scored most frequently from the front zone (33.20 ± 7.91%), followed by the mid zone (7.04 ± 3.51%) and rear zone (1.64 ± 1.57%), and finally the end zone (0.00 ± 0.00%). Although the paired sample t-test did not reveal a significant difference in scoring from the mid zone (M = 2.74%; SD = 4.78%; $t_{(13)}$ = 2.143; p = 0.052) between winning and losing teams, there was a large effect size (d = 0.83).

Figure 9 displays the means and standard deviations of the attempted passing probabilities for all teams, winning teams, and losing teams. On average, attempted passes were most frequently

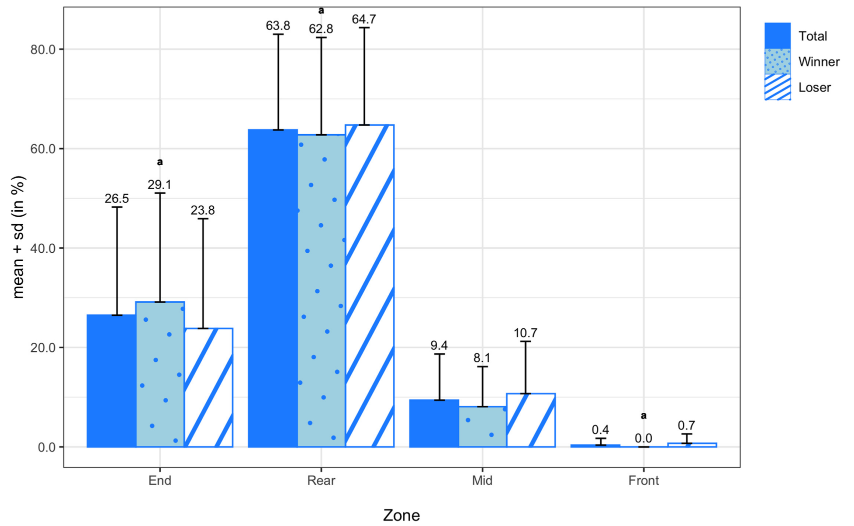

FIGURE 7 | Transition probabilities of pulls by zone for all teams, winning teams, and losing teams. Variables compared using a non-parametric test are marked with an [a].

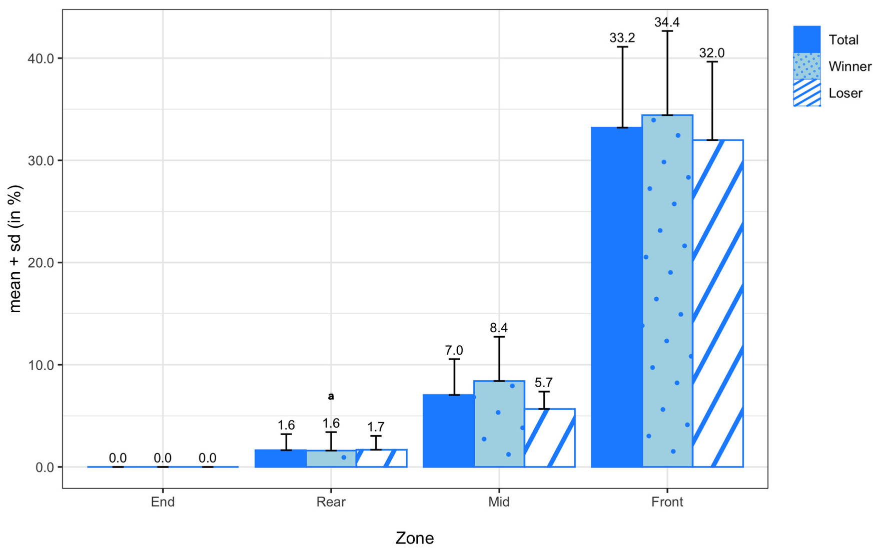

FIGURE 8 | Transition probabilities of points scored by zone for all teams, winning teams, and losing teams. Variables compared using a non-parametric test are marked with an [a].

thrown from the mid zone (39.44 ± 6.57%) and rear zone (35.17 ± 5.09%), followed by the front zone (17.40 ± 5.47%) and end zone (7.99 ± 3.47%). There were no significant differences in any of the attempted passing probabilities between winners and losers, but there was a medium effect size in attempted passes from the front zone ($d = 0.70$). In **Figure 10**, the means and standard deviations of the passing probabilities between adjacent zones are depicted for all teams, winning teams, and losing teams. In the comparison between winning and losing teams, the paired sample t-test revealed a significant difference in backward passing from the front zone to the mid zone ($M = -4.73\%$; $SD = 3.55\%$; $t_{(13)} = -4.980$; $p < 0.001$; $d = -1.16$).

DISCUSSION

This is the first study on tactical performance analysis in Ultimate. Thus, the findings from this article only begin to reveal the unique nature of the sport and the variables that contribute to the strengths and weaknesses observed in elite Ultimate competition.

PO% was included in the analysis but not considered a true performance indicator in Ultimate, as we were able to confirm that the rules of Ultimate enable equal opportunity to disc possession for both teams. The mean difference in PO% between winners and losers was less than 0.4%

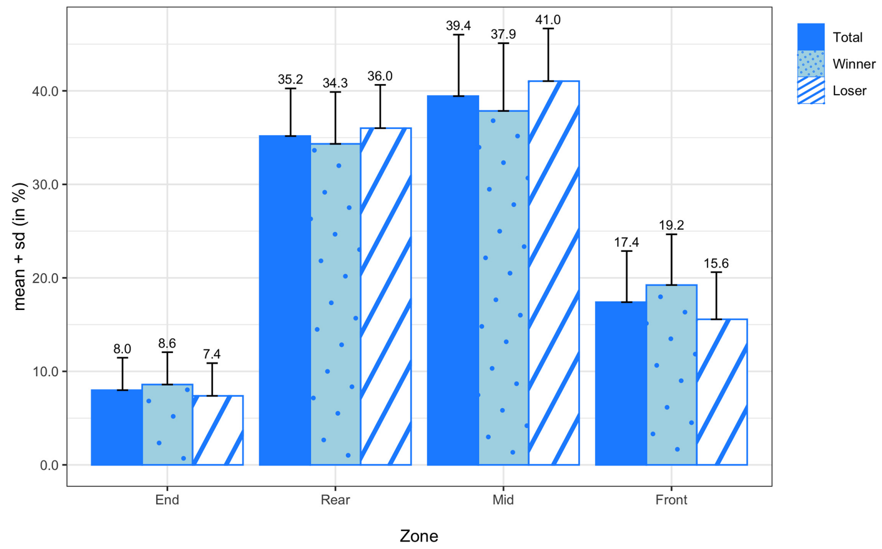

FIGURE 9 | Transition probabilities of attempted passes by zone for all teams, winning teams, and losing teams.

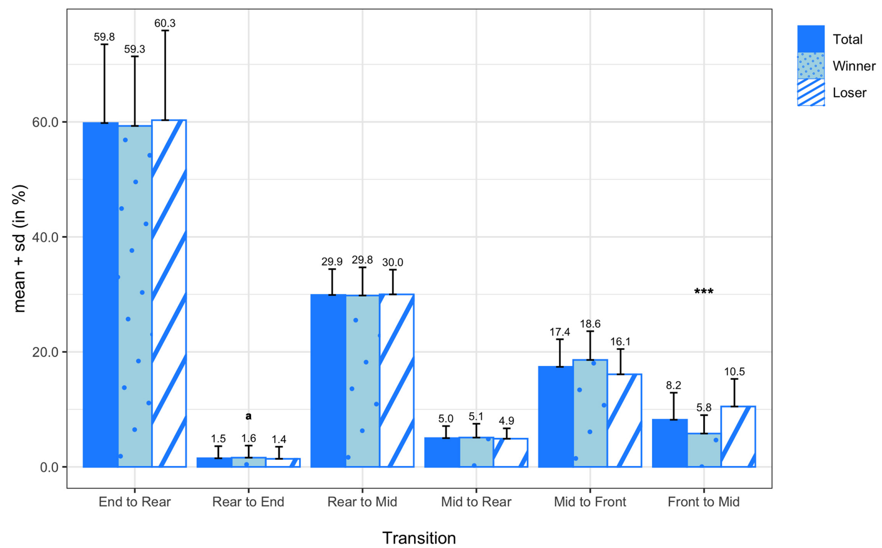

FIGURE 10 | Transition probabilities of passing between adjacent zones for all teams, winning teams, and losing teams. *** denotes a significant difference between winning and losing teams at a significance level of 0.001. Variables compared using a non-parametric test are marked with an [a].

and not statistically significant. Regarding the performance indicators, we found that PPG and BPG were significantly different between winners and losers, and large effects were observed for both. These indicators have been classified in previous work as general match indicators, which are those that provide basic information about performance (Hughes and Bartlett, 2002). This information is considered basic because the score is an inherent indicator of performance—for a team to win, it is a result of the game's structure that more points must be scored. Breakpoints in Ultimate are akin to breaking serve in tennis, where a player is more likely to win their own service games, thus treating breakpoints (the point before breaking serve) as the most important points in the game (O'Donoghue and Liddle, 1998). In Ultimate, the team that receives the pull and starts on offense is essentially playing their own service game. So, when the team who throws the pull and starts on defense is the team to score, it could suggest that they are beating the odds and increasing their overall likelihood of winning the game. Similar to other game sports, the number of BPG cannot solely be attributed to the team who scores them, but also to their opponent, as their behavior influences the dynamic interactions that occur in Ultimate (Lames and McGarry, 2007).

Winners committed significantly fewer TTPG, UTPG, and FTPG than losers. In rugby union, a significant association between turnovers and winning/losing performance has already been reported (Bremner et al., 2013). This is a reasonable association, considering turnovers result in a loss of possession and scoring is only possible when a team is in possession. Given that all three of these technical indicators showed statistical significance, it can be said that winners in Ultimate were maintaining disc possession by both making fewer mistakes (UTPG) and by counteracting the defensive actions of their opponents (FTPG). In soccer, turnovers have been recognized as indicators of technical weaknesses (Hughes and Bartlett, 2002; Korte and Lames, 2018). In the present study, UTPG is defined as a loss of possession due to an error. The cause of these errors was not scrutinized in this study, but further analysis of the effectiveness of throwing and catching techniques in Ultimate could be conducted to determine their effect on unforced turnovers. From a psychological perspective, winners could be less susceptible to unforced errors due to characteristics such as mental toughness, as was reported in badminton by Yadav et al. (2007). For FTPG, it could also be the case that winners were not in fact counteracting their opponent's defensive actions, but rather their opponents were simply making fewer attempts at provoking turnovers either due to lack of skill or poor choice of strategy. In any case, the results show that winners had significantly fewer forced turnovers than losers, and the probability of them occurring in the mid zone was statistically significant. Forced turnovers in Ultimate could thus benefit from not only a more in-depth technical analysis but also tactical, such as an analysis of the different types of defensive formations. Although not statistically significant, the state transition model also reported a large effect size in scoring from the mid zone and a medium effect size in unforced errors in the mid zone. These findings could suggest that the mid zone is where critical events in Ultimate occur, although it is worth noting that in the present state transition model, the mid zone is slightly larger than the other zones by 10 to 15 yards; the mid zone covers 30 yards, the rear and front zones cover 25 yards each, and the end zones cover 20 yards each.

As for passing behavior in Ultimate, the results from the state transition model show that winners had a significantly lower probability than losers when passing from the front zone to the mid zone. Passing is one of the most frequent actions in invasion sports, thus also making it one of the most important (Goes et al., 2019). Unlike rugby and American football, players in Ultimate can pass the disc in any direction—forward, backward, or laterally. However, players in Ultimate are not allowed to run with the disc. This unique combination of features from several sports, all played on similarly sized fields, creates an opportunity to understand the nuances that set Ultimate apart as its own invasion sport. Since passing backward is common in rugby, as passing forward is restricted, it would be more interesting to examine backward passing in soccer. Mindek et al. (2018) reported that backward passing occurred more frequently within the first-ranked teams in the English Premier League than the last-ranked teams during an eight-season period. The authors suggest that the first-ranked teams could be using backward passing as a method of maintaining ball possession; this reasoning is supported by the fact that soccer players are often dribbling the ball and must shield it from defenders. This is not applicable in Ultimate, as possession is secure as long as the player does not drop the disc. In this way, greater likelihood of backward passing from the front zone to the mid zone could be indicative of tactical weakness in losing teams, perhaps due to difficulty penetrating the defense. Conversely, less likelihood of backward passing near the opponent's end zone could suggest stronger offensive plays by winning teams.

Reasonably, being the first look at performance analysis in Ultimate, there are certain limitations regarding this work. The first is that the present study focused on games played within the AUDL where the rules differ slightly from other associations (American Ultimate Disc League, 2019). Perhaps most notably, the sport of Ultimate is unique in that it is typically self-officiated (known as Spirit of the Game), but the AUDL uses referees to arbitrate game violations. Likewise, the sample entities were chosen due to accessibility. Thus, we did not control for potential confounding factors such as home advantage (Lago-Peñas and Lago-Ballesteros, 2011), as our sample included only five different home teams. However, the respective data already provide indications for potential home advantage in the AUDL, as home teams in our sample scored significantly more points ($M = 5.00$; $p = 0.012$) and committed significantly fewer turnovers ($M = -5.18$; $p = 0.010$).

Furthermore, the stability of the performance indicators must also be accounted for when the sport involves dynamic interactions between teams, such as Ultimate (Lames and McGarry, 2007). Although this interaction effect was considered in the interpretations of the performance indicators identified in this study, the reliability of these indicators has yet to be investigated. However, other work that has served as a starting point for such research in Ultimate included an evaluation of the validity and reliability of technical indicators used in the sport (Russomanno et al., 2016a,b), facilitating the future use of sport-specific terminology to ensure mutual understanding within performance analysis research. Future performance analysis studies in Ultimate should normalize the performance indicators, as suggested by Hughes and Bartlett (2002). For example, in this study, turnovers are normalized to the total number of games played, but it would also be of interest to normalize based on the total number of possessions, which could inform the ratio of possessions lost to the different types of turnovers. Finally, future research should also aim to increase the number of sample entities and to consider other Ultimate contexts (United States Ultimate, World Flying Disc Federation) to allow for large-scale investigations on the performance analysis of Ultimate. This could also enable researchers to apply promising approaches such as T-pattern analysis to identify re-occurring chronological patterns (Magnusson, 2020). This methodology, which was initially developed in the field of ethological and human interaction research, has already been applied to handball and boxing in the sport science literature (Pic, 2018; Pic and Jonsson, 2021). However, we understand the difficulty of obtaining such a large dataset due to there being only niche interest in the sport for now.

CONCLUSION

This study is the first to apply state transition modeling that includes spatial information for tactical performance analysis outside of net games. By using states to represent different zones on the field, sports scientists will be better able to visualize disc movement within and between teams, facilitating our understanding of fundamental actions and events in Ultimate. Ideally, this approach will be used to examine tactical behaviors in other invasion sports. Future research can also build upon the findings of this work by expanding the sample to include elite-level Ultimate competition beyond the AUDL. This will hopefully further reveal the performance indicators that are uniquely relevant to Ultimate and can therefore contribute to the scientific knowledge base of this sport.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HL developed the observational system and the state transition model, collected the data, and performed a significant part of the statistical analysis. TR assisted in the development of the methodology and performed some statistical analyses. OK assisted in the development of the methodology and created the figures. ML assisted in the development of the methodology. All authors contributed to the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.664511/full#supplementary-material

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ORIGINAL RESEARCH
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Living in the "Bubble": Athletes' Psychological Profile During the Sambo World Championship

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Background: The COVID-19 pandemic has changed the way we conduct daily life, as well as sports training and sports competitions. Given the stress produced by COVID-19, and the "bubble" safety measures for the World Sambo Championship, held in Novi Sad, from the 6th to the 8th of November, 2020, athletes might have experienced more stress than athletes normally would in non-pandemic conditions. Therefore, the current study aimed to create a psychological profile of sambo athletes participating in the Sambo World Championship and living in this condition.

Methods: One-hundred-fifteen participants took part in the study, completing the Profile of Mood Scale (POMS), the Pittsburg Sleep Quality Index, the Perceived Stress Scale (PSS), and the Fear of COVID-19 Scale. A mediation model with Fear of COVID-19 predicting both stress level directly and stress level through mood disturbance was hypothesized. Gender differences were evaluated through *t*-test.

Results: The results showed that the sample presented higher levels of stress but no problems in sleeping. In particular, data analysis confirmed an indirect effect of Fear of COVID on Perceived stress through mood disturbance ($\beta = 0.14$, $Z = 2.80$, and $p = 0.005$), but did not have a significant impact on the direct effect ($\beta = -0.04$, $Z = -0.48$, and $p = 0.63$). Gender differences emerged in the perceived stress level ($t = -2.86$, $df = 114$, and $p = 0.005$) and daytime dysfunction ($t = -2.52$, $df = 114$, and $p = 0.01$) where females scored higher than males for both aspects.

Conclusion: The athletes participating to the World Sambo Championship experienced stress levels determined by the mood disturbance produced by the fear of the COVID-19 pandemic. Female athletes were more stressed and showed higher daytime dysfunction. The findings of the current study are useful to understand the psychological profile of the athletes competing in the "bubble" conditions during COVID-19 pandemic.

Keywords: combat sport, martial arts, stress, performance, COVID-19, quarantine

INTRODUCTION

The COVID-19 pandemic outbreak dramatically changed how we conduct our daily lives (Pišot et al., 2020; Serafini et al., 2020). From March 2020, countries worldwide are facing movement restrictions measures (e.g., quarantine) with the aim to limit the viral spread, but at the same time, these preventative measures have worsened people's mental health (Brooks et al., 2020). For instance, a meta-analysis has investigated this negative impact across 17 studies and found that the most prevalent reaction was anxiety, followed by depression and stress (Salari et al., 2020).

Previous studies have shown that the fear generated in response to the COVID-19 situation leads to increase in depression, anxiety and stress, impacting people's positive affect (Bakioglu et al., 2020). Specifically, the fear in response to the pandemic has raised anxiety levels and fear of the unknown, both in healthy individuals and individuals with pre-existing mental issues (Shigemura et al., 2020).

The fear related to the pandemic, including developing COVID-19 infection, also impacted mood balance (Usher et al., 2020), and stress (Makarowski et al., 2020). Furthermore, a low sleep quality, characterized by insomnia, nightmares, and sleep apnea, was strongly associated to mood disorders, particularly anxiety.

Considering gender differences, current data has shown that COVID-19 pandemic had a worse impact on women than in men for two main reasons: women were more likely to permanently lose their job than men (Dang and Nguyen, 2020) with females showing higher tendency of displaying more post-traumatic stress symptoms (Liu et al., 2020), and higher levels of anxiety, depression and acute stress than males (Garcia-Fernandez et al., 2021).

Concerning the domain of sports, the athletes underwent severe modifications in how they train, compete, and socialize. Depending on the country and specific national laws, many athletes had to cease their regular training regimen during various periods of the COVID-19 pandemic (Paoli and Musumeci, 2020), especially those involved in team sports. In this perspective, a world championship competition represents a huge source of stress, characterized by fear of failure, feelings of inadequacy, external control, and social evaluation (Gould et al., 1983).

Within this scenario, the current circumstances caused by the ongoing COVID-19 pandemic can likely aggravate already delicate psychological status of sambo athletes approaching the competition. Specifically, the sambo World Championship, held in Novi Sad from the 6th to the 8th of November 2020, was organized following a particular set of procedures named "the bubble," a sort of quarantined sport competition whereby athletes were only able to spend time in a hotel or sports arena.

Taking into account "bubble" atmosphere seen at many recent athletic events, specific competitive conditions caused by the pandemic are a potent stimulus Fear of COVID-19 in mood regulation disruption, and in turn, potential elevated levels of stress and insufficient sleep quantity and quality that can ultimately result in impaired health and performance decrements. Therefore, this study aimed to examine the psychological profiles of athletes participating in the World Sambo Championship, with a particular emphasis on gender differences. In addition, to understand the impact of COVID-19 on the perception of stress in the athletes, a mediation model was hypothesized, where the Fear of COVID determines mood disturbance, which in turns produces high levels of perceived stress in the athletes.

Moreover, based on the previous findings we hypothesized that females should report higher levels of fear of COVID-19, mood disturbance, and stress levels compared to the male counterparts.

MATERIALS AND METHODS

Participants

The initial sample originally consisted of 209 participants, but 94 were excluded as they did not complete all the measures. The final sample consisted of 115 participants (mean age = 22.3 years, SD = ±5.51 years), of which 78 were males (67.8%) and 37 were females (32.2%). The mean height was 171 cm (SD = ±10 cm) and the mean weight was 72.02 kg (SD = ±18.54). The average years of sambo experience was 11.26 years (SD = ±6.00 years). Data collection took place in the sports hall during the World Sambo Championship in Novi Sad, Serbia taking place from the 6th to the 8th of November 2020.

Athletes were asked to participate in the experiment prior to warm-up before fights or after they were eliminated from competing further. A team of several experienced researchers were responsible for handing out the questionnaires, instructing athletes how to respond, and making sure that questionnaires were fully completed. All questionnaires were translated and offered in Serbian, Russian, English, and French language. To assist in the data acquisition, a translator who spoke all four languages mentioned above was hired. In case an athlete handed out an obviously incomplete questionnaire, this sample was immediately eliminated.

The study was approved by the Institutional Review Committee of the University of Novi Sad (Ref. No. 46-06-02/2020-1) and was conducted following the principles indicated in the Declaration of Helsinki. All included participants provided an informed consent, and they were told that they were free to give up the fulfilling at any stage without any consequence.

The pre-requisites for each athlete's participation were the negative RT-PCR test (Reverse-Transcriptase-polymerase chain reaction), used to detect the infection Sars-CoV-2, mandatory face masks, regular temperature check, strict safety measures (such as social distancing, mask-wearing, and hand hygiene). Moreover, the transportation was strictly supervised: all the teams used separate busses that were sanitized twice a day and trained in separate sports facilities, such as personal mats that were usable after personal disinfection. When athletes and staff people were not training or competing, they spent their time in the hotel, and they were not supposed to go outside for any reason (further information can be found in **Supplementary Material 1**).

Measures

Profile of Mood Scale

For the assessment of athletes' mood, the Profile of Mood Scale—Abbreviated Version (Grove and Prapavessis, 1992) was employed. This self-report scale is specifically tested for athletes and consists of 40 adjectives measuring seven dimensions, namely tension (TEN), depression (DEP), anger (ANG), fatigue (FAT), confusion (CON), vigor (VIG), and esteem-related affect (ERA), on a scale going from 0 = not at all to 4 = Extremely. The Total Mood Disturbance (TMD) score was calculated through the formula suggested by the Authors:

$$TMD = [TEN + DEP + ANG + FAT + CON] - [VIG + ERA]$$

According to the Authors' instruction, higher scores indicate higher mood disturbance. For eliminating the negative scores, a constant of 100 was added to the TMD score. The scale revealed a good reliability ($\alpha = 0.88$).

Pittsburg Sleep Quality Index

The Pittsburg Sleep Quality Index—PSQI (Buysse et al., 1989) assesses the subjective quality of sleep retrospectively and considering the previous month through 10 questions. For the last question, the respondent should pose the question to the roommate or bed partner, but this part was excluded for the purpose of our research. The questionnaire consists of seven components (Subjective Sleep Quality, Sleep Latency, Sleep Duration, Habitual Sleep Efficiency, Sleep Disturbances, Use of Sleep Medication, and Daytime Dysfunction), plus a global PSQI score obtained through the sum of the previous dimensions. The global score ranges from 0 to 21, and after five the quality becomes poorer and poorer. The scale revealed a good reliability ($\alpha = 0.82$).

Fear of COVID-19

The Fear of COVID-19 scale (Ahorsu et al., 2020) is a 7-item unidimensional questionnaire assessing the negative feelings derived from the Coronavirus Disease pandemic (COVID-19). The questions are evaluated on a 5-point Likert scale from 1 = Strongly Disagree to 5 = Strongly Agree and concern the physical and psychological reactions when thinking about the pandemic. The scale revealed a good reliability ($\alpha = 0.80$).

Perceived Stress Scale

The Perceived Stress Scale—PSS (Cohen et al., 1994) is a 10-items unidimensional scale measuring the stress appraised in a particular situation. The scale also includes direct questions about the degree of stress currently experienced. The questions are evaluated on a scale ranging from 0 = Never to 4 = Always. The final score is obtained through the sum of the scores attributed to all the questions, where the higher is the score, the higher is the perceived stress. The scale revealed a good reliability ($\alpha = 0.76$), with a similar value detected in previous studies (Cohen et al., 1988; Baik et al., 2019).

Data Analysis

Data were analyzed through R software (version 3.2.5). Descriptive statistics were performed on the sociodemographic variables, such as age, height, weight, years of experience, and on the scores of perceived stress, fear of COVID-19, mood state, and sleep quality. Gender differences were also evaluated concerning the overmentioned variables through *t*-test comparison.

Since the overall sleep quality was classified as good for the sample, it was excluded from the subsequent analyses. Correlations among fear of COVID-19, perceived stress, and mood disorders were calculated through Pearson's correlation coefficient. Moreover, to assess if the stress experienced by athletes was partially determined by COVID pandemic, a mediation model with direct effect of Fear of COVID-19 on perceived stress [c'], and an indirect effect [c] of Fear of COVID-19 as predictor of mood disturbance [a] and mood disturbance as mediator of perceived stress [b], was evaluated (**Figure 1**). A direct and an indirect mediation effect from the fear of COVID-19 was hypothesized. Since the sample was not big enough to evaluate the intercorrelations among subdimensions, the model was built only for total scores. The mediation model was performed through the R package *Lavaan* and was conducted following the indications of Baron and Kenny (1986). The alpha level for refusing null hypothesis was set at $\alpha = 0.05$. The number of female athletes participating to the interview was not enough to test the mediation model distinguished by gender.

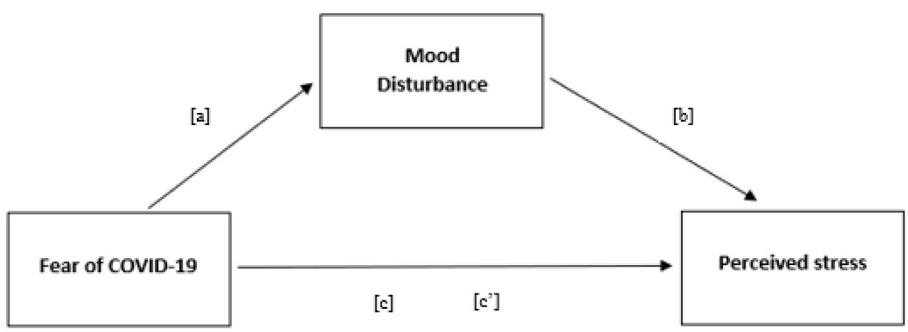

FIGURE 1 | Hypothesized mediation model with Fear of COVID-19 as predictor, mood disturbance as mediator, and perceived stress as outcome for the whole sample.

TABLE 1 | Descriptive statistics concerning sleep quality, perceived stress, fear of COVID-19, and mood state.

	Total		Males		Females		
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	***t***
Perceived stress	15.8	5.69	14.75	5.27	17.92	6.03	−2.87**
Total mood disturbance	104	21.6	104.43	20.08	101.53	24.83	0.65
Tension	6.29	4.61	6.18	4.34	6.51	5.18	−0.36
Anger	6.07	5.01	6.31	4.71	5.57	5.64	0.74
Depression	6.11	6.12	6.27	5.74	5.76	6.89	0.42
Fatigue	5.26	3.96	5.19	3.67	5.40	4.55	−0.27
Confusion	5.56	3.97	5.69	3.75	5.27	4.43	0.53
Vigor	12.8	4.36	12.59	4.39	13.36	4.30	−0.87
Esteem-related affect	12.0	3.20	12.01	3.38	12.05	2.81	−0.07
Fear of COVID-19	16.1	5.01	16.41	5.37	15.38	4.13	1.03
Sleep quality index	3.58	2.34	3.53	2.13	3.69	2.77	−0.34
Subjective sleep quality	0.50	0.58	0.51	0.53	0.49	0.69	0.23
Sleep latency	0.92	0.80	0.95	0.82	0.86	0.75	0.53
Sleep duration	0.36	0.91	0.34	1.03	0.40	0.60	−0.36
Habitual sleep efficiency	0.48	0.86	0.40	0.80	0.65	0.98	−1.36
Sleep disturbances	1.09	0.65	1.12	0.69	1.03	0.56	0.74
Use of sleep medication	0.22	0.56	0.18	0.45	0.29	0.74	−0.89
Daytime dysfunction	0.60	0.63	0.50	0.55	0.81	0.74	−2.52*

$^{*}p < 0.05$; $^{**}p < 0.01$.

TABLE 2 | Correlation among stress, mood disturbance, and fear of COVID-19 for the total sample.

	(1)	(2)	(3)
Stress (1)	1		
Mood disturbance (2)	0.43***	1	
Fear of COVID (3)	0.07	0.32***	1

$^{***}p < 0.001$.

RESULTS

Descriptive statistics of the sample are summarized in **Table 1**. As mentioned above, the average sleep quality index was 3.54, therefore under 5 that is the cut-off for sleep disorders. Moreover, all the subdimensions were far away from the maximum of each scale that is 3. Therefore, sleep quality was excluded from the subsequent analyses. The sample showed high levels of perceived stress than the normative scores ($t = 2.96$, $df = 114$, and $p = 0.002$).

Concerning gender differences, female athletes reported higher stress levels ($t = -2.86$, $df = 114$, and $p = 0.005$) and higher daytime dysfunction ($t = -2.52$, $df = 114$, and $p = 0.01$) compared to male athletes. No other gender differences emerged.

The intercorrelation among variables was good, as shown in **Table 2**. The mediation model resulted significant for the indirect effect of Fear of Covid-19 on perceived stress [c] through mood disturbance ($\beta = 0.14$, $Z = 2.80$, and $p = 0.005$), but not for the direct effect [c'] ($\beta = -0.04$, $Z = -0.48$, and $p = 0.63$). Fear of COVID-19 was related to mood disturbance [a] ($\beta = 0.31$, $Z = 3.45$, and $p < 0.001$), and mood disturbance impacted the perceived stress [b] ($\beta = 0.44$, $Z = 4.81$, and $p < 0.001$; **Figure 2**). Therefore, apart from the stress due to the competition, it can be stated that the fear of COVID-19 generated mood disorders in the athletes, which in turns enhanced the degree of stress.

DISCUSSION

The current paper aimed to examine the psychological profiles connected to the COVID-19 pandemic of the athletes competing in the World Sambo Championship, held in Novi Sad from the 6th to the 8th of November. Specifically, we hypothesized that the perceived stress was partially predicted by the fear of the pandemic through the mood disturbance resulting from this fear. We also elaborated on gender differences for the aforementioned variables, hypothesizing that female athletes should have displayed higher levels of Fear of COVID-19, higher mood disturbance, higher stress and worse sleep quality.

Acquired data showed that the Fear of COVID-19 actually produced mood disturbances which were reflected in a higher perception of stress, but the fear of COVID-19 did not predict directly the perceived stress. The gender comparison resulted in higher perception of stress and daytime disfunction in relation to sleep in females. No other gender differences appeared. It should be noted that nearly 90% of sambo athletes reported engaging in rapid weight loss (Drid et al., 2021), a practice that is defined as a ∼5% weight loss achieved over 5–7 days, which can certainly contribute to overall stress as shown in previous studies (Franchini et al., 2012).

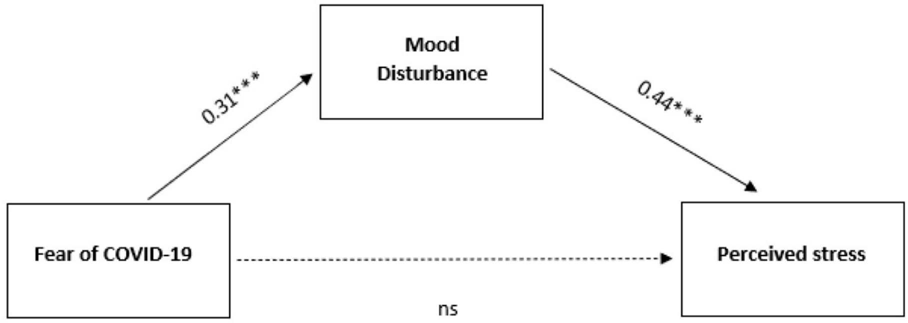

FIGURE 2 | Tested model with Fear of COVID-19 as predictor, mood disturbance as mediator, and perceived stress as outcome for the whole sample.

The researches available on the topic have shown that the exceptional circumstances of COVID-19 pandemic resulted in worsened mental health (O'Connor et al., 2020). Indeed, a study of Bakioglu et al. (2020) found that the Fear of COVID-19 directly influenced depression, anxiety, and stress, which in turn resulted in a decrease in positive thinking.

Another study showed that severe restrictions introduced during the pandemic had a direct impact on mood regulation, with high scores for tension, depression, anger, fatigue, and confusion (Terry et al., 2020). Namely, in the case of athletes, the COVID-19 national governments restrictions significantly increased their uncertainty about their careers and their future (Wilson et al., 2020), and preoccupation with training and physical shape (Schinke et al., 2020).

In the current study, the increase in negative mood affects in response to these restrictions has increased the athletes' perceived stress. Considering gender differences, females reported higher stress levels than males which is in alignment with findings of Di Fronso et al. (2020) who highlighted the negative effects of COVID-19 pandemic on athletes' perception of stress, confirming that women were more sensitive to this detrimental effect. Furthermore, the authors proposed two main explanations to be attributed to this diverse perception: first, females appear to ruminate on circumstances more than males (Nolen-Hoeksema and Jackson, 2001); second, during the pandemic, the uncertainty of female athletes' career and of their economic stability could have determined a bigger amount of perceived stress (Di Fronso et al., 2020).

Moreover, during the restrictions, other studies investigating the everyday life behavior found prolonged sleeping time (Pfefferbaum and North, 2020; Pišot et al., 2020). In addition, sleeping quality is an aspect that directly impacts the athletic performance, since it is an important component of recovery from training (Leeder et al., 2012). Indeed, athletes usually sleep worse before an important competition (Juliff et al., 2015). Our sample did not show any particular problem with respect to sleep quality and quantity. Regarding gender differences, they only appeared when it comes to daytime dysfunctions, where females obtained higher scores than males. Overall (regardless of the pandemic), daytime dysfunction problems are more common in females than males, probably because they are more involved in caregiving activities (Song et al., 2018).

The current study shows up with some limitations: first, the study has a correlational nature, therefore we do not know how this stress impacted the athletes' performance during the championship. Moreover, it would be interesting to examinate the intercorrelations among subscales, which was not performed due to reduced sample size. Therefore, it was impossible to perform two different models for males and females. Finally, the results are strictly connected to the pandemic situation and in a special condition ("the bubble") that is an exceptional case, thus the generalizability of the results is limited. However, some studies outline certain benefits that "bubble" environment can produce. In particular, a study of McHill and Chinoy (2020) examined the effects of "bubble" conditions on performance during National Basketball Association (NBA) finals whereby athletes did not have to travel across different time zones and upset their circadian rhythm which can lead to sleep loss and fatigue, further negatively affecting athlete's health, performance, recovery, and mood (Leatherwood and Dragoo, 2013).

CONCLUSION

However, the findings of the current study are useful to understand the psychological profile of athletes competing in a "bubble" conditions during the COVID-19 pandemic, characterized by a medium increase in stress levels in response to the mood oscillations generated by the pandemic. Competing in a similar situation is apparently safe, both for the limited risk of contagion and the psychological impact of the pandemic restrictions upon athletes' psychology.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Committee of the University of

Novi Sad (Ref. No. 46-06-02/2020-1). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AG, AB, NL, and PD wrote the article. AG, TT, AB, NL, FF, RR, SE, ST, NM, and PD designed the study, analyzed the data, discussed the results, reviewed, and approved the article. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.657652/full#supplementary-material

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The Relationship of Competitive Cognitive Anxiety and Motor Performance: Testing the Moderating Effects of Goal Orientations and Self-Efficacy Among Chinese Collegiate Basketball Players

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The purpose of this study was to examine the moderating effects of goal orientations and self-efficacy between competitive cognitive anxiety and motor performance under conditions featuring different levels of ego-threat. Eighty-one (40 females) collegiate-level basketball players (*M* age = 20.26 years and *SD* = 2.68) completed Sport Competitive Anxiety Test, Ego Orientation in Sport Questionnaire, and General Self-Efficacy Scale prior to the experiment. Athletes participated in two sessions of free-throw tasks. After the first session, which was under a control condition, participants performed in a free-throw competitive session while being provided opponents' scores that induced different levels of competitive cognitive anxiety. Performance is defined as the accuracy (%) in two free-throw sessions. A hierarchical multiple regression showed that high level of task-orientation and low level of ego-orientation can buffer the impairment of competitive cognitive anxiety on motor performance. The relationship between competitive cognitive anxiety and motor performance did not vary with self-efficacy. An a repeated-measured analysis of covariance after cluster analysis revealed that a high-task/low-ego profile benefited athletes the most regarding the impairment of competitive cognitive anxiety. Together, ego- and task-orientations and "goal profile" moderate the relationship between competitive cognitive anxiety and motor performance; however, self-efficacy may not serve as a moderator variable in between.

Keywords: competitive cognitive anxiety, motor performance, goal orientations, self-efficacy, goal profiles, moderating effect

INTRODUCTION

Mathew Emmons, a world record holder in shooting, encountered his first Olympic-sized mishap at Athens in 2004. He was leading the smallbore rifle, and a mediocre score on his final shot would have guaranteed him the gold medal. However, he fired, shooting at the bull's eye of the target in the next lane, and received no score. His second stumble came at Beijing in 2008. Again, he had a large lead heading into the final shot, and a score of 6.7 would have been enough for him to win the gold. Unexpectedly, he hit the trigger while lowering the gun, and a score of 4.4 put him in fourth place, leaving him off the podium.

The case of Chinese shooter Du Li is different. At Athens in 2004, in the women's 10-m air rifle event, she constantly lagged behind her main rival, Russian sharpshooter Lioubov Galkina, even before the final shot came. Surprisingly, Du got a 10.6 in the last shot, surpassed her rival Galkina, and won the gold medal.

These stories show us that competitive anxiety often interferes with motor performance. This phenomenon, often called "choking under pressure," is a common occurrence during competitions. However, the opposite is also possible: "choking under pressure" may not happen at all, or an increase in performance under pressure, known as a "clutch performance," may take place. It is not novel to raise the argument that competitive anxiety is not always negative and detrimental to performance (Fletcher and Hanton, 2001). Several models and theories about the mechanisms underlying the relationship between anxiety and performance have been proposed, including multidimensional anxiety theory (Martens et al., 1990a), reversal theory (Kerr, 1990), anxiety direction theory (Jones and Swain, 1992), zones of optimal functioning models (Hanin, 1980, 1986). Jones and Swain (1992), for instance, introduced the notion of "direction," expanding the original "intense" structure of anxiety based on multidimensional anxiety theory (Martens et al., 1990a; Jones, 1995). He proposed that individuals' interpretations of anxiety symptoms as either facilitating or debilitating to individuals affect their performance. These theories inspired many studies of the relationship between competitive anxiety and motor performance, in order to explore different ways in which diverse components of competitive anxiety can influence motor performance. In multidimensional anxiety theory, Martens et al. (1990a) divided competitive anxiety into three components: cognitive anxiety, somatic anxiety and self-confidence. Cognitive anxiety, also called "worry," is defined as "negative expectations and cognitive concerns about oneself, the situation at hand, and potential consequences" (Morris et al., 1981, p. 541). Competitive cognitive anxiety is typically seen as negatively associated with motor performance, as it represents the degree to which individuals sense threat when evaluating the probability of achieving a desired result in a competition (Martens et al., 1990b). In other words, individuals feel competitive cognitive anxiety when they negatively evaluate the resources available for winning in a certain situation. Given the intrusive nature of competitive cognitive anxiety, it is not surprising to see many studies indicating that higher levels of competitive cognitive anxiety result in poorer performance (e.g., Chapman et al., 1997; Kurimay et al., 2017). However, a meta-analysis (Woodman and Hardy, 2003) has shown that 40% of the included studies do not support the impairment of competitive cognitive anxiety, and 23% of those have revealed an opposite result. Another meta-analysis produced in the same year (Craft et al., 2003) has also demonstrated that, on average, the relationship between competitive cognitive anxiety and performance is actually weak (r = 0.01, CI = [−0.03, 0.04]). The disagreement in findings with regard to the relationship between cognitive anxiety and performance was the inspiration for this study. The most straightforward way of delving into these results is moderation testing. Several moderator variables have been found for the competitive cognitive anxiety-motor performance relationship. Gender is one such variable, as a significantly greater mean effect size has been demonstrated for men (r = −0.22) than for women (r = −0.03). Other variables that have yielded similar results include standard of competition (high, r = −0.27; low, r = −0.06), type of sport (team, r = 0.09; individual, r = 0.16), and type of skill (open, r = 0.23; closed, r = 0.01; Craft et al., 2003; Woodman and Hardy, 2003). In the same vein, this study aims to test possible moderator variables that have not been adequately studied before.

Achievement goal orientations represent how individuals define success in achievement settings, and in athletic competitions, success can be defined either as mastering a skill or as indicating superior performance to others (Nicholls, 1984). These two ways of conceiving success construct different achievement motivations, labeled as "ego-orientation" and "task-orientation." Task-orientation refers to a motivational propensity or state characterized by approaching goals, and ego-orientation refers to one characterized by avoiding goals (Nicholls, 1989). Along with achievement goal theory (Nicholls, 1984, 1989), subsequent research (Duda, 1989; Duda and Nicholls, 1992) has shown that task-orientation is related to a tendency of exerting consistent effort or persistence, as well as cooperating with others to try to fulfill the mastery of knowledge or a skill, while ego-orientation is related to the desire to attain a higher social status or other measure of superiority by outperforming others (Harwood et al., 2006). Differentiating between the two orientations is important because task-orientation tends to be positively associated with adaptive correlates and negatively associated with maladaptive correlates in sport, while ego-orientation tends to be positively associated with both maladaptive and adaptive correlates in sport (Lochbaum et al., 2016). Meanwhile, given that goal orientations are orthogonal, there are multiple ways of combination based on different levels of each goal orientation – high-task/low-ego; low-task/high-ego; or low-task/low-ego (Harwood et al., 2006) – that allow us to explore the relationships between "goal profiles" (Fox et al., 1994; Hodge and Petlichkoff, 2000) and performance in more complicated situations. It has been indicated that the balance between athletes' goal orientations (task and ego orientations) are more important for the formation of flow experience rather than the separate level of goal orientation (Stavrou et al., 2015). The complexity of competitive situations is that situational factors such as competitiveness sometimes change how propositional goal orientations affect performance (Harwood et al., 2006). For example, an individual with a high-level of ego-orientation would probably not act as usual when in a non-competitive situation (Harwood et al., 2006). Similar insights have been witnessed in Theory of Challenges and Threat States in Athletes, which assumes that individuals tend to adopt an adaptive goal orientation when they perceive the competition as a challenge, while tend to act in the opposite manner when perceiving the competition as a threat (Jones et al., 2009). Since competitive situations influence the demonstration of goal orientations, we can assume that different levels of potential competitive threat may interact with an individual's propensity goal orientations, as a result, may have different effects on performance. Thus, we were interested in examining the moderating effects of goal orientations in competitive settings that involve different levels of potential threat, and in exploring whether optimal "goal profiles" differ in such situations.

One of the most common potential threats in athletic competitions is the score gap between a competitor and his/her rival, which is highly related to the perception of winning/losing possibilities. Dunn and Syrotuik (2003) have identified sources of competitive anxiety as worry about failure, negative social evaluation and situational uncertainty; perceptions of score gaps are directly associated with the category of "worry about failure." At the same time, the classification of anxiety sources hints at the possible influence of different sources of anxiety in competitive situations on the inconsistent pattern of findings across these various studies of relationships between cognitive anxiety and performance in sport. These sources are significant because of their exploration of the effects of situational factors on performance and of their potential interactive effects with individuals' propensity to succeed or fail. Moreover, score gaps as salient potential threats are ego-threat/ego-boost situations (Vytal et al., 2013) which are potentially related to ego-orientation, and thus are potential influences on both adaptive and maladaptive correlates. Therefore, this study used score gaps as anxiety situations to test the moderating effects of goal orientations and self-efficacy between competitive cognitive anxiety and motor performance.

Self-efficacy was included in this study because it is generally regarded as a positive and facilitative factor in sport (Moritz et al., 2000; Jackson et al., 2007). The concept of self-efficacy, proposed by Bandura (1977), refers to one's appraisal of his/her ability to obtain a certain goal via his/her actions. Individuals who have higher degrees of self—efficacy are likely to be more motivated to perform a task, and to exert greater amounts of effort and persistence (Bandura, 1997), while individuals with low self-efficacy tend to evaluate the competitive situation as more of a threat (Zilka et al., 2019). Self-efficacy is also a key predictor of performance in both physical and cognitive tasks (Feltz and Magyar, 2006). Apart from the self-appraisal of ability, one's optimistic belief in his/her ability when experiencing frustration, which has been called "resiliency self-efficiency" (Bandura, 1997; Shipherd, 2019), is also an important factor. For example, a study on firefighters has demonstrated the moderating effect of self-efficacy on the relationship between perceived stress and burnout, which directly influences the job performance (Makara-Studzinska et al., 2019). Similarly, self-efficacy also serves as a moderating variable in the relationship between academic performance and cheating, because higher-achieving students with low levels of academic self-efficacy are more likely to cheat (Finn and Frone, 2010). As self-efficacy is considered a crucial mechanism of self-regulation (Makara-Studzinska et al., 2019), the effects of self-efficacy cannot be neglected in athletic competitions that exert tremendous pressure on their participants. However, there have been relatively few examinations of the moderation effect on self-efficacy in the relationship between competitive cognitive anxiety and motor performance.

The primary objective of this study is to address the question of whether the influence of competitive cognitive anxiety that induced by score gaps on motor performance is moderated by athletes' achievement goal orientations and self-efficacy. In sport, given that task-orientation is regarded as facilitative, while ego-orientation could be either facilitative or debilitative (Lochbaum et al., 2016), we anticipated that a high level of task-orientation will buffer the impairment of high competitive cognitive anxiety condition that features higher levels of ego-threat (Schoofs et al., 2008) on motor performance, while a low level of ego-orientation will buffer this impairment considering our situational settings are ego-related. Apart from the individual effects of goal orientations, we also anticipated moderating effects with the same directions in respect of goal profiles. In addition, given that high self-efficacy is typically related to adaptive emotions and behaviors in sport (see Bandura, 1997), we anticipated that self-efficacy had a moderating effect in the relationship between competitive cognitive anxiety and motor performance. To sum up, we hypothesized that: (1) a high level of task-orientation and a high level of self-efficacy will buffer the impairment of high competitive cognitive anxiety on motor performance, compared to low levels of them, meanwhile, a low level of ego-orientation will buffer this impairment compared to a high level of it; (2) high-task orientation profiles (e.g., high-task/high-ego, high-task/low-ego) benefit athletes more than low-task orientation profiles (e.g., low-task/high-ego, low-task/low-ego) on motor performance regarding the impairment of competitive cognitive anxiety; and (3) low-ego orientation profiles (e.g., high-task/low-ego, low-task/low-ego) benefit athletes more than high-ego orientation profiles (e.g., high-task/high-ego, low-task/high-ego) on motor performance regarding the impairment of competitive cognitive anxiety.

MATERIALS AND METHODS

Participants

Eighty-one Chinese collegiate-level basketball players (40 females, 41 males; *M* age = 20.26 years, *SD* = 2.68) who had won top 4 in a provincial tournament (n = 53: *M* age = 19.19 years, *SD* = 2.01) or participated in a national tournament (n = 28: *M* age = 22.52 years, *SD* = 2.54) were recruited in this study. According to G*Power calculation, adopting a power of 0.8, a total sample size of 77 participants were needed for the hierarchical multiple regression and a total sample size of 72 participants were needed for the repeated-measured a repeated-measured analysis of covariance (ANCOVA). All of the participants had at least 4 years professional basketball training experience (*M* sport experience = 6.54 years, *SD* = 1.54). Three participants (2 females, 1 male) were excluded because of conscious neglecting the opponent's scores that were provided.

Procedures and Anxiety Conditions

After obtaining approval from the institutional research ethics board, the principal investigator contacted athletes to introduce them the study. Participants were informed that they would be required to compete a 50-free-throw competition against an opponent whose scores had been recorded and their scores would also be recorded for next participant, and they also needed to complete a few questionnaires before and after the competition. Participants were also informed to receive 30-yuan cash if won the competition. Athlete participants were voluntary to participate in the study and were treated in accordance with the ethical guidelines for human research set forth by the American Psychological Association. All participants finished written informed consent was obtained prior to commencing the experimental competition.

Data collection prior to the experimental competition was conducted via internet. The presentation order of the Sport Competitive Anxiety Test (SCAT), *Task and Ego Orientation in Sports Questionnaire* (TEOSQ), and General Self-Efficacy Scale (GSES) was counterbalanced to reduce the potential impact of any presentation order effects.

The experimental competition took place in half a basketball court. One athlete participated in the study at one time. He or she was required to be standing behind the free throw line to shoot (see **Figure 1**). Upon signing the written consent, each participant had been introduced an overview of the competition and reminded that cash was to be awarded if he or she won. Then each participant was asked to draw lots, being randomly assigned to either low level competitive cognitive anxiety (*LA*) group ($n = 39$) or high level competitive cognitive anxiety (*HA*) group ($n = 39$). After 20 throws' practice, each participant had the first 50-free-throw without opponent but with the score recorded, followed by the first *Competitive State Anxiety Inventory-2R* (CSAI-2R) to assess participant's anxiety during the first session (S1). Then each participant had a 50-free-throw competition with an opponent of similar ability whose scores were shown on the scoreboard after he or she had shot (see **Figure 1**). Participants' scores were recorded by researchers. After that, the second CSAI-2R was filled by each athlete to assess the anxiety during the competition session (S2). Upon completion, participants completed a manipulation check items ("Have you been looking at the opponent's scores provided during the competition?", responses were either yes or no; "How much threat have you been feeling about that?"; responses were on a 1 = *not at all* to 7 = *very much* scale). Participants were debriefed and thanked.

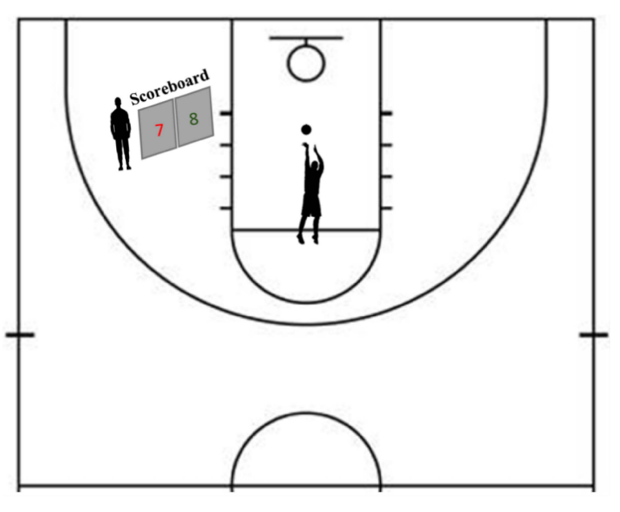

FIGURE 1 | Graphical representation (not to scale) of the competition.

Opponents' scores were manipulated by researchers to create conditions of competitive state anxiety. There were two groups which are low competitive cognitive anxiety (*LA*) and high competitive cognitive anxiety (*HA*). For *LA* group, opponents' scores were manipulated as lagging behind the participant and gaining 12 points (less than 25% hitting accuracy) in total, furthermore, the opponent did not gain the first point until the participant gain the first 3 points. For *HA* group, opponents' scores were manipulated as shadowing the participant's score during the first 40 throws, yet in the last 10 throws, opponent gained 10 points. A plot study has shown participants who were in *HA* group experienced higher intensity of competitive cognitive anxiety than those who were in *LA* group.

Measures

Prior to coming to the experimental competition, participants completed a demographic questionnaire and modified version of the SCAT (Martens et al., 1990b), TEOSQ (Duda and Nicholls, 1992), and GSES (Schwarzer and Jerusalem, 1995) to measure competitive trait anxiety, goal orientations in sport and self-efficacy. After practice session and the experimental competition, participants were required to fill in the CSAI-2R (Cox et al., 2003), respectively.

Sport Competitive Anxiety Test

The SCAT (Martens et al., 1990b) contains 15 items, 10 of which (e.g., "When I compete, I worry about making mistakes") measure symptoms associated with competitive anxiety, while the rest five are not scored for reducing the likelihood of an internal response-set bias. Items are rated on a 3-point evaluation scale including "Rarely," "Sometimes," or "Often" feel this way when competing in sport, with a higher score representing higher levels of competitive trait anxiety. It has been shown to have a reliable construct (internal consistency, i.e., $r = 0.95\sim0.97$; test-retest reliability, i.e., $r = 0.73\sim0.88$; Martens et al., 1990a), being adopted as a measure of CTA by at least 80 studies that have been published (Dunn and Causgrove Dunn, 2001). Translations of the SCAT (Zhu, 1993) into Chinese ($\alpha = 0.77$) were conducted.

Task and Ego Orientation in Sports Questionnaire

The TEOSQ (Duda and Nicholls, 1992) contains 13 items, asking the participants to evaluate the extent of agreement when they feel most successful in a particular sport in different situations, 7 of which reflecting task-oriented (e.g., "when I learn a new skill by trying hard"), while 6 others are reflecting ego-orientation (e.g., "I feel most successful in sport when the others cannot do as well as me"). Items are rated on a 5-point Likert scale anchored between strongly disagree (1) and strongly agree (5). Translations of the TEOSQ (Chen and Si, 1998) into Chinese were conducted, which have been shown to have satisfactory internal consistencies between $\alpha = 0.71$ and 0.78 (Asghar et al., 2013).

General Self-Efficacy Scale

The GSES (Schwarzer and Jerusalem, 1995) is an established measure of generalized self-efficacy that has been adopted in numerous studies in sport (e.g., Hewett et al., 2017; Sarı and Bayazıt, 2017). The GSES consists of 10 items (e.g., "It is easy for me to stick to my aims and accomplish my goals," "I can solve most problems if I invest the necessary effort") on a 4-point Likert scale, Cronbach's alphas ranged from 0.76 to 0.90 (Schwarzer and Jerusalem, 1995). The Chinese version of the GSES (C-GSES; Zhang and Schwarzer, 1995) which has demonstrated good reliability with a Cronbach's alpha of 0.92 were conducted (Cheung and Sun, 1999).

Revised Competitive State Anxiety Inventory-2R

The CSAI-2R (Cox et al., 2003) is a revised version of the Competitive State Anxiety Inventory-2 (CSAI-2; Martens et al., 1990a) that measures situational competitive anxiety in three dimensions: cognitive anxiety (5 items: e.g., "I am concerned about losing"), somatic anxiety (7 items: e.g., "My body feels tense"), and self-confident (5 items: e.g., "I'm confident about performing well"). Athletes were instructed to choose the appropriate number for each statement to indicate how they feel at this moment from 1 (not at all) to 4 (very much so). It has been revealed that CSAI-2R has stronger psychometric properties in terms of its factor structure than CSAI-2, as a Lagrange Multiplier test has shown an improved model fit after deleting 10 items from the original instrument (Cox et al., 2003). Validation studies of several versions CSAI-2R has shown adequate psychometric properties and suggested the revised version above the original, such as French (Martinent et al., 2010), Spanish (Fernández et al., 2007), Swedish (Lundqvist and Hassmén, 2005), Malaysian (Hashim and Baghepour, 2016), and Chinese (Chen et al., 2013). The Chinese version of CSAI-2R (Chen et al., 2013) were conducted. The internal consistency values for all subscales were acceptable (α s > 0.75).

RESULTS

Preliminary Data Analysis

The final sample contained 40 male and 38 female participants. To maximize the sample size for data analyses, we combined data across gender into a single data set. A non-significant Box's M statistic was obtained (*Box's* $M = 13.947$, F [10, 26936.595] = 1.315, and $p = 0.215$) indicating that there were no concerns regarding the heterogeneity of variance in the two gender data sets.

Table 1 contains the descriptive statistics (i.e., means, standard deviations, and bivariate correlations [r]) for goal orientations, self-efficacy, S1 free-throw accuracy, and S2 free-throw accuracy. The internal consistency values for ego (α = 0.77), task (α = 0.74) subscales and self-efficacy scale (α = 0.86) were acceptable.

Manipulation Check

To determine if the manipulation of the opponent's scores in the experimental competition was successful in creating higher perceived competitive cognitive anxiety—as would be evident if participants reported different elevated levels of competitive cognitive anxiety in *HA group* than in *LA group*—ANCOVA was conducted to examine differences in competitive cognitive anxiety changing from S1 (i.e., no score manipulation) to S2 (i.e., scores comparison provided) after adjusting the means of the SCAT in different groups. Competitive trait self-control served as covariate. A statistically significant interaction was obtained: F (1, 75) = 58.54, $p < 0.001$, $\eta^2 = 0.44$, and *Power* = 1.00. More specifically, from S1 to S2, participants in *HA group* reported larger elevation in competitive cognitive anxiety intensity ($M_{S1} = 9.90$, $SD_{S1} = 2.78$; $M_{S2} = 14.03$, $SD_{S2} = 2.76$), in comparison to that of those in *LA group* ($M_{S1} = 10.74$, $SD_{S1} = 3.04$; $M_{S2} = 10.97$, $SD_{S2} = 1.98$). Manipulation check results indicated that the manipulation of competitive cognitive anxiety was successful.

Main Analysis

Hierarchical Multiple Regression

Prior to conducting the regression analysis, data were screened for the presence of univariate and multivariate outliers. Subsequent data screening did not identify any univariate outliers (i.e., standardized z-scores for all variables ≤ | 3.29|) or multivariate outliers (i.e., all Mahalanobis distances < 18.467, $p < 0.001$: see Tabachnick and Fidell, 1996). The main dependent measure was the performance on free-throw tasks. To test hypothesis 1, we regressed S2 free-throw accuracy on S1 free-throw accuracy in Step 1 which revealed that that S1 free-throw accuracy significantly predicted S2 free-throw accuracy: $R^2 = 0.66$, F (1, 76) = 151.18, and $p < 0.001$. Then, we regressed S2 free-throw accuracy on participants' ego-orientation ($M = 3.32$, $SD = 0.89$; centered), task-orientation ($M = 4.28$, $SD = 0.39$; centered), self-efficacy ($M = 27.53$, $SD = 4.50$; centered), and competitive cognitive anxiety conditions (0 = LA, 1 = HA) in Step 2, and on the bivariate interactions (ego-orientation*anxiety conditions, task-orientation*anxiety conditions, self-efficacy*anxiety conditions)

TABLE 1 | Means, standard deviations, and bivariate correlations for goal orientations, self-efficacy, S1 free-throw performance, and S2 free-throw performance.

	Ego-orientation [a]	Task-orientation [a]	Self-efficacy [b]	S1 free-throw accuracy [c]	S2 free-throw accuracy [c]
Task-orientation	0.18				
Self-efficacy	0.02	0.35**			
S1 free-throw accuracy	−0.18	0.05	0.01		
S2 free-throw accuracy	−0.19	0.16	0.13	0.82**	
Mean	3.32	4.22	27.53	63.46	60.46
(SD)	(0.89)	(0.40)	(4.50)	(8.32)	(8.92)

*SD, Standard Deviation. **p < 0.01. (n = 78). [a]Items measured on a 5-point scale. Subscale score = sum score/number of items. [b]Items measured on a 4-point scale. [c]The accuracy of each free-throw session (%). Higher figures represent better performance.*

in Step 3. Competitive trait self-control (M = 21.33, SD = 3.79; centered) served as covariate. We found that adding the bivariate interactions significantly improved the predictive ability of the model, R^2 = 0.82, F (9, 68) = 38.71, $p < 0.001$, R^2 change = 0.05, F change (3, 68) = 7.06, and $p < 0.001$. We found significant interactions in the relationship between ego-orientation and competitive cognitive anxiety (ego*conditions; B = −1.70, SE = 0.52, 95% CI = [−2.72, −0.67], β = −0.24, sr = −0.16, and p = 0.002), as well as in the relationship between task-orientation and competitive cognitive anxiety (task*conditions; B = 4.51, SE = 1.29, 95% CI = [0.29, 3.49], β = 0.29, sr = 0.17, and p = 0.001; see **Figure 2**). None of the values of tolerance was less than 0.2 and, simultaneously, all the values of VIF were less than 10, indicating no concerns related with multicollinearity. The results are shown in **Table 2**.

Prediction of "Goal Profiles" on Free-Throw Competition Performance

To test hypothesis 2 and 3, we conducted a cluster analysis to create goal profile groups. This method has been commonly used for classifying sample participants into groups according to their task and ego orientation scores in sport psychology (Hodge and Petlichkoff, 2000; Wang and Biddle, 2001; Cumming and Hall, 2004; Harwood et al., 2004). We employed the procedures that Harwood et al. (2004) used which combine hierarchical cluster analysis and non-hierarchical cluster analysis. Both of them offer an advantage over the traditional methods (e.g., mean- or medium-split). Instead of a formative way of classification, they provide the researcher with multiple choices of solutions that fit the data differently (Hodge and Petlichkoff, 2000). The best fit solution should reflect within-cluster homogeneity and a maximized between-cluster difference (Hair et al., 1995).

The steps were guided by the procedures outlined by Hair et al. (2006), all of the dependent measures were first standardized using z scores (M = 0, SD = l). Goal profile groups were generated through a hierarchical cluster analysis, and then were validated by a non-hierarchical cluster analysis (Harwood et al., 2004). First, for the hierarchical cluster analysis, a Ward's method of linkage and a squared Euclidean distance were adopted to identify the number of cluster groups that should be formed by the present data. The Ward's method was chosen for creating cluster groups because it minimizes the within-cluster variance, meanwhile, a squared Euclidean distance was chosen because it is the recommended initial distance to use

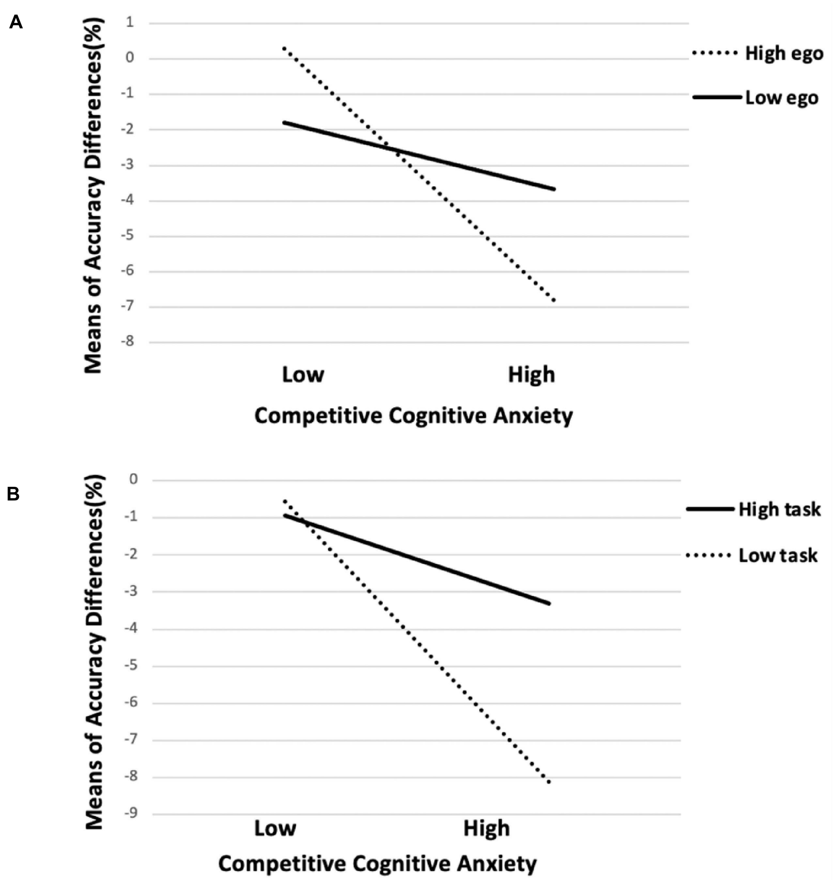

FIGURE 2 | The associations of competitive cognitive anxiety with accuracy differences between two sessions (S2–S1) among athletes with high and low ego-orientations **(A)** and high and low task-orientations **(B)**. Note. High ego, high ego orientation; Low ego, low ego orientation; High task, high task orientation; and Low task, low task orientation.

TABLE 2 | Regression analysis predicting free-throw competition (S2) accuracy.

Predictive variables	R^2	ΔR^2	ΔF	*B*	Standardized coefficientsβ	Semi-partial correlation *sr*	*t*
Step 1	0.66		151.18***				
S1 free-throw accuracy				0.87	0.82	0.82	12.30***
Step 2	0.77	0.12	7.98***				
S1 free-throw accuracy				0.78	0.73	0.69	12.61***
Trait anxiety				0.10	0.08	0.08	1.47
Conditions				−2.79	−0.31	−0.31	−5.56***
Ego-orientation				−0.34	−0.07	−0.07	−1.23
Task-orientation				1.97	0.17	0.15	2.81**
Self-efficacy				0.06	0.06	0.06	1.05
Step 3	0.82	0.05	7.06***				
S1 free-throw accuracy				0.84	0.78	0.72	14.76***
Trait anxiety				0.13	0.11	0.11	2.17*
Conditions				−2.71	−0.31	−0.30	−6.04***
Ego-orientation				0.77	0.15	0.10	2.05
Task-orientation				−1.22	−0.11	−0.06	−1.21
Self-efficacy				0.25	0.25	0.13	2.61*
EO*conditions				−1.69	−0.24	−0.16	−3.30**
TO*conditions				4.51	0.29	0.17	3.49**
SE*conditions				−0.22	−0.17	−0.09	−1.83

*Conditions, Competitive cognitive anxiety conditions; EO, Ego-orientation; TO, Task-orientation; and SE, Self-efficacy. *p < 0.05; **p < 0.01; and ***p < 0.001, all two-tailed (n = 78).*

when applying the Ward's method (Aldenderfer and Blashfield, 1984). The dendogram, which is a graphical representation of all the possibilities of the classifying solutions, suggested that a 3-, 4-, or 5-cluster solution might exist in the data. However, according to the agglomeration schedule, the largest increase in the agglomeration coefficient was seen between a 4-cluster and a 3-cluster solution. Therefore, it was concluded that a 4-cluster solution best fitted the data (Hair et al., 1998). Next, A non-hierarchical cluster analysis (e.g., K-means cluster) was conducted to validate the 4-cluster solution. A 4-cluster solution was then determined to be the best fit, based on the number of participants in each cluster and similarity between the final cluster centers. We also validated the stability of a 4-cluster solution by another K-means cluster analysis with a two-thirds random sample (Hair et al., 1998). Above 92% of the sample was classified to their original clusters, confirming the stability of this 4-cluster solution. The means, standard deviations, and standardized scores for the 4 clusters are presented in **Table 3**.

TABLE 3 | TEOEQ scores for clusters.

Clusters	*n*	Ego-orientation			Task-orientation		
		M	*SD*	*z*	*M*	*SD*	*z*
1. Low-ego/high-task	18	2.33	0.19	−1.11	4.59	0.20	0.78
2. Low-ego/low-task	20	2.52	0.20	−0.89	3.98	0.19	−0.77
3. High-ego/high-task	22	4.17	0.16	0.95	4.62	0.23	0.87
4. High-ego/low-task	18	4.17	0.18	0.95	3.89	0.17	−1.00

TEOSQ, Ego Orientation in Sport Questionnaire; M, Mean; and SD, Standard Deviation.

The interpretations of goal profile groups of being as low or high on the two goal orientations was using a *z* score criterion of ±0.50 (Hodge and Petlichkoff, 2000; Wang and Biddle, 2001; Harwood et al., 2004). According to this criterion, 18 participants in Cluster 1 had low-ego/high-task profiles, 20 participants in Cluster 2 had low-ego/low-task profiles, 22 participants in Cluster 3 had high-ego/high-task profiles, and 18 participants in Cluster 4 had high-ego/low-task profiles. A MANOVA was then employed to examine whether significant differences existed between the cluster groups on their task- and ego-orientation scores. A significant multivariate effect was found for goal orientations, *Pillai's Trace* = 1.71, F (6, 148) = 144.58, $p < 0.001$, $\eta^2 = 0.85$, and *Power* = 1.00, with an observed power of 100%. Significant univariate effects were found for ego orientation (F [3, 74] = 590.03, $p < 0.001$, $\eta^2 = 0.96$, and *Power* = 1.00) and task orientations (F [3, 74] = 73.12, $p < 0.001$, $\eta^2 = 0.75$, and *Power* = 1.00). A *post hoc* test showed that participants in Cluster 3 (high-ego/high-task) and Cluster 4 (high-ego/low-task) had a significantly higher score on ego orientation than participants in Cluster 1 (low-ego/high-task) and Cluster 2 (low-ego/low-task; *ps* < 0.01), while participants in Cluster 1 (low-ego/high-task), and Cluster 3 (high-ego/high-task) had a significantly higher score on ego orientation than participants in Cluster 2 (high-ego/low-task) and Cluster 4 (low ego/low-task; *ps* < 0.01). After labeling these groups, ANCOVA was calculated to examine for differences among the cluster groups under competitive cognitive anxiety conditions. Competitive trait anxiety served as the covariant. A significant interaction between competitive cognitive anxiety and goal profile groups, F (3, 69) = 5.85, $p = 0.001$, $\eta^2 = 0.20$, and *Power* = 0.94. Probing the interaction (see **Figure 3**) revealed that a high-task/low-ego profile benefited athletes the most under a high competitive cognitive anxiety condition, whereas a high-ego/low-task profile was shown to be the most detrimental to motor performance under a high competitive cognitive anxiety condition.

DISCUSSION

The primary purpose of this study was to examine the moderating effects of goal orientations and self-efficacy on the relationship between competitive cognitive anxiety and motor performance. Overall, our findings indicate that ego- and task-orientations and "goal profiles" moderate the relationship between competitive cognitive anxiety and motor performance; however, self-efficacy may not serve as a moderating variable.

Current research sheds important light upon relationships between competitive cognitive anxiety and motor performance. Previous investigations focused more on the main effects of goal orientations, goal profiles and self-efficacy on motor performance. Although those findings indicated the significant influences of these variables on athletic performance, a greater understanding of their moderating effects under stress will be more beneficial to researchers and practitioners in sport. This study examined the moderating effects of goal orientations, goal profiles and self-efficacy separately via multiple methods of analysis.

Previous studies have noted that in sport, task-orientation tends to be positively associated with adaptive correlates, while ego-orientation tends to be positively associated with both maladaptive and adaptive correlates (Lochbaum et al., 2016). The interaction effects we found in the current study extend previous research by illustrating the influence of goal-orientations on athletic performance under a high competitive cognitive anxiety. In this study, hierarchical multiple regression results (**Table 2**) revealed that higher task-orientation tends to benefit individuals more than lower task-orientation ($\beta = 0.29$, $p = 0.001$), while lower ego-orientation tends to benefit individuals more than higher ego-orientation ($\beta = -0.24$, $p = 0.002$), in terms of free-throw accuracy, under a high competitive cognitive anxiety condition that contains scores indicating lagging behind. In other words, these results showed that the contributions of high task-orientation and low ego-orientation were reflected not only in directly improving athletes' motor performance, but also in building "a facilitative process" intended to help athletes cope with high competitive cognitive anxiety. These results are in line with the findings of Albert et al. (2021) who proposed that task-orientation has positive correlations with multiple significant predictors of performance under stress, such as grit (Albert et al., 2021), and self-confidence (Lee et al., 2020). Importantly, in the current study we identify a dispositional characteristic that can buffer the impairment of competitive cognitive anxiety. In this regard, this study provided another possible explanation for the inconsistent findings concerning the relationship between competitive cognitive anxiety and motor performance. According to our findings, ego- and task-orientation both serve as moderator variables in this relationship. Regardless of the underlying reasons that explain why task orientation may boost athletic performance, the current findings strengthen Turner et al.'s (2021) findings and reveal that challenges and threat evaluations predict the performance under pressure (Turner et al., 2021), given that athletes tend to adopt task-orientation when they evaluate the competition as a challenge. With regard to the reverse moderating effect of ego orientation, Jones et al. (2009) has proposed that when athletes perceive the competition as a threat, they may be more likely to adopt maladaptive goal orientations. Therefore, it is possible that

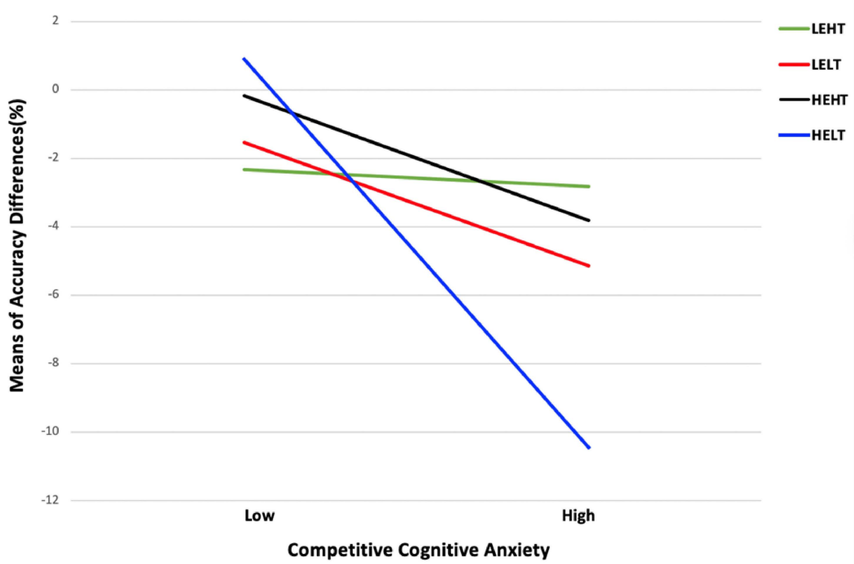

FIGURE 3 | The association of competitive cognitive anxiety with accuracy differences between two sessions (S2–S1) among athletes with four goal profiles. Note. LEHT, Low-ego/high-task; LELT, low-ego/low-task; HEHT, high-ego/high-task; and HELT, high-ego/low-task.

in the ego-threat situation we created based on the score gaps, athletes with higher levels of ego-orientation are more prone to act maladaptively than those with lower levels (Kavussanu et al., 2014).

In the same hierarchical multiple regression analysis, we also examined the moderating effect of self-efficacy. Contrary to our hypothesis, our findings did not show a statistically significant interaction between self-efficacy and competitive cognitive anxiety conditions ($\beta = -0.17$, $p = 0.07$). One possible interpretation for this result is that high and low self-efficacy may have an equal influence on the relationship between competitive cognitive anxiety and motor performance. Moreover, the main effect of self-efficacy that was regressed in the Step 2 was not significant as well ($\beta = -0.06$, $p = 0.30$). It also implied that in comparing a free-throw competition session that combines high and low competitive cognitive anxiety conditions to a non-competition session, we failed to witness significantly different effects of self-efficacy on free-throw accuracy. Our results demonstrated that self-efficacy affected motor performance under both competitive and non-competitive conditions equally. This result, therefore, is not inconsistent with previous findings showing a positive association between self-efficacy and motor performance (e.g., Sklett et al., 2018). It is worth mentioning that this method of analysis allowed us to examine "purer" moderating effects by accounting for the non-competition performance in the first step, which contains irrelevant factors that potentially interact with moderator variables that predict motor performance. It also emphasized our objective of testing moderating effects on the relationship between competitive cognitive anxiety and motor performance which indicated a distinct feature of "competitiveness." Thus, the focus of our study was the moderating effects in our hierarchical multiple regression, rather than the main effects.

Apart from investigating two independent moderating effects of goal orientations, we also attempted to examine the moderating effect of "goal profiles," which present the combination of both goal orientations, between competitive cognitive anxiety and motor performance. We first followed the procedures described by Harwood et al. (2004) to group the sample athletes into different profiles, in which a hierarchical and a non-hierarchical cluster analysis were successively conducted. Four cluster groups emerged from the analysis, which we labeled as low-ego/high-task (cluster 1), low-ego/low-task (cluster 2), high-ego/high-task (cluster 3), and high-ego/low-task (cluster 4) according to a *z*-score criterion of +0.5 (Hodge and Petlichkoff, 2000; Wang and Biddle, 2001). We then conducted an ANCOVA, the result of which supported our hypothesis that a profile consisting of a low ego orientation and a high task orientation benefits athlete the most when they are under a high competitive cognitive anxiety condition. This result is in keeping with what we have found in hierarchical multiple regression analysis, that the interaction effect demonstrates that the "low-ego/high-task" profile benefits athletes the most under a high competitive cognitive anxiety condition. In addition, ANCOVA results extend the regression results by revealing that goal orientations can be complementary under our experimental settings. More specifically, the "high-ego/high-task" profile and the "low-ego/low-task" seem to indistinctly affect athletes' motor performance under competitive cognitive anxiety conditions (see **Figure 3**). In comparing our findings to a previous study that has examined the relationship between goal profiles and psychological skills use (i.e., Harwood et al., 2004), we note some differences. Unlike Harwood et al. (2004) which has concluded that young athletes with "moderate-ego/high-task" tend to apply more psychological skills during competitions, we identified that under a high competitive cognitive anxiety the most performance boosting goal profile is "low-ego/high-task." In explaining this difference, it is possible that labels are sample-specific so conclusions drawn from multiple cluster patterns can be different. Although the limitation of the cluster analysis in result generalizing seems salient, the unique contribution of this analysis is to expand our knowledge regarding the balance of goal orientations which serve as two orthogonal dispositional characteristics (Sicilia et al., 2008; Harwood et al., 2015).

Practical Implications

Our findings have some important practical implications. First, we hope that practitioners in sport psychology will pay more attention to the applied importance of goal achievements in optimizing athletic performance. We propose that sport psychologists and coaches focus on helping athletes reduce ego-orientation and improve task-orientation. Athletes with high levels of ego-orientation tend to perform worse when experiencing high levels of competitive cognitive anxiety, and those with high levels of task-orientation seem to have more adaptive regulation in a situation that contains significant competitive threats. Focusing part of the mental training program before competition on goal orientations is likely to enhance athletic performance (Hogue et al., 2013; Hogue, 2020). Consequently, developing and implementing proper motivational climate interventions that specifically target the reduction of ego-orientation and the promotion of task-orientation seem essential, especially for younger athletes (Harwood et al., 2004). In addition, we suggest that in the face of competitive threat, a high level of task orientation and/or a low level of ego orientation may buffer the impairment of athletic performance due to anxiety. Thus, developing pre- and within-competition routines based on fostering a beneficial goal profile that may help athletes keep the necessary focus in front of competitive threat can be a great asset in an unpredictable competition. In light of our findings, we highly recommend developing interventions to shape optimal goal orientations across stages of preparation, pre- and within-competition.

Limitations and Future Directions

Certain limitations of our study should not be overlooked. First, caution must be applied when generalizing the results of this study that are related to cluster analysis. The labels in each cluster group are created in relation to the z scores and are therefore sample-specific. Even though the unstandardized means difference between a lower ($M = 2.43$) to a higher ($M = 4.17$) ego orientation and that between a lower ($M = 3.94$) and higher ($M = 4.61$) task orientation seem fair, we can easily recognize a typical positive skewing of task orientation (Harwood et al., 2004). It seems more noteworthy when we attempt to emphasize the balance of both goal orientations; yet the criteria for labeling them are not identical. Thus, although evidence supported the effectiveness of our cluster solution grouping the participants distinctly, we should be meticulous when generalizing these findings to a wider athletic population. Apart from that, as the sample participants in current study were limited to Chinese athletes, caution must also be applied when generalizing these findings to multi-ethnic athletes.

With regard to future work, researchers should consider exploring the neuroscientific mechanism that leads to debilitative outcomes among individuals with high levels of ego-orientation. In other words, determining the exact process of high level of ego-orientation impairing motor performance under a high competitive cognitive anxiety condition is imperative. More research is also needed to explore additional potential mediators, such as interpretations of anxiety and self-control.

CONCLUSION

The results of this study highlight the benefit of task-orientation when athletes face competition consisting of ego-threat conditions. The results also reinforce the importance of reducing ego orientation as much as possible for better preparation, as well as a situational coping strategy for the competition. Finally, the results do not support the moderating effect of self-efficacy, which indicates that self-efficiency may not have special effects on motor performance under a competitive condition when the level of cognitive anxiety seems high.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Psychology Ethics Committee, School of Psychology, Beijing Sport University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FP and L-WZ conceived the study. FP collected data. FP planned the analytical approach, performed the analyses, and wrote the manuscript, with feedback from L-WZ. Both authors approved the content of the manuscript.

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What Makes an Elite Shooter and Archer? The Critical Role of Interoceptive Attention

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It is well-acknowledged that attention is important for expert performance in sports. However, the role of interoceptive attention, i.e., the attentional mechanism of awareness and conscious focus of bodily somatic and visceral signals, in self-paced and far-aiming sports remains to be explored. This study aims to investigate the relationship of expertise level and interoceptive attention ability in shooting and archery, and to examine if interoceptive attention can be improved by mindfulness training in elite athletes of shooting and archery. We tested the performance differences of 41 elite athletes from the Chinese national team of shooting and archery and 43 non-elite athletes from a provincial team in breath detection task (BDT) and dot flash detection task (DDT), which were designed to measure interoceptive and exteroceptive attention (i.e., attention toward information input of primary sensory), respectively. Furthermore, we applied mindfulness training to the 41 elite athletes for 5–8 weeks and remeasured their performances of BDT and DDT. Results showed that elite athletes outperformed non-elite athletes in BDT (but not in DDT) both in accuracy ($\text{Diff}_{\text{BDT}} = 11.50\%$, $p = 0.004$) and in discrimination sensitivity (d', $\text{Diff}_{\text{BDT}} = 1.159$, $p = 0.002$). Difference in accuracy and d' reached significant level only in BDT (accuracy: $\text{Diff}_{\text{BDT}} = -8.50\%$, $p = 0.001$; d': $\text{Diff}_{\text{BDT}} = -0.822$, $p = 0.003$) before and after mindfulness training. These results indicate that elite athletes of shooting and archery (i.e., relative to non-elite athletes) can better perceive the somatic and visceral responses or changes and discriminate these signals from noises. Moreover, interoceptive attention can be improved by mindfulness training. These results have important implications for the selection and training of athletes of shooting and archery.

Keywords: shooting, archery, interoceptive attention, breath detection task, mindfulness training

INTRODUCTION

How to achieve excellent performance in sports or to become an elite athlete? In addition to professional skills, it is well-acknowledged that attention is vital for success in sports. Some researchers even claimed that there may be no other aspect of psychology that could be more important to athletic performance than attention (Moran, 2004; Abernethy et al., 2007). In general, attention refers to the ability to focus on specific stimulus or locations (Goldstein, 2011). It is an important part of cognitive functioning, which supports various activities of individuals and has many different manifestations, such as alerting, selective, sustained, and divided (Tamm et al., 2013; Reigal et al., 2020). Earlier studies have found that attention is related to other aspects of cognitive functioning, such as executive control, learning, and memory (Logue and Gould, 2014; Bialystok, 2015; Campillo et al., 2018). There are two lines of research with respect to the relationship between attention (as well as cognitive functioning) and sports. First, some studies focus on the benefits that physical activities bring on attention in childhood, adolescence, and senescence (Crespillo-Jurado et al., 2019; Xue et al., 2019; Hernández-Mendo et al., 2020). Second, studies have also explored the effect of attention on athletes of different sports with the intention to help them achieve success (Vestberg et al., 2017; Policastro et al., 2018; Hernández-Mendo et al., 2019). To enrich the discussion on the topic, in this study, we aimed to explore the relationship between specific attention ability (namely interoceptive attention) and expertise level in shooting and archery sports, and to examine if this attention ability can be improved through intervention.

Attention can be divided into exteroceptive attention, interoceptive attention, and executive control of attention according to information sources (Wang et al., 2019). Exteroceptive attention refers to attending to the external information input of primary sensory, such as visual stimulus. Interoceptive attention refers to attending to internal body signals, such as somatic and visceral signals. Executive control of attention refers to coordinating our actions and thoughts, such as those reflected in Stroop and flanker tasks. The roles of attentional modulation across perceptual inputs and executive control of attention have been discussed in different sports [for a review, see Memmert (2009)]. In shooting and archery sports, the roles of arousal, vigilance, orienting, and conflict control have been stressed (Bertollo et al., 2012; Kim et al., 2019; Lu et al., 2021). However, the fact that many athletes of shooting and archery are actually shortsighted reminds us that there may also be some other attention ability that contributes to the success in shooting and archery. For example, Yifu Wang, a champion of 10-m air pistol in 1992 Barcelona and 2004 Athens Olympics, whose uncorrected vision is only 0.1. Short sight makes it difficult for those athletes to rely solely on visual information to aim the target, so their internal states may also be used. Such cases indicate that attention toward the self-status (specifically, interoceptive attention, Farb et al., 2013; Wang et al., 2019) may also be important to athletes of shooting and archery. This inference is consistent with the self-paced and far-aiming features of these two sports. As Moran (2004) noted, "the structure of a sport can affect its psychological requirements." While some open skill sports (e.g., soccer and basketball) are physical-contact teamwork games with moving targets and may rely on visual attention, some closed skill sports, such as shooting and archery, are characterized by self-paced and far-aiming or targeting and thus may rely heavily on the status of athletes themselves. In shooting and archery sports, actions are mainly carried out at his/her own speed and without interference from others. This relatively isolated situation makes attention toward the self-status extremely important to achieve high performance and to become an elite athlete.

When considering attention toward the self-status, people may first consider proprioception. In fact, earlier research has found that there was a smaller body sway range in elite archers (Simsek et al., 2019) and that skilled air-pistol shooting players coordinated posture and upper-limb movements better than novice players (Ko et al., 2017). However, according to self-focus theories, when athletes perform automated skilled behaviors, directing their attention internally to themselves (i.e., focusing on task-related movements) would disrupt the automatic movements and thereby impair the performance (Masters and Maxwell, 2008). The body sway and coordination of limb movements, suggested by Simsek et al. (2019) and Ko et al. (2017), are the objective measures during shooting processes, rather than the focus of attention. It is likely that directing attention to proprioception may disrupt the automatic movement processes and exert negative influence on shooting and archery performances. Thus, we believed that attention to proprioception is not the self-status-oriented attention ability that acts as a positive contributor to an elite athlete.

If it was not attention to proprioception, then what is it that makes an elite shooter or archer? We proposed that interoceptive attention is important for an elite athlete in shooting and archery sports. Interoceptive attention represents a system associated with internal feelings of vasomotor activity, heartbeat, thirst, hunger, temperature, and other visceral sensations (Craig, 2002, 2003, 2010; Brener and Ring, 2016). The lamina I spinothalamocortical pathway, proposed by Craig (2002, 2003, 2010), provides a homeostatic afferent system that directly passes sensory signals of different modalities to the forebrain. The signals that represent physiological conditions of the body first input to lamina I and the nucleus of the solitary tract. Then, they are relayed by parabrachial nucleus, the medial dorsal nucleus and thalamus (i.e., the posterior ventral medial nucleus and the basal ventral medial nucleus) to the anterior cingulate cortex, insula, and other interoceptive cortex. The distinct feelings from the body appear as a result of the primary interoceptive representation in the dorsal posterior insula. Finally, these signals are transmitted into the right anterior insula where an ultimate meta-representation of the primary interoceptive activities emerges.

Under this lamina I spinothalamocortical pathway framework, an advantage in interoceptive attention may benefit athletes of shooting and archery in two ways. First, the representation of physiological conditions of the body (e.g., pain, temperature, muscular and visceral sensations, and vasomotor activity) may help the coordination of limb movements in aiming processes. Since the focus of attention is not the movement itself, interoceptive attention would not interrupt the automatic process of movements. In fact, when training athletes to pay attention to bodily signals such as heartbeat and respiratory signals, better performances were observed in running (Moran, 2000) and swimming (Couture et al., 1999). These results imply that interoceptive attention may be important for expert performance in sports. Second, it is believed that the integration representation of physiological condition of all tissues of the body underlies emotional awareness (Cannon, 1987; Damasio, 1996; Dolan, 2002; Craig, 2003; Critchley and Harrison, 2013). Sports performances are often impaired by anxiety of competition (Payne et al., 2019). Shooting and archery sports are no exception. Appropriate attention to physical state and accurate perception of internal sensory information are vital to maintain a normal physiological state and awareness of emotion (Craig, 2003, 2010; Critchley, 2005; Wiens, 2005). It is possible that shooters and archers with high interoceptive attention can accurately perceive the internal sensory signals and form an appropriate representation of physiological conditions of the body. This would enable athletes to avoid inappropriate emotions like anxiety that would negatively influence performance and would also help them perform better emotion regulation if inappropriate emotions arise. Therefore, we believed that interoceptive attention is important for shooting and archery, and there can be an advantage in interoceptive attention ability among elite athletes. The first aim of this study was to examine this hypothesis by testing the difference between elite and non-elite athletes of shooting and archery in interoceptive attention ability.

We used the breath detection task (BDT), suggested by Wang et al. (2019), as the interoceptive attention measurement in this study. In BDT, participants are asked to judge whether the respiratory curve displayed on screen is synchronized or delayed when compared with their own breathing rhythm. The control exteroceptive attention task asked participants to judge whether a red dot rapidly appeared on the respiratory curve (i.e., dot flash detection task, DDT). The accuracies of these two tasks represent the interoceptive and exteroceptive attention abilities of the individuals. By using BDT and DDT, Wang et al. (2019) demonstrated the involvement of the anterior insular cortex (AIC) in interoceptive attention. This finding appears to support the notion that an ultimate meta-representation of interoception forms in AIC (Craig, 2010; Critchley and Harrison, 2013). According to Garfinkel et al. (2016), there are three dimensions of interoception, namely, accuracy, sensibility, and metacognitive awareness. Earlier studies have proposed that accurate perceptions of physiological conditions of the body are important for emotion awareness (Critchley, 2005; Wiens, 2005; Craig, 2010). The association of reduced anxiety with greater accuracy of respiration task, suggested by Garfinkel et al. (2016), supported this perspective. Therefore, we focused on accuracy in this study. We chose the respiratory axis of interoception because compared with other axes (e.g., cardiac and stomach), respiration may be under greater voluntary control (Garfinkel et al., 2016). The availability of voluntary control may be important for implementing effective interventions. By comparing the difference in the performance of BDT and DDT between elite and non-elite athletes, we intended to improve our understanding of the relationship between expertise level and interoceptive attention in sports that are characterized by self-paced and far-aiming (e.g., shooting and archery).

If there is a relationship between expertise level and interoceptive attention ability, it preliminarily suggests that interoceptive attention is important for shooters and archers. Then, an important question is how to improve it. Recent research suggests that a promising candidate is mindfulness training. Mindfulness refers to "the awareness that emerges through paying attention on purpose in the present moment, and non-judgmentally to the unfolding of experience moment by moment" (Kabat-Zinn, 2003). Recent studies have found that mindfulness training significantly improved various attention abilities (He and Wang, 2020), such as sustained attention (MacLean et al., 2010; Jha et al., 2015; Bardart et al., 2018), conflict control (Elliott et al., 2014; Becerra et al., 2017), and selective attention distribution (Colzato et al., 2015; Schofield et al., 2015). In particular, a sport-specific mindfulness training program was applied to elite shooting athletes, and attention improvement was found after training (Bu et al., 2019). Since the mindfulness training program, such as mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1982, 1990) and mindfulness-based cognitive therapy (MBCT; Teasdale et al., 1995, 2000), contains mindfulness of breath, sweeping, and other perceptions of the body, we believed that interoceptive attention can also be improved after training. Thus, the second aim of this study was to examine whether interoceptive attention can be improved by mindfulness training.

The self-paced and far-aiming features of shooting and archery and the fact that many athletes of shooting and archery are shortsighted reminded us that interoceptive attention ability supported by the lamina I spinothalamocortical pathway may also be important for success in these two sports. This study aims to examine the relationship between expertise level and interoceptive attention ability by testing if there is an advantage of elite shooters and archers in BDT, in comparison with non-elite athletes, and to investigate whether mindfulness training can improve interoceptive attention. We compared the performances of athletes from national and provincial teams in BDT and DDT. We predicted that athletes from the national team would outperform their counterparts from the provincial team in BDT. We also had elite shooters and archers in the national team who would receive mindfulness training for the time course of 5–8 weeks. Our hypothesis is that the interoceptive attention of elite athletes of shooting and archery will be improved after training.

MATERIALS AND METHODS

Participants

Eighty-four athletes of shooting and archery participated in this study (46 females and 38 males, age: 21.73 ± 5.07 years, $Min_{age} = 14$, $Max_{age} = 40$). Forty-one of them (21 females and 20 males, age: 24.54 ± 5.38 years, $Min_{age} = 16$, $Max_{age} = 40$) were from the Chinese national team of shooting and archery, and the remaining 43 (17 females and 26 males, age: 19.05±2.85 years, $Min_{age} = 14$, $Max_{age} = 29$) were from the team of Hebei Province, China. We identified the athletes in the national team as the elite group because those athletes are top performers across the country and have been selected as candidates for international competitions. Informed consent was obtained from all athletes before the experiment. This study was approved by the Committee for Protecting Human and Animal Subjects, School of Psychological and Cognitive Sciences, Peking University, and it was conducted in accordance with the principles of the Declaration of Helsinki (World Medical Association, 2013).

Procedure

All of the athletes participated in the BDT and DDT tests. Athletes in the national team then received mindfulness training for 5–8 weeks and took the BDT and DDT tests again. The order of BDT and DDT was counterbalanced in athletes. All athletes completed BDT and DDT in a quiet room. They sat in front of the testing computer in a comfortable position and were required to breathe in a normal and natural way during the whole experiment.

The breath detection task (BDT) was designed to measure interoceptive attention, and DDT was designed to measure exteroceptive attention (**Figure 1**, Wang et al., 2019). The clear perception and autonomous control features of breathing make it feasible to measure interoceptive attention. The findings, suggested by Wang et al. (2019), which object interoceptive accuracy of BDT positively correlated with subjective rating of difficulty of interoceptive task has supported that BDT is a valid measurement of the interoceptive attention. According to Wang et al. (2019), the split-half reliabilities of both BDT and DDT in one sample are 0.86 and 0.85.

In BDT, breathing of the participants was converted into electronic signals by using the A/D converter (USB-1208HS-4AO, Measurement Computing, Inc., Norton, MA, USA), making recordings of their breathing as respiratory curves displayed on the screen. In each trial, after a 3-s relax screen, a respiratory curve would appear on the screen running from left edge to right edge for 12 s. The respiratory curve would be either real-time (non-delayed condition) or 0.4 s delay (delayed condition) to the breathing rhythm of the participants. Then, a response screen appeared for 3 s on which participants had to respond by choosing from two options to indicate whether the respiratory curve was synchronous or delayed. The interval between trials is 2 s. The procedure in DDT was similar to that in BDT, except that in half of the trials, a red dot would flash on the curve for 30 ms (dot condition) anytime during a 12 s period, and in the other half, no dot has appeared (no-dot condition). The task of the participants was to determine whether the red dot appeared. In the beginning, four illustration trials were administrated to help athletes get familiar with each task. The formal experiment began after eight practice trials. There are 40 trials in the formal experiment of each task (BDT and DDT) and 20 trials for each condition. It took about 50 min to finish these two tests.

The breathing of the athletes was recorded by using a respiratory transducer (TSD201, BIOPAC Systems Inc.) that was fastened around their upper chest to measure the thoracic circumference changes. Signals of circumference changes were sampled at 1,000 Hz by using the BIOPAC MP150/RSP100C system and passed through a DC amplifier with gain set to 10 V. The low-pass filtering was set at 1 Hz and high-pass filtering at 0.05 Hz. The digitalization of analog signals was finished by an A/D converter (USB-1208HS-4AO, Measurement Computing Inc., Norton, MA, USA), and the digitized signal was sent to a USB port of the test computer. The task program was run in E-Prime (Psychology Software Tools, Pittsburgh, PA, USA), which was used as an interface to present athletes the digitized signal from the USB port (indicated by continuous blue respiratory curves).

The mindfulness training comprised sweeping, mindfulness of breath, and other perceptions, which were adapted from MBSR (Kabat-Zinn, 1990) and MBCT (Teasdale et al., 2000). MBSR is an 8-week course of mindfulness training designed to help people achieve self-development, self-discovery, learning, and

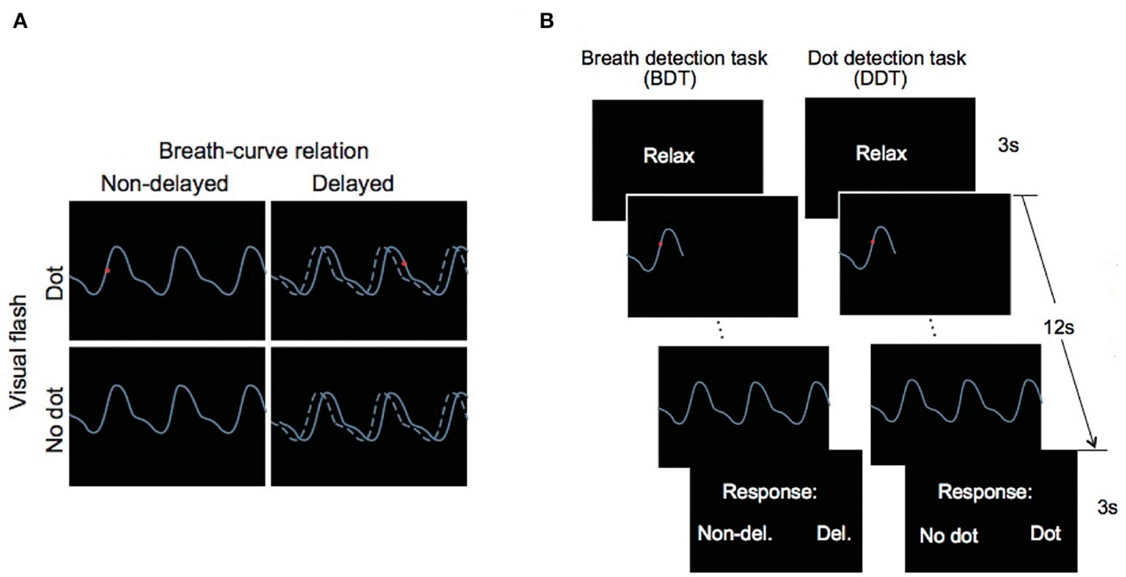

FIGURE 1 | (A) Possible conditions. The solid line represents the respiratory curve displayed on the screen. The dashed line represents the actual breathing curve. **(B)** Sample of a trial in the breath detection task (BDT) and the dot flash detection task (DDT). Adapted from Wang et al. (2019).

healing. MBCT is an intervention designed to help recovered recurrently depressed patients avoid relapse or recurrence. Some of the practices in MBCT were designed for depression, thus inappropriate for the present sample, so these practices were replaced by some content in MBSR (e.g., mindfulness yoga). In summary, the mindfulness training content included body scans, sitting meditation, walking meditation, and mindfulness yoga. Body scans referred to concentrating on the body sensation from head to toe. Sitting meditation referred to attending to and experiencing breath or thought when one is sitting in a comfortable position. Walking meditation referred to observing and sensing the moving parts of the body. Mindfulness yoga referred to focusing and keeping on stretching. Athletes of shooting and archery followed a professional coach to perform mindfulness training once a week for 1.5 h each time. They were asked to conduct a homework practice every day whenever they had time for 15 min.

Data Analysis

The SPSS software version 21.0 (IBM, Armonk, NY, USA) was used for the data analysis. Performance accuracy (%) and discrimination sensitivity (d') were calculated for BDT and DDT, respectively. We, first, compared performances of athletes with chance level by one-sample t-tests for both groups. Then, 2 (Group: National vs. Provincial) × 2 (Task: BDT vs. DDT) ANOVAs of accuracy and d' were conducted to investigate the difference of interoceptive attention and exteroception attention between elite athletes from the national team and non-elite athletes in the provincial team. Finally, 2 (Time: Pre vs. Post) × 2 (Task: BDT vs. DDT) repeated-measure ANOVAs of accuracy and d' were conducted to examine the effect of mindfulness training on interoceptive and exteroceptive attention in elite athletes. In addition, we also conducted a similar ANOVA analysis to examine the effect of mindfulness training for elite shooters and archers separately.

RESULTS

Accuracy and d' of two tasks in both teams were significantly above the chance level (50% and 0 for accuracy and d', respectively). For accuracy, $BDT_{national}$: $t(40) = 12.987$, $p < 0.001$, Cohen's $d = 2.03$; $DDT_{national}$: $t(40) = 24.406$, $p < 0.001$, Cohen's $d = 3.81$; $BDT_{provincial}$: $t(42) = 7.502$, $p < 0.001$, Cohen's $d = 1.14$; $DDT_{provincial}$: $t(42) = 32.286$, $p < 0.001$, Cohen's $d = 4.92$. For d', $BDT_{national}$: $t(40) = 10.138$, $p < 0.001$, Cohen's $d = 1.58$; $DDT_{national}$: $t(40) = 18.474$, $p < 0.001$, Cohen's $d = 2.89$; $BDT_{provincial}$: $t(42) = 6.554$, $p < 0.001$, Cohen's $d = 1.00$; $DDT_{provincial}$: $t(42) = 22.848$, $p < 0.001$, Cohen's $d = 3.47$. Accuracy and d' of two tasks after mindfulness training in national team were also significantly above the chance level. For accuracy, $BDT_{national}$: $t(40) = 26.730$, $p < 0.001$, Cohen's $d = 4.17$; $DDT_{national}$: $t(40) = 28.423$, $p < 0.001$, Cohen's $d = 4.44$. For d', $BDT_{national}$: $t(40) = 18.226$, $p < 0.001$, Cohen's $d = 2.85$; $DDT_{national}$: $t(40) = 21.191$, $p < 0.001$, Cohen's $d = 3.30$.

Differences in Interoceptive Attention Between Groups

Results of 2 (Group: National vs. Provincial) × 2 (Task: BDT vs. DDT) ANOVAs for accuracy (**Table 1**) showed a group effect, $F_{(1, 82)} = 7.835$, $p = 0.006$, partial $\eta^2 = 0.087$, $Diff_{national-provincial} = 6.04\%$, 95% CI = [1.7, 10.3%] and a task effect, $F_{(1, 82)} = 32.189$, $p < 0.001$, partial $\eta^2 = 0.282$, $Diff_{BDT-DDT} = -13.12\%$, 95% CI = [−17.5, −8.4%]. The group × task interaction was also significant, $F_{(1, 82)} = 5.773$, $p = 0.019$, partial $\eta^2 = 0.066$. The simple effect analysis indicated that accuracy difference reached significant level only in BDT between groups, $Diff_{BDT} = 11.50\%$, 95% CI = [3.7, 19.4%], $p = 0.004$. No significant difference was found in DDT, $Diff_{DDT} = 0.50\%$, 95% CI = [−3.6, 4.7%], $p = 0.797$.

Similar results were obtained by 2 (Group: National vs. Provincial) × 2 (Task: BDT vs. DDT) ANOVAs for d' (**Table 2**): group effect, $F_{(1, 82)} = 9.818$, $p = 0.002$, partial $\eta^2 = 0.107$, $Diff_{national-provincial} = 0.676$, 95% CI = [0.247, 1.105]; task effect, $F_{(1, 82)} = 30.127$, $p < 0.001$, partial $\eta^2 = 0.269$, $Diff_{BDT-DDT} = -1.246$, 95% CI = [−1.697, −0.794]; group × task interaction, $F_{(1, 82)} = 4.536$, $p = 0.036$, partial $\eta^2 = 0.052$. The simple effect analysis indicated that d' difference reached significant level only in BDT between groups, $Diff_{BDT} = 1.159$, 95% CI = [0.420, 1.898], $p = 0.002$; $Diff_{DDT} = 0.193$, 95% CI = [−0.287, 0.672], $p = 0.427$.

The results remained significant after controlling for age except the task effects for both accuracy and d'.

TABLE 1 | Accuracy (%) in BDT and DDT between the groups.

	BDT				DDT			
	M (SD)	*S*	*K*	*K–S*	*M (SD)*	*S*	*K*	*K–S*
National ($n = 41$)	83.59 (16.56)	−0.97	−0.05	1.06	91.07 (10.78)	−2.96	12.10	1.47*
Provincial ($n = 43$)	72.05 (19.27)	−0.18	−1.27	0.91	90.53 (8.23)	−1.89	4.33	1.43*
Difference	11.54**	–	–	–	0.54	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.
**p < 0.05, **p < 0.01.*

TABLE 2 | Discrimination sensitivity (*d′*) in BDT and DDT between the groups.

	BDT				DDT			
	***M* (*SD*)**	***S***	***K***	***K–S***	***M* (*SD*)**	***S***	***K***	***K–S***
National ($n = 41$)	2.80 (1.77)	−0.16	−1.27	0.75	3.56 (1.23)	−0.98	1.91	0.70
Provincial ($n = 43$)	1.64 (1.64)	0.56	−0.46	0.87	3.37 (0.97)	−0.31	0.49	0.93
Difference	1.16**	–	–	–	0.19	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.
$^{**}p < 0.01$.

TABLE 3 | Accuracy (%) in BDT and DDT before and after the mindfulness training in the national team ($n = 41$).

	BDT				DDT			
	***M* (*SD*)**	***S***	***K***	***K–S***	***M* (*SD*)**	***S***	***K***	***K–S***
Pre	83.59 (16.56)	−0.97	−0.05	1.06	91.07 (10.78)	−2.96	12.10	1.47*
Post	92.12 (10.09)	−2.38	6.84	2.02**	91.07 (9.25)	−3.38	15.20	1.70**
Difference	−8.53***	–	–	–	0.00	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Effects of Mindfulness Training on Interoceptive Attention in the National Team

Results of 2 (Time: Pre vs. Post) × 2 (Task: BDT vs. DDT) ANOVAs for accuracy (**Table 3**) showed a time effect, $F_{(1, 40)} = 8.636$, $p = 0.005$, partial $\eta^2 = 0.178$, $\text{Diff}_{\text{pre}-\text{post}} = -4.27\%$, 95% CI = [−7.2, −1.3%] and a time × task interaction, $F_{(1, 40)} = 9.575$, $p = 0.004$, partial $\eta^2 = 0.193$. The simple effect analysis indicated that accuracy difference reached significant level only in BDT before and after mindfulness training, $\text{Diff}_{\text{BDT}} = -8.5\%$, $p = 0.001$, 95% CI = [−13.5, −3.6%]; $\text{Diff}_{\text{DDT}} = 0$, $p = 1.000$, 95% CI = [−2.9, 2.9%]. Task effect was not significant, $F_{(1, 40)} = 1.792$, $p = 0.188$, partial $\eta^2 = 0.043$, $\text{Diff}_{\text{BDT}-\text{DDT}} = -3.22\%$, 95% CI = [−8.1, 1.6%].

Results of 2 (Time: Pre vs. Post) × 2 (Task: BDT vs. DDT) ANOVAs for d' (**Table 4**) revealed a time × task interaction, $F_{(1, 40)} = 11.461$, $p = 0.002$, partial $\eta^2 = 0.223$. The simple effect analysis indicated that d' difference reached significant level only in BDT before and after mindfulness training, $\text{Diff}_{\text{BDT}} = -0.822$, $p = 0.003$, 95% CI = [−1.344, −0.300]; $\text{Diff}_{\text{DDT}} = 0.229$, $p = 0.254$, 95% CI = [−0.171, 0.629]. Neither time effect nor task effect reached significant level, $F_{(1, 40)} = 3.049$, $p = 0.088$, partial $\eta^2 = 0.071$, $\text{Diff}_{\text{pre}-\text{post}} = -0.29$, 95% CI = [−0.639, 0.047]; $F_{(1, 40)} = 0.767$, $p = 0.386$, partial $\eta^2 = 0.019$, $\text{Diff}_{\text{BDT}-\text{DDT}} = -0.23$, 95% CI = [−0.784, 0.310], respectively.

Effects of Mindfulness Training on Interoceptive Attention in Elite Shooting Athletes in the National Team

Results of 2 (Time: Pre vs. Post) × 2 (Task: BDT vs. DDT) ANOVAs for accuracy (**Table 5**) showed a time effect, $F_{(1, 26)} = 14.856$, $p = 0.001$, partial $\eta^2 = 0.364$, $\text{Diff}_{\text{pre}-\text{post}} = -7.0\%$, 95% CI = [−10.7%, −3.3%], and a time × task interaction, $F_{(1, 26)} = 5.619$, $p = 0.025$, partial $\eta^2 = 0.178$. The simple effect analysis indicated that accuracy difference reached significant level only in BDT before and after mindfulness training, $\text{Diff}_{\text{BDT}} = -11.2\%$, $p = 0.002$, 95% CI = [−17.9, −4.6%]; $\text{Diff}_{\text{DDT}} = -2.8\%$, $p = 0.092$, 95% CI = [−6.0, 0.5%]. Task effect was not significant, $F_{(1, 26)} = 1.726$, $p = 0.200$, partial $\eta^2 = 0.062$, $\text{Diff}_{\text{BDT}-\text{DDT}} = -4.5\%$, 95% CI = [−11.6, 2.6%].

Results of 2 (Time: Pre vs. Post) × 2 (Task: BDT vs. DDT) ANOVAs for d' (**Table 6**) revealed a time effect, $F_{(1, 26)} = 7.832$, $p = 0.010$, partial $\eta^2 = 0.232$, $\text{Diff}_{\text{pre}-\text{post}} = -0.591$, 95% CI = [−1.025, −0.157], and a time × task interaction, $F_{(1, 26)} = 8.863$, $p = 0.006$, partial $\eta^2 = 0.254$. The simple effect analysis indicated that d' difference reached significant level only in BDT before and after mindfulness training, $\text{Diff}_{\text{BDT}} = -1.163$, $p = 0.001$, 95% CI = [−1.828, −0.498]; $\text{Diff}_{\text{DDT}} = -0.019$, $p = 0.937$, 95% CI = [−0.515, 0.477]. The task effect did not reach significant level, $F_{(1, 26)} = 0.728$, $p = 0.401$, partial $\eta^2 = 0.027$, $\text{Diff}_{\text{BDT}-\text{DDT}} = -0.315$, 95% CI = [−1.075, 0.444].

TABLE 4 | Discrimination sensitivity (*d*′) in BDT and DDT before and after the mindfulness training in the national team ($n = 41$).

	BDT				DDT			
	***M* (*SD*)**	***S***	***K***	***K–S***	***M* (*SD*)**	***S***	***K***	***K–S***
Pre	2.80 (1.77)	−0.16	−1.27	0.75	3.56 (1.23)	−0.98	1.91	0.70
Post	3.62 (1.27)	−0.80	0.37	0.93	3.33 (1.01)	−0.69	3.12	0.65
Difference	−0.82**	–	–	–	0.23	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.
***p < 0.01.*

TABLE 5 | Accuracy (%) in BDT and DDT before and after the mindfulness training in elite shooting athletes of the national team ($n = 27$).

	BDT				DDT			
	***M* (*SD*)**	***S***	***K***	***K–S***	***M* (*SD*)**	***S***	***K***	***K–S***
Pre	80.30 (17.56)	−0.76	−0.46	0.84	89.04 (12.55)	−2.49	8.41	0.99
Post	91.52 (11.41)	−2.25	5.83	1.71**	91.81 (10.00)	−4.21	19.97	1.69**
Difference	−11.22**	–	–	–	−2.77	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.
***p < 0.01.*

TABLE 6 | Discrimination sensitivity (*d*′) of BDT and DDT before and after the mindfulness training in elite shooting athletes of the national team ($n = 27$).

	BDT				DDT			
	***M* (*SD*)**	***S***	***K***	***K–S***	***M* (*SD*)**	***S***	***K***	***K–S***
Pre	2.46 (1.77)	0.09	−1.21	0.57	3.35 (1.36)	−0.81	1.25	0.62
Post	3.62 (1.35)	−0.96	0.53	0.98	3.37 (1.03)	−1.43	5.20	0.97
Difference	−1.16***	–	–	–	−0.02	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.
****p < 0.001.*

Effects of Mindfulness Training on Interoceptive Attention in Elite Archery Athletes in the National Team

Results of 2 (Time: Pre vs. Post) × 2 (Task: BDT vs. DDT) ANOVAs for accuracy (**Table 7**) revealed no significant effects. Time effect: $F_{(1, 13)} = 0.329$, $p = 0.576$, partial $\eta^2 = 0.025$, $\text{Diff}_{\text{pre-post}} = -1.0\%$, 95% CI = [−2.8%, 4.8%]. Task effect: $F_{(1, 13)} = 0.088$, $p = 0.771$, partial $\eta^2 = 0.007$, $\text{Diff}_{\text{BDT-DDT}} = -0.07\%$, 95% CI = [−5.9%, 4.5%]. Time × task interaction: $F_{(1, 13)} = 3.868$, $p = 0.071$, partial $\eta^2 = 0.229$.

Results of 2 (Time: Pre vs. Post) × 2 (Task: BDT vs. DDT) ANOVAs for d' (**Table 8**) revealed no significant effects. Time effect: $F_{(1, 13)} = 1.482$, $p = 0.245$, partial $\eta^2 = 0.102$, $\text{Diff}_{\text{pre-post}} = 0.272$, 95% CI = [−0.211, 0.754]. Task effect: $F_{(1, 13)} = 0.056$, $p = 0.816$, partial $\eta^2 = 0.004$, $\text{Diff}_{\text{BDT-DDT}} = -0.086$, 95% CI = [−0.863, 0.692]. Time × task interaction, $F_{(1, 13)} = 2.576$, $p = 0.133$, partial $\eta^2 = 0.165$.

DISCUSSION

This study demonstrated the relationship between expertise level and interoceptive attention and showed that mindfulness training can effectively improve interoceptive attention in elite athletes of shooting and archery. These results provided preliminary evidence for the importance of interoceptive attention in shooting and archery sports.

TABLE 7 | Accuracy (%) of BDT and DDT before and after the mindfulness training in elite archery athletes of the national team ($n = 14$).

	BDT				DDT			
	***M* (*SD*)**	***S***	***K***	***K–S***	***M* (*SD*)**	***S***	***K***	***K–S***
Pre	89.93 (12.71)	−1.40	0.87	1.16	95.00 (4.15)	−0.94	1.35	0.64
Post	93.29 (7.13)	−2.18	6.23	1.01	89.64 (7.75)	−0.57	−0.46	0.63
Difference	−3.36	–	–	–	5.36	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.

TABLE 8 | Discrimination sensitivity (d') of BDT and DDT before and after the mindfulness training in elite archery athletes of the national team ($n = 14$).

	BDT				DDT			
	***M* (*SD*)**	***S***	***K***	***K–S***	***M* (*SD*)**	***S***	***K***	***K–S***
Pre	3.44 (1.63)	−0.67	−0.81	0.69	3.96 (0.83)	−0.28	0.75	0.62
Post	3.61 (1.14)	−0.32	0.04	0.47	3.26 (1.01)	1.03	0.14	0.77
Difference	−0.17	–	–	–	0.70	–	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov test; BDT, breath detection task; DDT, dot flash detection task.

Comparisons of performances between the national and provincial groups showed that elite shooters and archers outperform athletes from provincial teams in BDT, whereas the two groups did not significantly differ from each other in DDT. A similar pattern was found in d' results which showed that the sensitivity of elite shooters and archers was higher than that of provincial athletes in BDT, but not in DDT. These results suggest that elite shooters and archers indeed have higher interoceptive attention ability. In other words, they can better perceive the somatic and visceral responses or changes and discriminate these signals from noises. According to Critchley and Harrison (2013), the afferent input of the internal body signals serves as sources on which individuals organize cognitive, emotional, and behavioral responses. This may be the mechanism through which the advantage of elite athletes in interoceptive attention exerts its influence. Higher ability in interoceptive attention may be important in the preparation stage during which athletes can adjust their postures based on the current physiological states. It may also benefit the regulation of negative emotions, given the notion that the arising of emotions is inseparable from somatic reactions and visceral signals (Critchley, 2005; Wiens, 2005; Craig, 2010). During the competition, once negative emotion like anxiety arises, accurately perceiving the accompanied physiological changes such as increased heartbeat and muscle stiffness may be the first step to adjustment and further regulation of negative emotions.

The results of mindfulness training showed that the performance of elite shooters and archers improved significantly in BDT but remained unchanged in DDT after receiving mindfulness training. The sensitivity in BDT, but not in DDT, also improved after mindfulness training. Even though elite shooters and archers showed better performance in BDT than provincial players, mindfulness training still improved their interoceptive attention ability. This improvement may benefit from the content of mindfulness training. The content includes keeping focus on a particular point or experience, such as sweeping and mindfulness of breath in a non-judging way (Kabat-Zinn, 1982). Athletes were instructed to redirect their focus to the current attention (e.g., sweeping and breathing) whenever they found their mind drifting somewhere else. Through continuous practice, they were eventually able to keep their attention on bodies for a long period of time, allowing them to quickly and accurately detect physiological changes. We speculated that the neural mechanism that supports this improvement may rely on AIC. On the one hand, the lamina I spinothalamocortical pathway hypothesis indicates that AIC is the destination of transmission of signals that represent physiological conditions of the body. The right AIC integrates the afferent signals and generates an ultimate meta-representation of the primary interoceptive activities (Craig, 2002, 2003, 2010). The finding of AIC activity related to interoceptive attention, suggested by Wang et al. (2019), supports this hypothesis. On the other hand, studies on mindfulness training consistently report increased activity (Lutz et al., 2014; Wheeler et al., 2017; Young et al., 2018), gray matter thickness (Lazar et al., 2005), and gyrification (Luders et al., 2012) of the AIC. So, it may be possible that the mindfulness training increases AIC activity, gray matter thickness, gyrification, or all of them in the elite athletes, and these increased characteristics of

AIC lead to accurate perception of bodily states, which manifest in higher performance of BDT. This may also explain why there was no improvement in the performance of DDT. However, the result that no improvement was found in the performance of DDT does not lead to the conclusion that mindfulness training has no effect on exteroceptive attention. The sensory input of exteroceptive attention has different modalities. We used visual stimulus in this study. Future studies can examine the effect of mindfulness training on other modalities of exteroceptive attention (e.g., auditory stimuli). There are possibilities that mindfulness training may influence the attentional modulation of different perceptual and sensory inputs.

Studies have demonstrated that 4 weeks of mindfulness training could have an influence on dimensions of trait variables in the athletes (Kaufman et al., 2009). Although we initially planned an 8-week training period, due to the different training schedules of elite athletes, it is hard to guarantee the full training period of each athlete. But we managed that all athletes received at least 5 weeks of mindfulness training. A recent review on mindfulness using meta-analysis concluded that a course of 5 weeks would be sufficient to influence the trait mindfulness of an individual (Buhlmayer et al., 2017). Thus, we believed that mindfulness training in this study did exert influence. But it is possible that the additional 3-week training further improved some performance of the athlete compared with the 5-week training. This indicates that our results may reflect a moderate effect of mindfulness training on interoceptive attention. Future studies are recommended to explore the relationship of mindfulness training period and its effect on interoceptive attention in shooting and archery. Some may raise concerns that our experimental design cannot rule out the possibility of practice effect since there was no control group. Should it be a mere practice effect, the performance of the athletes in both BDT and DDT should have been improved. Instead, the results of this study showed an enhancement only in BDT. These results suggest that the improvement of interoceptive attention was not merely a practice effect, but resulted from mindfulness training. Follow-up studies can further investigate the effect of mindfulness training on interoceptive attention in athletes of shooting and archery through random sampling or by adding a control group that does not receive mindfulness training or with brain imaging techniques such as fMRI.

We admitted that there are limitations in this study, and future research can further investigate the role of interoceptive attention in shooting and archery sports in the following aspects. First, our results provide preliminary evidence for the relationship between expertise level and interoceptive attention. But the causal relationship cannot be specified because we did not measure shooting and archery performances. It is possible that the advantage in interoceptive attention results from the high expertise level of elite athletes. Future studies can improve our knowledge about this issue by measuring performances of shooting and archery simultaneously in longitudinal designs. Studies have shown that mindfulness training can improve shooting competition performances (Solberg et al., 1996; John et al., 2011) and facilitates emotion regulation (Wheeler et al., 2017). We speculated that there may be the mediation effects of interoceptive attention and emotion on mindfulness training improving shooting and archery performances. Future studies are encouraged to test these hypotheses by monitoring performances, interoceptive attention during mindfulness training.

Second, the mindfulness training in this study was part of a Psychology Service Program of General Administration of Sport of China for the national team of shooting and archery, thus were only offered to elite athletes. Although it would be more rigorous if the non-elite athletes (provincial team) also received mindfulness training, we believed that the study of mindfulness training in elite athletes also benefits the literature. Our results showed that even though elite athletes had an advantage in interoceptive attention, they still had the possibility of further improvement. We speculated that the effect of mindfulness training has also to be observed in non-elite athletes, and we hope that the findings in this study are also helpful for non-elite athletes. Future studies are welcomed to investigate the effect of mindfulness training on athletes with different skill levels.

Third, in this study, we focused on athlete population only. The comparison between elite and non-elite athletes will give its own contribution to the field. The experiment with non-athlete would further justify the importance of interoceptive attention for elite shooters and archers. We admit that an inclusion of a control group in the mindfulness training experimental design would be more rigorous. Though researchers have found that gender can influence the mindfulness training effect on emotion regulation (Brown et al., 2020), the fact that there was no gender ratio difference between the national and provincial teams relieved us from the suspicion of gender difference confounding. Future studies are still welcomed to explore how gender moderates the effect of mindfulness training in sports of shooting and archery.

On the topic of relationship between interoceptive attention and sports of shooting and archery, this study suggests at least two directions for future research. First, we identified the advantage and improvement of elite athletes in interoceptive attention and proposed its possible influence in shooters and archers, but it remains unknown how the interoceptive attention helps athletes in performance. In addition to better emotional regulation, another possibility is that interoceptive attention may facilitate the formation of automatic movements. The follow-up studies can explore the influence of interoceptive attention on the formation and implementation of automatic movements that are believed important for excellent performance. These can be done by comparing the differences between elite and novice athletes in the longitudinal research. Furthermore, in addition to shooting and archery, future research can also investigate the effect of interoceptive attention on other self-paced and far-aiming sports, such as golf. Interoceptive attention may exert a similar influence on golfers to achieve excellent performances.

Second, at present, in order to help athletes of shooting and archery better perceive their own physiological state during daily training, biofeedback devices are used (Mullineaux et al., 2012; Ortega and Keng, 2018). The biofeedback instrument amplifies the physiological signals to the extent at which they are visually salient to help athletes adjust their coordination of body parts.

However, in official competitions, athletes are not allowed to bring the biofeedback equipment on the field. Whether the athletes can still accurately perceive their own bodily signals or responses and make timely adjustments without the aid of the instrument remains to be seen. According to our results, mindfulness training can improve the interoceptive attention of athletes without using external equipment that amplifies the signals. Subsequent research can test whether the combination of biofeedback and mindfulness training may further assist athletes of shooting and archery.

CONCLUSION

In this study, we found that when compared with athletes in the provincial team, the elite athletes in the national team performed better in BDT, but not in DDT. This result demonstrated the relationship between expertise level and interoceptive attention ability. Moreover, we found that mindfulness training could improve the BDT performance in elite athletes of shooting and archery. These results intensified our understanding of the role of interoceptive attention in self-paced far-aiming sports and have important implications for the selection and training of shooting and archery athletes. Interoceptive attention may be one of the key cognitive abilities for an elite shooter or archer. From the results, we suggested that mindfulness practice can be included in the training of athletes of shooting and archery.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Committee for Protecting Human and Animal Subjects, School of Psychological and Cognitive Sciences, Peking University. Informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

PL contributed to the experimental design, data collection and analysis, and drafting of the manuscript. QL contributed to the experimental design and data collection. QW contributed to the experimental design, data analysis, and revision of the manuscript. XL contributed to the data collection and examined the study. YW conceived of and examined the study, and revised the manuscript. All authors contributed to the article and approved the submitted version.

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The Effect of 6-Week Combined Balance and Plyometric Training on Change of Direction Performance of Elite Badminton Players

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The study aimed to investigate the effect of combined balance and plyometric training on the change of direction (COD) performance of badminton athletes. Sixteen elite male badminton players volunteered to participate and were randomly assigned to a balance-plyometric group (BP: $n = 8$) and plyometric group (PL: $n = 8$). The BP group performed balance combined with plyometric training three times a week over 6 weeks; while the PL group undertook only plyometric training three times a week during the same period. Meanwhile, both groups were given the same technical training. All participants were tested to assess the COD ability before and after the training period: Southeast Missouri (SEMO) test and 5-0-5 test, dynamic balance ability (Y-Balance test, YBT), and reactive strength index (RSI). Repeated-measure ANOVA revealed that after the intervention there was a significant time × group interaction for 5-0-5 COD test, YBT of both legs and RSI ($p < 0.05$, partial $\eta^2 = 0.26$–0.58) due to the better performance observed at post-test compared with a pre-test for the BP group [effect size (ES) = 1.20–1.76], and the improvement was higher than that of the PL group. The change in SEMO test did not differ between BP and PL ($p < 0.159$, partial $\eta^2 = 0.137$), but the magnitude of the with-group improvement for BP (ES = 1.55) was higher than that of PL (ES = 0.81). These findings suggest that combined training could further improve the COD performance of badminton athletes than plyometric training alone and might provide fitness trainers a more efficient COD training alternative.

Keywords: balance training, plyometrics, change of direction, badminton athletes, badminton

INTRODUCTION

Badminton is one of the fastest racket sports in the world and is highly competitive and dynamic (Phomsoupha and Laffaye, 2015). During the match, the players perform 6–12 strokes within a rally duration ranging from 6 to 10 s. Due to the fast speed of the shuttlecock and high hitting frequency, the sport exerts a great demand on the abilities of player to run, accelerate, decelerate, jump, lunge, and change direction (Laffaye et al., 2015; Lee and Loh, 2019). A previous study showed that among all physical capacities, the COD performance served as the best physical predictor of badminton excellence ($r = 0.74$) (Hughes and Cosgrove, 2006) so that badminton players maximize such ability to enhance on-court success. Until now, several tests for COD ability have been widely used for badminton assessment, such as the Hexagon test, the 5-0-5 COD test, and the Modified SEMO test, and they were verified as representative methods to determine on-court performance of players (Jeyaraman et al., 2012; Ozmen and Aydogmus, 2016; Wong et al., 2019).

In terms of training programs, traditional resistance training has been used to improve the power and COD ability (Brughelli et al., 2008). However, recent studies have revealed that plyometric training and combined plyometric and resistance training presented greater efficiency in improving these abilities (Asadi et al., 2016; Fischetti et al., 2018, 2019). The actual mechanism of plyometric exercise is a lengthening (eccentric contraction) of the muscle-tendon unit followed directly by a shortening or concentric contraction, otherwise termed as a stretch-shortening cycle (SSC) (Markovic and Mikulic, 2010). In practice, it consists of exercises related to jumping, hopping, and skipping with multi-joint actions on stable or unstable surfaces (Negra et al., 2017a,b). While numerous studies have proved that plyometric training could be applied to improve the COD ability in players in racket sports like tennis (Salonikidis and Zafeiridis, 2008; Barber-Westin et al., 2010; Fernandez-Fernandez et al., 2016, 2018), few attempts have been made for badminton (Lim Joe et al., 2012; Majeed and Latheef, 2016; Middleton et al., 2016). Nonnato and colleagues have recently found that plyometric training cannot improve the 5-0-5 COD test performance of professional female soccer players due to a merely small effect on the COD with 180° angle (Nonnato et al., 2020), and such movement is frequently involved in a badminton match. Therefore, the effect of plyometric training on the COD ability of badminton players remains to be unveiled.

The previous finding has evidenced the importance of balance for the COD performance in that it helps players control the center of gravity (COG) during the accelerations and decelerations phase (Rouissi et al., 2018). For badminton players, balance also plays an important role in addressing issues of controlled COG and other situations challenging their balance, such as twisting movements (particularly of the pivot foot) during jump smash and offensive and defensive attacks. It is logical to undertake balance training to improve movement performance in badminton, particularly COD performance. Previous studies have explored the effect of combined plyometric and balance training on professional female basketball athletes and young soccer players (Makhlouf et al., 2018; Muehlbauer et al., 2019; Bouteraa et al., 2020). The results showed that such a combined program could produce greater performance improvements in balance, power, and COD, as opposed to the single plyometric intervention. However, it was suggested that immaturity or a lack of optimal balance capabilities might compromise the plyometric training adaptations (Bouteraa et al., 2020).

Despite a growing body of literature on combined training in other sport modalities and athletes, there is a paucity of research related to the applications of such training method in badminton. Therefore, it is unclear whether combined training could lead to greater improvement of COD ability in badminton players, or to mention the generalizability of results and practical recommendations from other studies. In order to explore refined fitness programing, the current study was aimed to investigate the effect of 6-week combined balance training and plyometric training on COD performance in elite badminton athletes. We hypothesized that the combined training protocol would further increase the COD and balance performance in badminton athletes when compared with plyometric training alone.

MATERIALS AND METHODS

Participants

Sixteen male elite badminton players (eight players had played the quarterfinalists of national youth games and the rest had played the finals at the provincial level) were recruited in this study. The participants belonged to the same club and were physically healthy, free from severe lower-body injuries related to anterior cruciate ligament (ACL), hamstring, meniscus, and ankle, or any medical and orthopedic problems. All players were right-handed and undertook three training sessions per week with each session formed by 2–3 h of technical and physical training drills (See **Figure 1** for participante recruitment process). All participating players volunteered for random allocation to either balance and plyometric training group (BP, $n = 8$) (age: 20.5 ± 1.1 years, height: 177.8 ± 5.1 cm, weight: 68.1 ± 7.2 kg, and training experience: 11.4 ± 1.4 years) or a control group (PL) (age: 19.1 ± 2.2 years, height: 179.1 ± 6.1 cm, weight: 69.88 ± 8.94 kg, and training experience: 10.6 ± 1.1 years) that performed only plyometric training regimen ($n = 8$). There were no statistically significant differences between the groups in these personal characteristics. Before data collection, the participants were informed about the benefits and possible risks associated with the study, and the participants provided written informed consent to participate. The players were in their normal routine of diet and had caffeine-free beverages during the whole study period. The study protocol was approved by the Beijing Sport University Institutional Research Commission (Approval number: 2020008H), and all procedures were conducted in accordance with the Declaration of Helsinki.

Procedures

All experimental training programs were conducted along with a weekly technical training routine. Participants from the BP and PL groups followed a balance combined with a plyometric training program (40 min of plyometrics and 20 min of balance training) three times per week with 24–48 h of recovery between each training session. In order to control the 20-min balance training protocol, the PL group was required to perform the same drills as the BP group. However, unlike the latter that undertook all the exercises under unstable conditions (i.e., BOSU ball, Swiss ball, and Balance pad), they practiced on the floor. Before the commencement of the study and the initiation of testing, all players completed a 2-week trial period (three sessions/week) in order to become familiarized with the physical training programs during the formal experimental course of the study. A detailed description of balance and plyometric training protocols and biweekly progression are presented in **Tables 1**, **2**. During each session,

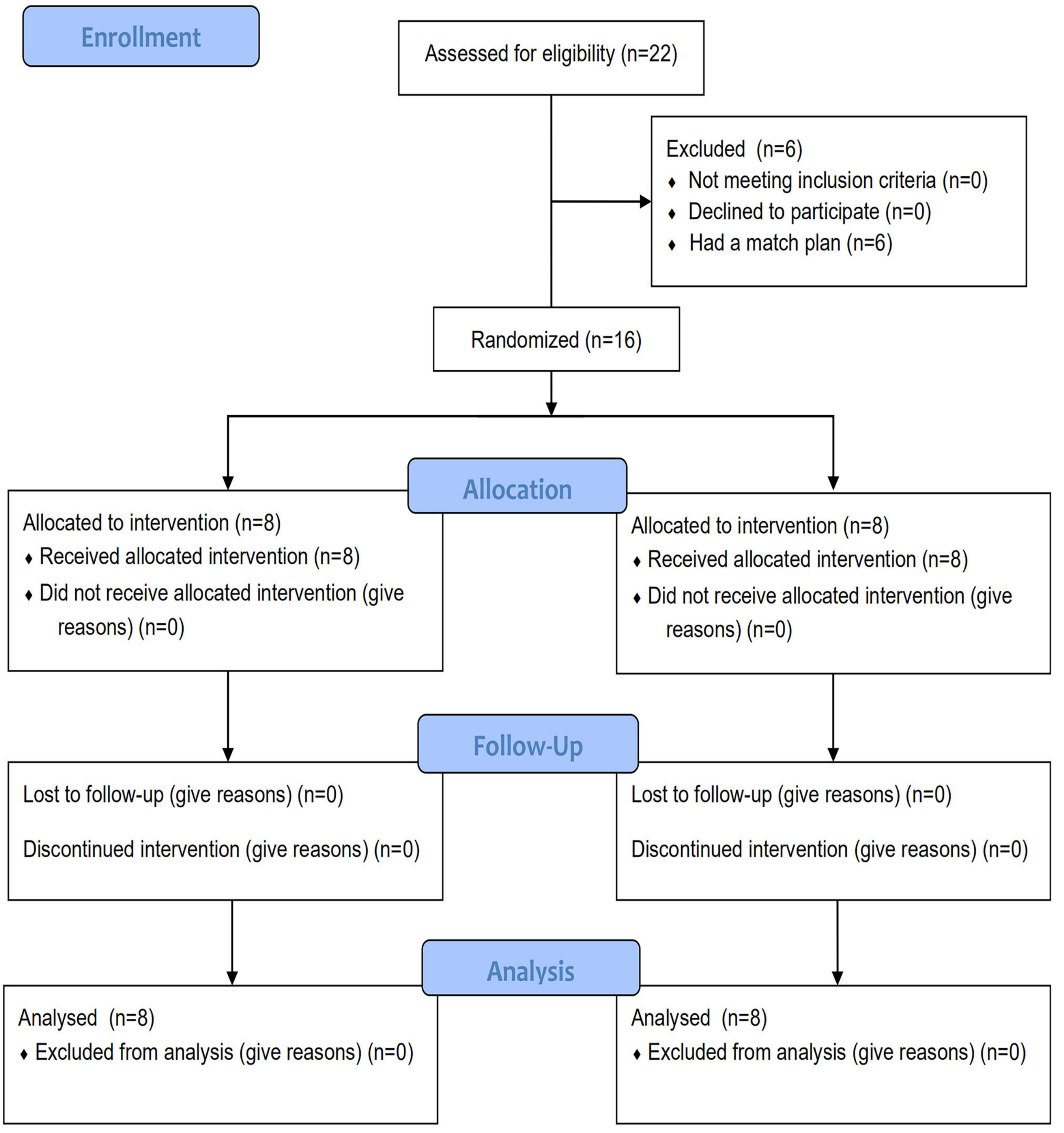

FIGURE 1 | Flow diagram of the participants recruitment process.

players received consistent instructions from certified strength and conditioning coaches on proper techniques for agility drills, balance exercises, plyometric exercises, and landing. All the protocols were designed and supervised by one of the authors, who is an experienced researcher in strength and conditioning, and a fitness trainer with a master degree in strength and conditioning, who works as the fitness coach for the Chinese National Junior Team (U-17) of Badminton and collegiate team of badminton and has been certified by the State General Administration of Sport.

Test Program

Data of COD testing were collected before and after the implementation of the 6-week training intervention at the indoor

TABLE 1 | The balance training program for balance-plyometric (BP) (combined training) group.

Exercises	The first stage (1–2 weeks)	The second stage (3–4 weeks)	The third stage (5–6 weeks)
Stand on the balance board exercise	Static standing on the board with two legs (3 sets: 30 s/set)	Static standing on the board with two legs and eyes closed (3 sets: 30 s/set)	Squat on the plate with eyes closed (3 sets: 10 reps/set)
Supine straight leg bridge on Swiss Ball	Isometric supine straight leg bridge on Swiss Ball (3 sets: 30 s/set)	Isometric supine single-leg bending bridge on Swiss Ball (3 sets: 30 s/set)	Dynamic supine single-leg bending bridge on Swiss (3 sets: 10 reps/set)
Side-plank with inflated balance disc	Side-plank with inflated balance disc with elbow (3 sets: 30 s/set)	Side-plank with inflated balance disc and the non-supporting leg stretches backward (3 sets: 10 reps/set)	Side-plank with inflated balance disc and the non-supporting leg stretches backward with elastic band (3 sets: 10 reps/set)
Lunge squat on BOSU ball	Lunge squat on BOSU ball (3 sets: 10 reps/leg/set)	Lunge squat on BOSU ball and inflated balance disc (3 sets: 10 reps/leg/set)	Lunge squat on BOSU ball and inflated balance disc with 5 kg dumbbells (3 sets: 10 reps/leg/set)
Airex® Balance-pad Elite exercise	Single-leg squat with balance-pad (3 sets: 10 reps/leg/set)	Single-leg standing with balance-pad and the non-supporting leg stretches backward (3 sets: 12 reps/leg/sets)	Single-leg support with balance-pad elite and the non-supporting leg stretches backward with elastic band (3 sets: 12 reps/leg/sets)
Rest	Between exercise: 60 s Between sets: 3 min		

TABLE 2 | The plyometric training program for BP and plyometric (PL) training group.

Exercises	The first stage (1–2 weeks)	The second stage (3–4 weeks)	The third stage (5–6 weeks)
Front barrier jump (6 hurdles)	Double-leg front barrier jump (15 cm) (3 sets: 10 reps/set)	Single-leg front barrier jump (15 cm) (3 sets: 5 reps/leg/set)	Single-leg front barrier jump (30 cm) (4 sets: 5 reps/leg/set)
Lateral high-knees with hurdles	4-hurdle (15 cm) (3 sets: 2 reps/set)	6-hurdle (30 cm) (3 sets: 4 reps/set)	6-hurdle (30 cm) (3 sets: 6 reps/set)
Lateral barrier jump	Double-leg jump (15 cm) (3 sets: 10 reps/set)	Double-leg jump (30 cm) (3 sets: 12 reps/set)	Single-leg jump (30 cm) (3 sets: 15 reps/leg/set)
Depth jump	Jump with 20 cm box (3 sets: 8 reps/set)	Jump with 30 cm box (3 sets: 8 reps/set)	Jump with 40 cm box (3 sets: 8 reps/set)
Multi-direction jumps with hurdles	Triangle jump with double-leg (3 hurdles) (3 sets: 6*3 reps/set)	Square jump with single-leg (4 hurdles) (3 sets: 8*3 reps/set)	Hexagon jump with single-leg (6 hurdles) (3 sets: 12*3 reps/set)
Intensity and number of contact with ground	Low intensity 144	Middle intensity 234	High intensity 325
Rest	Between exercise: 60 s Between sets: 3 min		

sports science center and badminton court of local institution of authors. The testing consisted of Modified SEMO Test, Modified 5-0-5 COD test, Y-balance test (YBT), and reactive strength index (RSI) test, and they were performed and completed within 1 day. Players were already accustomed to the testing procedures used in this research as they routinely performed these tests in the club. Prior to testing, participants completed a warm-up that included a 5-min dynamic stretching, 8-min movement integration, and 2-min neural activation. Post-training testing was performed 3 days after the last training session to ensure optimal recovery, and no intensive training was implemented 24 h before testing to prevent the effects of fatigue. Each testing was completed at the same time of the day, at the same site, with the same sporting shoes, and surveilled by the same investigators. The set of tests and measurements were detailed in the following context:

Modified SEMO Test

This test evaluates the capacity of making quick changes of direction, forward sprints, diagonal backpedaling, and side shuffling, which are the most frequent movements performed during badminton matches (Jeyaraman et al., 2012). The test area was set up on the half of the badminton court with a length of 6.70 m and a width of 6.10 m. Four cones were placed on four corners of the court to mark each site of change of direction (see **Figure 2**). At each trial, participants first started side shuffling (facing the court) on instructions of the coach, and then back-pedal diagonally across the court, sprint forward, back-pedal diagonally across court again, sprint forward, and finally side-shuffle (facing the court) to the finishing point. Test times were recorded using SmartSpeed PT Timing Gate System (Fusion Sport, Coopers Plains, Australia), which was installed at the start/finish point of the test. Three consecutive trials were performed and separated by 2 min of passive rest, with the highest values being recorded for analysis (intraclass correlation coefficients of a two-way random model: 0.85, 95% CI: [0.74, 0.92]).

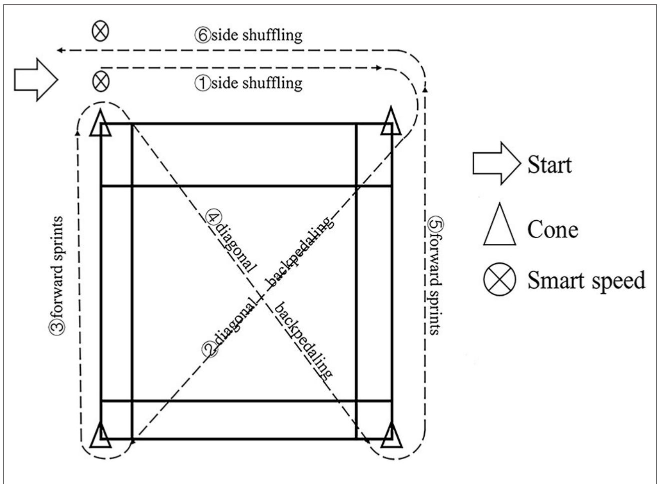

FIGURE 2 | Modified Southeast Missouri (SEMO) test.

Modified 5-0-5 COD Test

The 5-0-5 COD test is widely used to evaluate the COD ability of athletes in various sports, which is very suitable for those sports that require short-distance acceleration and COD, such as basketball, rugby, tennis, and badminton (Hughes and Bopf, 2005). Due to the short moving distance in the badminton court, players often involve in COD with 180° angle, which is highly similar to the 5-0-5 COD test. In order to suit badminton specifically, the researcher adjusted the running distance of the test to be similar to the distance inside the badminton court, as shown in **Figure 3**. Two cone buckets A were placed symmetrically at the starting line, then two other cone buckets B were placed at a position 3 m to the right of the parallel A point, and finally, the cone bucket C was placed at a position 3 m to the left of the parallel A point. Smart Speed (Fusion Sport, Coopers Plains, Australia) was placed behind each pair of cones. After hearing the command "Ready, start," the participants made a quick right turn and ran from A to B. Upon arrival, the participant quickly turned around and sprinted to C, then quickly turned around and ran back to A. Each participant performed three tests, and the best of the three tests was the final valid score. There was a 5–10 min recovery period between each test. Smart Speed was automatically timed at the beginning and the end of the test. Three consecutive trials were performed and separated by 2 min of passive rest, with the highest values being recorded for analysis (intraclass correlation coefficients: 0.88 [0.79, 0.94]).

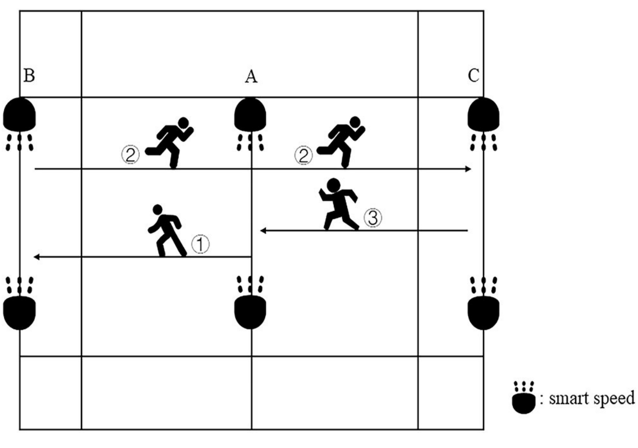

FIGURE 3 | Modified 5-0-5 COD test.

Y-Balance Test

The test was used to assess the dynamic balance of players (Shaffer et al., 2013). While barefoot, participants balanced themselves with one foot on the center board of a commercially available YBT instrument (Move2Perform, Evansville, IN). To perform the test, they need to place their hands on the hips and reach as far as possible by pushing the board with the reaching limb into the anterior, posteromedial, and posterolateral directions and return to the original start position (see **Figure 4** for the illustration). Reach distance was measured at the nearest edge of the reach indicator to the closest 0.5 cm. All participants performed three practice trials in each of three directions on each leg before three formals test trials. YBT reach distances were normalized to leg length (%), which was obtained by measuring the length from the right anterior superior iliac spine of the players to right medial malleolus in supine. The highest composite score was recorded for analysis using the following formula:

$$\text{Composite Score} = \frac{(\text{Anterior} + \text{Posteromedial} + \text{Posterolateral})}{3 \times \text{Right Limb Length}} \times 100$$

where anterior, posteromedial and posterolateral represent the distances reached in each direction (intraclass correlation coefficients: 0.92 [0.85, 0.96]).

Reactive Strength Index Test

The test is applied to evaluate how athletes perform during plyometrics by measuring the muscle-tendon stress and their reactive jump capacity so that their ability to quickly and effectively moving through the strength-shortening cycle is demonstrated (Ebben and Petushek, 2010). In practice, the RSI is strongly related to COD speed and acceleration speed and depth jump from the height of 30 cm could provide a valid result of RSI (Flanagan et al., 2008; Byrne et al., 2017). Therefore, in this study, the RSI was measured using depth jump from a 30 cm plyometric

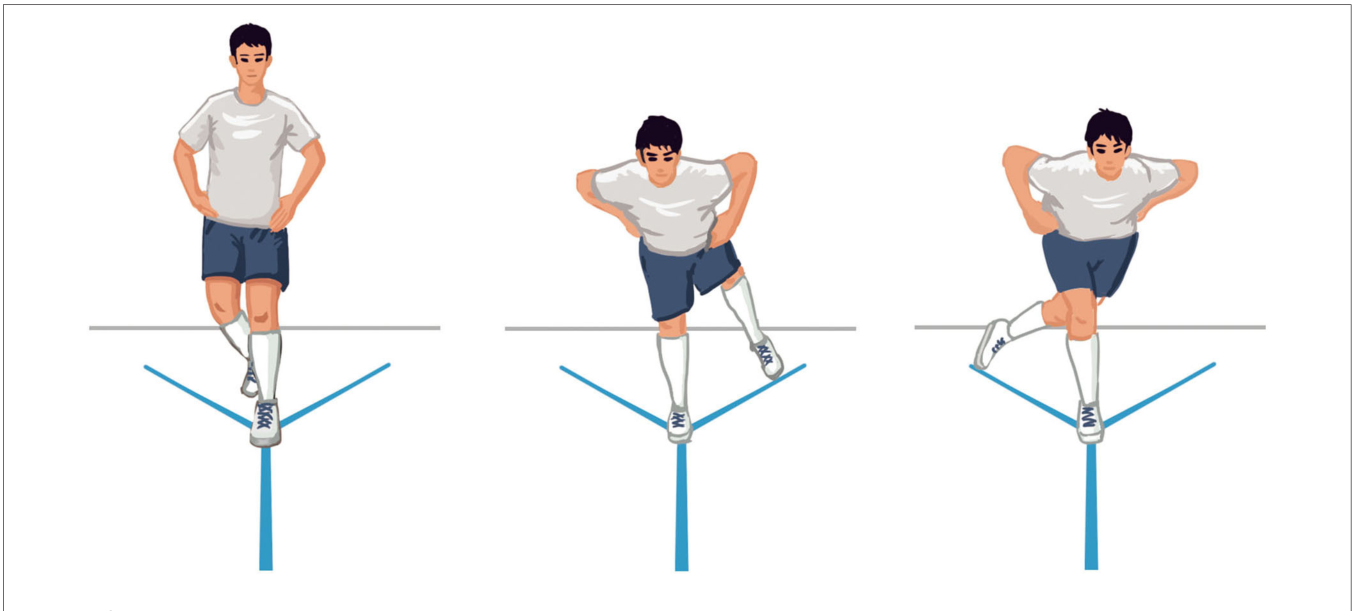

FIGURE 4 | Y-balance test (YBT).

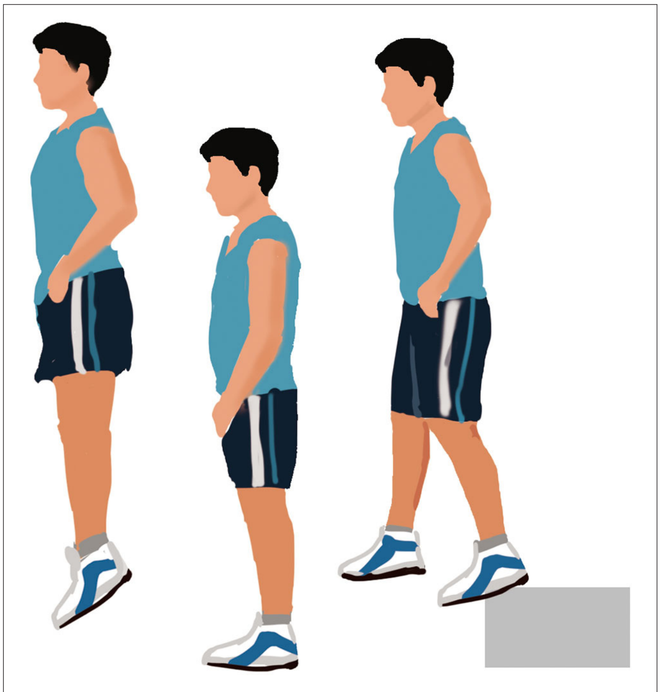

FIGURE 5 | Reactive Strength Index (RSI) test.

box (see **Figure 5**). During the test, participants were instructed to perform the depth jump with two hands on their hips and step forward off the box without stepping down or jumping up. After observing the demonstration, each player was then allowed to carry out two practice trials before formal testing. On falling, players would land on an in-ground force plate (Kistler 9281CA, Winterthur, Switzerland) that has a sampling frequency of 1,000 Hz. They were requested to jump as high and quickly as possible after landing, and the jump height was calculated from take-off velocity derived from their respective force-time data. Later, the RSI score was calculated using the highest jump height recorded from three trials using the below formula (intraclass correlation coefficients: 0.86 [0.75, 0.93]):

$$\text{RSI} = \frac{\text{Jump height}}{\text{ground contact time}}$$

Statistical Analysis

Data are presented as means and SD. The normality of data distribution was confirmed using the Shapiro-Wilk test. Training-related effects were assessed by 2-way repeated-measure ANOVA (group × time) on SEMO Test, 5-0-5 COD test, YBT, and RSI, with the Greenhouse-Geisser adjustment was applied. Partial η^2 was used as the effect size (ES) estimation for the time by group interaction effect with its strength being interpreted as the following: <0.06 as small, <0.14 as moderate, and ≥0.14 as large (Cohen, 1988), while the Cohen's *d* converted from partial η^2 was used to represent the ES of main effect (Cohen, 1988). When a significant effect was found, Bonferroni *post-hoc* correction was performed to identify pairwise differences. The absolute value of each test result was used to calculate the ES for the within- and between-group comparisons, represented as Cohen's *d*. It was interpreted according to the following thresholds: <0.2 as trivial, 0.2–0.6 as small, 0.6–1.2 as moderate, 1.2–2.0 as large, and >2.0 as very large (Hopkins et al., 2009). The Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA, version 22.0) was used for all analyses. The level of significance was set at $p < 0.05$ for all tests.

RESULTS

Table 3 presents the descriptive statistics of all COD tests, results of repeated ANOVA for pre-and post-training fitness testing,

TABLE 3 | Descriptive statistics of agility test results for BP group and PL group before and after the 6-week training intervention.

	BP group			PL group			Time		Group*Time	
	Pre	Post	ES	Pre	Post	ES	*p*	Cohen's *d*	*p*	Partial η^2
SEMO agility test (s)	13.38 ± 0.45	12.78 ± 0.31	*1.55	13.37 ± 0.37	13.06 ± 0.38	*0.81	<0.001	1.49	0.159	0.14
5-0-5 COD test (s)	3.76 ± 0.25	3.44 ± 0.15	*1.55	3.72 ± 0.16	3.62 ± 0.17	*0.61	<0.001	3.03	0.001	0.58
YBT (dominant foot)	97.33 ± 5.32	104.94 ± 7.21	*1.20	96.16 ± 7.78	97.06 ± 7.75	0.12	0.002	1.16	0.008	0.38
YBT (non-dominant foot)	96.22 ± 5.58	104.78 ± 7.35	*1.31	96.08 ± 8.14	97.41 ± 6.53	0.18	<0.001	1.62	0.003	0.48
RSI	1.27 ± 0.14	1.50 ± 0.12	*1.76	1.22 ± 0.12	1.35 ± 0.15	*0.96	<0.001	2.52	0.045	0.26

*Statistically significant difference between pre- and post-test, $p < 0.05$.
SEMO, modified southeast Missouri; 5-0-5 COD test = 5-0-5 change of direction test; YBT, Y-Balance test; RSI, reactive strength index.

and corresponding ESs. No statistically significant differences between groups were found at baseline for all test measures.

For both BP and PL groups, training resulted in statistically significant improvement in SEMO test, 5-0-5 COD test, and RSI ($p < 0.001$, partial $\eta^2 = 0.598$, 0.835, and 0.783, respectively), but BP showed higher ESs than PL (1.55 vs. 0.81, 1.55 vs. 0.61, and 1.76 vs. 0.96). Significant group by time interaction effects were shown between groups for 5-0-5 COD test [$F_{(1,14)} = 19.273$, $p = 0.001$, and partial $\eta^2 = 0.579$], indicating a significantly greater improvement in the above test performance after the BP intervention when compared with the PL intervention. Moreover, a statistically significant increase in YBT was shown for the BP group on both dominant and non-dominant feet (ES = 1.20 and 1.31). Significant group by time interaction effects were shown between groups for YBT (dominant foot) [$F_{(1,14)} = 8.710$, $p = 0.008$, and partial $\eta^2 = 0.384$], YBT (non-dominant foot) [$F_{(1,14)} = 12.674$, $p = 0.003$, and partial $\eta^2 = 0.475$] and RSI [$F_{(1,14)} = 4.831$, $p = 0.045$, and partial $\eta^2 = 0.257$], indicating a significantly greater improvement in the above test performance after the BP intervention when compared with the PL intervention. **Figure 6** depicts within- and between-group ESs for comparisons of test results.

DISCUSSION

The purpose of the study was to investigate the effectiveness of the 6-week combined balance and plyometric training program on the COD performance of elite badminton players. To the best of our knowledge, this is the first study comparing the effect between combined training and plyometric training. Based on the results, we found the combined protocol to be more effective in improving COD ability, dynamic balance, and RSI of players when compared with the latter. As COD ability, dynamic balance, and RSI are valid indicators of the movement performance of badminton players (Hughes and Bopf, 2005; Masu et al., 2014), the current findings could help enrich the badminton-specific strength and conditioning routines and improve the on-court performance.

Findings of the study imply that 6 weeks of BP training-induced better adaptations in COD, balance, and reactive strength performances. As the well-developed COD ability requires not only strong lower limb power to move quickly, but also a good balance to control body posture and to overcome the inertia caused by decelerations and brakings, adding an extra balance training indeed played an important role in boosting such performance (Sekulic et al., 2013). Former research documented a high correlation (r = 0.83) of COD ability with badminton performance during competitive matches (Tiwari et al., 2011), which are characterized by high-intensity rallies with short rest intervals (Alam et al., 2010). Although the directions and trajectories of shuttlecock are fixed during rallies, they are randomly determined by players at milliseconds of time before each stroke (Lees, 2003). Therefore, players are requested to execute rapid CODs, consecutive jumps, lunges, and multiple accelerations and decelerations (Manrique and Gonzalez-Badillo, 2003), and possessing decent COD is the key to applying the most efficient footwork into reaching the correct places and hitting the shuttlecock. As previously revealed that the most frequent moving patterns during badminton matches were forward-backward movements, lateral movements, and CODs (Phomsoupha and Laffaye, 2015), results of the SEMO Test and the 5-0-5 COD test would be a performance indicator of on-court COD of a player. Meanwhile, although sufficient investigations have already evidenced positive adaptations in the COD ability of athletes after plyometric training (Manouras et al., 2016; Asadi et al., 2017), the current study provided novel findings that a combined training could induce greater improvement, which is in consensus with findings of Bouteraa et al. (2020) when applying similar training methodology to female basketball players.

The results further revealed a significant increase in both Y-Balance and RSI performance for the BP group, while reporting only meaningful adaptation in RSI for the PL group. It could be inferred from this result that badminton-specific COD ability has been improved after plyometric training, but not as much as a combined training protocol, which is consistent with the previous research where significant adaptations were reported in female basketball players and ordinary adolescents after combined training (Chaouachi et al., 2014; Bouteraa et al., 2020). RSI is an indicator of how efficiently athletes perform the SSC. Although plyometric training has been shown to significantly improve the efficiency of SSC utilization (Jeffreys et al., 2019; Dallas et al., 2020), it is interesting to note that the BP group exhibited a greater increase in RSI. A potential reason could be that balance training enhanced the body control of players

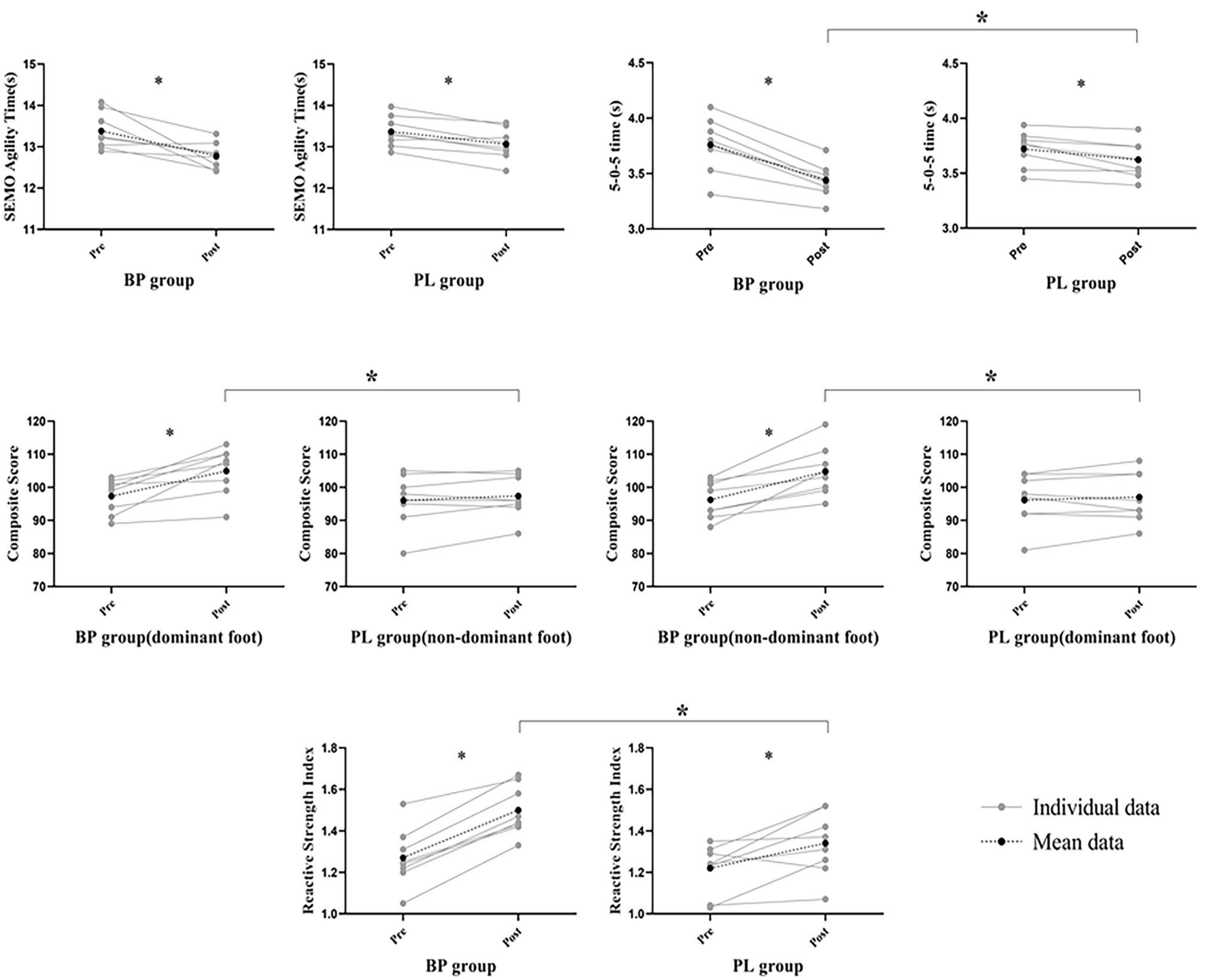

FIGURE 6 | Individual and mean values for agility related tests during before and after Balance-Plyometric (BP) and Plyometrics (PL) training. Note: $^{*}p < 0.05$.

and finally reduced the time spent on the landing during jumps. It is also possible that balance training could be beneficial for the power improvement of the lower limbs. Kean et al. (2006) found a 10% increase in vertical jumping after 5-week balance training, which helped decrease the sway of the COG, allowing athletes to land more consistently with optimal vertical jump angles. Lower limb reactive strength and posture control are important factors affecting quick COD of athletes, body stability as well as effective prevention of injuries (Borghuis et al., 2008). In this regard, the combined training paradigm could be more preferable for the complex, high-speed, unilateral, repetitive dynamic badminton movements that request a high extent of postural control.

To understand the benefit of combined training to badminton performance from a physiological point of view, the coordinated work of the visual system, vestibular system, and proprioceptive system should be addressed. When a player is changing his directions quickly and the body is imbalanced, the aforementioned systems will work together to regain the balance and maintain body stiffness. During this process, the proprioceptors (muscle spindles and Golgi tendons) and other joint receptors will sense changes in body posture, and then the vestibular system will send feedback to the central nervous system to generate kinesthetic awareness. Subsequently, in order to control body balance, the central nervous system needs to transmit signals to effectors (muscles), which will ultimately respond appropriately by adjusting the COG of the body (Sekulic et al., 2013). Therefore, the ability to change direction and make fast acceleration/deceleration is attributed to the joint effort of proprioceptors and effectors. In essence, the plyometric training could only strengthen the function of the effector (muscle), but not the proprioceptive system, which would be improved *via* balance training. Therefore, the combined balance and plyometric training should be prioritized in boosting both the performance of the proprioceptive system and muscle function simultaneously.

The results of our study evidenced the promising effects of the combined training paradigm on badminton COD ability so that it seems feasible to apply balance training into the already existed plyometric training routines of players. Moreover, from a practical perspective, fitness coaches are suggested to vary the format and sequence of exercises, training volumes, and intensities of such training prescription in order to add more stimuli. For example, instead of separating plyometrics and balance training apart, coaches could adopt a circuit training protocol that involves two training modalities in each circuit, using balance training as an alternative for passive rest between different sets of exercises. Finally, coaches and sports scientists are suggested to investigate whether incorporating reaction training drills to combined training protocol could further improve badminton on-court COD performance.

Despite the new information about the effect of combined training on badminton COD ability, several limitations need to be acknowledged. First, due to the fact that most elite male badminton players usually have fixed match and training planning (traveling to compete and train) that are not possible to be alternated, the study could only include a comparatively small sample size. Second, it should be noted that an experiment period of 6 weeks was chosen in order to verify that a shorter intervention than the commonly-used 8 weeks to induce favorable adaptation, as the experiment schedule had to be acceptable for both the coaches and players. Researchers should be, therefore, cautious when interpreting and generalizing the current findings.

CONCLUSIONS

In summary, the 6-week training intervention for elite male badminton players showed that combined training (BP) induced an overall better adaptation for the SEMO TEST, the 5-0-5 COD test, the YBT, and the RSI test than plyometric training (PL). Moreover, considering the completion of balance training is relatively time-efficient (20 min in the current study), it is suggested that adding such exercises would allow optimal training adaptation for badminton players.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Beijing Sport University Institutional Research Commission (Approval number: 2020008H). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ZG, YH, and DB: conceptualization. ZG, YH, YC, and DB: methodology, validation, and writing—original draft preparation. ZG and YC: software and visualization. ZG, WG, and YC: formal analysis. ZG, ZZ, and BL: investigation. BL and DB: resources. ZG and YH: data curation. ZG, YH, and YC: writing—review and editing. DB and YC: supervision, project administration, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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The Effects of Mindfulness-Based Intervention on Shooting Performance and Cognitive Functions in Archers

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This study investigated the effects of a mindfulness-based intervention (MBI) called mindfulness-based peak performance (MBPP) on athletic performance and cognitive functions in archers, as well as the role of psychological status and the dose-response relationship of MBPP in archery performance. Twenty-three archers completed a simulated archery competition and the Stroop task prior to and after MBPP training, which consisted of eight sessions over four weeks, while the mindfulness and rumination levels of the archers were assessed at three time points, namely, before, at the mid-point of, and after the MBPP program. The results revealed that the MBPP program significantly improved the shooting performance ($p = 0.002$, $d = 0.27$), multiple cognitive functions ($ps < 0.001$, $d = 0.51{\sim}0.71$), and mindfulness levels of the archers on the post-test, compared to the pre-test ($p = 0.032$, $\eta_p{}^2 = 0.15$ for general; $p = 0.004$, $\eta_p{}^2 = 0.22$ for athletic). Additionally, negative ruminations level was decreased from the pre-test to the middle-test and post-test ($ps < 0.001$, $\eta_p{}^2 = 0.43$). These findings provide preliminary evidence to support the view that MBPP could serve as a promising form of training for fine motor sport performance, cognitive functions, and specific psychological status, such that it warrants further study.

Keywords: mindfulness intervention, fine motor, cognitive functions, dose-response, archer

INTRODUCTION

Mental ability is one of primary foundations for successful sport performance (Kim et al., 2015), and mindfulness has recently been recognized as a novel aspect of sport-related mental ability (Jones et al., 2020). Mindfulness is believed to reflect both focus on and awareness of one's moment-to-moment experiences through a non-judgmental attitude (Kabat-Zinn, 2003; Creswell, 2017). Mindfulness also is described as a trait or disposition that involves the amount of tendency of the individual to be mindful in daily life (Birrer et al., 2012). Relatedly, mindfulness levels have been considered a key factor in ensuring the optimal psychological status necessary to achieve peak performance in fine motor sports (Gooding and Gardner, 2009; Zhang et al., 2016).

Mindfulness-based interventions (MBIs) involving mental concepts, specific exercises, and class discussions that are intended to induce positive effects in terms of individual focus, mindfulness-related body sensations, cognitive factors, and emotional regulation (Kabat-Zinn, 1982, 2003; Creswell et al., 2019), have been observed to efficiently cultivate mindfulness through regular practice in athletes (Birrer et al., 2012; Josefsson et al., 2019; Nien et al., 2020). Additionally, MBIs have been found to directly affect fine motor sport performances in sports involving precision, accuracy, and dexterity (Bühlmayer et al., 2017; Noetel et al., 2019), such as shooting (John et al., 2011) and dart throwing (Zhang et al., 2016), in addition to being linked to enhanced psychological parameters (Birrer et al., 2012; Bühlmayer et al., 2017), such as improved flow experiences, self-confidence, and competitive anxiety, in archers (Kaufman et al., 2009; Thompson et al., 2011).

The beneficial effects of MBIs on sport performance may be derived through improvement of cognitive functions (Scharfen and Memmert, 2019; Nien et al., 2020). A recent meta-analysis reported superior cognitive functions [e.g., executive function (EF), visuoperceptual function], with small to medium positive effect sizes, in experts and elite athletes compared with non-elite athletes (Scharfen and Memmert, 2019). Among the variety of cognitive functions, EF is a higher-order cognitive function responsible for top-down processes aimed at achieving goal-directed behaviors (Audiffren and André, 2019; Etnier and Chang, 2019; Chen et al., 2020). Previous studies have shown that there is a link between EF and peak performance in athletes (Sakamoto et al., 2018; Ishihara et al., 2019). EF contains three distinguishable components (e.g., inhibitory control, working memory and cognitive flexibility) (Diamond and Ling, 2016), and the inhibitory control aspect of EF may play a crucial role in fine motor sports (Jacobson and Matthaeus, 2014), because athletes competing in these sports must maintain extremely high levels of concentration on their targets while also ignoring internal and external distractions (Diamond and Ling, 2016). López-Navarro et al. (2020) found that a long-term mindfulness exercise integrated with rehabilitation treatment improved inhibitory control in patients with psychotic disorder. Nien et al. (2020) further reported that a five weeks MBI improved participant performance on inhibition-related conditions (i.e., the incongruent condition) of the Stroop task and increased the durations at which participants completed an exhaustion running test, suggesting associations among MBI, EF, and sport performance.

The beneficial effects of MBIs on sport performance may be associated with psychological processes (Birrer et al., 2012). Josefsson et al. (2017) suggested that less rumination is an essential mechanism between mindfulness and coping skills in a sports context. Rumination is regarded as a psychological process that repetitively and passively focuses on distress and is associated with a variety of maladaptive cognitive styles (e.g., depression and pessimism), and may connect to sport-related coping factors in athletes (e.g., concentration and arousal regulation) (Birrer et al., 2012). It should be noted, moreover, that rumination is associated with EF and that lower EF is associated with higher levels of negative rumination and with negative affect (De Lissnyder et al., 2010). However, few studies have simultaneously examined the influences of rumination and inhibitory control in the relationship between MBIs and fine motor sport performance.

Another research gap relates to the minimal doses of MBIs necessary to achieve the desired effects. There has been shown that a dose-response relationship obtains between the number of sessions per week of psychotherapy intervention and depression symptoms (i.e., an increase from one to two sessions per week increased the effect size) in the past meta-regression analysis (Cuijpers et al., 2013). In mindfulness research, Creswell (2017) suggests that MBIs lasting at least 8 weeks have greater effects on adverse negative psychological outcomes (e.g., anxiety). However, it should be noted that the majority of related studies have adopted the mindfulness-based stress reduction (MBSR, Kabat-Zinn, 1982, 2003) principle as a standard program, and MBSR entails the use of an 8 weeks course with one session per week lasting 2–2.5 h. Meanwhile, Roos et al. (2019) evaluated the effect of eight MBI sessions within 4 weeks on mental health in patients with substance use disorders and found that participants who attended more than two sessions could achieve significantly better mental health and higher mindfulness at discharge. A meta-regression study further suggested that mindfulness outcomes could be predicted by greater contact with, intensity of, and actual use of MBIs, but no significance in other psychological outcomes (Strohmaier, 2020). These studies suggest that an MBI course may be shorter than 8 weeks, as long as the minimum number of necessary sessions is included. However, whether a dose-response relationship exists between the number of sessions in MBIs and mindfulness levels, including account for rumination, remains unclear.

The present study thus sought to examine the effects of an MBI called mindfulness-based peak performance (MBPP) on archery performance while also examining the roles of mindfulness level, cognitive function (e.g., inhibitory control), and rumination, as well as the associated dose-response relationships in terms of the number of sessions in the MBPP program. We hypothesized that the MBPP program would enhance the shooting scores, Stroop task performance, and mindfulness levels of the participating archers, in addition to reducing their rumination levels. Additionally, the dose-response relationship between the MBPP program and behavioral and psychological outcomes was also investigated.

MATERIALS AND METHODS

Participants

Twenty-three competitive archery athletes (19 men and 4 women, mean age = 20.64 ± 1.20 years) were recruited from National Taiwan University of Sport, and their mean experience in their sport was 7.47 ± 1.89 years. The participants were included in the study based on the following criteria: (a) no prior experiences of mindfulness related training (e.g., meditation, yoga, or Tai Chi); (b) no history of psychiatric or neurological disorders; (c) not taking medicines affecting the central nervous system or brain; and (d) normal or corrected-to-normal vision and no color blindness. Furthermore, the participants filled in a written informed consent form approved by the Center for

Research Ethics of National Taiwan Normal University before the initiation of the experiment.

Measurements

Shooting Performance

An Olympic archery individual competition was simulated to assess the shooting performance of the participants. The shooting position of the target was set according to international standards, with the distance from the archer to the target being 70 meters, and each archer shot a total of 72 arrows (in six ends, or groups, of 12 arrows). The score for each shot was determined by how close the arrow was to the center of the target. The participants were assessed at a pre-test and post-test (which followed the 8 sessions of the MBPP program), both of which occurred during the regular archery training season and took place on the outdoor archery training field of National Taiwan University of Sport. In order to reduce the disturbances caused by wind, a vane anemometer was used to measure the wind speed, and it was found that the wind speeds during the pre-test ranged from 0.1 to 1.2 m/s while those during the post-test ranged from 0.0 to 1.3 m/s. The final results of each shooting test were obtained from the coach after the simulated competition, with higher shooting scores indicating greater athletic performance.

EF: Stroop Task

The paper-pencil version of the Chinese Stroop color-word task was used to assess multiple aspects of cognitive functioning (i.e., information processing speed, selective attention, and inhibitory control) (Chu et al., 2016). The Stroop task consists of three types of conditions: (a) neutral (in which colored squares are presented); (b) congruent (in which the meaning of the words presented corresponds to the color of ink in which they are presented); and (c) incongruent (in which the meaning of the words presented does not correspond to the color of ink in which they are presented). Both of the latter conditions consist of a string of Chinese color-words [i.e., "紅" (red), "綠" (green), and "藍" (blue)] that are presented individually on A4 size paper (210 mm × 297 mm; 10 rows, 5 columns), and each condition includes 50 stimuli.

During the Stroop task, the participants were asked to ignore the meaning of each word and to verbally name the color of the ink in which each word was presented as rapidly and accurately as possible, going from top to bottom and left to right. If the participant being tested made a mistake, he or she was asked to try again until the correct color was named. The reaction times were recorded from the first stimulus to the final stimulus in each condition as the score indexing the cognitive performance.

Self-Reported Psychological Outcomes

Chinese Mindful Attention Awareness Scale

The general mindfulness level of each participant was measured using the Chinese version of the Mindful Attention Awareness Scale (CMAAS) (Chang et al., 2011), a revised version of the original Mindful Attention Awareness Scale (MAAS), which is a widely adopted mindfulness scale designed to assess mindfulness levels in general states (Brown and Ryan, 2003). The CMAAS is a 15-item questionnaire that uses a 6-point Likert scale ranging from 1 (almost never) to 6 (almost always) for each item. The items include statements such as "It seems I am 'running on automatic' without much awareness of what I'm doing" and "I find myself doing things without paying attention." Higher scores indicate greater general dispositional mindfulness. In this study, the CMAAS produced satisfactory internal consistency across the three time points ($\alpha = 0.82 \sim 0.93$).

Chinese Mindfulness Inventory in Sport

The athletic mindfulness level of each participant was measured using the Chinese version of the Mindfulness Inventory in Sport (CMIS) (Peng and Shen, 2016), a revised version of the original Mindfulness Inventory in Sport (MIS) developed by Thienot et al. (2014). The CMIS consists of two sub-dimensions, attentional control and non-judgment, and is intended to assess mindfulness levels associated with sports contexts. The attentional control sub-dimension consists of ten items (e.g., "I pay attention to the type of emotions I am feeling"), while the non-judgment sub-dimension consists of five items (e.g., "When I become aware that I am really upset because I am losing, I criticize myself for reacting this way"). The CMIS thus has a total of 15 items, with a 6-point Likert scale ranging from 1 (rarely) to 6 (every time) used for each item. Higher scores indicate greater athletic mindfulness levels. In the present study, there was satisfactory internal consistency for the total CMIS ($\alpha = 0.83 \sim 0.94$), the attentional control sub-dimension ($\alpha = 0.80 \sim 0.92$), and the non-judgment sub-dimension ($\alpha = 0.76 \sim 0.86$) across the three time points.

Chinese Multidimensional Rumination Questionnaire

The Chinese version of the Multidimensional Rumination Questionnaire (CMRQ) (Tu and Hsu, 2008), a revised version of the original Multidimensional Rumination Questionnaire (MRQ) developed by Fritz (1999), was utilized to assess each participant's level of rumination. The CMRQ is designed to measure three sub-dimensions, namely, emotional-focused rumination (13 items regarding thinking about thoughts, feelings, or affect in relation to negative experiences), meaning-searching rumination (7 items regarding searching for the meaning of negative experiences or events), and instrumental rumination (5 items regarding thinking about what approach can be used to address negative events), with a 5-point Likert scale ranging from 1 (almost never) to 5 (almost always) used for each item. There was satisfactory internal consistency for the emotional-focused rumination sub-dimension ($\alpha = 0.95 \sim 0.97$), the meaning-searching rumination sub-dimension ($\alpha = 0.79 \sim 0.91$), and the instrumental rumination sub-dimension ($\alpha = 0.90 \sim 0.91$) across the three time points.

Mindfulness-Based Peak Performance Program

The Mindfulness-Based Peak Performance (MBPP) program utilized in the current study was adopted from the mindfulness components of MBSR (Kabat-Zinn, 1982, 2003) (i.e., awareness, paying attention on purpose, being in the present moment, and experiencing things non-judgmentally), as well as our own previous MBI program (Nien et al., 2020). The MBPP program consisted of a total of eight 60-min sessions conducted twice per week over 4 weeks, the aim of which was to enhance mindfulness levels and performance. The sessions covered two fundamental concepts, namely, mindfulness in general and mindfulness in sports contexts, and included six core modules regarding various findings of brain science related to successful performance, such as findings about habits, stress, rest, attention, emotion, and executive functioning. Additionally, the MBPP sessions also focused on mindfulness exercises, which included mindful check-ins, the raisin exercise, mindful breathing, body scanning, seated meditation, mindful walking, mindful listening, and mindful Bagua Dǎo yin, with each exercise corresponding to the given session topic.

The MBPP course was conducted by a scholar with a Ph.D. in sport and exercise psychology and three certificated instructors with master's degrees in sport psychology. Each session of the MBPP program started with a brief story about performance aimed at inducing the learning motivation of the participants, after which the content of the preceding session and associated homework were reviewed and discussed, followed by a theoretical discussion introducing a new topic and then a mindfulness exercise. Finally, each session concluded with a discussion of the specific application of mindfulness concepts and skills during sports competition situations (e.g., mindful breathing before shooting or mindful walking on the way from a shooting position to the target) (Nien et al., 2020), as well as providing advice on the barriers suffered during the homework.

To enhance adherence (Zhang et al., 2016), the team coach would guide the athletes in practicing the mindfulness skills for 15-min in a group before regular training, and the athletes were also encouraged to perform the assigned 20-min daily home practice. Moreover, all of the athletes received an MBPP program handbook that included a scheduled timetable and notes regarding the mindfulness exercises. The MBPP program was conducted in a classroom of National Taiwan University of Sport. The **Appendix I** presents a summary outline of the MBPP program protocol.

Procedure

A one-group pretest-posttest design was employed to examine the effects of the MBPP program on the shooting performance of the participating archers. An orientation was conducted to thoroughly explain the nature of the study so that both the coach and athletes would understand the experimental procedure. The first data collection (i.e., the pre-test) was conducted before the first MBPP program session, the second data collection (i.e., the middle-test) was conducted immediately after the fourth session, and the third data collection (i.e., the post-test) was conducted immediately after the eighth session. MBPP sessions started at 1:00 p.m., and all measurements at three time points were conducted between 3:00 p.m. and 5:00 p.m. Participants were also asked not to consume caffeine for at least 3 h before testing. In addition, so as to avoid the practice effect from tests (Chen et al., 2013), the measures of shooting performance and cognitive functions were only administered at the pre-test and post-test, the measures of psychological outcomes including the mindfulness and rumination levels were administered at the pre-test, middle-test, and post-test.

Statistical Analysis

SPSS software version 26.0 was used in this study. Descriptive statistics were utilized to calculate the means and standard deviations of the demographic data. Normal distribution confirmation was used by applying the Shapiro-Wilk test, and all of the data were normally distributed across each of the time points. A paired sample *t*-test was conducted to compare the pre-test and post-test shooting score and cognitive function performances. The respective results of the three psychological outcome measures (i.e., the CMAAS, CMIS, and CMRQ) were compared using a one-way analysis of variance (ANOVA), with Bonferroni adjustments being performed for multiple comparisons in the further analysis, to determine whether the MBPP program affected the psychological outcomes over time. Cohen's d and partial eta-squared ($\eta_p{}^2$) are presented was used to estimates the effect size for *t*-test and one-way ANOVA, respectively. In addition, Pearson correlation analysis was performed for post-test to assess the relationships among the shooting score, cognitive function performances, and the three psychological outcomes. A p-value <0.05 was set as the level of statistical significance for all analyses.

RESULTS

Shooting Performance

The paired sample *t*-tests revealed a significant difference between the pre-test and post-test results [$t(22) = -3.58$, $p = 0.002$, $d = 0.27$], with higher shooting scores in the post-test ($M = 621.70$, $SD = 32.08$) compared to the pre-test ($M = 613.48$, $SD = 29.72$) (**Figure 1A**).

Cognitive Function Performance: Stroop Task

One of 23 participants was unable to complete the Stroop task, which resulted in total sample of 22 participants for the final analysis. Regarding the neutral condition, the paired sample *t*-tests revealed a significant difference between the pre-test and post-test results [$t(21) = 6.90$, $p < 0.001$, $d = 0.71$), with a shorter mean reaction time for the post-test ($M = 19.77$, $SD = 3.75$) compared to the pre-test ($M = 22.69$, $SD = 4.24$). For the congruent condition, the paired sample *t*-tests also revealed a significant difference between the pre-test and post-test results [$t(21) = 5.05$, $p < 0.000$, $d = 0.51$], with a shorter mean reaction time for the post-test ($M = 17.59$, $SD = 3.72$) compared to the pre-test ($M = 19.62$, $SD = 4.21$). Finally, for the incongruent condition, the paired sample *t*-tests likewise revealed a significant difference between the pre-test and post-test results [$t(21) = 4.56$, $p < 0.001$, $d = 0.64$], with a shorter mean reaction time for the post-test ($M = 29.01$, $SD = 6.45$) compared to the pre-test ($M = 33.70$, $SD = 8.05$) (**Figure 1B**).

Dispositional Mindfulness

A one-way ANOVA of the CMAAS revealed a significant difference across the three time points [$F(2, 44) = 3.74$, $p =$

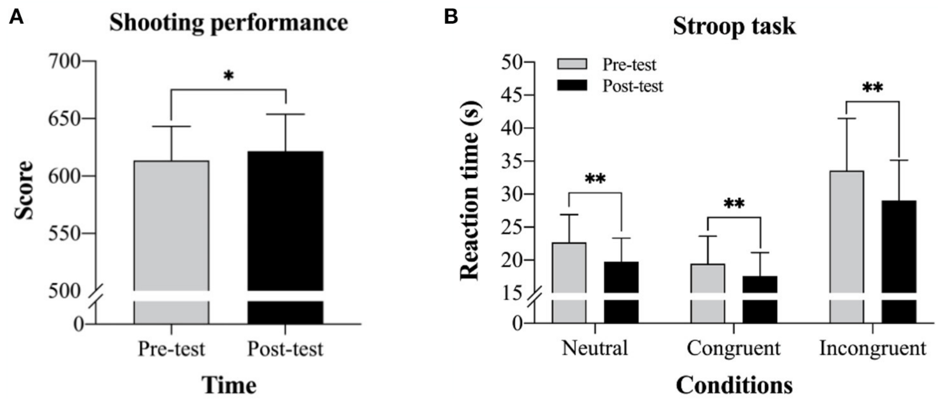

FIGURE 1 | Sport and cognitive function performance results in the pre-test and the post-test following the mindfulness-based peak performance (MBPP) program. **(A)** Comparison of shooting score ($M \pm$ SE) results between the pre-test and post-test and **(B)** Comparison of Stroop task condition results between the pre-test and post-test. $^*p < 0.05$, $^{**}p < 0.01$.

0.032, $\eta_p{}^2 = 0.15$]. *Post-hoc* analysis Bonferroni adjustments revealed that the mean post-test score ($M = 4.67$, $SD = 0.91$) was significantly greater than the mean pre-test score ($M = 4.36$, $SD = 0.74$) ($p < 0.05$), while no other significant differences were observed (middle-test, $M = 4.52$, $SD = 0.80$) (**Figure 2A**).

A one-way ANOVA for the total score of the CMIS revealed a significant difference across the three time points [$F_{(2, 44)} = 6.29$, $p = 0.004$, $\eta_p{}^2 = 0.22$]. *Post-hoc* analysis Bonferroni adjustments revealed that the mean post-test score ($M = 3.96$, $SD = 0.38$) was significantly greater than the mean pre-test score ($M = 3.67$, $SD = 0.44$) ($p < 0.05$), while no other significant differences were observed (middle-test, $M = 3.78$, $SD = 0.39$) (**Figure 2B**).

A one-way ANOVA for the attentional control sub-dimension of the CMIS revealed a significant difference across the three time points [$F_{(2, 44)} = 6.58$, $p = 0.003$, $\eta_p{}^2 = 0.23$]. *Post-hoc* analysis Bonferroni adjustments revealed that the mean post-test score ($M = 4.72$, $SD = 0.82$) was significantly greater than the mean pre-test score ($M = 4.27$, $SD = 0.74$) ($p < 0.05$), while no other significant differences were observed (middle-test, $M = 4.36$, $SD = 0.78$) (**Figure 2C**). Meanwhile, a one-way ANOVA for the non-judgment sub-dimension revealed no significant differences across the three time points [$F_{(2, 44)} = 6.22$, $p = 0.541$, $\eta_p{}^2 = 0.03$; pre-test, $M = 4.55$, $SD = 0.87$; middle-test, $M = 4.38$, $SD = 0.84$; post-test, $M = 4.56$, $SD = 0.89$].

Ruminations

A one-way ANOVA of the emotional-focused rumination sub-dimension revealed a significant difference across the three time points [$F_{(2, 44)} = 16.46$, $p < 0.001$, $\eta_p{}^2 = 0.43$]. *Post-hoc* analysis Bonferroni adjustments revealed that the mean pre-test score ($M = 3.29$, $SD = 1.01$) was significantly higher than the mean middle-test score ($M = 2.81$, $SD = 1.00$, $p < 0.01$) and the mean post-test score ($M = 2.40$, $SD = 1.14$, $p < 0.001$), while there was no significant difference between the middle-test and post-test means ($p > 0.05$) (**Figure 3A**).

A one-way ANOVA of the meaning-searching rumination sub-dimension revealed a significant difference across the three time points [$F_{(2, 44)} = 16.46$, $p < 0.001$, $\eta_p{}^2 = 0.43$). *Post-hoc* analysis Bonferroni adjustments revealed that the mean pre-test score ($M = 3.19$, $SD = 0.82$) was significantly higher than the mean middle-test score ($M = 2.78$, $SD = 0.87$, $p < 0.05$) and the mean post-test score ($M = 2.46$, $SD = 1.09$, $p < 0.01$), while there was no significant difference between the middle-test and post-test means ($p > 0.05$) (**Figure 3B**).

A one-way ANOVA of the instrumental rumination sub-dimension revealed no significant differences across the three time points [$F_{(2, 44)} = 0.44$, $p = 0.650$, $\eta_p{}^2 = 0.02$; pre-test, $M = 4.04$, $SD = 0.63$; middle-test, $M = 4.00$, $SD = 0.75$; post-test, $M = 3.94$, $SD = 0.74$].

Correlation

The Pearson correlation analysis revealed a positive correlation between the shooting score and the total score of the CMIS ($r = 0.426$, $p = 0.043$), but the shooting score was not significantly correlated with the cognitive function performance or the other psychological outcomes.

DISCUSSION

The present study sought to determine the effects of an MBPP program on fine motor sport performance, to examine the potential role of psychological status, and to investigate the optimal dose of an MBI program for achieving desired changes in archery. The primary results revealed higher post-test shooting scores, cognitive function performances, and both general and athletic mindfulness levels compared to those for the pre-test. Additionally, decreased negative ruminations has revealed since the middle-test. Lastly, a positive correlation between the shooting scores and the mindfulness levels induced by the MBPP program was also observed.

Shooting Performance

The finding of the present study that the MBPP program resulted in improvements in shooting performance was consistent with

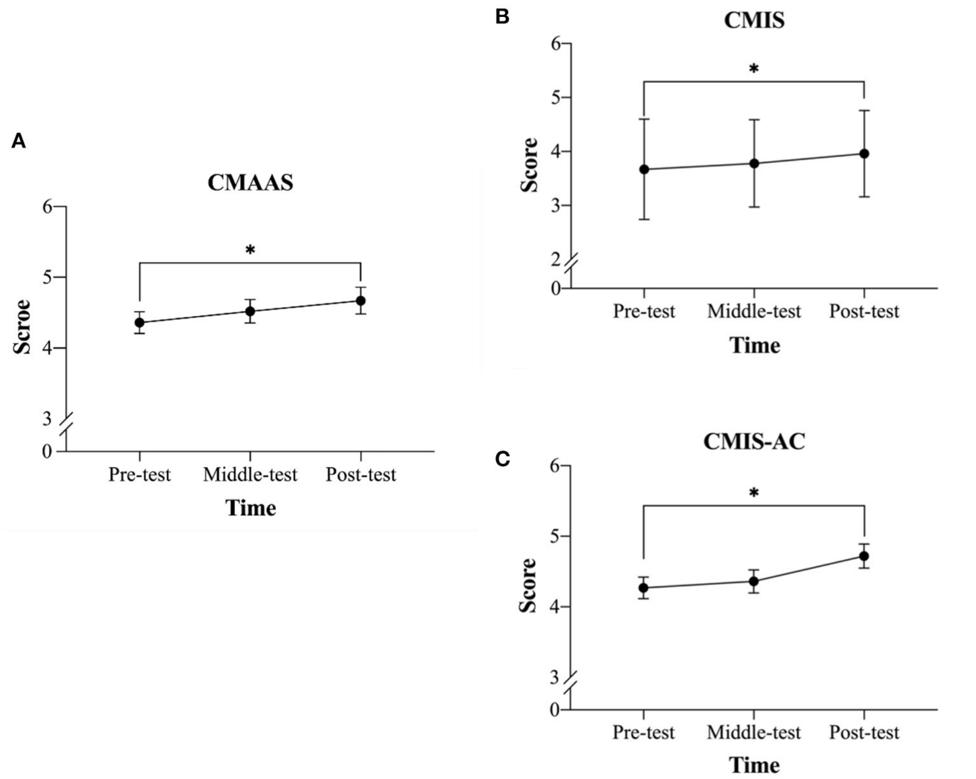

FIGURE 2 | Changes in mindfulness levels across three time points before, at the mid-point of, and after the mindfulness-based peak performance (MBPP) program. **(A)** Comparison of the scores ($M \pm$ SE) on the Chinese version of the Mindful Attention Awareness Scale (CMAAS) across the three time points, **(B)** Comparison of the total scores on the Chinese version of the Mindfulness Inventory in Sport (CMIS) scale across the three time points, and **(C)** Comparison of the scores for the attentional control sub-dimension of the CMIS across the three time points. $^{*}p < 0.05$.

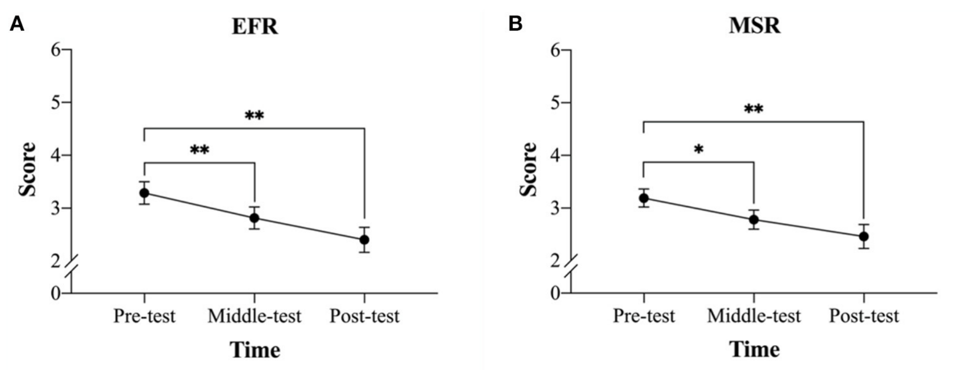

FIGURE 3 | Changes in rumination score across three time points ($M \pm$ SE) before, at the mid-point of, and after the mindfulness-based peak performance (MBPP) program. **(A)** Comparison of the scores for the emotional-focused rumination (EFR) sub-dimension and **(B)** comparison of the scores for the meaning-searching rumination (MSR) sub-dimension. $^{*}p < 0.05$, $^{**}p < 0.01$.

those of previous studies that utilized dart throwing (Zhang et al., 2016) and shooting (John et al., 2011), while also expanding upon studies that have indicated that MBIs can directly affect fine motor sports performance (Bühlmayer et al., 2017). Notably, the strength of this study was that performance in a simulated athletic competition was adopted as an objective assessment that provides a better understanding of the beneficial effects of MBI on performance, including better ecological validity (Gross et al., 2018; Josefsson et al., 2019). In a contrasting example, a previous study by Kaufman et al. (2009) failed to observe any effects of an MBI via the self-report approach in golfers and archers. Taken together with the results of our study, the results of that earlier study imply that the effects of MBIs can be more effectively evaluated with objective assessments that reflect the reality of athletic performance rather than with subjectively biased self-reports.

Cognitive Functions

The archers who participated in the present study showed enhanced Stroop task performances across all the Stroop conditions (i.e., the neutral, congruent, and incongruent conditions) after the MBPP program, suggesting that multiple aspects of the athletes' cognitive functioning, from basic information processing to inhibitory control, were simultaneously enhanced by the MBPP program (Moore and Malinowski, 2009; Allen et al., 2012; Nien et al., 2020). These results are crucial because better basic information processing (e.g., processing speed, visual search ability) and EF have been found to distinguish elite athletes (Scharfen and Memmert, 2019) and elite gamers from low-ranked athletes and gamers and are hallmarks of peak performance (Toth et al., 2019). The improved inhibitory control induced by an MBI may be affected by reducing conflict monitoring in neural processes. For instance, Nien et al. (2020) reported that athletes who attended mindfulness training exhibited higher accuracy scores across all conditions of the Stroop task and smaller N2 amplitudes (a sensitive marker of response inhibition that reflects the conflict monitoring related to cognitive control) than those in a control group. Additionally, a neuroimaging study also found that, compared with relaxation training, an MBI increased the resting-state functional connectivity among EF-related brain networks (i.e., the dorsolateral prefrontal cortex and dorsal and ventral networks) in individuals with psychological distress (Taren et al., 2017).

Our results showed non-significant correlations between the investigated cognitive functions and shooting performance, which is inconsistent with previous studies (Verburgh et al., 2014; Huijgen et al., 2015; Sakamoto et al., 2018). It should be noted that the majority of those past reports were focused on gross motor sport performance (e.g., that of soccer athletes), whereas fine motor sport performance (i.e., archery performance) was focused on in this study. Jacobson and Matthaeus (2014) have suggested that different types of sport experiences may moderate the sport effects on cognitive performance. Moreover, the nature of the cognitive tests used may also result in differences. For example, several studies have employed the stop-signal task to detect motor inhibition (Verburgh et al., 2014; Huijgen et al., 2015); however, we utilized the Stroop task to measure selective attention-related inhibitory control. Further studies are thus suggested in order to better understand the relevance of the sport and cognitive assessments applied.

Psychological Outcomes

The findings that the archers exhibited greater general as well as athletic mindfulness levels in the post-test compared to the pre-test not only support previous findings regarding the beneficial effects of MBIs in athletes (Bühlmayer et al., 2017), university students (Dawson et al., 2019), persons with psychosis (Jansen et al., 2020), and patients with cancer (Xunlin et al., 2020), but also demonstrate that comprehensive improvement in different types of mindfulness can be induced by MBIs. The results also imply that the MBPP program used is effective in increasing mindfulness levels in athletes. Furthermore, a positive correlation between athletic mindfulness, but not general mindfulness, and shooting performance, was demonstrated, suggesting that athletic mindfulness levels may be considered a potential mediator affecting fine motor sport performance, a finding which extends to past studies that employed basketball free throw performance (Gooding and Gardner, 2009) and middle-distance running performance (Jones and Parker, 2016). This result may implicate that athletic mindfulness is more suitable for assessing the sport performance of athletes, compared with general mindfulness (Josefsson et al., 2019). On the other hand, the results showed a significant increase in the mindfulness level, which means archers improved their ability to concentrate on their present-moment experiences, which may improve the archer's coping skills, relative to a variety of sport-related challenges from internal and external events (Josefsson et al., 2017).

Furthermore, the MBPP program reduced the negative rumination levels of the participating archers, a result that is consistent with those of previous studies using MBSR and mindfulness-based cognitive therapy programs (Campbell et al., 2012; Frostadottir and Dorjee, 2019). Decreased rumination has been linked to increases in mindful attention and enables individuals to focus their attention on present-moment environmental cues (Campbell et al., 2012). Reduced rumination has also been found to be associated with superior cognitive performance (De Lissnyder et al., 2010; Zhang et al., 2019), which may contribute to athletic performance enhancement in athletes. Indeed, decreases in negative ruminations are also highly relevant to coping skills for athletic performance, and reducing the manifesting of unwanted emotion (Josefsson et al., 2017). Notably, both emotional-focused and meaning-searching aspects of ruminations were improved following the MBPP program in this study, and given that these two dimensions of rumination may be related to the emotional regulation of stressors in competitions (Rood et al., 2009; Josefsson et al., 2017), our findings indicate that the MBPP program can improve upon poor adjustment and maladaptive coping in emotional regulation. Specifically, the athletes who have a relatively higher mindfulness level and less negative ruminative thoughts, and who may experience a lower intensity of negative emotions at the same time, by achieving such balanced mental states could perhaps be better enabled to focus completely on goal-directed behaviors, in order to achieve their optimal performance in the competitions (Thompson et al., 2011; Josefsson et al., 2017). Taken together, the results of this study indicate that a reduction of rumination can be induced by MBIs, providing additional evidence that athletes should be encouraged to engage in MBIs to prevent negative emotions and achieve optimal athletic performance.

Dose-Response Relationship

One of the strengths of the present study was that it examined the dose-response relationship between an MBI and its associated changes of psychological status (i.e., mindfulness and ruminations), with assessments at three time points (i.e., the pre-test, middle-test, and post-test) having been employed. Both general and athletic mindfulness levels were improved at the post-test, meaning that the improvements of mindfulness have occurred in the late stage of the MBPP program. Nevertheless, this result does not correspond with findings of the previous clinical study by Roos et al. (2019), whereas there was found that mindfulness level was improved after the eighth session of MBPP in the present study, which is not supporting their results, that more than two sessions only could be associated with higher mindfulness level. The inconsistent findings might result from the differences in components of the programs and characteristics of their practitioners.

Contrarily, decreased ruminations were observed just after middle-test and maintained until the end of the MBPP program, suggesting that the rumination levels could have been improved only in the early stage of the MBPP program. This finding was found to be partly similar to results of Roos et al. (2019), in that they found that attending more than two sessions of mindfulness could predict the improvement of mental health. It should be noted that although a 4 weeks program was used in this study, the frequency of sessions was set at twice per week, for an overall dose that was similar to those of past studies (Creswell, 2017; Roos et al., 2019). These findings provide an initial explanation of the dose-response relationships of the MBPP program, in terms of training frequency and overall length, on different psychological outcomes in athletes.

Alterative dose-response relationships associated with session duration and frequency may be presented. In contrast to Kaufman et al. (2009) they observed no effect on performance following a mindfulness program constituted of 2.5–3 h sessions, done weekly, for 4 weeks (i.e., four times with longer session times), whereas we observed a significant improvement in archer performance following a twice per week 1 h session, for 4 weeks (i.e., eight times with a shorter time). The difference may be associated with session duration, in which studies have suggested that long mindfulness sessions may produce hindrances (e.g., self-critical or confusing reactions) during practice (Banerjee et al., 2017; Strohmaier et al., 2021). These findings suggest that mindfulness programs with short duration and more frequency may lead to a larger effect on performance, and this requires further investigation.

Strength and Limitations

The strengths of the present study include the fact that its examination of the effects of the MBPP program on athletic performance had better ecological validity than some previous studies, as well as its investigation of many aspects of psychological status and the dose-response relationship of the MBPP program through multiple assessments. However, our results should be also interpreted cautiously for several reasons. First, the lack of a control group prevents the drawing of any cause-effect interpretations. Additionally, given the relatively small number and unbalance of gender of the elite level participants engaged in a specific sport, which may limit statistical power, and cause the generalizability of the findings to be limited. As such, in order to better understand how the MBPP program might affect the investigated outcomes, further studies using quasi-experimental designs or randomized controlled trials with larger sample sizes from more sport types are needed in the future. Another limitation is that the present study did not administer the structured post intervention follow-up, which may not adequately measure the effectiveness of the MBPP program across the entire training progress of participants, and its carry-over effects. Future research should employ a longitudinal design with a follow-up, in order to better understand the efficacy and effectiveness of the MBPP program for athletes. Third, despite the simulated competition having been adopted for the purpose of assessing the participants' performances objectively, the limited authenticity of the simulated archery competition may mean that the study results are not generalizable to any highly competitive genuine competitions. Lastly, despite that each session in the MBPP program included a discussion section, the data of running the program (e.g., interaction between the experts and the athletes) were not collected. It would be required to use qualitative methods so as to better and more deeply understand the applications of the MBPP program in future works.

CONCLUSION

The present study provides empirical and preliminary evidence that supports the benefits of an MBPP program for archers in terms of shooting performance, multiple cognitive functions, and psychological outcomes. Additionally, the MBI ameliorated mindfulness and ruminations in the late-stage and middle-stage, respectively. Lastly, the MBPP program may be a promising approach for enhancing athletic performance, suggesting that athletes and coaches could integrated the MBPP program into sport training routines. However, further studies considering performance-relevant outcomes, and implemented with high-quality methodology, are needed in order to replicate the findings of the present study.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Center for Research Ethics of National Taiwan Normal University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

T-YW, Y-CC, H-CC, and Y-KC contributed to the conception of the work. T-YW, Y-CC, H-CC, and Y-KC contributed to the design of the work. J-TN, GK, C-HW, and H-CC conducted the literature search, selection, data extraction, and analysis.

T-YW, J-TN, GK, and C-HW wrote the first draft of the manuscript with support from H-CC. All authors contributed to the manuscript revisions and agreed with final approval of the version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.661961/full#supplementary-material

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Physical Activity and Life Satisfaction: An Empirical Study in a Population of Senior Citizens

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Objective: The specialised literature indicates that the two key aspects in active ageing are performing physical activity and life satisfaction. Regarding physical activity, this not only improves physical aspects of senior citizens, but also has a positive impact on mental well-being and satisfaction with one's own life. The aim is to demonstrate the relationship between these two variables to explain healthy ageing.

Method: In a sample of 300 senior citizen subjects, the influence of various sociodemographic variables (age, sex, institutionalisation, and level of education) on the performance of physical activity and life satisfaction, is analysed. The research design is a non-experimental study with two unique cross-sectional and correlational measurement groups.

Results: An analysis of the results indicates that people with a higher level of education present differences in physical and motivational reserves. Furthermore, age and institutionalisation have an impact on physical reserves. Analysis using structural equation models allows key relationships between the variables analysed to be predicted, which can guide the implementation of active ageing.

Conclusion: Motivational reserves affect healthy cognitive ageing through their positive impact on cognitive and physical reserves.

Keywords: ageing, physical activity, life satisfaction, senior citizens, healthy ageing

INTRODUCTION

Economic and sociosanitary improvements over recent decades have generated a change in sociodemographic curves on a global level, although this is more obvious in developed countries. The consequences of longevity represent a significant social achievement that poses a challenge for healthcare systems (Mari, 2018). As the World Health Organization (2016a) has pointed out, we have never lived in better conditions than we do now, but maintaining well-being levels implies holding all those involved in healthcare, including individual responsibility, responsible for developing healthy habits. This is the case, for example, for Spain, where the female population, with an average life expectancy of 85.5 years, puts it in third position worldwide, only being surpassed by their counterparts in Japan and Singapore. We, therefore, need to understand the beliefs and representations of these sectors of the population to implement programmes that have a positive impact on health behaviours (Velardi, 2018). Furthermore, we must consider that the ageing process is a stage of the life cycle that presents significant differences between individuals regarding the physical and cognitive state of senior citizens (Pérez et al., 2017), which, in some cases, leads to loss of physical, cognitive, and physical capacity (Frazão et al., 2018).

One of the relevant aspects of the way we age is the performance of physical activity, and this is seen in the literature, independently or combined with the development of other aptitudes (Diaz et al., 2019). We understand physical activity as any body movement produced by the skeletal muscles themselves that requires the expenditure of energy (World Health Organization, 2016b; Parra, 2017). But it is essential to understand the recommendations made by the World Health Organization (2010) so that people aged 65 and over manage to keep themselves in the best possible physical condition. The guidelines state that adults should perform a minimum of 150 min per week of moderate aerobic physical activity and should perform muscle strengthening activities twice a week or more. Because the performance of physical activity not only improves aesthetic aspects of senior citizens, but also has a positive impact on self-perception and mood, as well as reducing anxiety and stress (Infante et al., 2011; Windle, 2014). It is very important to highlight evidence of positive involvement in the immune system as a protective factor against disease (Guerrero et al., 2020). For this reasons, some authors (Devereux-Fitzgerald et al., 2016) have indicated the importance of interventions being focused on encouraging physical activity through fun, joyous, achievable pastimes for senior citizens, and with significant short-term benefits.

Related to physical activity is quality of life, and an important aspect, is life satisfaction, which is understood to be the key to the development of successful ageing. Positive Psychology deems well-being to be a globalising concept that includes satisfaction, happiness, life considered as a whole, high morale, personal adjustment, good attitudes towards life, and competence (Seligman, 2011). Theoretical conceptualisation, which has been proven in studies that show that active people have a better quality of life (Gomez-Piriz et al., 2014). Within this disciplinary field, the term subjective well-being, which is deemed to be a complex construct associated with one's own experience, what is deemed to be a "good life", and having full use of one's faculties, is of special interest (Kahneman, 1999). Hence, two schools of thought regarding well-being emerge, the hedonic (focusing on happiness and the avoidance of pain and the pursuit of pleasure) and the eudaimonic (focusing on meaning and self-realisation), as indicated by Ryan and Deci (2001). Therefore, assessing the personal well-being of senior citizens allows us to get close to the intrinsic ageing process and understand their perceived reality. This also includes being able to understand paradoxical results such as, as the years go by, senior citizens being able to express greater satisfaction with life and a reduction in the search for meaning (Avellar et al., 2017).

Scientific literature has proven the relationship that exists between disease and low levels of well-being, as well as life satisfaction and dementia combined (Peitsch et al., 2016). Following this line, greater satisfaction has been shown in terms of the health, good functional skills, a large number of social contacts, marital status, and the educational level of the senior population (Montenegro and Soler, 2013; Martín Aranda, 2018). Over recent years, other research has shown interest in studying life satisfaction in the intermediate and final stages of life, with results that do not always coincide (Guillén and Angulo, 2016; Jiménez et al., 2016; Cabaco and Fernández, 2019).

Finally, and in relation to changes that occur in the ageing process, sociodemographic variables should be considered to assess both cognitive processes and the performance of physical activity and a person's own life satisfaction since the importance of certain variables (age, sex, level of education, and residential care home) has already been proven as an important indicator that some functions decline to a greater or lesser extent (Arenaza-Urquijo et al., 2013; Gómez et al., 2018; Raimundo et al., 2020).

Given that, in the literature, there is still not a broad consensus on how different sociodemographic variables are related, and based on the aforementioned research, the objective of this research was derived with the intention of providing greater clarification. The relationship between gender, age, level of education, and whether or not the person is in institutional care and the performance of physical activity and the meaning of life of those aged over 55. Furthermore, we intend to establish a predictive model of the interdependence of variables associated with physical, cognitive, and motivational reserves.

MATERIALS AND METHODS

The research design is a non-experimental study with two unique cross-sectional and correlational measurement groups.

Participants

The sample is made up of 300 subjects, 224 being women (75%) and 76 men (25%), of whom 150 subjects are in institutional care and 150 live independently. The whole sample is made up of subjects aged between 55 and 99 years with an average age for the men of 74.66 and 74.7 for the women, the overall average age being 74.68.

With respect to the group of institutionalised subjects, this is made up of 107 women (71%) and 43 men (29%), with ages ranging from 55 to 99 and whose average age is 83.17. The group of non-institutionalised subjects is made up of a total of 117 women (78%) and 33 men (22%) with ages ranging from 55 to 84 with an average age of 66.21.

Regarding the level of education of the sample, 10% have had no kind of schooling, bordering on illiteracy, 51% completed primary education, 20% secondary education, and 19% studied at university. On the other hand, the relationship between gender and education was analysed, showing that both men and women present similar levels of education throughout the sample. As can be seen, there are no difference between genders in terms of educational level.

The criteria for inclusion were the same for both groups, firstly, being 55 or older, not presenting cognitive impairment and being institutionalised in a residential care home or living at home.

Instruments

The assessment battery consisted firstly of a sociodemographic data sheet that also includes information about the senior citizen such as gender, age, level of education, and institutional care home, in the case of those belonging to that subsample. Secondly, the battery consisted of the following questionnaires:

International Physical Activity Questionnaire (IPAQ). This questionnaire was developed by the World Health Organization (2012) and is made up of seven items, whereby the replies are quantified by means of the minutes or hours spent performing an activity in the last 7 days, as indicated for each item. The reliability of the IPAQ, in its short version, is 0.65 (rs = 0.76; IC95%:0.73–0.77). With this scale, we obtain data relating to physical activity associated with health, and it is currently being used with senior citizens.

Purpose In Life test (PIL). This is an attitude scale designed by Crumbaugh and Maholick (1964) to measure the degree to which an individual feels that his/her life has meaning and purpose, as well as for detecting an existential void. This test is currently the most used instrument in research on meaning of life due to high internal consistency (in all cases, greater than 0.80 in Cronbach's Alpha) obtained in numerous studies with different populations (Martínez et al., 2012). This test is made up of 20 items, whereby the subjects should reply individually by means of a Likert-type scale from 1 to 7 between two extreme feelings.

Procedure

Two phases were determined for the development of the research. In the first of these, the sample was recruited such that contact between the centres where the research was to be conducted was initiated, for both the independent and institutionalised groups. The first group, subjects belonging to the non-institutionalised group, is made up of students from the University of Experience of the Pontifical University of Salamanca and the SABIEX Programme of the Miguel Hernández University of Elche. Participants from the institutionalised group were obtained from various residential care homes from the Autonomous Communities of Castilla y León and Valencia, to maintain the same contextual characteristics as the first group.

Once contact had been made with each centre and institution, the second phase was launched, whereby the application of a battery of tests was undertaken. These tests were administered individually, lasting approximately an hour and a quarter for each senior citizen. The assessments were performed between the months of March and October 2017 and, in all cases, informed consent for participation was obtained beforehand. Furthermore, the study strictly complied with the ethical criteria indicated in the Helsinki Declaration (2013, review) for research of this type.

Finally, as criteria for inclusion, as well as accepting the conditions indicated (voluntary participation, presenting legal authorisation and waiving remuneration), they should not present cognitive impairment. Failure to meet any of the above criteria was grounds for exclusion.

Analysis of the Results

For the calculation of the statistical analyses, the SPSS V.24 statistical programme was used. For the comparison between two groups, the Student *t*-test was calculated and, for the comparison between several groups, the ANOVA of a factor. Pearson's linear correlation statistic was used to study the relationships between variables. Descriptive statistics (mean and SD) for each variable being studied were also studied.

Considering the interrelation between several variables (e.g., correlation between age and education known in Spanish population), a structural analysis was performed using the lavaan package (Rosseel, 2012) in R statistical language. The tested model included all four predictors (age, education, sex, and institutionalisation) and both dependent variables (life satisfaction and physical activity) simultaneously. Common fit indices were calculated: root mean square error of approximation (RMSEA), comparative fit index (CFI), standardised root mean residual (SRMR), and Tucker-Lewis index (TLI). Indications of a good fit were values of 0.08 or lower for the RMSEA and SRMR, and values of 0.90 or higher for CFI and TLI. Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used to confirm if the model with all predictors included (sex, education, age, and institutionalisation) showed a better fit than simpler models: one with only age as a predictor, and another one only modelling the means of physical activity and life satisfaction. Smaller AIC and BIC values indicate better fit.

RESULTS

Regarding the first objective, the results found for the sociodemographic variables analysed are shown. For all these, physical reserves (assessed using the IPAQ) and motivational (assessed using meaning of life with the PIL test) measurements are considered. On both these scales, the scores are interpreted such that the higher the score in the PIL test, the greater the meaning of life (motivational reserves); and, on the IPAQ scale, the higher the score, the less activity and, therefore, lower physical reserves.

With respect to possible differences according to *gender*, after performing contrast analysis using the Student *t*-test, no significant differences were obtained between men and women ($p > 0.05$), or in physical or motivational reserves (see **Table 1**).

As regards the relationship between *age* and both physical and motivational reserves, Pearson's linear correlation test shows that there is no significant correlation between age and meaning of life (r_{xy}: 0.050; sig: 0.351 > 0.05); although there is between age and physical activity (IPAQ), indicating that, the older they are, the less physical activity senior citizens do (r_{xy}: 0.196; sig: 0.001 < 0.05).

The third sociodemographic variable refers to *educational level* to determine whether there are differences in physical and motivational reserves. For Meaning of Life (PIL), means contrast only shows significant differences ($p < 0.05$) between the "Without Studies" (SE) and "University" (UN) groups, such that the university educated group scores higher (greater meaning of life; see **Table 2**).

With respect to Physical Activity (IPAQ), it can be seen that the trend is that more physical activity is performed as the level of education rises, such that, the without studies group performs less physical activity than the primary studies group, and these do less than the secondary or university education groups (there are no differences between secondary and university education; see **Table 2**).

Finally, we studied whether there are differences between senior citizens regarding physical activity and meaning of life, according to whether they live in an *institutionalised environment* (care home) or not (at home). Mean contrast (*t*-test) shows that there are no significant differences for meaning of life, although there were for physical activity (sig <0.001; TE: 0.59), indicating that the non-institutionalised group perform more physical activity than the institutionalised (see **Table 3**).

Finally, in order to separate out the effects that each assessed variable has, and to integrate it into the other variables, in other words, to properly monitor the separate effects, a structural analysis was performed that would allow the effects to be broken down.

A model with the variables Institutionalisation (whether the senior citizen is institutionalised, 0 = No, 1 = Yes), Gender (0 = Male, 1 = Female), Education (an ordinal variable, 1 = Without studies, 2 = Primary, 3 = Secondary, 4 = University), and Age as predictors, and both variables of physical activity (IPAQ) and life satisfaction (PIL) as dependent variables. The model showed an excellent fit, as the main indices show, CFI = 1, TLI = 1, RMSEA = 0, SRMR = 0. Comparison indices between models show that this model has a better fit (AIC = 3,264, BIC = 3,312) than one in which the only predictor is age (AIC = 3,288, BIC = 3,314), and another one only modelling the means for physical activity and life satisfaction (AIC = 3,299, BIC = 3,317).

Figure 1 shows the results whereby it can be seen that, by controlling the effects of all the variables at the same time, educational level remains an important predictor of both physical and motivational reserves. The higher the educational level, the more physical activity is performed, and the greater the life satisfaction.

It can also be seen that the factor of being institutionalised reduces physical activity. However, age is no longer a relevant factor for physical activity. This would be explained by the age differences between non-institutionalised and institutionalised subjects, since age was higher in the latter group (66.2 vs. 83.2 years old). Finally, there is a statistically significant correlation between physical activity and life satisfaction (−0.18, $p < 0.01$).

These analyses strengthen the conclusion that educational level and institutionalisation have separate effects on physical activity and life satisfaction, as well as a correlation between them that is added to these sociodemographic indicators.

TABLE 1 | Differences by sex in physical and motivational reserves.

	Sex (mean, SD[1])		Levene test (sig.)	*t*-test (sig.)
	Men	Women		
Motivational reserves (PIL)	140.5 (19.1)	140.9 (17.2)	0.177	0.865
Physical reserves (IPAQ)	2.07 (0.783)	1.97 (0.765)	0.423	0.345

[1]*SD, standard deviation.*

DISCUSSION

In light of the results obtained, we can affirm that, with respect to the role sociodemographic variables play in physical

TABLE 2 | Differences according to educational level and physical and motivational reserves.

Reserves		Educational level				Contrast tests		
		SE[1]	PR[1]	ES[1]	UN[1]	PL[2]	PA[2]	Comparison between groups (P. Scheffe)
PIL	Mean	133.9	141.0	138.3	145.7	0.837	0.026	SE = PR, ES; SE < UN*
	SD	18.76	18.90	16.38	18.85			PR = ES, UN
	N	30	152	60	58			ES = UN
IPAQ	Mean	2.60	2.19	1.68	1.76	0.129	<0.001	SE < PR*; SE < ES, UN**
	SD	0.498	0.761	0.725	0.733			PR < ES, UN**
	N	30	152	60	58			ES = UN

[1]*SE, without studies; PR, primary studies; ES, secondary studies; UN, university.*
[2]*PL: Levene's test (significance); PA: ANOVA test (significance).*
**Significance: <0.05.*
***Significance: <0.001.*

and motivational reserves, there are no differences between sexes; by contrast, those with higher educational levels do present greater physical and motivational reserves.

TABLE 3 | Differences according to life context (institutionalised or not) on physical and motivational reserves.

	Institutionalised (mean, SD[1])		Levene test (sig.)	*t*-test (sig.)	TE[2] Cohen's *D*
	No	Yes			
Motivational reserves (PIL)	141.4 (18.2)	139.9 (18.9)	0.610	0.515	0.11
Physical reserves (IPAQ)	1.83 (0.76)	2.27 (0.74)	0.891	<0.001	0.59

[1]*SD, standard deviation.*
[2]*TE, effect size (Cohen's D test).*

Although in this study there are no differences between men and women, it is important to highlight the predominance of the female sex in old age, since life expectancy at birth is 85.4 years compared to that of the male sex who is in 79.9 years (Abellán et al., 2017). This can be understood due to the fact that in the programmes for the elderly, there are more women than men, as is the case in general with the elderly population (Moreno-Crespo et al., 2018; INE, 2020, 2021). In relation to the age difference in the groups of institutionalised subjects in residential centers and the group of non-institutionalised subjects, it is due to the fact that in Spain, as indicated by the INE (2020), there is a population of 46,934,632 people, corresponding to 19.64% to people over 64 years of age. In addition, regarding life expectancy, the Spanish population lives an average of 83.5 years, which is much higher than the rest of the world.

The Continuous Household Survey published by the INE (2020), states that 2,037,700 people aged 65 or over live alone in Spain (43.1%), of which 1,465,600 (71%) are

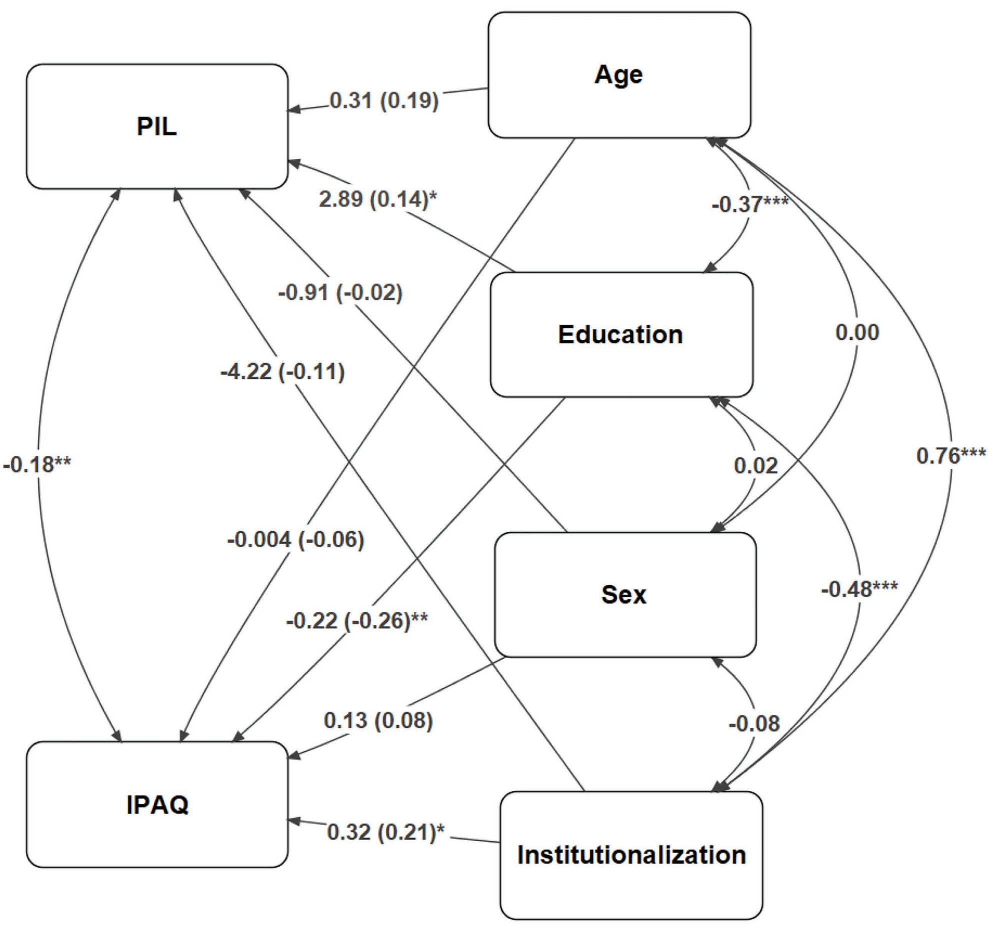

FIGURE 1 | Structural equations model with the sociodemographic variables institutionalisation, gender (sex), education, and age as predictors of physical activity (IPAQ) and life satisfaction (PIL). Institutionalisation: 0 = Non-institutionalised, 1 = Institutionalised. Sex: 0 = Male, 1 = Female. Education: 1 = Without Studies, 2 = Primary, 3 = Secondary, 4 = University. After taking into account the correlations between predictors, institutionalisation remains a predictor of physical activity, and education remains a predictor of both physical activity and life satisfaction. Values for one-sided arrows: natural estimates (standardised values). Values for two-sided arrows: standardised correlation indices. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

women and 270,000 older people live in residential centers (Barrera-Algarín et al., 2021).

Regarding the education variable, it is observed that in the group of institutionalised subjects, the educational level is lower, because the mean age is higher, as stated by Estrada et al. (2013) in a study carried out with 276 institutionalised older adults, in which the predominant educational level was primary (51.1%), followed by secondary (25%), it was found that 17.4% did not have any level of training.

With regard to the other variables, age relates to physical reserves (the older they are, the less physical activity they perform) but not to motivational reserves, as is the institutionalisation variable (non-institutionalised people perform more physical activity). The results broadly confirm those found in the initial literature (Martín Aranda, 2018; Guerrero et al., 2020). However, there are studies that demonstrate the existence of a significant disparity in the prevalence of physical inactivity. According to the World Health Organization (2015), this prevalence is higher among women than men, which differs from the results obtained in this study. By contrast, and regarding age, it indicates that senior citizens are less active than young people. Along the same line, Crombie et al. (2009) have shown that there is a reduction in physical activity among the adult population.

A recent study carried out with 415 non-institutionalised older women described the influence of age on the level of physical activity, muscle mass, and strength in older women. In this sample, the amount of muscle mass showed an association with upper and lower limb strength and physical performance. Therefore, they concluded that the increase in age, muscle mass, and strength gradually decreased (Enríquez et al., 2019).

Regarding life satisfaction, the studies indicate that there are two related concepts, which are the feeling of presence and the search for meaning. Avellar et al. (2017) have assessed the extent to which the feeling of presence and the search for meaning change according to life cycle. They conclude that as life stages advance, meaning increases, although, by contrast, search for meaning decreases. On the other hand, their results indicated that those included in the senior citizens group perceived greater presence of meaning in the present compared to the group of young people. Although, in our study, we do not have a young sample for comparison, the results are similar to other research developed using the same instrument, even with clinical populations (Armas et al., 2018).

In a study carried out by Chacón et al. (2017), they related the performance of physical activity with a person's state of mind. This research was conducted with a total of 1,002 subjects over the age of 18 and subdivided into age groups by means of a descriptive and correlational non-experimental study. The instruments used were, to measure physical activity they used the questionnaire designed by the IKERKI Group (Arribas et al., 2006), whereby those people who have performed some kind of physical-sporting activity over the last 12 months are deemed to perform physical activity, and, secondly, the State of Mind Questionnaire (CEA; Arruza et al., 2008), which measures the degree of presence of positive and negative feelings over the last year. The results indicated that those people who perform any kind of physical activity have a more positive state of mind than those who have not performed any kind of activity as these are characterised by a greater presence of sadness, tiredness, etc.

Carmona (2009) carried out a study that aimed to analyse personal well-being and factors that facilitate its development and maintenance. The results showed that there is a significant predictive relationship between education, health, independence, and social interactions and the personal well-being of senior citizens. By contrast, the age, marital status, sex, and socioeconomic variables did not contribute in a significant way to the personal well-being of participants in the study, results that coincide with those obtained in this research. Along this line, authors such as Montenegro and Soler (2013) have affirmed that satisfaction increases according to the health, good functional capacities, a larger number of social contacts, marital status, and educational level of senior citizens.

In another study, Franke, 2013 carried out with senior citizens in which the PIL questionnaire was used, it was observed that more elderly people presented significantly more meaning of life. This line is still in an embryonic stage with the development of the gerotranscendence construct (Tornstam, 2011), and there is a debate (ethics of care vs. ethics of needs) about which are the keys to be included in both diagnostic research as well as derived lines of intervention (Cabaco and Fernández, 2019).

Other studies (Vinaccia et al., 2017) affirm the importance of assessing the relationship between quality of life and health and perception of disease. They deem it to be important to study these variables since, according to Palomera (2009), happiness consists of positive and negative emotions as well as life satisfaction, indicating that, if the person presenting an illness maintains a positive emotional state, this results in an improvement in his/her well-being. According to Quiceno and Vinaccia (2010), cognitive and emotional factors are key in the patient's perception of his/her illness, which has an impact on his/her progress.

García et al. (2017) have studied, using a descriptive correlational design (in a sample of 140 retired people, 90 women and 50 men with an average age of 61.23 years), the relationship between sociodemographic variables and the quality of life of these participants. The results affirm that there is a significant correlation between perception of quality of life and variables such as retirement age and physical activity. Continuing with the results, the relationship between sociodemographic variables and dimensions of quality of life, they identified significant correlations between the age of the participant and dimensions such as physical health, psychology, and social relationships. Variables that have been studied in other research (Rojas, 2011), that show that the higher the age of retirement, the lower the perception of the quality of life in these areas. Similar results were found by Tanferri et al. (2017) whereby differences appear between these dimensions and retirement age. Results that suggest that the greater the age, the lower the quality of the dimensions of physical health, psychology, and social relationships. Although the important modulating role played by cognitive reserves in mitigating cognitive impairment should be considered (Wöbbeking et al., 2020).

This study shows that motivational reserves (assessed in this study using meaning of life) have a healthy impact on physical reserves. This evidence and already considering the age, sex, educational level, and institutionalisation status of senior citizens.

Bearing all the variables of this study in mind, it seems obvious that, in light of the literature reviewed, that facing the challenges of demographic changes inevitably involves the strengthening of dimensions associated with the CR construct as a driver of healthy ageing. Particularities deriving from the circumstances of senior citizens (institutionalisation), or other keys of an ideographic or personal nature, should be the object of further research.

As far as the continuity of this line of research is concerned, in order to overcome some of the limitations of the work described, it would be necessary to be able to carry out the study in a longitudinal way, broaden the sociodemographic variables (especially those linked to cognitive reserves) and delve more deeply into motivations that influence the performance of physical activity. It will also be relevant to identify the relationship between age, institutionalisation, and physical activity with larger samples and controlling the years spent in care homes factor. The reason for the proposal is justified in that the results presented herein indicate that institutionalised senior citizens could possibly benefit from spending more time performing physical activity, adjusted to their capacities, as part of the activities of their geriatric centre.

An interesting point, which is revealed by the correlation found between physical activity and life satisfaction, and which goes beyond what is explained by the sociodemographic variables reviewed, is in the possibility of influencing life satisfaction through physical activity, or vice versa.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MW, AS, and BB-L contributed to the development and design of the study, as well as to the application and correction of tests. JDU and MM performed the statistical analyses and wrote the methodology section of the manuscript. ML carried out a full review of the article, including bibliographical references. All authors contributed to the article and approved the submitted version.

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Associations Between Executive Functions and Physical Fitness in Preschool Children

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Considering the current agreement on the significance of executive functions, there is growing interest in determining factors that contribute to the development of these skills, especially during the preschool period. Although multiple studies have been focusing on links between physical activity, physical fitness and executive functions, this topic was more investigated in schoolchildren and adults than in preschoolers. The aim of the current study was to identify different levels of physical fitness among pre-schoolers, followed by an analysis of differences in their executive functions. Participants were 261 5–6-years old children. Inhibitory control and working memory were positively linked with physical fitness. Cognitive flexibility was not associated with physical fitness. The research findings are considered from neuropsychological grounds, Jean Piaget's theory of cognitive development, and the cultural-historical approach.

Keywords: cognitive flexibility, working memory, inhibitory control, physical fitness and sport, motor performance

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INTRODUCTION

The transformations of modern lifestyle add special pertinence to the investigation of the role of children's physical development. This involves the phenomena such as digitalization of the education, the loss of priority of traditional games, and the shifting structure of children's communities (Linebarger et al., 2014; Lillard et al., 2015). Hypodynamia and the metabolic and cardiovascular problems linked to above-mentioned phenomena are not the only issues this study addresses, it also considers the influence on children's mental development which has been shown in recent studies (Bames et al., 2012). The domain that is most strongly associated with physical development is the formation of executive functions (Diamond, 2000). Therefore, we will look closely at the links between them.

Executive Functions

The exact definition of executive functions has been subject to discussion for a long time. In terms of our study, we rely on the following definition: "cognitive processes that are required for the conscious, top-down control of action, thought, and emotions, and that are associated with neural systems involving the prefrontal cortex" (Lerner et al., 2015, p. 271). The main executive functions parameters are three cognitive competences: (i) inhibitory control (resisting habits, temptations, or distractions); (ii) working memory (retaining and using information); and

(iii) cognitive flexibility (Miyake et al., 2000; Nelson et al., 2016). executive functions competences develop intensively throughout the preschool years and have a significant effect on child's later performance (Best and Miller, 2010).

Executive functions crucially impact the formation of academic skills such as word reading, vocabulary, spoken and written language comprehension, mastering of initial mathematical concepts, development of speech skills, as well as the outcomes in high school (Zelazo et al., 2003; Blair and Razza, 2007; Utendale et al., 2011; Blankson et al., 2012; Cheie et al., 2015; Torres et al., 2015; Gagne, 2017). Studies indicate the presence of individual variations in executive functions development by the time children start school (Liebermann et al., 2007; Garon et al., 2008; Lan et al., 2011). Children with considerably lower executive functions indicators are disadvantaged even before their first school year. This starting difference between the advantaged and the less advantaged only grows over time (Prencipe et al., 2011; Skogli et al., 2017; Lensing and Elsner, 2018). Considering the current agreement on the significance of executive functions in early years, there is growing interest in determining factors that contribute to the development of these skills, especially during the preschool period.

Physical Activity and Physical Fitness

Physical fitness includes about eleven components which can be divided into two groups. The first group comprises health orientated fitness parameters such as muscle strength, power, muscle endurance, cardiorespiratory fitness, and flexibility. The second one spans skill-related physical fitness such as agility, coordination and speed (Corbin and Le Masurier, 2014). In order to investigate both areas of physical fitness in preschoolers, a number of complex tests was designed, generally including the same set of "core" tests: (1) standing broad jump which allows to assess the explosiveness of the lower limbs; (2) sit-ups to assess the endurance of the trunk muscles; (3) agility shuttle running to assess speed coordination; (4) flexibility tests, which usually include different variations of sit and reach exercises and are used to assess the flexibility of the lower back and hamstrings; and (5) a multistage fitness test, i.e., progressive 20 m shuttle running test designed to assess cardiorespiratory fitness (Council of Europe, 1988; Měkota and Kovář, 1995; Morrow et al., 2009; Meredith and Welk, 2010; Ruiz et al., 2011; Ortega et al., 2015). Typically, the physical fitness level is calculated based on a number of motor tests which evaluate physical readiness. The readiness is significantly associated with health benefits or risks, as well as to physical activity (US Department of Health and Human Services, 2008; Bermejo-Cantarero et al., 2017).

Physical activity was defined as follows in the study of Welk et al. (2000, p. 65): "Physical activity refers to any bodily movement produced by skeletal muscles that results in energy expenditure" (Caspersen et al., 1985). This formulation of physical activity bears resemblance with the physical fitness definition. Nonetheless, it needs to be noted that physical activity is a biological process which can considerably activate and stimulate children's central nervous system to gain knowledge (Rowland, 1998) and possibly improve the development of cognitive functions (Pellegrini and Smith, 1998; Biddle and Asare, 2011; Carson et al., 2016). Thus, physical activity in children must not be evaluated using only physical fitness parameters, as was indicated by several studies (Welk et al., 2000; DeBate et al., 2009). To conclude, although both physical fitness and physical activity are important markers of both physical and mental health in children, the link between the two is not necessarily direct.

Executive Functions and Physical Fitness

Physical activity and physical fitness are crucial to human development (Silva and Annamalai, 2008; Dumith et al., 2011; Rarick, 2012). These concepts are not only considered important parameters of physical health (Robinson et al., 2015), but are also strongly associated with cognitive development. A study of factors associated with executive functions competences and its correlates indicates that physical activity and physical fitness can be seen as a specific domain (Best, 2010). Both physical activity and physical fitness generate natural motivation, create lasting conditions of "challenge," and minimize the impact of factors inhibiting executive functions: stress, boredom, lack of sleep, and oxygen (Diamond and Ling, 2016).

From the perspective of neurological and microstructural changes it was found that during physical activity (PA) a higher production of neurotropic factors like the brain derived neurotropic factor (BDNF) or the neurotropic growth factor (NGF) responsible for increasing of neuroplasticity in brain regardless of age and sex are present (Barde, 1989; Vaynman and Gomez-Pinilla, 2006; Shim et al., 2008) and positive changes in the white matter microstructure (Arvidsson et al., 2018; Chaddock-Heyman et al., 2018) occur. These neural growth changes along with altered synaptic transmission and induction of brain vascularization during physical activities (e.g., fitness, motor competence actions) influencing particularly prefrontal cortices responsible for thinking, decision making, or behavior were summarized under the executive function hypothesis (Kopp, 2012; Diamond, 2013).

In the last four decades research has proved that physically active breaks during a school day (Grieco et al., 2009), or different movement/physical interventions lasting from 10 to 40 min (Ellemberg and St-Louis-Deschênes, 2010; Kamijo et al., 2011) have a moderate to strong positive effect on increasing of on-task behaviors, attention, or working memory in pre-adolescents and adolescents. Although multiple studies have been focusing on links between physical activity, physical fitness and EF, this topic was more investigated in schoolchildren and adults than in preschoolers (Dwyer et al., 2001; Colcombe and Kramer, 2003; Sibley and Etnier, 2003; Planinsec and Pisot, 2006; Davis et al., 2007; Roebers and Kauer, 2009; Fedewa and Ahn, 2011; Verburgh et al., 2014). Number of studies documented positive links between physical activity and cognitive performance in preschool age children (Sibley and Etnier, 2003; de Greeff et al., 2018). Further, previous research pointed on significant relation between physical activity and physical fitness (Latorre-Román et al., 2016). Therefore, the degree of physical fitness in preschoolers might be candidate significantly related to the degree of cognitive or executive functions (Visier-Alfonso et al., 2020). Even though, recent studies support this assumption

(Maurer and Roebers, 2019; Visier-Alfonso et al., 2020) the role of physical fitness and its certain components (a) muscular and (b) motor component in development of executive functions skills is still open issue.

García-Hermoso et al. (2020) found a significant relationship between the effect of intervention and attention and concentration when changing in cardiorespiratory fitness. However, the authors note a significant limitation of the study, which is the lack of other specific cognitive abilities that composed executive functions. Mulvey et al. (2018) revealed that gross motor skills program led to significant improving of executive functions in preschool children. Oberer et al. (2018) found interrelations between visual and motor coordination and reading and counting skills. Further, in this study it was suggested that the positive influence of physical fitness on academic achievement is substantial but indirect via executive functions. Chang et al. (2012) concluded that motor skills are a predictor of cognitive flexibility and working memory, and they in turn predict the development of reading skills with a high degree of reliability in preschool age children 5–6 years old. On the other hand, recent study of Houwen et al. (2017) did not support this finding in children 3–4 years. The authors investigated the relationship between three variables: motor skills, executive function and passive vocabulary in children aged 3–4 years.

Review of the research indicates that it mostly considered the association between physical activity and executive functions in preschool-age children, while the connection between physical fitness and executive functions is still insufficiently understood. This can be due to the fact that children's physical activity can be investigated using survey methods that are not challenging in its application, while the study of physical fitness necessitates the in-person examination of children, a suitable sports facility, and setting up all the equipment required for the tests. In our view, investigating links between physical fitness and executive functions can be more informative for a number of reasons. First, data that is collected on physical fitness is more objective, since it is acquired in an in-person examination of children, rather than through a survey of parents. This is confirmed by the inadequacy of survey-based methods in studying child development (McDonald, 2008). Second, even regular sports activities over a long period of time don't necessarily lead to a high level of physical fitness, because children may skip classes, the activities may be inadequate for their age and capabilities, or aimed only at specific physical fitness indicators.

Given that the positive influence of physical fitness on the executive and cognitive functions seems to benefit brain development, our study was designed to verify whether the physical fitness in pre-schoolers were significantly linked to their performance in specific executive functions. Following hypotheses were formulated to explore these relationships: (1) the results from the five physical fitness tests will constitute a two-factor structure composed of the physical fitness and a motor skill construct; and (2) high level of physical fitness positively relates to main executive functioning skills among children. Thus, the main purpose of the study is to identify different levels of physical fitness among children aged 5–6 years, followed by an analysis of differences in their EF. This research question is whether there are any differences in children's executive functions performance depending on their physical fitness measures separately or on the general physical fitness status.

Method

Participants

Participants were 261 typically developing 5–6-year-old (M = 5.77, SD = ± 0.32) children (boys n = 130, girls n = 131) from primarily medium-income families. Boys and girls in our sample non-significantly differed in their mean age: boys $\bar{x}$ = 5.79 ± 0.33; girls $\bar{x}$ = 5.76 ± 0.31; t = 0.76, p = 0.45. Children were attending four various pre-kindergarten classrooms located in Moscow. Assessment of executive functions was carried out individually with each child. This study and consent procedures were approved by the Ethics Committee of Faculty of Psychology at Lomonosov Moscow State (approval no. 2020/72). All parents provided written informed consent for their child's participation in the study.

Executive Functions Measures

The Dimensional Change Card Sort (DCCS, Zelazo, 2006) is an executive functions task aimed at measuring cognitive flexibility. In the DCCS task, a child is asked to sort cards in three rounds, according to different rules. The first sorting is based on the picture's color (pre-switch trial), the second on shape (switch trial), and the third on conflicting rules: on color or shape of card depending on is their presence of frame on the card or not (post-switch trial). In the analysis we used the final score of the methodology with a range of scores from 0 to 24.

The subtest *Inhibition* (Korkman et al., 2014) is an executive functions task that assesses the child's ability to inhibit automatic cognitive responses. It includes two series of shapes (circles/squares, and arrows). Firstly, the child is asked to name the shape or direction (Naming trial). In the second part of the task, a child is asked to name the shape or direction conversely: to name circles when squares are presented and squares when circles are presented (Inhibition trial).

The subtest *Sentences Repetition* (Korkman et al., 2014) aimed to assess verbal working memory. This technique uses 17 sentences, gradually increasing in their complexity (sentences become longer and syntactically more complex). For example, while the first sentence consists of 2 words and has a simple structure – "Good night," the twelfth sentence consists of 14 words and has a complex structure – "The woman, who stands next to a man in a green jacket, is my aunt." Omitting a word, replacing it or adding another word was considered as an error. Changes in word order, as well as word relocation, were also considered as an error. An accurately reproduced sentence received 2 points, a sentence containing 1 or 2 errors received 1 point, a sentence with 3 errors or more received 0 points. If a child received 0 points for four consecutive sentences, then the test was terminated.

The subtest *Memory for Designs* (Korkman et al., 2014) aimed to assess visual working memory. Two parameters of visual memory were measured – memorization of "pictures" (selection of pictures, as in a presented sample, from an array of similar pictures) and memorization of a spatial arrangement of the pictures (recall the cards' position in a sample). For each task, 2 points were awarded for each correctly chosen card (called "Content score") and 1 for each correctly indicated place (called "Spatial score"). Two bonus points were given on each trial if a child correctly selected the card and placed it on its right place (called "Bonus score"). As a result, four estimates were obtained for visual working memory: a content score, a spatial score, a bonus score and a total score (sum of all points in all tasks), as described in the NEPSY-II battery.

All methods have been adapted and validated in the Russian sample and have shown high psychometric qualities (Almazova et al., 2020). Trained researchers measured the variables and outcomes of the study under standardized conditions. All data were collected at the same time in the morning, between 8:00 am and 11:00 am. All values were converted to Z-scores.

Physical Fitness Measures

According to one of the most widely used models – the Stodden model – the physical fitness is composed from the muscular component (power or explosive strength, isometric strength, muscular endurance) and the motor skill component (agility, balance, coordination, speed of movement) (Bouchard et al., 1994; Malina et al., 2004). This study has attempted to cover both components. Thus, four physical fitness tests were used to asses physical fitness. All of them have been determined based on the principle of having relevant physical activity in children's everyday lives.

Broad jump

Standing behind the starting line with legs slightly apart (feet shoulder width apart), the participant will flex the knees and extend the body forward as arms extend behind the body. Extending the arms forward and then upward, the participant will take off and jump as far as he can. The length of the jump in centimetres is evaluated, each participant has 3 attempts. The distance is measured from the starting line to the rear edge of the last footprint. The motor task is explained and demonstrated.

Sit and reach test

The child is asked to sit down against the wall, straighten the lower limbs and lean against the wall with the whole back. The child is then asked to straighten the back. The modified bench which is 25 centimetres high (about 5 centimetres lower against original sit and reach bench) is moved to the legs (feet), so that the entire surface of the child's feet rests on one side of the bench. Subsequently, the child is asked to stretch the arms forward. The metric scale is moved to the tip of the middle finger. Then the child performs a forward bend. While bending, the child must not flex the knees of the lower limbs. The examiner checks this by holding his hand on the child's knees throughout the whole trial. The maximum distance the child reaches without breaking knees for 2 s is recorded. The child performs the entire test twice, in rapid succession.

Shuttle run 4 × 5 meters

For the test, a distance of 5 m must be marked. The first base (a colored cone) is located 20 cm before the starting line, the second cone is located at a distance of 5.2 m. The participant starts from a semi-crouched start and starts running following the signal, touches the top of the cone and returns. Here he touches the second cone, again runs to the cone he touched first colored cone and touch it for second time. Then the participant runs back and must touch the finish (starting) colored cone. Each child has a trial run, after that each participant has two attempts. The time the participant needed to run the whole track is recorded. The time is recorded on the stopwatch and the time is stopped when the participant touches the finish (starting) colored cone.

Throwing a tennis ball

Children are given a tennis ball (always start with the right hand). The child has to throw by overhead technique the ball as far as possible. The examiner demonstrates the execution of the throw. Each child throws the ball three times with the right hand and three times with the left hand. The throws follow immediately one after another. The examiner checks that the child does not step on the line representing the starting line for the throw. He also observes whether the child stands in a cross position of the lower and upper limbs, but does not correct the position if the child stands in a different position.

Data Analysis

Since we have results from both sexes from tests which are sex dependent in the age range overcoming one age category (5.01 to- 6.50 years) we used raw scores from test only to show dependency between sex and Executive function degree and Physical fitness level applying appropriate type of parametric or non-parametric T-test. For other analyses we have converted all values regarding age and sex to Z-scores. Firstly, we tested whether the used motor tests were significantly related to the physical fitness constructs. For the purpose of this investigation, we conducted a confirmatory factor analysis. Since the Mardia test, the Henze-Zirkler's test and the Royston's test rejected multivariate normality of the used motor tests we used maximum likelihood with a robust standard errors (MLR) estimation parameter for verification of the proposed two factor structure. For assessing the quality of the suggested model we used the recommended fit indices along with the suggested cut offs: (1) model discrepancy: Chi-square (S-BX2), model significance $p > 0.05$; (2) approximating error: Root Mean Square Error of Approximation (RMSEA) <0.06, Standardized Root Mean Square Residual (SRMR) ≤0.08; and (3) incremental fit indices: Comparative Fit Index (CFI) >0.95, Tucker-Lewis Index (TLI) >0.95 McDonald, 1999; Maydeu-Olivares, 2006; McDonald and Marsh, 1990). To investigate the main effect between physical fitness and each component of the cognitive profile we used one-way non-parametric ANOVA. The Duncan *post hoc* Z-test for concrete differences between groups was used with cut off >2.39. All statistical procedures were carried out in Mplus6 and NCSS2007 (Hintze, 2007) software.

Results

Factor Structure of Physical Fitness Construct

In the first step, we tested structural hypothesis that the results from the five used physical fitness tests will constitute a two-factor structure composed of the physical fitness and a motor skill construct. Results of two confirmatory factor analyses (CFA) showed that all four used tests fit well the suggested two factor model with moderately correlated $r = 0.58$ factors: (a) physical fitness (broad jump, sit and reach, 4×5 m shuttle running) and (b) dynamic strength of upper limb and trunk (throwing), instead of a unidimensional structure (S-$B_X{}^2 = 0.59$, DF = 4, RMSEA = 0.00, RMSEA 90% C.I. = 0.000 – 0.000, CFI = 1.00) (see **Figure 1** and **Table 1**).

Previous research found that executive functions development as well as physical fitness development are sex dependent. Therefore, in the next step we compared the results of boys and girls achieved in executive function tests and physical fitness tests.

All executive function tests displayed non-normal data distribution. Therefore, median statistics Mann Whitney *U* test was used for comparison. Despite, for better readability we decided to present mean and standard deviation values in **Table 1**. From the results of the executive function tests (see **Table 2**) it is evident that girls significantly outperformed boys with the largest differences in the area of working memory. Only in Inhibition trial (Corrected error) no significant difference between boys and girls was found. Since the physical fitness tests passed normal distribution requirements, the parametric two sample *T*-test was applied. Boys performed significantly better in agility and dynamic strength of trunk and upper limb fitness tests, while girls significantly outperformed boys in flexibility.

Differences in Executive Functions Depending on the Level of Physical Fitness

Further, the Z-scores of each participant on the motor test were weighted by its factor loading received from the two-factor structural model. We designated it as the composite physical fitness score. According to this composite score, we separated the children into three groups:

(1) Below-average physical fitness: ≤25th centile $n = 78$ (boys $n = 38$, girls $n = 40$) age $\bar{x} = 5.75 \pm 0.32$ years
(2) Average physical fitness: 26 – 74th centile $n = 113$ (boys $n = 55$, girls $n = 58$) age $\bar{x} = 5.75 \pm 0.31$ years
(3) Above-average physical fitness: ≥75th centile $n = 70$ (boys $n = 37$, girls $n = 33$) age $\bar{x} = 5.85 \pm 0.33$ years

In further analysis, the differences in the defined cognitive areas considering the centile group based on composite physical fitness score in all children regardless of their sex were compared. Since the results in **Table 2** showed significant differences in executive functions performance between boys and girls, we also converted all raw scores obtained from executive function tests into Z-scores respecting sex differences. As it was found that the data from executive function tests were not normally distributed, we used non-parametric Kruskal Wallis Analysis of Variance (see **Table 3**).

Analyses revealed significant differences in the degree of physical fitness in inhibition (Naming Uncorrected Errors; Naming Time and Inhibition Time) and the working memory variables (both visual and verbal). Furthermore, a *post hoc* Dunn's test analysis revealed that children with above-average physical fitness achieved significantly better scores in visual and working memory. These children also made significantly fewer mistakes in the test involving inhibition control (Naming Uncorrected Errors) than peers in the below-average motor competency group.

The tests Naming trial (Time) and visual working memory (Bonus and Total Scores) were even more sensitive to the degree of the children's motor competencies. In these tests, children with above-average and average motor competencies scored significantly better than children with below-average motor competencies. The Naming time variable in the inhibition task produced the greatest differences in executive functioning performance, considering the degree of motor competencies. In this test, a *post hoc* Dunn's test showed significant differences between all three groups of children. The children with an above-average degree of motor competencies had the best scores.

Differences in Physical Fitness Depending on the EF

Further, we investigated whether performance in each physical fitness test is differently related to EF. Therefore, we divided, according to the same rules converting into Z-scores, children into three groups: (1) Under average performance ≤25th centile, (2) Average performance 26th – 74th centile, and (3) Above average performance ≥75th centile, for each physical fitness test. **Table 4** shows the distribution of frequencies in these three categories considering sex.

The main point was to find whether the association between executive functions tests and physical performance could be dependent on the movement character of the motor test. Therefore, **Table 5** shows in which of physical fitness tests the performance level is significantly related to performance in executive functions tests previously found as significantly associated with PF.

A detailed analysis presented in **Table 5** showed the strongest association between performances in physical fitness tests and Naming shapes time. Performance in this test was positively associated with performance in all five physical fitness tests. A *post hoc* analysis revealed that children with above-average performances in these motor competency tests achieved significantly better results in Naming shapes time compared to children with under-average performance. Moreover, children with average performances in flexibility and throwing with right as well as left hand achieved significantly better results in Naming shapes time compared to peers with under-average performances in motor competency tests. Children with under-average performance in all physical fitness tests scored worse in verbal working memory test (Sentences Repetition) compared to counterparts with above-average performance. Moreover, in Throwing with left hand also children with average performance scored significantly better in SR compared to counterparts whose performance in Throwing with left hand was under-average. Visual working memory (Memory for Design Total Score) showed a significant relation with three motor competency tests. Children who achieved above-average performances in tests which demanded higher coordination, such as shuttle run and throwing with either right or left hand, scored significantly better compared to counterparts with under-average results (see **Table 5**).

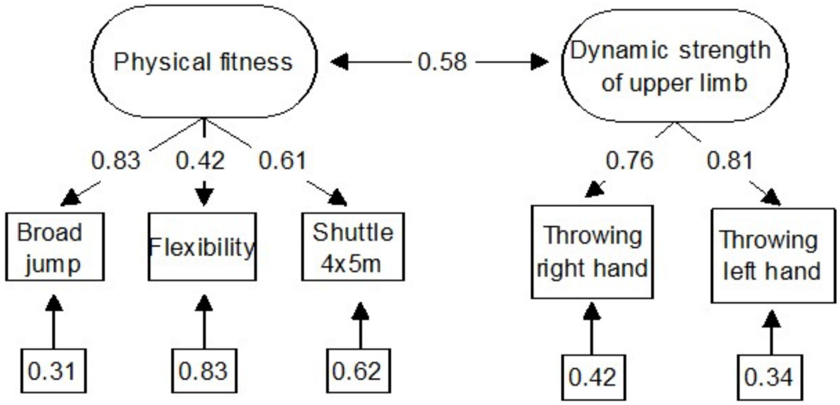

FIGURE 1 | Path diagram two-factors structure of physical fitness indicators.

TABLE 1 | Unidimensional and two factor model of physical fitness construct.

Model	*N*	S-B χ^2	*p*	DF	RMSEA	RMSEA 90% C.I.	SRMR	CFI	TLI
One factor model	261	68	0.000	5	0.22	0.175 – 0.268	0.074	0.77	0.54
Two factor model	261	0.59	0.96	4	0.00	0.000 – 0.000	0.009	1.00	1.03

TABLE 2 | Sex differences in executive function and physical fitness performance.

Items	Boys Mean ± SD	Girls Mean ± SD	*z*-value	*p*
Executive functions				
Cognitive flexibility (DCCS score)	18.1 ± 2.9	19.3 ± 2.7	3.45	< 0.001***
Naming trial (Uncorrected Errors)	0.8 ± 1.4	0.6 ± 1.4	2.2	0.02*
Naming trial (Corrected Errors)	1.1 ± 1.2	0.9 ± 1	2.18	0.02*
Naming trial (Time)	46.3 ± 13.4	42.5 ± 10	2.1	0.02*
Inhibition trial (Uncorrected Errors)	4.3 ± 6.6	2.9 ± 5.6	2.6	0.002**
Inhibition trial (Corrected Errors)	2.3 ± 1.9	1.9 ± 1.6	1.4	0.09
Inhibition trial (Time)	60.8 ± 15.7	57.1 ± 12.8	2.1	0.02*
Visual working memory (Content Score)	37.2 ± 6.6	40.8 ± 5.6	4.3	< 0.001***
Visual working memory (Spatial Score)	18.4 ± 4.6	20.3 ± 4.2	3.2	< 0.001***
Visual working memory (Bonus Score)	18.9 ± 12.8	22.9 ± 14.3	2.2	0.02*
Visual working memory (Total Score)	74.5 ± 22	83.8 ± 21.4	3.4	< 0.001***
Verbal working memory (Total Score)	18 ± 4.9	20.1 ± 4.9	4.0	< 0.001***
Physical fitness				
Running 4×5 m s	9.5 ± 1	9.7 ± 0.7	2.52	0.012*
Broad jump cm	100.8 ± 18.8	97.8 ± 18	1.02	0.15
Flexibility cm	13.4 ± 5.7	17.4 ± 6.3	5.40	< 0.001***
Throwing right hand cm	612 ± 165	520 ± 142	4.80	< 0.001***
Throwing left hand cm	478 ± 140	403 ± 120	4.70	< 0.001***

**p < 0.05 (2-tailed), **p < 0.01 (2-tailed), ***p < 0.001 (2-tailed).*

The Role of Physical Fitness in Executive Functions Performance for Girls and Boys

The level of physical fitness and the outcomes in executive functions tests are not univariate in gender. As it was found that the data from executive function tests were not normally distributed, and a non-parametric Two-way Analysis of Variance (ANOVA) is not available, we used a non-parametric One-way ANOVA for each sex separately. The level of physical fitness was shown to play a significant role both for boys and girls in two executive functions variables: Naming trial (Time) and Visual working memory (Spatial Score). In Naming trial (Time) girls and boys with above-average physical fitness scored significantly higher than children with average and below-average physical fitness (boys Chi-square = 8.50 p = 0.014); (girls Chi-square = 18.32 $p < 0.001$) which was more pronounced in girls. In visual working memory, boys with above-average physical fitness

TABLE 3 | Differences in results of executive functioning test between three defined groups of children based on the composite physical fitness score.

	Under-average Median Z-score	Average Median Z-score	Above-average Median Z-score	Chi-square	*p*
Cognitive flexibility (DCCS score)	−0.08	−0.02	0.03	4.29	0.12
Naming trial (Uncorrected Errors)	−0.41[(a)]	−0.21	0.41	6.78	0.03*
Naming trial (Corrected Errors)	0.12	0.12	0.81	5.7	0.06
Naming trial (Time)	−0.08[(b)]	0.25[(b)]	0.48[(b)]	19.52	<0.001***
Inhibition trial (Uncorrected Errors)	−0.35	−0.50	−0.35	2.45	0.29
Inhibition trial (Corrected Errors)	−0.15	0.05	−0.15	1.37	0.50
Inhibition trial (Time)	−0.12	0.32[(c)]	0.41[(c)]	12.17	0.002**
Visual working memory (Content Score)	−0.19	−0.15	0.12	1.78	0.41
Visual working memory (Spatial Score)	−0.24	0.24[(c)]	0.39[(c)]	12.7	0.002**
Visual working memory (Bonus Score)	−0.51	0.21[(c)]	0.07[(c)]	11.20	0.004**
Visual working memory (Total Score)	−0.15	0.21	0.34	8.36	0.02*
Verbal working memory (Total Score)	−0.23	−0.02	0.18	6.47	0.03*

[(a)] Significant difference between above-average and under-average motor competencies groups.
[(b)] Significant differences between all three groups of children.
[(c)] Significant differences between above-average and average and under-average motor competencies groups; no significant difference between average and under-average groups.
**p < 0.05 (2-tailed), **p < 0.01 (2-tailed), ***p < 0.001 (2-tailed).*

TABLE 4 | Frequency of under-average, average and above-average physical fitness performance in each test.

	Under-average performance		Average performance		Above-average performance	
	Boys	Girls	Boys	Girls	Boys	Girls
Broad jump	*n* = 37	*n* = 48	*n* = 51	*n* = 39	*n* = 41	*n* = 45
Flexibility	*n* = 41	*n* = 47	*n* = 49	*n* = 41	*n* = 39	*n* = 44
Shuttle run	*n* = 26	*n* = 41	*n* = 64	*n* = 45	*n* = 39	*n* = 46
Throw right	*n* = 44	*n* = 40	*n* = 40	*n* = 51	*n* = 46	*n* = 40
Throw left	*n* = 39	*n* = 41	*n* = 51	*n* = 54	*n* = 39	*n* = 37

scored significantly higher than boys with average and below-average physical fitness (boys Chi-square = 6.01 p = 0.049). In girls, *post hoc* Dunn's test indicated that girls with below-average physical fitness scored significantly lower than girls with above and average physical fitness (girls Chi-square = 9.74 p = 0.008).

Significant links between the level of physical fitness and Inhibition (Corrected Errors), Inhibition (Time), Visual working memory (Bonus Score), Visual working memory (Total Score) were only shown in girls. In Z-Inhibition trial (Corrected Errors) score, girls with average physical fitness achieved significantly lower results than girls with above-average or below-average physical fitness (girls Chi-square = 8.48 p = 0.014). In Z-Inhibition trial (Time), girls with average and above-average physical fitness scored significantly higher than girls with physical fitness below-average (girls Chi-square = 6.65 p = 0.036). Unlike in boys, in the girls' sample, the physical fitness level played a significant role in Visual working memory (Bonus Score). Girls with above-average physical fitness performed significantly better than girls with average and below-average physical fitness (girls Chi-square = 12.17 p = 0.002). Moreover, girls with above average and average physical fitness scored significantly higher on Visual working memory (Total Score) than girls with below-average physical fitness (girls Chi-square = 11.65 p = 0.003).

DISCUSSION

Theories and studies on physical fitness significantly contributed to our understanding of the strategies to improve executive functioning in children. One of the important paths for further investigation of executive functions in preschoolers should lead to elaboration of specific evidence-based strategies to improve their executive functioning skills. Studies confirm the potential impact of physical activity and physical fitness on the development of the inhibitory control and visual and verbal working memory which might be significantly linked to changes in the production of neurotrophic factors such as NGF and BDNF, which are responsible for the development of neural networks.

One of the research goals was to verify hypothesis concerning a two-factor structure of physical fitness in preschoolers. Confirmatory factor analysis confirmed that the data collected is compliant with the two-factor Stodden model, including physical fitness and motor competences. This outcome suggests that children's physical fitness is not an elementary one-factor construct, but a more complex two-factor structure. This points to the need of using a number of tests both for physical fitness and a motor skill construct in terms of the physical fitness evaluation.

TABLE 5 | Differences in physical fitness performance depending on Naming shape time.

	Under-average median	Average median	Above-average median	Chi-square	*p*-value
Naming shape time					
Broad jump	−0.12	0.29(c)	0.43(c)	11.13	0.004***
Flexibility	0.08	0.39(c)	0.36(c)	12.33	0.002**
Shuttle run	0.13	0.28	0.43(a)	7.26	0.03*
Throw right	0.18	0.15	0.41(a)	8.18	0.02*
Throw left	0.08	0.22(c)	0.46(c)	10.39	0.006**
SR					
Broad jump	−0.30(d)	0.03	0.18	8.83	0.01**
Flexibility	−0.20(d)	−0.07	0.30	7.93	0.02*
Shuttle run	0.28(d)	0.13	0.43	7.26	0.03*
Throw right	0.18	0.15	0.41	8.18	0.02*
Throw left	0.08(d)	0.22	0.46	10.39	0.006**
Spatial					
Shuttle run	−0.03	0.14	0.43	7.08	0.03*
Throw right	−0.27 ± 1	0.17 ± 1.02	0.51	7.28	0.03*
Throw left	0.01	0.26	0.50	8.24	0.02*
Bonus					
Shuttle run	−0.45	−0.12	0.01	6.79	0.03*
Throw right	−0.3	−0.09	−0.02	8	0.02*
Throw left	−0.45	−0.18	0.22	11.39	0.004**
Total score					
Shuttle run	−0.38	−0.19	−0.09	6.97	0.03*
Throw right	−0.39	0.07	0.02	7.2	0.03*
Throw left	−0.46	0.02	0.27	10.15	0.006**

(a) Significant difference between above-average and under-average motor competencies groups.
(c) Significant differences between above-average and average and under-average motor competencies groups; no significant difference between average and under-average groups.
(d) Significant difference between above-average and under-average motor competencies groups.
$*p < 0.05$ (2-tailed), $**p < 0.01$ (2-tailed), $***p < 0.001$ (2-tailed).

The next step was to test the hypothesis that high level of physical fitness positively relates to main executive functioning skills among children. Comparison of the executive function's tests scores throughout all three groups with high, medium, and low overall physical fitness levels has shown a number of differences. The analysis has indicated that children with high level of total physical fitness generally score better than their peers with low or average total physical fitness level in relation to executive functioning. Hence, the most significant differences were found in the inhibitory control and in children's ability of memorizing spatial location of new objects in the visual-spatial memory test. In respective tasks, the participants with above-average or average physical fitness performed significantly better than their peers with below-average motor skills. Also, children with above-average physical fitness scored significantly higher than their peers with below-average physical fitness. Therefore, it is likely that physical fitness positively influences children's ability to deal with executive functioning tasks. No differences have been found in the development of cognitive flexibility depending on physical fitness. Previously conducted research has indicated that the relationship between executive functions and physical fitness is possibly bi-directional.

The analysis of physical fitness's impact on children's executive functions has shown that physical fitness significantly influences the results of boys and girls in two executive functions tests: Naming trial (Time) and Visual working memory (Spatial Score). In the Naming trial (Time) girls and boys with above-average physical fitness scored significantly higher than children with average and below-average physical fitness. Nonetheless, in some aspects of development, outcomes varied depending on gender. In boys, high level of physical fitness was significantly positively linked with memorizing the spatial positions of visual elements. Girls with good physical fitness scored lower in memorizing objects' spatial positions. Additionally, a significant association between physical fitness and the indicators of inhibitory control, and the overall score on the visual-spatial memory assessment test was only found in girls. Even though girls with high physical fitness showed poorer results at memorization the spatial positions of objects, they performed better at the tests in general, comparing to the girls with medium and low physical fitness levels.

The relation between physical activity and the development of executive functions is typically explained through one of the three main hypotheses. The first one relies on the J. Piaget theory which asserts the mutual dependency of cognitive and physical development: well-developed motor skills enable children to engage more actively in the interaction with their environment, which positively influences their cognitive development (Piaget and Inhelder, 1966). That's why Oberer underlines those sports activities not only require high motor coordination but also directly make children implement their executive functions competences (planning, focusing on a goal, adapting to changing environment) (Oberer et al., 2018). The second hypothesis has neuropsychological grounds: the results suggest that the same areas of the cerebral cortex are engaged during executive functions tests and physical exercises (Diamond, 2000). Moreover, earlier research also has indicated that physical activity stimulates the production of neurotrophic factors such as BDNF and NGF which are instrumental in developing neural networks (Cho et al., 2012; Roh et al., 2017). Higher level of physical activity, which is likely to lead to better physical fitness, turned out to be linked to a higher NGF level and indirectly associated with the level of BDNF (Arvidsson et al., 2018). Some researchers suggest that this indirect and more complex function of BDNF in relation to physical activity is due to the BDNF found in blood samples and stored in platelets, which could also play key role in maintaining the energetic balance (Cho et al., 2012). Nevertheless, it was demonstrated that the impact of physical exercise on the production of BDNF is positively linked to the executive functioning level (de Assis and Almondes, 2017). This neurobiochemistry hypothesis was also confirmed by Ghafori et al. (2018). They discovered that after a motor exercise sequence, both the serum level of BDNF and executive functions in children with dysgraphia were significantly increased.

Interpreting these outcomes in terms of the cultural-historical approach, we introduce a third hypothesis to explain the relationship between physical fitness and the development of executive functions in preschool children. Physical development is the process of learning to control one's own body. In the course of the physical development, children improve their motor coordination and handle complex exercises with more and more success. It can be assumed, that this progress is partly determined by physiological mechanisms (maturation of cortical areas, oxygen supply), but also by assimilating cultural means. Cultural means can be described as mental representations that children use to control their movements. High-class athletes and their coaches use a particular technique based on this principle – training through visualization. It consists in working through all the elements of the movement in one's head. Using the imagination, athletes go through the exercise mentally, preparing to perform it. We suggest that thoroughly imagining the precise execution of an exercise can help children to better master the series of movements and to better control them while actually performing it. Mental representations involved in executing complex exercises (such as a shuttle run or a broad jump) can be separated into two big groups: visual representations of the required movements and visual representations of the environment. The current study supports this view. Preschoolers with high levels of physical fitness have better visual-spatial working memory. They tend to mentally go through complex tasks step by step and form an image of their actions before carrying them out. It is also possible that visualizing the surrounding situation and their following actions not only allows children to better coordinate their movements but also helps with the performance anxiety, which can also impact children's outcomes. Therefore, we are inclined to believe that the physical fitness and the executive functions are linked bi-directionally. This has been supported by empirical data from our study and other research (Piché et al., 2012, 2015; Howard et al., 2018). This seems to be consistent with the cultural-historical perspective. Well-developed executive functioning skills enable children to score higher during the physical fitness evaluation, as they include greater ability to retain movement sequences and form mental representations. And vice versa, sport activities not only allow children to better control their bodies but also positively influence the ability to regulate cognitive processes. Moreover, doing sports requires the ability to follow a regime and rules, to concentrate, and distribute one's resources. These are the competences that will help children to manage their resources, for example, in school. In some measure, this can account for the executive functions' role as a moderator in a relation between physical fitness and children's academic outcomes.

CONCLUSION

This study was designed to identify different physical fitness levels among 5–6-year-old children and then analyze the differences in their executive functions. The study verified a two-factor model including physical fitness and motor competences in preschoolers and indicated that two of the three main components of executive functions – inhibitory control and both visual and verbal working memory – are positively related to children's physical fitness. The greatest contribution to the differences in inhibitory control and both visual and verbal working memory among children by shuttle running and throwing, which have highest demanded for CNS in coordination of movement.

The study has the advantage of providing a comprehensive investigation of both executive functions and physical fitness rather than examining selected indicators, and of novelty in analyzing the contribution of different physical skills executive functioning in girls and boys. A limitation of the study are the rather small sample size and its cross-sectional design, which to some extent limits the reliability and depth of the conclusions. Further longitudinal analyses of the relationship between physical fitness and executive functions are planned for which data are already being collected as part of the project. However, despite these limitations, the study findings contribute to clarification of the relationship between the main executive functions and physical fitness skills in preschoolers, and verified a two-factor Stodden model structure which can be easily and repeatedly used to assess physical fitness and motor competences in kindergarten environment. The findings can be of great practical importance in the educational environment and, in particular, for the development of school curricula or the selection of the most effective physical education tasks aimed at promoting the development of preschool children's executive functioning.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Committee of Faculty of Psychology at Lomonosov Moscow State (approval no. 2020/72). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AV was responsible for research planning and organization of research activities (ethical approvals, contracting, and funding). He was actively involved in writing the manuscript. MG was responsible for organizing individual diagnostics of children, preparing data for analysis, and writing part of the text. VY was involved in the process of individual diagnosis of children and contributing to the writing of the text. MM supervised the research, participated in the planning and design of the study, worked with data, completely carried out statistical analysis, and participated in the writing of the text. All authors contributed to the article and approved the submitted version.

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Differences in Technical Development and Playing Space in Three UEFA Champions Leagues

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The analysis of football grows exponentially, with many researchers adopting it as an object of study. The thematic range that addresses it, as well as the different methodologies used, are of a very different nature—physical, psychological, technical, tactical—enriching every day the knowledge, and understanding of the game itself. The objective of this study has been to identify the differences between the different styles of play that lead to becoming the champion of the UEFA Champions League in the last 3 years of the pre-COVID stage, by analyzing the spatial performance developed, the association between the players that make up the different lines of the game system and the analysis of the various technical actions that are developed to carry out the offensive phase of each team. For this, the Observational Methodology and two types of analysis have been used: quantitative, by calculating X^2, and qualitative, by applying the Polar Coordinates technique. The results obtained show the relationship that is established between the different lines that make up the offensive systems of the champion teams of this competition, as well as the relationship of significance that is established between the use of space—width and depth—and the technical means used to achieve success, the goal.

Keywords: soccer, polar coordinates, analysis performance, observational methodology, density of players, orientation change

INTRODUCTION

Performance analysis in men's soccer is experiencing rapid growth in the last decade. Much of the available studies have focused on the offensive phase of the game (Mackenzie and Cushion, 2013; Sarmento et al., 2020). This is common, since it is known that in soccer achieving more goals than the rival is the greatest indicator of success. One of the main characteristics that differentiate soccer from other sports is its low level of goal achievement (Wallace and Norton, 2014).

The performance analysis of the different high-level competitions is allowing us to know how the teams play and what their level of performance is Pratas et al. (2018). The UEFA Champions

League is considered the most important team competition at European level. The best teams from each country compete against each other for the title of European team champion.

There are several studies available that analyze this competition from different points of view: the perspective of injuries (Waldén et al., 2005), the physical intensity of the matches (Rave et al., 2018), athletic abilities (Di Salvo et al., 2010), gender differences depending on the distances traveled (Bradley et al., 2014), and even economic circumstances (Espitia-Escuer and García-Cebrián, 2010).

Regarding the measurement of the technical and tactical-strategic components of the game, for 10 years it has been possible to verify an increase in the number of publications. Specifically, the study by Yi et al. (2018), analyzed the technical differences between the different players, finding that the greatest differences were found between defenders and attackers. Specifically, the former achieved better performance in variables related to the pass, and the latter in variables related to the goal and offensive organization. On the other hand, García-Rubio et al. (2015), analyzed the UEFA Champions League competitions between the years 2009 to 2013, they found significant differences in the place of the match, the effect of the first goal and the quality of the rival in this competition, depending on the stage in which it is (group stage or elimination). Along the same lines, the study Yi et al. (2020), also analyze the technical differences depending on the phase in which the teams are, also concluding that the situational variables such as quality of the team and the opponent and the result of the match show variations depending on the technical performance of the players. Likewise, Almeida et al. (2014), also analyze these situational variables and their relationship with the ball's recovery in 28 UFL games. In their work, they conclude that local and unsuccessful teams defend in more advanced areas of the field, and that the defensive strategies of the best teams involve more intense, organized collective processes that are further from the goal itself.

Regarding the difference between the winning and losing teams in this competition, the study by Lago-Peñas et al. (2011), found that the main variables that discriminate between the winning and losing teams are shots at goal, crosses, ball possession, place of match, and quality of opposition. Tiago et al. (2017), through the use of social networks, analyze 12 matches of the UFC 2015/2016, and observe a negative relationship between the density and the success of offensive action. The reduced density was associated with a greater number of offensive actions, although these have not been successful. Finally, the work of Yi et al. (2019), analyze the differences between teams from different leagues and their performance in the UEFA Champions League, concluding that despite the fact that the differences between teams are small, these could be explained by a cultural aspect, style of play, the characteristics of the players, and the philosophy of the coach.

Given that soccer has evolved tactically at the highest level in recent years (Wallace and Norton, 2014; Bradley et al., 2016), and the constant exchanges of players and coaches produced by the globalization process, it is interesting to investigate the level of performance of the last champions of this competition. Therefore, the objective of this study has been to identify the differences between the different styles of play (Hewitt et al., 2016; Gómez et al., 2018; Lago-Peñas et al., 2018; Castellano and Pic, 2019) that led to the conquest of the UEFA Champions League in the last 3 years of the pre-COVID stage, by analyzing the developed space performance, the association between the players that make up the different lines of the game system, and the analysis of the various technical actions that are developed to carry out the offensive phase of each team.

MATERIALS AND METHODS

The present work has made use of the observational methodology (Anguera, 1979), an ideal methodology to develop its potential in sport (Anguera and Hernández-Mendo, 2013). According to Anguera et al. (2011), an observational design has been established: (a) Inter and intra-session follow-up -explanation-; (b) nomothetic -the participating teams-; and (c) multidimensional. The observation has been non-participant and the degree of perceptiveness was total.

Participants

The participants in this study were the champions of the last three pre-Covid UEFA Champions League, that is, the champions of the 2016–2017 (Real Madrid CF), 2017–2018 (Real Madrid CF), and 2018–2019 (Liverpool FC) competition. All the offensive actions carried out by these teams during the development of their matches are part of this study. In total, 3000 multi-events have been recorded, which have resulted in 387 complex offensive actions (**Table 1**), made up of all the actions and interventions on the ball that the players perform (simpler actions). Being in turn these individual actions of the players (actions simpler than the final play and that give rise to it), composed of the corresponding multi-events that occur in its development. The collected data belongs to type IV and is, therefore, concurrent and base-time.

Of all the offensive actions analyzed by team and season, we are interested in analyzing the depth (Garganta, 1997), the width (Amatria et al., 2019b), and the orientation changes of the different offensive sequences. Likewise, the level of success (Hughes and Bartlett, 2002) achieved in the development of the offensive phase has been analyzed, as well as the level of elaboration and density of the play (Tenga et al., 2009; Sgrò et al., 2016; Amatria et al., 2019a; **Table 2**).

To measure the depth and width of the offensive game, the proposal by Garganta (1997) and Maneiro et al. (2020) has been used (**Figures 1**, **2**).

TABLE 1 | Distribution of offensive actions analyzed by team and season.

Season	Team	Plays	Multievents
16–17	Real Madrid CF	100	845
17–18	Real Madrid CF	185	1570
18–19	Liverpool CF	102	586

TABLE 2 | Density of players in the elaboration of the play.

Number of players involved	Player density
0–1	Non-existent
2–3	Very low
4–5	Low
6–10	Médium
11–15	High
16 or more	Very high
Number of different players	**Player density**
0–1	Very low
2–3	Low
4–5	Médium
6–8	High
9–10	Very high
11	maximum
Number of passes	**Level of elaboration**
0–1	Non-existent
2–3	Very low
4–5	Low
6–10	Médium
11–15	High
16–20	Very high
21 or more	Maximum

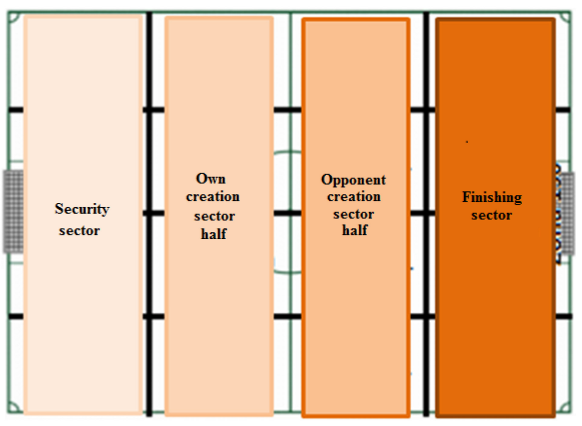

FIGURE 1 | Division into sectors to assess depth. Source: Garganta (1997).

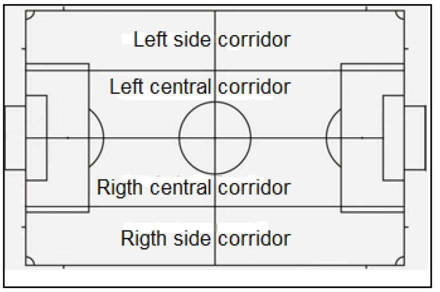

FIGURE 2 | Division into sectors to assess width. Source: Maneiro et al. (2020), adapted from Garganta (1997).

TABLE 3 | Kappa concordance results of the different intra-observer and inter-observer dimensions.

Dimension	Inter-observer Kappa concordance
Ball possession	1
Player	1
Start of action zone	0.96
End of action zone	0.98
Ball contact	0.95
Interruptions	1
Interceptions	1
Completion	1

Observation Instrument

The observation instrument used has been the one proposed by Maneiro and Amatria (2018), which is a combination of field format and category systems (Anguera et al., 2007); in which all the dimensions of the field format are displayed in category systems by meeting the requirements of exhaustivity and mutual exclusivity (Anguera and Hernández-Mendo, 2013).

Recording and Coding

The Lince software (Gabin et al., 2012), version 1.2.1, has been used to record the data.

Data Reliability

The data were recorded by two observers, graduated in Physical Activity and Sports Sciences, both with the title of National Soccer Coach and with extensive experience in the field of observational methodology and the analysis of soccer performance.

In order to determine the reliability -as concordance- of the data obtained from the observation instrument, the GSEQ version 5.1 software was used (Bakeman and Quera, 1995). The Cohen's Kappa values corresponding to the data packages corresponding to the observations made by both observers have been calculated, comparing the dimensions that make up the observation instrument independently, obtaining a minimum value of $\kappa = 0.95$ (**Table 3**), which guarantees the reliability of the data that support the present work (Fleiss et al., 2003).

Data Analysis

Two types of analysis have been carried out for this study. Regarding quantitative analysis, Pearson's chi-square statistic (χ^2) has been used, using the following formula: χ2 = Σk i,j = 1 [(Fij−F^ij)2/F ^ ij]. To obtain the result of this statistic, the SPSS version 20.0 software was used.

On the other hand, taking into account the qualitative analysis, the Polar Coordinate analysis technique has been used to identify the association that occurs between the players of the observed team. This analysis technique is based on Cochran's Zsum (Cochran, 1954), which in turn takes from the principle that the sum of a number N of independent z scores is normally distributed, with Z = 0 and s = N, so the statistic (where n is the number of lags), according to Sackett (1980), allows us to

TABLE 4 | Contingency table: Season * Start Sector * Final Sector.

			Final sector			
			Defensive (%)	CP creation (%)	CR creation (%)	Definition (%)
Season 16–17	Start sector	Defensive	8.20	38.80	18.40	34.70
		CP creation	6.50	9.70	29.00	54.80
		CR creation	0.00	0.00	42.90	57.10
		Definition	0.00	0.00	33.30	66.70
Season 17–18	Start sector	Defensive	10.50	36.80	26.30	26.30
		CP creation	0.00	19.40	25.80	54.80
		CR creation	4.80	9.50	19.00	66.70
		Definition	0.00	0.00	30.80	69.20
Season 18–19	Start sector	Defensive	9.20	37.90	21.80	31.00
		CP creation	0.00	23.10	26.90	50.00
		CR creation	0.00	0.00	17.60	82.40
		Definition	0.00	0.00	10.00	90.00

TABLE 5 | Contingency table: Season * Start Lane * Final Lane.

			Final lane				
			Banda Iz (%)	Centro Iz (%)	Centro D (%)	Banda D (%)	Z 130 (%)
Season 16–17	Start lane	Left band	20.00	40.00	20.00	0.00	20.00
		Left center	23.10	41.00	17.90	10.30	7.70
		Right center	25.00	17.90	25.00	32.10	0.00
		Right band	8.70	30.40	17.40	34.80	8.70
Season 17–18	Start lane	Left band	36.70	20.00	16.70	23.30	3.30
		Left center	30.80	23.10	19.20	23.10	3.80
		Right center	17.40	17.40	30.40	21.70	13.00
		Right band	20.80	8.30	20.80	41.70	8.30
Season 18–19	Start lane	Left band	40.00	20.00	15.00	15.00	10.00
		Left center	24.10	34.50	17.20	10.30	13.80
		Right center	29.00	25.80	9.70	32.30	3.20
		Right band	4.50	9.10	27.30	54.50	4.50

measure the associative consistency between different behaviors. This technique, developed by Sackett (1980) and improved by Anguera (1997), allows us to identify the relationship of excitation or inhibition between the focal behavior (conditioning behavior), and the rest of the conditioned behaviors (behaviors with which the focal behavior is related). This analysis was carried out both prospectively (+1 to +5) and retrospectively (−1 to −5), obtaining as a result a vector for each behavior related to the focal behavior, with a specific angle and radius. Considering the angle obtained from the analysis, the vector occupies one of the four sectors or quadrants that make up the graphical representation of the Polar Coordinate.

For the representation of the vector map, the R program has been used (Rodríguez-Medina et al., 2019).

TABLE 6 | Contingency table: Season * Presence of CO.

	CO presence	
	No (%)	Yes (%)
Seas 16–17	73.00	27.00
Seas 17–18	69.90	30.10
Seas 18–19	94.10	5.90

RESULTS

Study of the Depth of the Game

In reference to the study of game depth, **Table 4**, there are significant differences in all seasons (2016–2017: x^2 = 20.085; gl = 9; $p < 0.017$; 2017–2018: x^2 = 20.317; gl = 9; $p < 0.016$; 2018–2019: x2 = 31.824; gl = 9; $p < 0.001$) when analyzing the sector of the start of the offensive action and the sector where it ends. Highlighting, in all seasons, the actions that begin in the definition sector and conclude in the same sector are those with a higher percentage. In this sense, the results obtained in the 2017–2018 season are highlighter, and those plays that have their origin in the sector Creation of the Rival Field and end in the Definition sector have a percentage very close to those that start and end in the same sector, the Definition sector, while it can be seen how there are plays that end in the rest

TABLE 7 | Contingency table: Season * Level of Success.

	Success level I		Success level II		Success level III		Success level IV	
	GOAL		End Zone 130		End Zone Area		End Zone Def Sec	
	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)
Seas 16–17	96.0	4.0	93.0	7.0	63.0	37.0	54.0	46.0
Seas 17–18	98.1	1.9	93.2	6.8	72.8	27.2	51.5	48.5
Seas 18–19	98.0	2.0	92.2	7.8	66.7	33.3	46.1	53.9

of the sectors, an aspect that does not happen in either of the other two seasons.

Study of the Width of the Game

In relation to the study of the depth of the game, **Table 5**, there are significant differences in the season 18–19 (x^2 = 31.824; gl = 9; $p < 0.000$) when analyzing the lane where the offensive action starts and the lane of completion. Highlighting the actions that begin in the Center Right lane and that end in the same lane are those with a lower percentage, the opposite occurring in the rest of the lanes, that is, the plays that reach a higher percentage in each lane are those that end in the same lane, except for the one mentioned.

Use of Orientation Change

Continuing with the use of width as a means to develop offensive action, the Change of Orientation (CO) has been studied as a key element to carry it out. In this case, significant differences have been detected (x^2 = 21.372; gl = 2; $p < 0.000$) between the seasons and the presence of orientation changes in them. Highlighting the high percentage of non-presence of CO in the 18–19 season (**Table 6**).

Analysis of the Levels of Success of Offensive Actions

Considering the study of the levels of success of the offensive actions that occur in each of the studied seasons, no significant differences have been identified between them. It should be noted in this sense, as in all seasons, that the success rates increase as the level of success is lower, with Level I being the highest level of success and Level IV being the least successful – **Table 7**.

Game Density

In reference to the analysis of the density of the game, three clearly differentiated aspects have been taken into account.

In the first place, the density of players of the observed team has been studied, later the total density of players who participate in the development of the play has been studied, where the sporadic participation of the opponents through the IOC has been taken into account, and finally, the level of development of the offensive action, understood as the number of times the ball is intervened in the development of the offensive action.

Team Player Density

Considering the total number of participants involved in the play by the observed teams, significant differences have been found in the number of players involved in the offensive action (x^2 = 38.530; gl = 10; $p < 0.000$) between the seasons analyzed. As a result, a density of players that intervene in the offensive action by the observed team, of a Low level being the one with the highest percentages in the three seasons, followed by a Medium level of density in season 16–17, a High level of density of players of the team observed in the 17–18 season, and a Very Low density level in the 18–19 season (**Table 8**).

TABLE 8 | Contingency table: Season * Density of players of the observed team.

	Density_JUG_Eq					
	Very low (%)	Low (%)	Medium (%)	High (%)	Very high (%)	Max. (%)
Seas 16–17	13.0	36.0	21.0	20.0	10.0	0.0
Seas 17–18	8.7	37.9	17.5	24.3	10.7	1.0
Seas 18–19	23.5	56.9	12.7	6.9	0.0	0.0

TABLE 9 | Contingency table: Season * Total player density.

	Total_Density				
	Inexistent (%)	Very low (%)	Low (%)	Medium (%)	High (%)
Seas 16–17	11.0	36.0	21.0	31.0	1.0
Seas 17–18	6.8	36.9	17.5	35.0	3.9
Seas 18–19	16.7	52.9	21.6	8.8	0.0

Total Density

Considering the total number of participants involved in the play, no significant differences were found in the number of players involved in the offensive action (x^2 = 30.626; gl = 8; $p < 0.000$) between the seasons analyzed. Resulting in a Very Low density, the one with the highest percentages in the three seasons, followed by a Medium level of elaboration in the 16–17 and 17–18 seasons, and a Low level of total density of players in the 18–19 season (**Table 9**).

Level of Elaboration of the Action

Regarding the study of the level of elaboration of the play, significant differences have been found (x^2 = 35.403 gl = 12; $p < 0.000$) in the number of passes made in offensive actions and seasons studied, where the highest percentages of very low production levels are presented in the three seasons, however,

TABLE 10 | Contingency table: Season * Elaboration level.

	Elaboration level						
	Inexistent (%)	Very low (%)	Low (%)	Medium (%)	High (%)	Very high (%)	Max. (%)
Seas 16–17	11.0	29.0	23.0	16.0	15.0	2.0	4.0
Seas 17–18	6.8	34.0	14.6	22.3	10.7	5.8	5.8
Seas 18–19	16.7	49.0	18.6	12.7	2.9	0.0	0.0

TABLE 11 | Contingency table: Season * Demarcation * Type of contact.

		Contact							
		C1 (%)	C2 (%)	C3 (%)	C4 (%)	C5 (%)	C12 (%)	C23 (%)	C24 (%)
Seas 16–17	PORT	68.40	21.10	5.30	0.00	0.00	5.30	0.00	0.00
	DEF	30.60	51.90	8.90	5.00	2.30	0.40	0.00	0.80
	MED	33.30	38.40	15.30	9.80	1.20	0.80	0.00	1.20
	DEL	28.80	28.80	15.10	5.50	6.80	5.50	5.50	4.10
Seas 17–18	PORT	33.30	42.90	23.80	0.00	0.00	0.00	0.00	0.00
	DEF	28.80	47.20	14.60	1.90	5.10	0.60	0.60	1.30
	MED	28.10	43.50	18.30	4.30	0.70	2.20	2.50	0.40
	DEL	30.00	29.10	24.50	4.50	2.70	2.70	1.80	4.50
Seas 18–19	PORT	34.40	59.40	6.30	0.00	0.00	0.00	0.00	0.00
	DEF	42.80	26.90	19.30	0.00	9.00	0.70	1.40	0.00
	MED	41.20	20.60	23.50	0.00	10.30	2.90	1.50	0.00
	DEL	34.70	21.30	24.00	2.70	12.00	1.30	2.70	1.30

TABLE 12 | Results of the analysis of polar coordinates for the different focal categories in relation to the rest of the lines that make up the game structure of the 2016–2017 season.

CF	Category	Quadrant	Prospective P	Retrospective P	Ratio	Angle
PORT	DEF	IV	2.23	−0.63	2.32 (*)	344.22
	MED	III	−1.44	−0.78	1.63	208.46
	DEL	II	−1.49	1.22	1.93	140.74
	JR	II	−0.4	0.64	0.75	121.9
DEF	PORT	II	−0.63	2.23	2.32 (*)	105.78
	DEF	III	−0.21	−0.21	0.29	225
	MED	IV	0.57	−0.66	0.87	311.05
	DEL	IV	0.44	−0.35	0.57	321.41
	JR	II	−0.72	0.85	1.11	130.25
MED	PORT	III	−0.78	−1.44	1.63	241.54
	DEF	II	−0.66	0.57	0.87	138.95
	MED	I	0.61	0.61	0.87	45
	DEL	IV	0.52	−0.91	1.05	299.96
	JR	III	−0.25	−0.29	0.39	228.75
DEL	PORT	IV	1.22	−1.49	1.93	309.26
	DEF	II	−0.35	0.44	0.57	128.59
	MED	II	−0.91	0.52	1.05	150.04
	DEL	III	−0.37	−0v37	0.52	225
	JR	IV	2.32	−0.64	2.41 (*)	344.6

in season 17–18 the average production level stands out as the second highest percentage (**Table 10**).

Typology of Contact Developed

In reference to the study of the technical performance developed by the champion teams of the three seasons reflected by the analysis of the different types of contact that the players make on the ball, significant differences are found in all seasons (season 16–17: $x^2 = 120.458$; gl = 35; $p < 0.000$; season 17–18: $x^2 = 74.213$; gl = 35; $p < 0.000$; season 18–19: $x^2 = 72.663$; gl = 35; $p < 0.000$) when analyzing the lines that make up the offensive systems and the type of contact made by the players belonging to the lines that

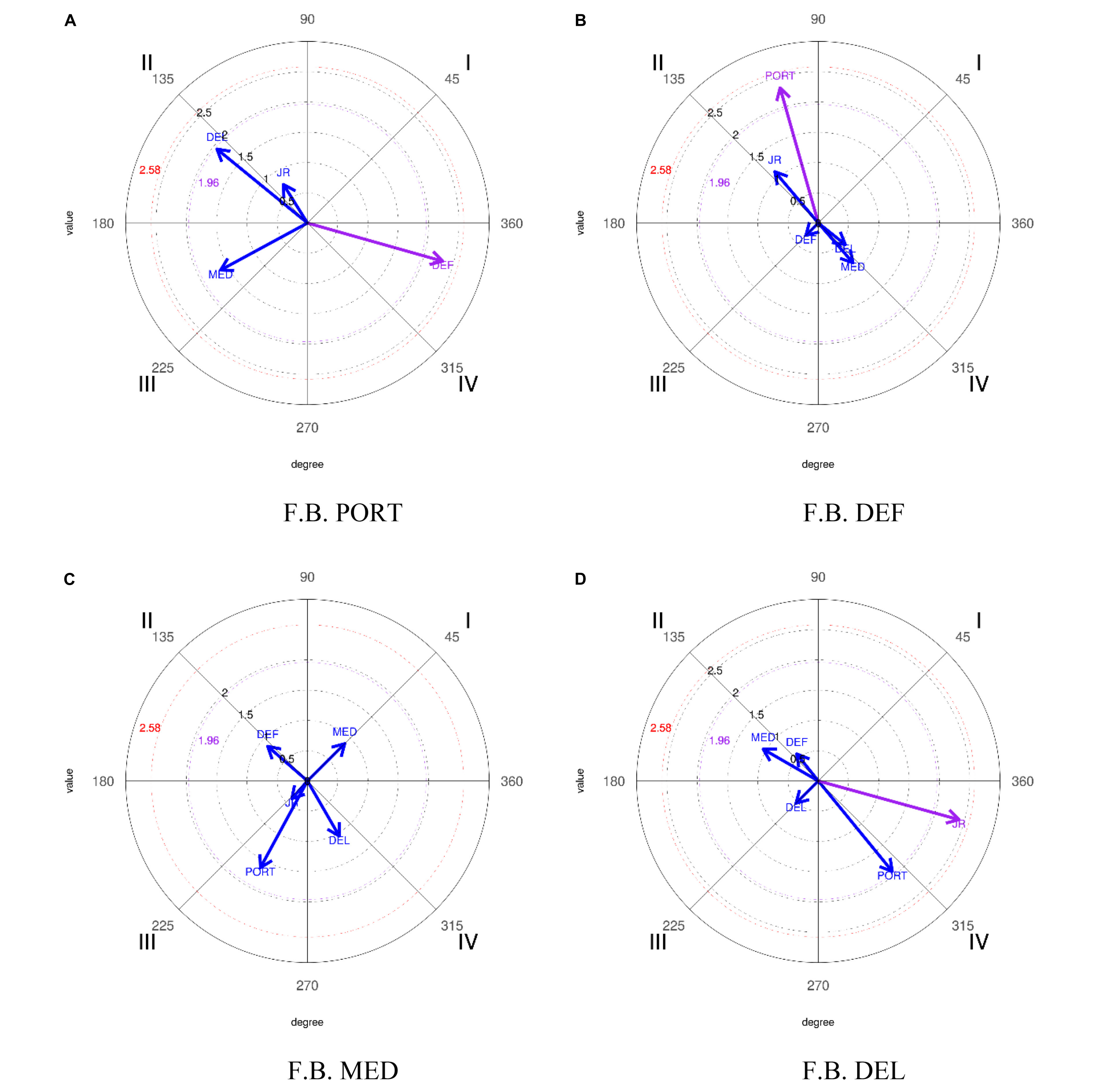

FIGURE 3 | Representation of the behavioral maps establishing the different categories as focal behavior, in relation to the lines that structure the team for the 2016–2017 season. *FB, focal behavior.

make up the game system. Highlighting, in all seasons, the types of contact C1 and C2 in the different demarcations (**Table 11**).

Polar Coordinates Analysis

In order to make a more clarifying presentation of the results, the results have been structured according to the three seasons analyzed, placing in each of them the demarcation to be studied as the corresponding focal behavior. Thus, through these analyses it is intended to check the predisposition of the players that make up the different lines with their teammates.

Results Corresponding to the 2016–2017 Season

In the execution of the analysis, taking PORT as focal behavior and relating it to the rest of the categories that make up this dimension (DEF, CEN, DEL, and JR) the results obtained (**Table 12** and **Figure 3A**) show the criterion category DEF (line of defense) with a radius of 2.32 and an angle of 344.22° in such a way that the vector generated is established in quadrant IV, where the focal behavior activates the appearance of the mating behavior in the prospective plane but not in the retrospective one.

Taking DEF as focal behavior and relating it to the rest of the categories that make up this dimension (PORT, DEF, CEN, DEL, and JR), the results obtained (**Table 12** and **Figure 3B**) show the criterion category PORT (goalkeeper line) with a radius of 2.32 and an angle of 105.78° in quadrant II, where the focal behavior inhibits the appearance of the mating behavior in the prospective plane and activates it in the retrospective one.

Finally, establishing DEL as focal behavior and relating it to the rest of the categories that make up this dimension (PORT, DEF, CEN, DEL, and JR), the results obtained (**Table 12** and **Figure 3D**) show the criterion category JR (Rival Player) with a radius of 2.41 and an angle of 344.6° in such a way that the vector generated is established in quadrant IV, where the focal behavior activates the appearance of the mating behavior in the prospective plane but not in the retrospective.

Results Corresponding to the 2017–2018 Season

In the execution of the analysis, taking as focal behavior the different categories that make up this dimension, no significant results are obtained in any of them except for the DEL category which, relating it to the rest of the categories (PORT, DEF, CEN, DEL, and JR) shows the criteria category DEL (Front Line) in the results obtained (**Table 13** and **Figure 4**) with a radius of 2.08 and an angle of 45° in such a way that the vector generated is established in quadrant I, where the focal behavior activates the appearance of mating behavior at the prospective and retrospective levels.

Results Corresponding to the 2018–2019 Season

In the execution of the analysis, establishing PORT as focal behavior and relating it to the rest of the categories that make up this dimension (DEF, CEN, DEL, and JR), the results obtained (**Table 14** and **Figure 5A**) show the criterion category JR (Rival Player) with a radius of 2.7 and an angle of 232.28° in such a way that the vector generated is established in quadrant III, where the focal behavior inhibits the appearance of the mating behavior in the prospective and the retrospective plane. Taking DEF as focal behavior and relating it to the rest of the categories that make up this dimension (PORT, DEF, CEN, DEL, and JR), shows the criterion category DEF (Line of Defense) in the results obtained (**Table 14** and **Figure 5B**) with a radius of 2.03 and an angle of 45° in quadrant I, where the focal behavior inhibits the appearance of the mating behavior in the prospective plane and activates it in the retrospective one. Finally, establishing DEL as focal behavior and relating it to the rest of the categories that make up this dimension (PORT, DEF, CEN, DEL, and JR), the results obtained (**Table 14** and **Figure 5D**) show the criterion category DEL (Front Line) with a radius of 3.02 and an angle of 45° in quadrant I, where the focal behavior activates the appearance of the mating behavior in the prospective and retrospective plane.

DISCUSSION

This work has been prepared in order to identify the existing differences between the champion teams of the last three Champions Leagues both quantitatively and qualitatively.

Regarding the use of depth in the development of the offensive action, we identified a difference in terms of the achievement of the goal by the three finalists (4, 1.9, and 2% respectively), results that are not in line with those obtained by Kite and Nevill (2017) who obtained results close to 1%. The results obtained in this study are closer to those identified by Amatria et al. (2019a) that amounted to 1.6%, being in all cases higher or much higher. However, when analyzing the real depth of the game, it

TABLE 13 | Results of the analysis of polar coordinates for the different focal categories in relation to the rest of the lines that make up the game structure of the 2017–2018 season.

CF	Category	Quadrant	Prospective P	Retrospective P	Ratio	Angle
PORT	DEF	II	−0.06	1.33	1.33	92.7
	MED	IV	0.45	−0.86	0.97	297.75
	DEL	III	−1.2	−1.47	1.9	230.64
	JR	I	0.04	0.38	0.38	83.96
DEF	PORT	IV	1.33	−0.06	1.33	357.3
	DEF	I	0.18	0.18	0.26	45
	MED	II	−0.26	1.07	1.1	103.59
	DEL	IV	0.61	−1.22	1.36	296.48
	JR	III	−1.54	−0.86	1.76	209.29
MED	PORT	II	−0.86	0.45	0.97	152.25
	DEF	IV	1.07	−0.26	1.1	346.41
	MED	III	−0.29	−0.29	0.41	225
	DEL	III	−0.55	−0.13	0.57	193.6
	JR	II	−0.29	0.98	1.03	106.46
DEL	PORT	III	−1.47	−1.2	1.9	219.36
	DEF	II	−1.22	0.61	1.36	153.52
	MED	III	−0.13	−0.55	0.57	256.4
	DEL	I	1.47	1.47	2.08 (*)	45
	JR	IV	1.27	−1.44	1.92	311.41

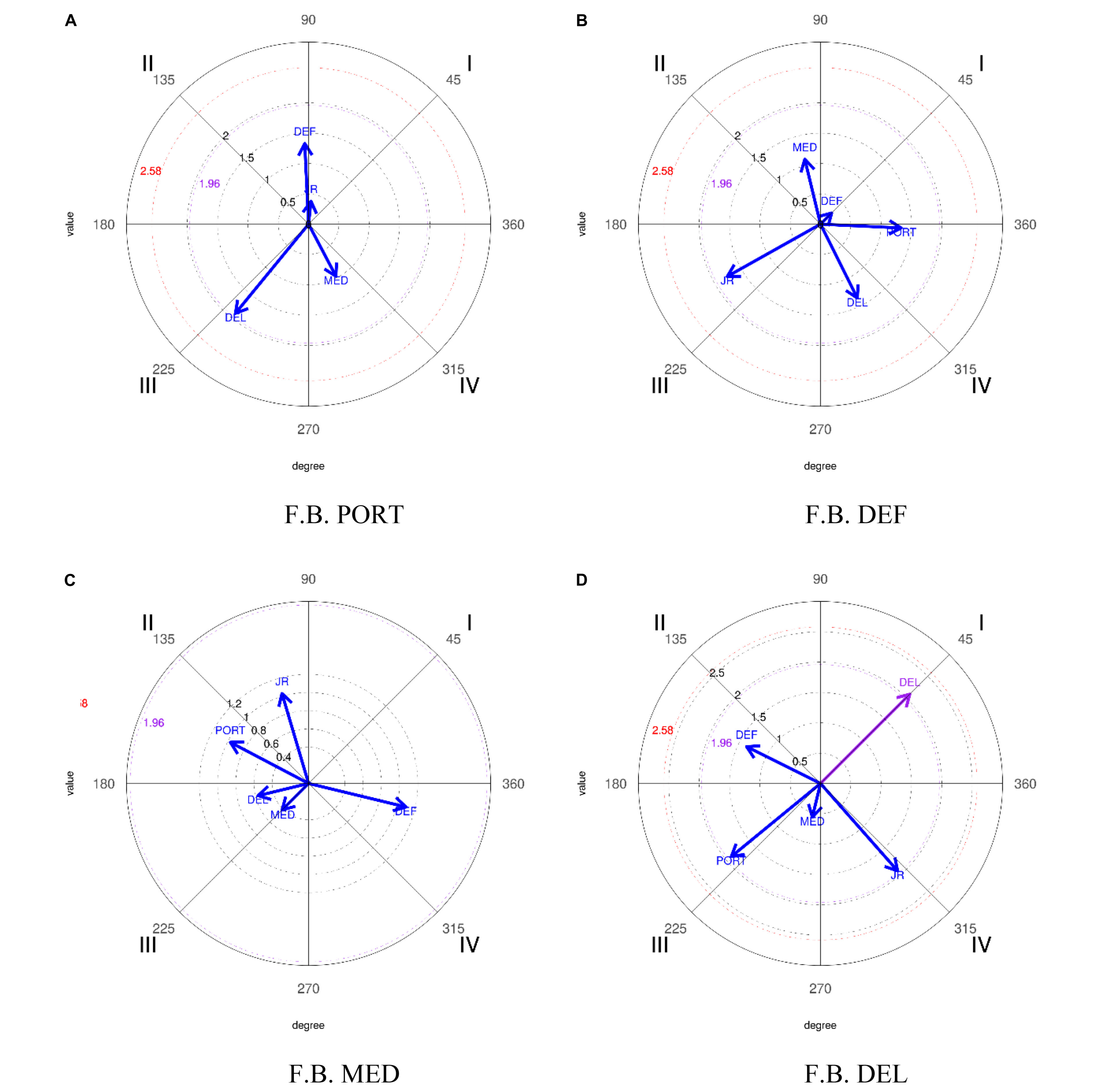

FIGURE 4 | Representation of the behavioral maps establishing the different categories as focal behavior, in relation to the lines that structure the team for the 2017–2018 season. *FB, focal behavior.

is observed that more than 50% of the actions that start in any sector other than defensive end in the definition sector, this sector being the one that houses the optimal areas of action (Pollard et al., 2004), with the results being superior to those obtained by Amatria et al. (2019a).

Regarding the development of the amplitude of the game and the use of the spaces that are generated in the side lanes, three different uses for them are identified, highlighting the results of the champion of the 2017–2018 season with results higher than 20% in offensive actions that starting in one side lane finish in the opposite side lane, both from left to right and from right to left (Amatria et al., 2019b). These results show a highly developed use of the amplitude, causing the rival team to perform complete defensive swings (from one side of the field to the other) trying to cause defensive imbalances and taking advantage of favorable numerical-spatial situations. Likewise, it is appreciated how the change of orientation stands as an essential tool to carry out this spatial and numerical use, using this resource in more than 27%

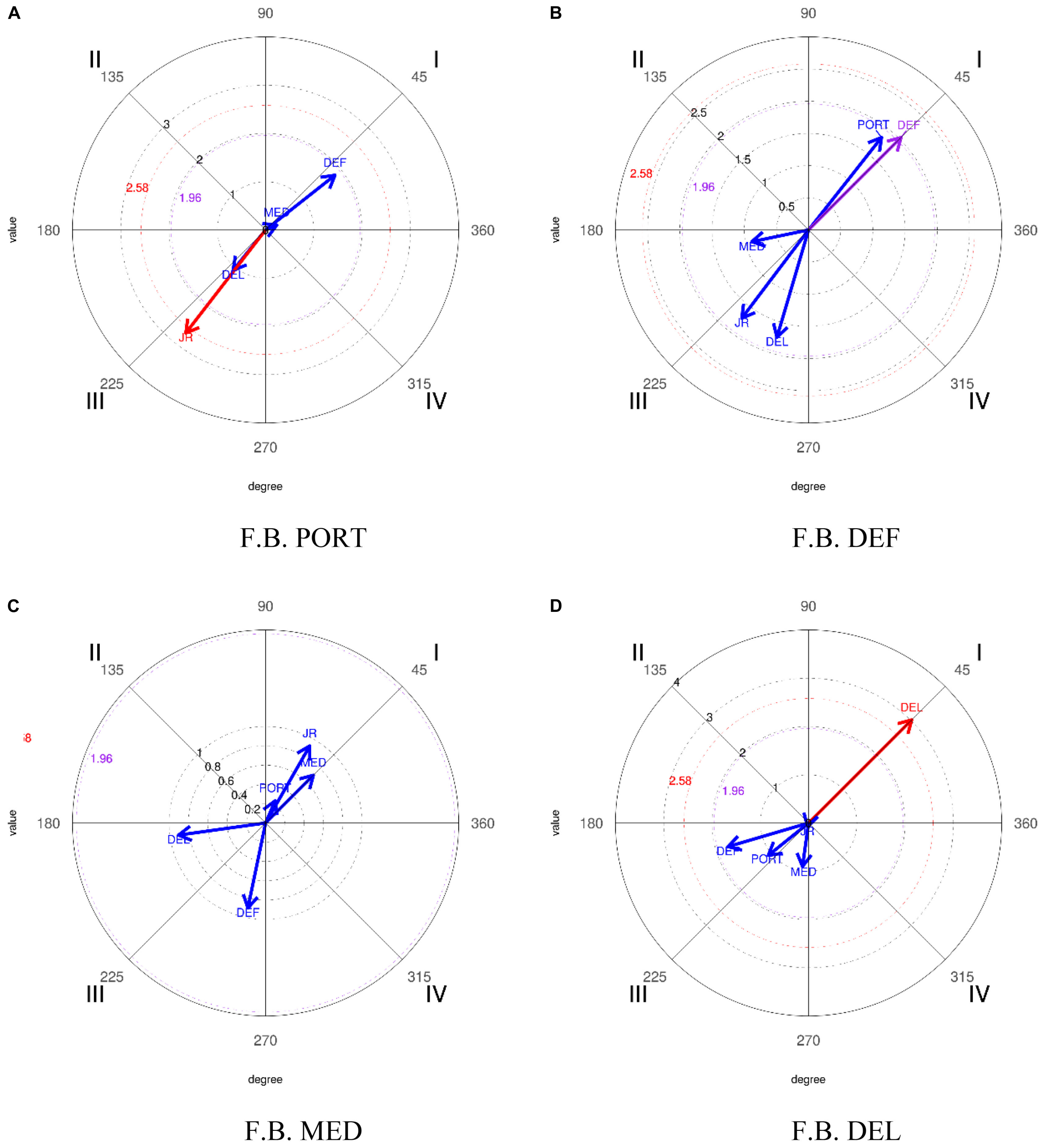

FIGURE 5 | Representation of the behavioral maps establishing the different categories as focal behavior, in relation to the lines that structure the team for the 2018–2019 season. *FB, focal behavior.

of offensive actions, that is, 1 in 4, an aspect that ratifies the Garganta's theory (1997) and the use of Orientation Changes as a strategic resource to avoid defensive density in the central areas of the field and in the side lanes where the ball is located.

In reference to the number of players, the highest percentages in offensive actions with a low participation of players in the three champions is evidenced. These results are not in line with those obtained by Hughes and Franks (2005) and Lago et al. (2012), although there is a manifest trend toward a high intervention of players (6–8) to reach the shot and send the ball to finishing situations, this type of density—high density—is reflected in the second highest percentages of the first two finals (16–17 and 17–18), not being the case in the final of the 2018–2019 season. The results are in line with those of Tenga et al. (2010) and Maneiro et al. (2019). These results could be explained by the style of play of the finalist teams in terms of the elaboration of the plays (Hewitt et al., 2016), with fast attacks or counterattacks being the ones that occur the most in the three seasons, but in the first two, it alternates with densities that show a more complex development and elaboration of the play, where teams try to play with time and space, and try to overcome a positioned and organized defense. While in the case of the 2018–2019 season, the highest percentages of density of the champion team respond to a game model closely related to the counterattack, reaching, between the Low and Very Low density levels, a percentage close to 70% of the offensive actions. If we identify the teams studied, Real Madrid (champion in the 2016–2017 and 2017–2018 seasons) and Liverpool (champion in the 2018–2019 season), the data corroborate the premise accepted and established by Lago-Peñas and Dellal (2010) which states that successful Spanish teams are the ones with the highest associative percentage, unlike teams of other nationalities (Bradley et al., 2013).

Regarding the analysis of polar coordinates, when analyzing the different lines and their interrelation, in reference to the goalkeeper's demarcation—PORT—being established as a focal behavior, there are relations of reciprocal activation with the DEF category—the defense line—in quadrant I. This highlights the choice by Real Madrid to develop its offensive action from the most backward positions, the goalkeeper in this case, to develop the action progressively and gradually, in such a way that the opposing team sees itself with the obligation to separate their defensive lines either from each other, or from favorable areas for the completion of the same with a shot or auction.

By taking the defensive line (DEF) as focal behavior, where all the other lines act as mating behaviors, the results are in accordance with what was presented in the previous paragraph. The strong relationship (radius of 2.32) that is established between the defense and the goalkeeper is observed, both prospectively and retrospectively—quadrant I.

Regarding the relationships that are established between the lines, taking the front line as focal behavior and the rest of the lines as mating behaviors, a reciprocal activation—quadrant I—is appreciated between the focal behavior DEL and the JR mating behavior, which manifests the direct interaction between the players who finalize the actions whose main assigned mission is to achieve the goal and the opposing players who try to avoid it by being in field areas of maximum risk for their interests, usually central areas close to the goalkeeper's area and, consequently, to the goal they must defend.

When performing the same analysis in the 2017–2018 season, we can see that there is no significant relationship between any of the lines established as focal behavior and the rest of the lines as mating behaviors. These results, which at first glance can be misleading, are clarified by the previous statistical analysis. This is because significant results are not appreciated, not because of the lack of relationship between the lines, but because of the variability that is established between them, the permeability and the high degree of connection between the players of the champion team is so high that the relationship between all the lines is similar and consequently there are no significant results. This shows the great capacity for association and the versatility and reading of the players during the development of the game, appearing and participating in the offensive action in areas that, due to their demarcation with stereotyped and pre-established functions, do not correspond which makes the relationship between the players of the different lines constant. Despite this, a relationship of mutual activation—quadrant I—is appreciated, by taking as focal behavior the front line—DEL—and establishing the rest of the lines as conditioned, also compared to itself. This

TABLE 14 | Results of the analysis of polar coordinates for the different focal categories in relation to the rest of the lines that make up the game structure of the 2018–2019 season.

	Category	Quadrant	Prospective P	Retrospective P	Ratio	Angle
PORT	DEF	I	1.44	1.14	1.83	38.27
	MED	I	0.23	0.1	0.25	23.33
	DEL	III	−0.67	−0.83	1.07	231.12
	JR	III	−1.65	−2.13	2.7 (*)	232.28
DEF	PORT	I	1.14	1.44	1.83	51.73
	DEF	I	1.44	1.44	2.03 (*)	45
	MED	III	−0.88	−0.18	0.9	191.76
	DEL	III	−0.49	−1.67	1.74	253.61
	JR	III	−1.04	−1.37	1.72	232.92
MED	PORT	I	0.1	0.23	0.25	66.67
	DEF	III	−0.18	−0.88	0.9	258.24
	MED	I	0.5	0.5	0.7	45
	DEL	III	−0.9	−0.13	0.91	187.93
	JR	I	0.46	0.8	0.92	60.19
DEL	PORT	III	−0.83	−0.67	1.07	218.88
	DEF	III	−1.67	−0.49	1.74	196.39
	MED	III	−0.13	−0.9	0.91	262.07
	DEL	I	2.13	2.13	3.02 (*)	45
	JR	III	−0.02	−0.08	0.08	254.48

indicates that, although there is great participation by all the players that make up the team in the development of the offensive action, when the ball reaches the front line, they end the action either individually, in which the player receives and ends himself, or by interacting with a partner on the same line, but not with colleagues from farther lines. These data are consistent with what was presented in the previous analysis when studying the density of players, as well as the spatial use of the offensive game by this season's champion, Real Madrid CF.

Finally, when analyzing the different lines and their interrelation, in reference to the 2018–2019 season, establishing the demarcation of the goalkeeper—PORT—as focal behavior, there are reciprocal activation relationships with the category JR—Rival Player—in the quadrant I. This shows how the Liverpool goalkeeper chooses in his interventions to move the ball away from his goal, generating divided balls, and creating duels where the dispute of the same and the intervention of the rival player occurs more frequently, as it is not an action where the control of the ball is maintained.

By taking the defensive line—DEF—as focal behavior, with the rest of the lines acting as mating behaviors, the results show an association of mutual excitation—quadrant I—with itself. This is indicated by the scarce elaboration of the actions and the underdeveloped game by Liverpool in this final, where the defenders relate to each other, without evaluating the possibility of combining with the other lines of the team to develop their offensive action. The same occurs when taking as focal behavior the front line—DEL—and the rest of the lines as conditioned behaviors, where a behavior of mutual excitement with itself is appreciated, this again indicates that when the front line intervenes, they only relate with themselves and not with the different lines of the team. In this sense, if we relate these results with the previous ones presented in the quantitative analysis, we see that when studying both from the global perspective, a direct game and against it is manifested, where the player belonging to the indicated line takes the ball and is that same player or another on his line who ends the offensive action.

CONCLUSION

As a final conclusion of this study, it can be said that there is no single model that brings together the offensive phase of the last three UEFA Champions League champions in their pre-Covid stage. Despite this, the style of play of each of the champion teams can be identified and described both quantitatively and qualitatively, where there are similarities between the first two seasons (16–17 and 17–18) since the champion team and the line-up were the same ones in both years, the Real Madrid CF, where the use of the depth and width of their game is seen, and the use of orientation changes for their development stands out, at a technical level making use mostly of the control and the pass and elaborating the offensive actions with patience elaborating plays that contain between 6 and 10 passes and with an intervention that oscillates between 4 and 5 players. On the other hand, in the last season a much less elaborate and direct style of play is seen, where the depth of the game is very present but the use of the amplitude is not very high, starting and ending the plays in the same lane, an aspect that influences the lack of presence of orientation changes, and developing low or very low levels of processing, where the type of contact that occurs the most is in the C1, a single touch. These marked characteristics respond to the archetype of English football, an aspect that fits in with the champion team of that edition, Liverpool CF.

Finally, it can be stated that there is no single way to achieve victory in a championship of these characteristics and that any path, adjusting to the potential of the players and the circumstances of the match, is valid for achieving victory. However, it is necessary to emphasize that the last champion team was favored by the signaling of a penalty, through which they put themselves ahead on the scoreboard, in the second minute of the game, an aspect that has been able to completely condition the approach of the tactical development of the match by Liverpool FC.

FUTURE LINES OF RESEARCH

Future studies go through continuing to investigate the tactical structure of other top-level teams, proposing new tactical alternatives to coaches in their professional performance.

LIMITATIONS

Some of the limitations of the present study are found in the teams analyzed, since two of the three UEFA Champions League champions have been the same team. Another possible limitation can be found in that we do not know the performance of the finals played during the circumstances produced by COVID-19, since confinement and the absence of group training can alter the normal performance of the teams.

PRACTICAL APPLICATIONS

The practical applications derived from this study include providing tactical alternatives to the different teams participating in international tournaments with the UEFA Champions League format in its Pre-Covid stage. Determining the type and intensity of the relationships that the team establishes between the different lines when it is in possession of the ball will allow the design of specific training tasks, resulting in possible improvements from both an offensive and defensive point of view of the game.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MA and RM: data collection and interpretation of the results. JL and XI: methodology. CC and AA: literature review. SP and HS:

data analysis. All authors contributed to the article and approved the submitted version.

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Early Environmental and Biological Influences on Preschool Motor Skills: Implications for Early Childhood Care and Education

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Early motor skills underpin the more complex and specialized movements required for physical activity. Therefore, the design of interventions that enhance higher levels of early motor skills may encourage subsequent participation in physical activity. To do so, it is necessary to determine the influence of certain factors (some of which appear very early) on early motor skills. The objective of this study was to examine the influence of some very early environmental variables (delivery mode, feeding type during the first 4 months of life) and some biological variables (sex and age in months) on preschool motor skills, considered both globally and specifically. The sample was composed by 43 preschool students aged 5–6 years. The participant's parents completed an *ad hoc* questionnaire, reporting on delivery mode, feeding type, sex, and age in months. The children's motor skills were assessed using observational methodology in the school setting, while the children participated in their regular motor skills sessions. A Nomothetic/Punctual/Multidimensional observational design was used. Results revealed that certain preschool motor skills were specifically influenced by delivery mode, feeding type, sex, and age. Children born by vaginal delivery showed higher scores than children born via C-section in throwing ($p = 0.000$; $d = 0.63$); total control of objects ($p = 0.004$; $d = 0.97$); total gross motor skills ($p = 0.005$; $d = 0.95$); and total motor skills ($p = 0.002$; $d = 1.04$). Children who were exclusively breastfed outperformed those who were formula-fed in throwing ($p = 0.016$; $d = 0.75$); visual-motor integration ($p = 0.005$; $d = 0.94$); total control of objects ($p = 0.002$; $d = 1.02$); total gross motor skills ($p = 0.023$; $d = 0.82$); and total motor skills ($p = 0.042$; $d = 0.74$). Boys outperformed girls in throwing ($p = 0.041$; $d = 0.74$) and total control of objects ($p = 0.024$; $d = 0.63$); while the opposite occurred in static balance ($p = 0.000$; $d = 1.2$); visual-motor coordination ($p = 0.020$; $d = 0.79$); and total fine motor skills ($p = 0.032$; $d = 0.72$). Older children (aged 69–74 months) obtained higher scores than younger ones (aged 63–68 months) in dynamic balance ($p = 0.030$; $d = 0.66$); visual-motor integration ($p = 0.034$; $d = 0.63$); and total balance ($p = 0.013$; $d = 0.75$). Implications for early childhood care and education are discussed since this is a critical period for motor skill development and learning.

Keywords: motor skills, early childhood, delivery mode, feeding type, sex, relative age effect, observational methodology, early childhood care and education

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INTRODUCTION

The World Health Organization has declared that 81% of all school-aged children fail to engage in the minimum recommended amount of daily physical activity (World Health Organization, 2010; Bull et al., 2020). This means that a large number of children do not receive the many physical, mental, and socio-emotional benefits of regular physical activity. This can be corrected, however, since physical activity (or the lack thereof) is a modifiable behavior. An initial step is to identify and determine the factors underlying this lack of physical activity in children. These variables include the level of motor skills acquired during early childhood (De Niet et al., 2021; Moghaddaszadeh and Belcastro, 2021). Motor skills include the movement and coordination of one's muscles and body (Matheis and Estabillo, 2018). They are classified into two groups: (1) Gross motor skills and (2) Fine motor skills (Gonzalez et al., 2019; Goodway et al., 2019; Meylia et al., 2020). (1) Gross motor skills refer to developmental aspects associated with the child's ability to move using their large muscle groups to perform activities such as walking and jumping. (2) Fine motor skills refer to precise movements using smaller muscle groups to perform more delicate tasks such as picking up small objects, threading beads, and writing. They require control and coordination of the distal musculature of the hands and fingers. Both gross and fine motor skills can be divided into more specific typologies (Goodway et al., 2019; Bolger et al., 2020; Meylia et al., 2020). (1) Three types of gross motor skills have been established: (1.1) Locomotor skills: these are movements having the fundamental objective of moving the body from one point in space to another, such as: running, jumping, rolling, etc. (1.2) Balance: this is the ability to maintain a controlled position or posture during a specific task. Here, differentiation is made between: (1.2.1) Static balance: it is the ability to maintain postural stability and orientation with the center of mass over the base of support while the body is at rest. It is necessary, for example, to perform squats; and (1.2.2) Dynamic balance: it refers to the same ability to maintain postural stability and orientation with the center of mass over the base of support but while the body parts are in motion. An example of dynamic balance task is stair climbing. (1.3) Object control skills: skills that allow the individual to move or receive objects, be it with the feet, hands, or even the body. Differentiation is made between: (1.3.1) Propulsive skills: they involve sending an object away from the body, such as throwing, or batting a ball; and (1.3.2) Receptive skills: they involve receiving an object, such as catching a ball, or a frisbee (Kokstejn et al., 2017; Bolger et al., 2020). As for (2) Fine motor skills, two separate elements have been established: (2.1) Visual-motor coordination (also referred to as Fine motor coordination): it refers to small muscle movements with a visual component. It includes abilities such as finger dexterity, motor sequencing, and fine motor speed and accuracy. These skills are used in tasks such as building with blocks; finger tapping, and imitative hand movements. (2.2) Visual-motor integration (also called Visual-spatial integration or Fine motor integration): it involves the organization of small muscle movements in the hand and fingers with the processing of visual stimuli. It implies that visual information from the environment is processed and integrated using fine motor movements. It requires more visual perception than Visual-motor coordination. Visual-motor integration skills are often captured by tasks that involve writing and copying (Goodway et al., 2019).

Early motor skills are essential for subsequent physical activity. They are the basis of more advanced, complex, and specialized movements needed to participate in games, sports, and other context-specific physical activity (Chang et al., 2020; Moghaddaszadeh and Belcastro, 2021). Therefore, promoting and obtaining a suitable level of early motor skills is a positive element that may stimulate and enhance the onset and maintenance of physical activity. Children with good motor skills are perceived as being competent, leading to increased enjoyment and engagement in more and wider variety of motor and physical activity experiences. Increased physical activity provides more opportunities to promote motor skill development. Therefore, a positive spiral or dynamic relationship is evident between motor skills and physical activity (Stodden et al., 2008). On the other hand, less-skilled children will have a lower perceived competence and will perceive many tasks as being more difficult and challenging, therefore being less likely to engage in them. Hence, having good motor skills, even in early childhood, may contribute to becoming a physically active individual, or even an elite athlete (De Niet et al., 2021).

Despite the clear importance of these early motor skills in the life and development of children, they tend to be overlooked on a research and practical/educational level (Lopes et al., 2021). This has led to an increase in the number of children with poor motor skills and an upward trend of motor difficulties over recent years (Honrubia-Montesinos et al., 2021; Lopes et al., 2021).

One of the issues that seems to have contributed to this lack of research and promotion of early childhood motor skills is the misconception that they will develop naturally over time. However, to attain an appropriate motor skill level, these skills must be learned, practiced, and reinforced over time (Honrubia-Montesinos et al., 2021; Moghaddaszadeh and Belcastro, 2021). Preschool years are an especially important life phase for the development and learning of motor skills (Wang et al., 2020; Lopes et al., 2021). During these years, development occurs quickly and it is closely linked to the quality and quantity of the stimuli received by the children. Therefore, during early childhood children should be offered enriched environments, allowing them to achieve their full motor potential (Lopes et al., 2021; Moghaddaszadeh and Belcastro, 2021). Early Childhood Education classrooms are an ideal context for this since a large number of children attend these schools, spending many hours there (European Commission/EACEA/Eurydice, 2019; Spanish Ministry of Educational Professional Training, 2020).

However, we should note that, for Early Childhood Education experiences to be effective, they should be intentionally designed taking into account the child's current level of development (Darling-Hammond et al., 2020). However, a problem arises for educators. Even children in the same academic year and enrolled in the same class may display different motor skills levels, given their distinct characteristics and past and present experiences. Numerous and diverse factors may affect motor skill levels in children (Wang et al., 2020). Learning more about these potential factors and their influences on children's motor skills is necessary to design individualized interventions that optimize motor skills for all children.

Given all of this, as well as the current literature on the topic, the purpose of this study was to provide knowledge as to the influence of certain variables (some of which are present from a very early age) on global and specific motor skills, on preschool-age children (5- and 6-year-olds). The following variables of influence on preschool motor skills were considered: delivery mode, feeding type during the four first months of life, sex, and age (specifically, the relative age effect), since, according to the literature, there is still an ongoing discussion regarding its relationship with motor skills.

Each of these variables is discussed below.

Delivery Mode

A possible impact of delivery mode on the neurodevelopment of children has been considered. The mode of delivery has been directly related to biochemical and structural changes in the central nervous system, although their consequences are not well-known. Thus far, literature on this area (especially referring to the influence of the delivery mode on motor skills) has been inconclusive, since studies are scarce and they offer conflicting results (Blazkova et al., 2020; Takács et al., 2020).

Vaginal delivery is considered to be the ideal mode of delivery for the child's development. It is the most natural delivery mode and tends to lead to a lower number of complications for both mother and child (World Health Organization, 2018). In this mode of delivery, certain inherent mechanisms may be produced, possibly triggering certain protective and strengthening processes for the child's appropriate development (Tribe et al., 2018). Over recent years, however, the rate of cesarean deliveries (C-sections) has increased considerably in numerous countries (World Health Organization, 2018). It has been due an overuse of the procedure, and not to medical indications (World Health Organization, 2018), such as mothers' wishes to have a planned birth (King, 2021). Many studies have warned of the harmful consequences that this may entail, since, like any other surgery, C-sections are associated with short- and long-term risks that may persist years after the intervention and which may affect the child's health and development (Chojnacki et al., 2019; King, 2021). Specifically, about the effect of C-sections on motor development, further research is necessary given the literature is limited and does not offer conclusive results.

Some studies have found no evidence to affirm that children born by C-section display poorer gross and fine motor skills than those born by vaginal delivery (Zhou et al., 2019; Takács et al., 2020).

Other studies have found the opposite results, suggesting that delivery mode affects the child's motor development. Rebelo et al. (2020) studied the influence of delivery mode on motor skills (both gross and fine) in children aged 12–48 months. Their results indicated that: (1) children born via vaginal delivery had better motor skills, both gross and fine, as compared to those born via C-section. More specifically, in older children (36–48 months), differences based on delivery mode were statistically significant in object control, visual-motor coordination, and visual-integration skills, as well as in the score on total gross motor skills and total fine motor skills. No statistically significant differences were found for locomotor and balance skills; (2) the effect of delivery mode on motor skills became more pronounced as the children became older. Blazkova et al. (2020) also found that the mode of delivery had a major effect on visual-integration skills in 5-year-olds: those born via vaginal delivery had higher visual-motor integration than those born by C-section. No additional measures regarding motor skills were included in said study.

In summary, along with the disparate results found between studies regarding the influence (or lack of) of delivery mode on motor skills, it has been found that most of the studies offer only partial results and fail to consider all specific gross and fine motor skills that have been identified in the literature (and explained above). Given these limitations and lack of knowledge, it was decided to include this variable in this study.

Feeding Type

Appropriate feeding practices are vital for children's optimal growth and development. Breastfeeding is recognized as the gold standard for infant nutrition (Chen et al., 2021). Many of the components of breast milk offer multiple benefits to the child's health, growth, and development, over the middle- and long-term. Breastfeeding has been associated with appropriate cerebral development, improved immunity, and a decreased risk of infections, metabolic diseases (including obesity and diabetes), asthma, and cardiovascular risk. It also may result in better mental health, improved cognitive and language development and academic performance (Grace et al., 2017; Jardí et al., 2018). Few studies exist, however, regarding its effect on motor development (Hernández Luengo et al., 2019). And said studies have focused more on analyzing the effects of a longer or shorter duration of breastfeeding on motor development rather than on the effects of breastfeeding as compared to other types of infant feeding (such as formula feeding). Among the limited studies that have considered this topic, results have been non-conclusive. Moreover, studies analyzing the effects beyond 3 years are even more few.

Bellando et al. (2020) found that, at the age of 3 months, breastfed infants displayed better motor development than formula-fed infants. However, at 12 and 24 months, no differences were found between both groups. Similar results have been found by Michels et al. (2017), who suggested that the type of feeding during the first 4 months of life does not impact the ages at which gross motor milestones (standing and walking alone) are achieved.

Other studies have offered distinct results, suggesting that associations exist between infant feeding type and motor skills. Jardí et al. (2018) found that children who were exclusively breastfed for the first 4 months of life (as compared to those who were formula-fed or mixed-fed during that time) displayed better motor development at 6 months and 1 year of age. Results found by Kádár et al. (2021) suggest the same. At 1 year of age, children who were exclusively breastfed for 6 months showed the lowest incidence of delays in their motor development. Those who were exclusively formula-fed during this time had the highest incidence of delays.

This set of studies presents some important results, although motor development is only considered in a general manner, and without differentiating between different motor skills. Very few studies have made this differentiation and those that have revealed discrepancies as to whether or not the infant feeding type influences gross and fine motor skills. Sacker et al. (2006) reported that at 9 months of age, children who had never been breastfed were the most likely to have delays in motor development (both gross and fine). Similarly, and further supporting the positive effects of breastfeeding as compared to other infant feeding types for gross and fine motor skills, Dee et al. (2007) found that breastfeeding was a protective factor against developmental delays (for both gross and fine motor skills) in children aged 1–5. The results of Leventakou et al. (2015) were somewhat different, however. They found that at 18 months, no differences existed in the gross motor skill level of children who were never breastfed as compared to those who were. On the other hand, differences were found between children in terms of fine motor skills, which were lower in children who were never breastfed. Therefore, according to these authors, fine motor skills are more sensitive to the effects of feeding than gross motor skills. We are unaware of studies that have analyzed the effects of infant feeding type on different specific gross and fine motor skills.

Given the wide variety of results and this gap, there is clearly a need for additional research to determine the impact of early feeding type on motor skills, specifically considering its influence on different specific gross and fine motor skills. Existing studies have failed to consider this issue.

Sex

Numerous studies have suggested differences in the motor skills of boys and girls (Kokstejn et al., 2017; Matarma et al., 2020; Mecías-Calvo et al., 2021). These differences have been primarily explained by the different stereotyped activities, sporting or other, that are carried out by the different sexes, and not by differences in their physical characteristics (body type, body composition, strength, and limb length), since, before puberty, these characteristics are quite similar in both boys and girls (Bolger et al., 2020; Matarma et al., 2020). Some studies, however, have failed to find differences in preschool motor skills between boys and girls (Martínez-Moreno et al., 2020).

Discrepancies exist even among those who defend the idea that there are differences in motor skills according to sex. The influence of sex on infant motor skills appears to depend on the specific motor skill at hand, but there is no consensus as to the specific associations. Thus, discrepancies exist as to which sex displays better performance on each of the motor skills.

Regarding gross motor skills, some studies have found that boys outperform girls (Bolger et al., 2018, 2020; Wang et al., 2020), while other studies have suggested that girls outperform boys (Matarma et al., 2020) and others have found no differences between both sexes (Peyre et al., 2019; Martínez-Moreno et al., 2020). In terms of fine motor skills, girls have been found to have better performance than boys (Kokstejn et al., 2017; Peyre et al., 2019; Mecías-Calvo et al., 2021), although other studies have suggested that fine motor skills are very similar between both sexes (Martínez-Moreno et al., 2020).

These discrepancies regarding which motor skills present differences and which do not, and whether said differences favor boys or girls, become even greater when we consider the different specific skills making up the gross motor skills. Some studies have suggested that locomotor skills are higher in girls (Bolger et al., 2018, 2020; Wang et al., 2020), while other works claim that they are higher in boys (Robinson, 2010); and other studies have failed to detect any significant differences between both sexes (Bakhtiar, 2014; Foulkes et al., 2015; Barnett et al., 2016; Bolger et al., 2018, 2020). As for balance skills, some studies have shown that these skills are higher in girls (Venetsanou and Kambas, 2016; Kokstejn et al., 2017; Mecías-Calvo et al., 2021) while others indicate that they are similar for both sexes (Singh et al., 2015; Barnett et al., 2016). As for control object skills, some studies show higher levels in boys (Foulkes et al., 2015; Barnett et al., 2016; Venetsanou and Kambas, 2016; Kokstejn et al., 2017; Bolger et al., 2018, 2020; Mecías-Calvo et al., 2021) while others find similar levels between both sexes (LeGear et al., 2012; Bakhtiar, 2014). We are unaware of studies that have focused on the analysis of potential differences based on sex for the distinct specific preschool fine motor skills.

Given the disparity of results and this gap, additional research is clearly necessary in this area. Therefore, in our study, we have included the sex variable to analyze its influence on (global and specific) motor skills.

Age

It is well-known that as children grow, their motor skills improve (Bolger et al., 2018). What is not so well-known is whether significant differences exist between the motor skills of children born in the same year. In Spain (where this research was conducted), the educational policy groups together children based on their date of birth, with all children born in the same natural year (January 1 to December 31) being grouped in the same academic year. This is an attempt to seek the minimum number of differences between children in the same academic year, and to offer appropriate experiences for all. However, in fact, this means of grouping leads to cases of an almost full year's difference in the age of some students who are in the same academic year (12 months minus 1 day). That is, there is a chronological age difference between children of the same cohort. The results of this phenomenon are referred to as the "relative age effect" (RAE) (Gladwell, 2008). The RAE refers to the effects of being relatively younger or older than peers. It may result in children who are born earlier in their year of birth outperforming children of the same cohort who were born later in the year. Therefore, being born later potentially puts these children at a disadvantage as compared to their peers with earlier birthdays. The size of the RAE is inversely correlated with age, such that the RAE is more prominent in early grades (Aune et al., 2018).

Some studies have found that even as early as in Early Childhood Education, children born at the beginning of the year displayed higher levels of gross and fine motor skills than their peers with later birthdays (Martínez-Moreno et al., 2020; Mecías-Calvo et al., 2021; Navarro-Patón et al., 2021). This appears to be due not only to their nervous and muscular system having matured for a longer period of time, but also to their increased opportunities for motor practices, experiences, and feedback; issues that may help to refine their motor skills (Bolger et al., 2020; Cupeiro et al., 2020).

Although these studies have revealed the existence of an RAE on preschool motor skills, it should be noted that their results also suggest that the RAE does not affect all of the preschool motor skills, with discrepancies arising when attempting to determine which motor skills have an RAE and which do not. In addition, the use of distinct assessment instruments and the consideration of different motor skills prevent the comparison of studies. Therefore, for example, Imbernón-Giménez et al. (2020) found an RAE on the control of objects, visual-motor integration, and total gross motor skill score. However, they did not find it on locomotor, balance, or total score for fine motor skills. Visual-motor coordination and the total motor skill score were not considered in this study. Mecías-Calvo et al. (2021) did not find results that coincide with those of prior authors, since they found an RAE on balance but not on object control. Other results of Mecías-Calvo et al. (2021)–referring to motor skills not considered by Imbernón-Giménez et al. (2020)–found the existence of an RAE on visual-motor coordination and total motor skills score. Navarro-Patón et al. (2021) found an RAE on object control –coinciding with Imbernón-Giménez et al. (2020)–, as well as for visual-motor coordination –coinciding with Mecías-Calvo et al. (2021)–. However, they did not find an RAE on balance –unlike Mecías-Calvo et al. (2021), but like Imbernón-Giménez et al. (2020)–. They also failed to find an RAE on the total motor skills score –an aspect that also diverges from Mecías-Calvo et al. (2021)–. More specific results were found by Imamoglu and Ziyagil (2017). These authors analyzed the RAE on locomotor and object control skills, detecting that only some, –not all– locomotion skills were affected by this effect. The object control skills, as suggested by Mecías-Calvo et al. (2021) did not reveal an RAE, unlike the results of Imbernón-Giménez et al. (2020) and Mecías-Calvo et al. (2021).

Given the wide variety of results, based on partial studies that do not consider all of the specific gross and fine motor skills identified in the literature, further research is necessary to determine which of the specific preschoolers' gross and fine motor skills are influenced by an RAE.

AIM

The objective of this study was to analyze whether there were influences of delivery mode, type of feeding during the first 4 months of life, sex, and age (more precisely, the RAE) on motor skills (considered at both a global and specific level), assessed in 5- and 6-year-old preschoolers.

Based on the existing literature on this area, we proposed the following hypotheses:

- H_1: Differences will be found in childhood motor skills based on the delivery mode: children born by vaginal delivery will have higher motor skills than children born by C-section.
- H_2: Differences will be found in childhood motor skills based on the type of feeding during the first 4 months of life: children who were exclusively breastfed during this time will have higher motor skills than children fed with formulas or mixed-fed.
- H_3: Differences will be found in childhood motor skills based on sex: boys will outperform girls on certain motor skills while, in other motor skills, the opposite will occur. Moreover, in other skills, no differences will be found between both sexes.
- H_4: There will be an RAE on certain preschool motor skills: children born over the first half of the year will outperform their classmates who were born over the second half of the same year on some motor skills.

We believe that determining whether these variables have an influence on the motor skills of 5- and 6-year-olds may be of great assistance to educators as well as health, sports, and physical activity professionals, who may subsequently design more effective personalized interventions. These results may be relevant for policymakers when implementing public health, social, and educational policies that promote appropriate motor skill development from very early ages, thereby enhancing physical activity and healthy lifestyles in the children.

MATERIALS AND METHODS

Methodology and Design

Data for this study are a subset of a broader research project focusing on the analysis of diverse childhood skills and competencies.

A multimethod and mixed methods approach was used (Elliott, 2007; Sánchez-Algarra and Anguera, 2013; Anguera et al., 2018a). The multimethod approach consisted of selective methodology to determine the delivery mode, feeding type during the first 4 months of life, sex, and age (a questionnaire was used for this), as well as information referring to the sample's inclusion/exclusion criteria (questionnaires and standardized batteries were used); and observational methodology to observe preschool motor skills in the school context while the children participated in their regular motor skills sessions. Our study was also carried out from a mixed methods approach because observational methodology itself is considered a mixed methods, since it integrates qualitative and quantitative elements in a succession of QUAL-QUAN-QUAL macro-stages (Sánchez-Algarra and Anguera, 2013; Anguera et al., 2018a, 2020a,b). In the first QUAL stage, an *ad hoc* observation instrument is built and applied to code the behaviors that are the subject of the study, taking into account the natural setting in which they occur. Then, in the QUAN stage, observational data quality is tested and analyses through quantitative techniques are carried out to respond to the study objectives. The quantitative results obtained are qualitatively interpreted in the third and last stage (QUAL stage), considering the research problem and the literature. All this permit a seamless integration.

Observational methodology plays an essential role in our study. It is a robust scientific method for analyzing regular behavior (like the motor behaviors studied in this work) in natural settings (such as the scholastic one, the context in which this research was carried out) (Suárez et al., 2018, 2020; Escolano-Pérez et al., 2019a,b; Anguera et al., 2020a,b; Sagastui et al., 2020). Furthermore, observational methodology is the most appropriate methodology for studying the behavior of young children (like those in this study who were 5 and 6 years of age) (Anguera, 2001; Early Head Start National Resource Center, 2013; Blanco-Villaseñor and Escolano-Pérez, 2017; Escolano-Pérez et al., 2017; Escolano-Pérez et al., 2019b).

Of the eight types of existing observational designs (Anguera et al., 2018b), we employed a Nomothetic/Punctual/Multidimensional design. It was: "Nomothetic" because various units of observation were studied (43 children); "Punctual" because for each child, an observation session was carried out to study each of the motor skills of interest in the study; and "Multidimensional" because different response levels were observed, that is, distinct aspects were observed regarding the gross and fine motor skills, thereby following the theoretical proposal of distinct authors (Matheis and Estabillo, 2018; Gonzalez et al., 2019; Goodway et al., 2019; Meylia et al., 2020). These response levels are reflected in the observation instrument used (available in the **Supplementary Material**).

The observation was active, based on scientific criteria, non-participatory and direct (the level of perceptibility of the behaviors was complete). It was performed by direct observation of recorded film (Anguera et al., 2018b).

Participants

Preschool children aged 5 and 6 ($N = 43$: 15 boys and 28 girls; 34.88% and 65.12%, respectively) in the third year of Early Childhood Education ($M_{age} = 68.6$ months; $SD_{age} = 3.59$) from an intentionally selected public school participated in the study. The school was located in a middle-upper (socioeconomic) class neighborhood, in a city in the northeast of Spain.

All children had the following characteristics (meeting exclusion/inclusion criteria established for study participants): (1) absence of a history of pre, peri, or postnatal problems, neurological disease, sensory disturbance, mental or other clinically diagnosed impairment (such as attention-deficit hyperactivity disorder, developmental coordination disorder, developmental dysphasia, etc.) or special needs, according to the information provided by the parents of the children; (2) according to the school's management team, all participants were enrolled in the school since the 1st year of Early Childhood Education. That is, they were completing the entire second cycle of this educational stage (from 3 to 6 years of age) at this school; (3) they had appropriate IQ for their age, according to the assessment carried out by the research team using the BADyG-I (Battery of Differential and General Abilities I; Yuste and Yuste, 2001).

The study was part of a broader research project endorsed by the Research Unit of the University of Zaragoza. All participants were treated in accordance with the principles of the Declaration of Helsinki. Written informed consent was required from the children's parents.

Instruments

Instruments Used for Selective Methodology

An *ad hoc* questionnaire to be completed by the participants' parents was used to determine the following: (1) Information related to the exclusion criterion referring to a history of pre, peri, or postnatal problems, neurological disease, sensory disturbance, mental or other clinically diagnosed impairment (such as attention-deficit hyperactivity disorder, developmental coordination disorder, developmental dysphasia, etc.), or special needs; (2) Information on the delivery mode, type of feeding during the first 4 months of life, sex, and age of each participant. More specifically, and regarding these variables, the questionnaire requested that the following be indicated: (a) delivery mode: select between vaginal delivery and C-section, according to the classification used in similar past studies, such as those by Khalaf et al. (2015) and Grace et al. (2017); (b) feeding type during the first 4 months of life: select between exclusive breastfeeding; exclusive formula or artificial milk feeding; and mixed-feeding (combination of breast and formula feeding), according to the classification proposed by other similar past studies (Tozzi et al., 2012; Michels et al., 2017; Jardí et al., 2018; Chojnacki et al., 2019). It should be noted that this age (4 months) was selected because, according to the studies conducted in Spanish contexts, this is a turning point in infant feeding. Most Spanish mothers tend to stop breastfeeding at this point, given that their maternity leave ends and they have to return to work. At this point, many mothers resort to other feeding options for their children (Jardí et al., 2018; Cabedo et al., 2019); (c) sex: select between masculine and feminine; (d) date of birth, indicating the day, month, and year. The questionnaire also contained a section for additional "considerations" allowing parents to clarify any responses.

To gather information referring to the inclusion criterion of being enrolled in the school since the 1st year of Early Childhood Education (that is, to be completing the entire second cycle of this educational stage in the school), another *ad hoc* questionnaire was used, to be completed by the preschool management team.

To determine whether all of the participants complied with the inclusion criterion of having an appropriate IQ for their age, the BADyG-I (Battery of Differential and General Abilities I; Yuste and Yuste, 2001) was used. It is one of the most widely used instruments in Spain (where the study was conducted) to measure student IQ, since it has suitable psychometric properties and provides a complete measurement including distinct verbal (Numerical-Quantitative Concepts, Information, and Graphic Vocabulary) and non-verbal (Reasoning with Figures, and Logic Puzzles) fields. BADyG-I offers a Verbal, Non-verbal, and General IQ.

Instruments Used for Observational Methodology

According to the GREOM (Guidelines for Reporting Evaluations Based on Observational Methodology; Portell et al., 2015), it is necessary to differentiate between recording (to record or code data) and observation (to observe a specific topic) instruments.

Recording instruments

The following recording instruments were used: (1) a video camera to record the children's motor sessions and (2) the free software Lince v.1.2.1 (Gabin et al., 2012) to code actions indicative of infant motor skills.

Observation instrument

We created a modified version of the original *ad hoc* observation instrument by Escolano-Pérez et al. (2020). The modifications included new categories, the elimination of other categories, and some more specific definitions. The observation instrument was a combination of a field format and systems of categories, given that the observational design was multidimensional (Anguera et al., 2018b). This observation instrument consists of a total of 26 criteria. Each criterion was broken down into a system of exhaustive, mutually exclusive categories. Overall, the observation instrument contained 82 categories. The selection of criteria and categories was based on the information provided by theoretical and empirical studies on childhood motor skills (Hestbaek et al., 2017; Oberer et al., 2017; Goodway et al., 2019; Haywood and Getchell, 2019); the Spanish Early Childhood Education curriculum, which determines the motor skills worked on during this educational stage (Education Science Ministry of Spanish Government, 2007), and the information obtained from the reality observed. The observation instrument is fully available (criterion; criterion description; category systems; category description, and category code) in the **Supplementary Material**. **Table 1** shows its criteria and categories.

Data Analysis Software

All analyses were carried out using IBM SPSS version 25 (IBM Crop, 2017).

Procedure

The preschool management team was informed of the purpose, procedure, and benefits of the study. Once their approval was obtained, the parents were also informed and asked to complete the informed consent to authorize the participation of their children in the study.

Then, the parents that signed and delivered the informed consent were given an *ad hoc* questionnaire so that they could provide the information for the participant's exclusion criteria (having a history of pre, peri, or postnatal problems, neurological disease, sensory disturbance, mental or other clinically diagnosed impairment, or special needs), as well as information related to delivery mode, feeding type during the first 4 months of life, sex, and age. The preschool management team was given an *ad hoc* questionnaire to determine whether the potential participants complied with the first inclusion criterion: having been a student at the school since 1st year of Early Childhood Education.

Children who did not present exclusion criteria and who complied with the first inclusion criterion were assessed by the research team using the BADyG-I to verify their compliance with the second inclusion criterion: having a suitable IQ for their age. BADyG-I was administered following the instructions of its manual.

TABLE 1 | Observation instrument: criteria and categories.

Criterion	Category systems
Participant	Participant 1
	Participant 2
	…
Recreational motor activity	Leaping hare
	Blind frog
	Jumping flea
	Flamethrower dragon
	Ball-catching dog
	Centipede wiping its feet
	Cunning fox
Specific motor skill	Locomotor skills
	Static Balance
	Dynamic Balance
	Propulsive skills
	Receptive skills
	Fine Motor Coordination
	Fine Motor Integration
Extremity	Right
	Left
Arm position	Backwards
	Forwards
	Across the body
	In the form of a cross with arms extended
	In the form of a cross with arms bent
	Others
Jump phase	Impulse
	Flight
	Landing
Leg position	Knees bent
	Knees not bent
Distance to the ground	Feet on the floor
	Heels lifted
	Feet in the air
Centimeters	Quartile 1 distance
	Quartile 2 distance
	Quartile 3 distance
	Quartile 4 distance
Base of support	Feet together
	Feet separated
	Feet widely separated
Type of landing	Without bouncing
	With a bounce
Precision of the jump	The 2 feet within the square
	At least one foot steps on a line of the square
	Outside of the square
Trunk position	Upright
	Inclined
Time	Quartile 1 time
	Quartile 2 time
	Quartile 3 time
	Quartile 4 time

(Continued)

TABLE 1 | Continued

Criterion	Category systems
Finger	Pinky finger
	Ring finger
	Middle finger
	Index finger
Direction	Direct
	Reverse
Part of the finger	Fingertip
	Other
Way of catching the ball	With both hands
	Supporting on body
	Not catching
Hand position	Together
	Separate
Height of the catch	Chest
	Neck head
	Abdomen
	Thighs
	Knee
	Under the knee
Attempt	1
	2
	3
	+3
Passing through	Transfer
	Touch
	Diverted
Shape orientation	Exact
	Inexact
Length of sides	Adequate
	Inadequate
Amplitude of angles	Appropriate
	Inappropriate
Intersection	Equal
	Unequal

To observe the children's motor skills, the research team designed recreational motor activities, taking the following into account: (1) the study objective; (2) theoretical and empirical studies on childhood motor development (Hestbaek et al., 2017; Oberer et al., 2017; Goodway et al., 2019; Haywood and Getchell, 2019); (3) the Spanish Early Childhood Education curriculum, which determines the content related to motor skills to be worked on during this educational stage and the pedagogical resources to be used for it, being *play* especially highlighted (Education Science Ministry of Spanish Government, 2007); (4) spatial-temporal characteristics of the motor skill sessions carried out by the children during their regular school programming. Based on all of this, seven recreational motor activities were created, requiring the use of the gross and fine motor skills that are the subject of interest of this study (and previously defined in the Introduction Section). These skills are: locomotor skills; static balance; dynamic balance; receptive skills; propulsive skills (all referring to gross motor skills); visual-motor coordination and visual-motor integration (referring to fine motor skills). All of the recreational motor activities designed were accompanied by a brief fantasy-type story about animals, which was used to attract the children's attention, increase their motivation and encourage their engagement in the activities. This was done so since the imagination and fantasy, together with play, are the most common pedagogical resources used in Early Childhood Education (McLachlan et al., 2018), and animals are a common focus of attention in preschoolers (Born, 2018). Specifically, the seven recreational activities designed to promote the use the different motor skills were:

- Leaping hare: this game required the use of locomotor skills. From a specific point, the child was to jump with both feet together, as far as possible. When landing the jump, the child was unable to help using his/her hands, so the landing was made on foot. The child had three successive attempts (without recovery time) to do this.
- Blind frog: this recreational activity required static balance skills. The child was to remain as long as possible with his/her eyes closed, in a squatting position over the balls of the feet, keeping his/her body bent and the arms extended horizontally to the sides. If they lasted <5 s in this position, they could try again a second time (without recovery time).
- Jumping flea: this game involved dynamic balance. The child was to jump up and down without leaving a 25 cm square area, painted on the ground, looking forward (not at the ground).
- Flamethrower dragon: this game referred to propulsive skills. The child was to horizontally throw a tennis ball from the height of his/her shoulder so that it passed through a 30 cm diameter hoop that was 1.5 m away. They had to throw the ball 8 times (four successive throws with each hand and without recovery time between the throws made by each hand).
- Ball-catching dog: this game implied receptive skills. The child was to catch a ball thrown by an adult from a distance of 1.5 m. The adult made four successive throws.
- Centipede wiping its feet: this game entailed visual-motor coordination. Using their thumb, the child was to touch the fingertips of the other four fingers of the same hand. They were to do this successively, beginning with the pinky finger until reaching the index finger. Once touching this finger, they were to repeat these movements in reverse order, that is, from the index finger to the pinky finger. This series of movements was to be carried out once with each hand. They had three successive attempts to accomplish the task.
- Cunning fox: this game involved visual-motor integration, the child was to copy consecutively six shapes appearing on a sheet. The child could not review the figure to copy it. During the copying, the child could erase but not after the completion of the figure. The 6 figures to be copied were: a cross, triangle, square, arrow cross, rhombus, and triangle within another triangle.

The observation sessions were carried out in the school's motor development room, where the children's regular motor skills activities were carried out. Participants making up each class group attended the motor sessions at their regular time, together with their teacher, as usual. Before beginning each recreational motor activity, the teacher read the children the fantasy-based story corresponding to each activity. Visual instructions and a demonstration of each motor skill required were presented, maintaining the regular work method for the children and complying with the pedagogical guidelines indicated in the literature (Hamilton and Liu, 2018). The participants knew about this working method, but not the tasks, which were new to the participants; i.e., it was the first time that the participants performed these tasks. The tasks were carried out in five motor sessions that were developed on alternate days (respecting, as already indicated, the school schedule of the children's motor sessions). The tasks performed in each motor session were the following: 1st session, Blind frog; 2nd session, Ball-catching dog and 20 min later, Leaping hare; 3th session, Jumping flea and 20 min later, Centipede wiping its feet; 4th session, Cunning fox; and 5th session, Flamethrower dragon. This distribution of the tasks was carried out taking into account the usual duration of the motor sessions. The execution of each participant in each recreational motor activity was recorded for its subsequent observation and analysis.

These recordings were imported to the Lince software and were coded using the observation instrument (available in the **Supplementary Material**). An expert observer in observational methodology, Early Childhood Education, and motor development coded all of the observation sessions (301 sessions). Two months later, they were once again coded to calculate intra-observer reliability. A second observer, also an expert in these areas, coded all of the observation sessions to calculate the inter-observer reliability. To do so, the coded data were converted into a matrix of codes.

Data Analysis

Data quality was calculated from a classic perspective that assessed the correlations arising in the categories of the observation instrument coded in each of the two recordings made by the first observer (intra-observer reliability), as well as the correlations between the categories coded in one recording of the first observer and those coded by the second observer (inter-observer reliability), based on the correlation coefficients of Pearson, Kendall's Tau-b, and Spearman. In addition, an index was sought out to relate to the association concept, using Cohen's Kappa.

To determine whether the variables of interest (delivery mode, feeding type during the first 4 months of life, sex, and age) influence motor skills, it was necessary to transform the observational data. For each participant, each category observed during the execution of each recreational motor activities was transformed into a score based on its degree of suitability for the execution of this activity, according to the literature on this area (Goodway et al., 2019; Haywood and Getchell, 2019). For each participant, the scores obtained in each activity were added. Thus, every participant obtained seven scores, each referring to one of the seven specific motor skills studied in this work: locomotor skills; static balance; dynamic balance; propulsive skills; receptive skills, visual-motor coordination, and visual-motor integration. Based on these scores, the following scores were also calculated: total balance score (total of the scores obtained on static balance and dynamic balance); total object control skills score (total of the scores on propulsive and receptive skills); total gross motor skills score (total of the scores on locomotor skills; static balance; dynamic balance; propulsive skills; and receptive skills); total fine motor skills score (total of the scores on visual-motor coordination and visual-motor integration); and total motor skills score (total of the scores on the 7 specific motor skills: locomotor skills; static balance; dynamic balance; propulsive skills; receptive skills, visual-motor coordination, and visual-motor integration). Therefore, each participant received a total of 12 scores.

To analyze whether there were differences in the motor skills based on delivery mode, the children's motor scores were grouped into two groups: those corresponding to children born via vaginal delivery and those of the children born via C-section.

To analyze whether there were differences in the motor skills based on feeding type during the first 4 months, the children's motor scores were grouped into two groups: one group made up of scores belonging to children who were exclusively breastfed and another group made up of scores for the rest of the children (those fed exclusively with formula + children receiving mixed-feeding), that is, those who received formula feeding to a greater or lesser extent. Given the sample size, it was impossible to create three groups based on the three types of feeding that were initially considered in the questionnaire. Therefore, and as with Tozzi et al. (2012), this classification was made based on two groups: exclusive breastfeeding and formula feeding.

To analyze whether there were differences in motor skills based on the participant's sex, their motor scores were grouped based on their sex, creating two groups: boys and girls.

To analyze whether there were an RAE on motor skills, the motor scores of the participants were grouped together into 2 groups based on the half of the year in which they were born -according to the grouping criteria used in past studies (Imbernón-Giménez et al., 2020; Martínez-Moreno et al., 2020)-: group 1 = children born during the last half of the year, that is from July 1 to December 31, who were the youngest participants. Their ages were between 63 and 68 months; group 2 = children born during the first half of the year, that is, from January 1 to June 30. These were the oldest participants. Their ages ranged from 69 to 74 months.

We calculated descriptive statistics in terms of group means (M) and standard deviations (SD). In all of the analyses of comparison of means, it was verified that the data followed a normal distribution through the Shapiro-Wilk test. In cases in which the data followed a normal distribution, a one-way ANOVA was used. In all other cases, for those not having a normal distribution, the Mann-Whitney U was used, although significant differences were never obtained with this test. All *p*-values lower than 0.05 (two-tailed) were considered statistically

TABLE 2 | Means (M) and Standard Deviations (SD) of motor skill scores based on delivery mode.

Motor skills	Vaginal delivery		C-section delivery	
	M	SD	M	SD
Locomotor skills	18.05	3.15	17.46	2.87
Static balance	12.15	1.89	13.07	1.38
Dynamic balance	64.36	16.01	56.46	15.81
Throwing*	24.00	3.69	20.69	4.13
Catching	38.94	4.45	32.76	13.23
Visual-motor coordination	43.47	14.35	35.15	21.05
Visual-motor integration	7.36	2.16	5.61	1.32
Total balance	76.52	15.97	69.53	14.94
Total object control*	62.94	5.46	53.46	12.45
Total gross motor skills*	157.52	15.10	140.46	1.79
Total fine motor skills	50.84	14.38	40.76	20.22
Total motor skills*	208.36	21.28	181.23	23.79

Motor skill scores in which significant differences were detected, with $p < 0.05$.

TABLE 3 | Means (M) and Standard Deviations (SD) of motor skills scores according to feeding type during the first 4 months of life.

Motor skills	Exclusively breastfeeding		Formula feeding	
	M	SD	M	SD
Locomotor skills	17.23	3.12	18.90	2.54
Static balance	12.61	1.77	12.36	1.74
Dynamic balance	63.04	15.40	57.54	17.71
Throwing*	23.76	3.65	20.54	4.39
Catching	39.00	4.67	31.54	13.83
Visual-motor coordination	41.00	16.12	38.36	20.72
Visual-motor integration*	7.33	1.98	5.36	1.50
Total balance	75.66	14.59	69.90	17.75
Total object control*	62.76	5.70	52.09	12.73
Total gross motor skills*	155.66	15.15	140.90	18.91
Total fine motor skills	48.33	16.13	43.72	6.07
Total motor skills*	204.00	23.66	184.48	25.94

Motor skill scores in which significant differences were detected, with $p < 0.05$.

significant. For each of the differences obtained, the effect size was calculated using Cohen's *d* (Cohen, 1988), applied to the comparison of the means between groups, establishing the cut-off points of 0.00–0.19 = negligible; 0.20–0.49 = small; 0.50–0.79 = medium; and as of 0.80 = high.

RESULTS

The intra-observer agreement revealed a Kappa value = 0.99; a Pearson's r value = 1.00; Kendall's Tau b = 0.99 and Spearman = 0.99. The inter-observer agreement had a Kappa value = 0.92; a Pearson's r value = 0.99, Kendall's Tau b = 0.96 and Spearman = 0.97. In relation to Kappa intra-observer agreement, for each of the criteria, we obtained: Trunk position = 0.91 and for the rest of the criteria used, Kappa value = 1. The inter-observer Kappa value obtained for each of the criteria was: Attemp = 0.98; Arm position = 0.93; Distance to the ground = 0.91; Leg position = 0.91; Part of the finger = 0.89; Centimeters = 0.88; Hand position = 0.73; Trunk position = 0.69; and Height of the catch = 0.68. For the rest of the criteria, Kappa value = 1.

Therefore, the intra and inter observer reliability was found to be excellent, as was the quality of our observational data.

Significant differences were obtained in some of the motor skills measured based on delivery mode, type of feeding during the first 4 months of life, sex, and age.

Regarding the mode of delivery, children born by vaginal delivery were always found to have higher scores than children born via C-section (**Table 2**), except in Static balance. These differences were significant in: throwing [$F_{(1,33)} = 4.56$; $p = 0.000$, $d = 0.63$]; total control of objects [$F_{(1,32)} = 9.57$; $p = 0.004$, $d = 0.97$]; total gross motor skills [$F_{(1,31)} = 8.99$; $p = 0.005$, $d = 0.95$]; and total motor skills [$F_{(1,31)} = 11.40$; $p = 0.002$, $d = 1.04$].

Regarding the type of feeding during the first 4 months of life (exclusively breastfeeding or formula-feeding), significant differences were found (with children who were exclusively breastfed obtaining the highest values) for the following: throwing [$F_{(1,32)} = 6.48$; $p = 0.016$, $d = 0.75$]; visual-motor integration [$F_{(1,34)} = 33.44$; $p = 0.005$, $d = 0.94$]; total control of objects [$F_{(1,31)} = 11.88$; $p = 0.002$, $d = 1.02$]; total gross motor skills [$F_{(1,30)} = 5.77$; $p = 0.023$, $d = 0.82$]; and total motor skills [$F_{(1,30)} = 4.52$; $p = 0.042$, $d = 0.74$] (**Table 3**).

TABLE 4 | Means (M) and Standard Deviations (SD) of motor skills scores according to sex.

Motor skills	Boys		Girls	
	M	SD	M	SD
Locomotor skills	17.00	3.48	18.05	2.41
Static balance*	11.30	1.60	13.52	1.41
Dynamic balance	63.84	15.22	57.70	17.06
Throwing*	22.34	4.14	21.64	4.30
Catching	39.15	4.39	36.47	7.96
Visual-motor coordination*	33.38	16.34	47.58	14.96
Visual-motor integration	7.00	2.30	6.05	2.07
Total balance	75.15	15.50	71.23	16.40
Total control of objects *	64.00	6.39	58.11	8.68
Total gross motor skills	156.15	16.76	147.41	18.40
Total fine motor skills*	40.38	16.55	53.64	15.04
Total motor skills	196.53	26.52	201.05	25.19

Motor skill scores in which significant differences were detected, with $p < 0.05$.

As for sex (**Table 4**), statistically significant differences were found (higher scores in boys) for throwing [$F_{(1,28)} = 4.16$; $p = 0.041$, $d = 0.74$] and total control of objects [$F_{(1,26)} = 5.73$; $p = 0.024$, $d = 0.63$]. Girls had statistically significant and higher scores on the following: static balance [$F_{(1,28)} = 17.71$; $p = 0.000$, $d = 1.2$]; visual-motor coordination [$F_{(1,30)} = 6.02$; $p = 0.020$, $d = 0.79$]; and total fine motor skills [$F_{(1,30)} = 5.06$; $p = 0.032$, $d = 0.72$].

TABLE 5 | Means (M) and Standard Deviations (SD) of motor skills scores according to age.

Motor skills	63–68 months		69–74 months	
	M	SD	M	SD
Locomotor skills	18.38	2.81	17.55	2.95
Static balance	12.80	1.69	12.16	1.72
Dynamic balance*	58.00	16.83	69.27	10.82
Throwing	23.00	4.95	22.61	4.44
Catching	36.38	9.93	38.00	7.23
Visual-motor coordination	38.23	17.92	40.72	17.02
Visual-motor integration*	6.00	1.61	7.38	2.30
Total balance*	70.80	16.51	81.44	10.56
Total control of objects	59.38	11.53	60.61	7.67
Total gross motor skills	148.57	19.22	159.61	14.73
Total fine motor skills	44.23	17.85	48.11	17.20
Total motor skills	192.80	26.21	207.72	23.92

**Motor skill scores in which significant differences were detected, with $p < 0.05$.*

Regarding age (**Table 5**), statistically significant differences were found for dynamic balance [$F_{(1,41)} = 5.08$; $p = 0.030$, $d = 0.66$]; visual-motor integration [$F_{(1,43)} = 4.78$; $p = 0.034$, $d = 0.63$]; and total balance [$F_{(1,41)} = 6.73$; $p = 0.013$, $d = 0.75$]. In all cases, the higher scores were obtained by the group made up of the older children (aged 69–74 months), that is, those born in the first half of the year. Therefore, there were an RAE on the indicated motor skills.

DISCUSSION

This study has examined whether there were influences of delivery mode, feeding type during the first 4 months of life, sex, and age (more precisely, RAE) on motor skills (considered globally and specifically) evaluated in 5- and 6-year-old preschoolers. The results obtained suggest that this is a complex topic given that the influence of each of these variables on the studied motor skills is specific. In other words, their influence varies depending on the specific motor skills to be considered and depending on whether or not it is an overall score. Therefore, given that some (but not all) of the examined motor skills are found to be influenced by delivery mode, type of feeding during the first 4 months of life, sex, or age, it may be determined that two of the initially proposed hypotheses were corroborated (H_3 and H_4), while the other two being only partially supported (H_1 and H_2). It is difficult to make direct comparisons of these results with those from the literature, and it should be carefully done given the heterogeneity of the samples from each study (different ages, distinct socioeconomic and cultural contexts, etc.), the different motor skills studied, and the distinct activities/tasks and instruments used.

H_1 affirmed that differences existed in the children's motor skills based on delivery mode. It was expected to find that children born via vaginal delivery would have higher motor skills than those born via cesarean section. The results indicate that not all of the motor skills revealed differences between the two types of children. Children born via vaginal deliveries displayed higher scores on: throwing, total object control, total gross motor skills, and total motor skills; there was a medium or large effect size in all of the cases. For the remaining motor skill scores, no significant differences were found. Therefore, only some gross motor skills, no fine motor skills, as well as total motor skills were found to be influenced by delivery mode. These results support the findings of past studies such as those by Rebelo et al. (2020), who also found that the influence of delivery mode on motor skills varied depending on the type of motor skill considered. Our results are coherent with those of these authors, as they suggest differences favoring children born by vaginal delivery for object control skills and total motor skills, and no difference for locomotor and balance skills. However, unlike the results found by these authors, we have not found an influence of delivery mode on visual-motor coordination, visual-motor integration, or total fine motor skills (all referring to fine motor skills). Similarly, our results vary from those found by Blazkova et al. (2020), who also found differences in visual-motor integration based on the children's delivery mode. Considering our results, and unlike those of other studies (Grace et al., 2017), it is not possible to absolutely declare that being born by C-section will result in poorer motor skills. However, it may be suggested that its influence appears to be specific to certain motor skills. The discrepancies arising between studies may be due not only to the previously mentioned variables (different sample characteristics, motor skills, tasks, and instruments used) but also to the classification of the delivery modes that was used in each study. Therefore, in our study, even using a classification that has been previously used in the literature, there was no differentiation made as to whether the vaginal delivery involved the use of instruments or not (for example, the use of forceps, vacuum, and spatulas), or whether the C-section was programmed or due to an emergency. Some authors have indicated that these aspects, not considered in our work, may have distinct effects on children's motor development (Tribe et al., 2018; Takács et al., 2020).

As for H_2 (referring to the existence of differences in the children's motor skills based on the type of feeding received during the first 4 months of life, it was expected to find that children that were exclusively breastfed during this period would have better motor skills than those fed with formula or via a mixed-feeding mode). The results indicate that only some of the motor skills presented differences based on feeding type (although the effect size was always medium or large). These skills are: throwing; visual-motor integration; total control of objects; total gross motor skills, and total motor skills, with the children that were exclusively breastfed obtaining the higher scores. For the rest of the motor skills analyzed, there were no statistically significant differences found. These results are distinct from those of Bellando et al. (2020) and Michels et al. (2017), who did not find any effect of feeding type on motor skills beyond the 3 first months of life. Our results are along the lines of those of Jardí et al. (2018) and Kádár et al. (2021) since we found that the influence of infant feeding type on motor skills continue for longer periods of time. Furthermore, like Dee et al. (2007), this influence is found for some gross and some fine motor skills. In our study, more gross motor skill scores (4) than fine ones (1) were influenced by feeding type, allowing us to conclude that gross motor skills appear to be more sensitive to the influences of feeding type than fine motor skills, unlike the findings of Leventakou et al. (2015).

Once again, these differences may be due to distinct factors. In addition to those mentioned above, the feeding time period that participants were asked about in the distinct studies should be considered. As explained above, in our study, parents were asked about the feeding type for the first 4 months of life, given that, in Spain, this is when maternal leave ends and mothers tend to go back to work, often deciding to no longer breastfeed (Jardí et al., 2018; Cabedo et al., 2019). Therefore, asking about the feeding type beyond these first 4 months of life would probably not have resulted in the creation of a group of children that were exclusively breastfed. Other studies on breastfeeding and infant feeding, carried out in other countries (not Spain), also used this time period as the turning point in infant feeding (Michels et al., 2017). However, other works have used a cut-off point of 6 months (Grace et al., 2017; Kádár et al., 2021). This temporal difference may contribute to the distinct results found among the different studies. Some works have also considered the frequency of feeding (how often a child was breastfed or how much milk drank each day) (Khan et al., 2019), an issue that may also lead to the variable results of the literature.

As for the influence of sex on the children's motor skills (H_3), as we hypothesized, the results indicate that boys outperformed girls on certain skills (throwing and total object control) while girls outperformed boys on other motor skills (static balance; visual-motor coordination and total fine motor skills). In all of the cases, the effect size was medium or large. Also in line with the hypothesis, for certain motor skills (the remaining motor skills studied), no significant differences were found between both sexes. Our results are coherent with those found by other authors who also failed to detect differences in locomotor skills (Bakhtiar, 2014; Foulkes et al., 2015; Barnett et al., 2016; Bolger et al., 2018, 2020), and who found better object control skills in boys (Foulkes et al., 2015; Barnett et al., 2016; Venetsanou and Kambas, 2016; Kokstejn et al., 2017; Bolger et al., 2018, 2020; Mecías-Calvo et al., 2021). It should be noted that other studies have obtained distinct results, defending the existence of differences in locomotor skills between genders, in favor of boys (Robinson, 2010), or girls (Bolger et al., 2018, 2020; Wang et al., 2020), or no differences in object control (LeGear et al., 2012; Bakhtiar, 2014). As for balance skills, our results have demonstrated a better static balance in girls, but no difference between both sexes in dynamic balance and total balance. The lack of a difference between both sexes in total balance is in line with the findings of other studies (Singh et al., 2015; Barnett et al., 2016) although it contradicts others that found higher scores in girls (Venetsanou and Kambas, 2016; Kokstejn et al., 2017; Mecías-Calvo et al., 2021). The remaining results referring to the balance skills (better static balance in girls and no differences in dynamic balance), cannot be compared with past works since the studies do not differentiate between both types of balance skills, offering an overall score on balance skills. Therefore, our work offers additional information to overcome this information deficiency in the literature regarding specific balance skills of preschoolers.

Our results also offer novel information on the influence of sex on specific preschool fine motor skills, given that there was a gap in the literature regarding this issue. Our results indicate higher scores for girls on visual-motor coordination and total fine motor skills and a lack of differences in visual-motor integration. Therefore, it may be concluded that sex appears to distinctively influence motor skills, when considered both globally and specifically. According to many authors, these differences between girls and boys are not necessarily due to their physical characteristics (since before puberty, they are quite similar) but rather, they may be caused by the distinct experiences of boys and girls participating in different activities. This may be related to gender stereotypes, often promoted by parents and teachers (Bolger et al., 2020; Matarma et al., 2020). Therefore, girls tend to be more likely to participate in cultural and artistic activities (painting, drawing, handicrafts, or playing an instrument, which are more related to fine motor skills) and are less likely to be involved in sporting activities (more associated with gross motor skills). When they participate in physical and sports activities, they tend to be those such as ballet (associated with balance) as opposed to ball sports such as soccer or tennis (related to object control) (Hernández Luengo et al., 2019; Bolger et al., 2020; Matarma et al., 2020). However, co-education and gender equality policies are becoming increasingly frequent in our country (Venegas et al., 2019), which may explain why, in our study, there was a larger number of motor skills in which no differences were found based on sex, as compared to those in which differences did indeed exist.

H_4 refers to the RAE on preschool motor skills. We hypothesized that children born during the first half of the year would outperform those born during the second half of the same year on certain motor skills. Our results corroborate this hypothesis. Children born during the first half of the year, that is, the older children, displayed better visual-motor integration, dynamic balance, and total balance, with a medium to large effect size in all of the cases. No differences were found in the remaining motor skills examined. These results support some of the results found in the literature but they contradict others. While some other authors also found an RAE on balance (Mecías-Calvo et al., 2021) and on visual-motor integration (Imbernón-Giménez et al., 2020), other studies have not confirmed the existence of differences in balance (Imbernón-Giménez et al., 2020; Navarro-Patón et al., 2021). In our study, as in other works, no differences were found in total object control (Imamoglu and Ziyagil, 2017; Mecías-Calvo et al., 2021) or total motor skills (Navarro-Patón et al., 2021). Other works contrast with these results (the existence of differences in object control: Imbernón-Giménez et al., 2020; Navarro-Patón et al., 2021; and in total motor skills: Mecías-Calvo et al., 2021). Our study also failed to find an RAE on visual-motor coordination, unlike other studies (Mecías-Calvo et al., 2021; Navarro-Patón et al., 2021). It also did not find an RAE on locomotor skills. As for the latter, Imamoglu and Ziyagil (2017) found differences in some of these, but not in others, suggesting a great specificity of the RAE on motor skills, since even within one type of motor skills, such as locomotor, depending on the specific task or activity being analyzed, the results may vary. Therefore, as mentioned above, the distinct tasks used to assess the motor skills in the diverse studies make the direct comparison of results quite difficult (De Niet et al., 2021) and may contribute to the variety of results in the literature. We are unaware of studies that have analyzed the RAE on the remaining specific motor skills considered in our study: throwing, catching, static balance, and dynamic balance, aspects in which, except for the latter, we have not detected an RAE.

To conclude, the distinct motor skills analyzed reveal distinct degrees of sensitivity to the influence of delivery mode, infant feeding type, sex, and RAE. Vaginal delivery, having been exclusively breastfed for the first 4 months of life, and being older than one's peers (as opposed to being born via C-section, having been formula-fed, and being younger than one's classmates) are characteristics that appear to favor certain motor skills. Although not all of the motor skills are positively influenced by these aspects, no motor skills are negatively influenced by them. Sex influences some (but not all) motor skills, with boys outperforming girls for some skills, and the opposite being found for others.

The specificity of the results obtained suggests the need to design individualized interventions aiming at improving the motor skills which may be at risk for each child, based on their present (such as sex and age) and past (such as delivery mode and feeding type) characteristics. According to other authors, this series of results allows us to conclude that certain biological events (such as sex and age), and some experiences in very early life (such as delivery mode and type of feeding during the first 4 months), are especially influential on preschool motor skills and that the influences of some very early experiences on human development may be evident even years later (Nelson and Gabard-Durnam, 2020).

Although these results should be carefully considered due to the limitations of this study (see below), they may be quite relevant, given is the current lack of knowledge on preschool motor skills (Imbernón et al., 2021). This study attempts to fill this gap, providing information on the influence of certain factors on these skills, an essential aspect to design effective interventions that respond to the distinct needs of children. It should be noted that a highlight of our study is the analysis of the influence of four factors on these motor skills. In the majority of studies of this type, only one factor is considered (Barnett et al., 2016). Therefore, our study offers information that may be of great interest as it permits a deeper understanding of preschool motor skills. It is especially relevant and useful for teachers, other professionals, and researchers working with children in healthcare, educational, social, or sporting environments. Our results should also be considered by policymakers, given that they suggest the need to implement public policy strategies aiming to improve children's motor skills and that would, thereby, promote a physically active and healthy lifestyle. This will be considered in greater detail below.

As for the contributions and implications of this study on daily teaching practices, we consider that the information about the recreational motor activities and the assessment process of motor skills, as well as the observation instrument offered, can be very useful. This is even more so if we consider that: (1) Education Science Ministry of Spanish Government (2007) and other international institutions (Early Head Start National Resource Center, 2013) indicate that preschooler development and learning must be assessed using direct and systematic observation; and (2) many early childhood teachers recognize their lacking of knowledge, skills, and resources in the motor assessment field (Cueto et al., 2017). Therefore, we believe that the detailed and extensive assessment process of preschool motor skills conducted via systematic observation is another strong point of this work. This suggests that the assessment of motor skills was: (1) objective –not subjective as some teachers had admitted to being (Cueto et al., 2017)– and was not based on third party information, as it often occurs in studies (Khalaf et al., 2015; Takács et al., 2020), despite the limitations that this may imply (Blanco-Villaseñor and Escolano-Pérez, 2017); (2) carried out in the child's natural setting, such as at school, capturing the spontaneous motor execution by the children during recreational activities that are significant and of interest to them. This assessment is characterized by a high ecological validity (Blanco-Villaseñor and Escolano-Pérez, 2017), and allows us to overcome the ecological validity issues present in other studies on motor skill assessment (Tamplain et al., 2020); and (3) carried out using an instrument created based on the objective and context of the study. In other words, not using an instrument created from a clinical perspective, like the majority of the tools intended for the assessment of children's motor skills and which, despite their limitations, are often used in studies carried out in scholastic contexts (Lindsay et al., 2018; Klingberg et al., 2019; Morley et al., 2019). It should be noted that, despite the previously mentioned relevance of Early Childhood Education for the appropriate development and learning of children's motor skills, the literature highlights a lack of instruments available to assess said skills in the educational environment (Klingberg et al., 2019; Morley et al., 2019). Our study, and specifically the observation instrument offered, which is also free of charge, contributes to eliminating this gap. This instrument also overcomes the limitations of the instruments for motor skill assessment developed from a clinical perspective, which are of extended use without considering the context in which the assessment is performed [such as, the Motor Assessment Battery for Children-2 (MABC-2), the Motor-Proficiency-Test (MOT4-6), or the Test for Gross Motor Development-2 (TGMD-2)]: (1) These instruments require specific materials, unavailable in the school setting (Platvoet et al., 2018); (2) In these instruments, aimed at the assessment of children with risks or difficulties, the spectrum of levels of the motor skills assessed tends to be limited. Consequently, they do not allow for the determination of the large variability of skills that may be demonstrated by children with more typical development, or even the levels of motor skills that may be demonstrated by children with more advanced or highly stimulated development (Klingberg et al., 2019; Morley et al., 2019). The observation instrument used in this study overcomes these limitations since: (1) it does not have equipment requirements; (2) it permits the assessment of a broad spectrum of motor skill levels (from low to high performance), which are also considered at both a global and specific level. This is noteworthy since many motor skill assessment instruments only permit the evaluation of specific motor skills, but not all the skills that have been identified on a theoretical level. Thus, many motor skill assessment instruments reveal incoherencies between the theoretical and practical aspects. Although at a theoretical level this classification of gross and fine motor skills is widely accepted, along with the differentiation of various specific motor skills within each category, most assessment instruments do not reflect this structure, being restrictive and insufficient to assess the large set of abilities making up the motor skills (De Niet et al., 2021). Furthermore, this instrument, according to the recommendations of the most recent literature (Palmer et al., 2021), considers process-oriented motor skills assessment (how a movement is performed) and product-oriented assessment (the outcome of a movement). To date, product-based measures are the most common (Chang et al., 2020), with very few studies using both product- and process-based assessments to measure preschool motor skills (Szeszulski et al., 2021). Our study has addressed this gap. Despite considering both approaches, the process-approach is more important in our instrument, since this approach provides more useful information so that teachers can provide instructional skill-specific feedback to the children on their performance, a necessary element for educational practices aimed at the development of motor skills to be more effective (Bolger et al., 2020).

Ultimately, all of the characteristics that define our instrument make it useful and appropriate so that teachers may perform an objective, thorough, and profound assessment of the preschoolers' specific gross and fine motor skills. Based on this information, educational practices responding to the needs of each child may be designed.

All this issues can be also interesting to researchers given comprehensive assessment of children's motor skills is a significant concern in the contemporary child motor research field (Chang et al., 2020).

Our results suggest the need to develop public health, social and educational policies that promote infant motor skills. Therefore, in clinical practice, it is necessary to raise awareness so that obstetricians adopt the World Health Organization (2018) recommendations to reduce unnecessary cesarean sections and to develop high-quality antenatal education programs that offer information to parents on the effects of cesarean delivery, to avoid C-sections by demand. The same should occur with regard to feeding. In addition to informing parents as to the benefits of breastfeeding, a social environment should be created to favor it. Social policies should be implemented and facilities should be offered to promote this practice, such as increased maternity leave or the creation of breastfeeding rooms at work and social sites. Our results also suggest the need to reflect on the organizational policies of the school system, given the RAE detected on certain motor skills. Grouping students based on the half-year in which they were born, and not based on the entire year, would result in more similar levels of motor skills for children attending the same class, thus promoting a more beneficial educational experience for all.

Certain study limitations should be considered. The information referring to the mode of delivery and type of feeding during the first 4 months of life was collected retrospectively from the parents, therefore, some recall bias may have taken place. However, the retrospective collection of these type of data is a widely used resource in the literature to obtain perinatal data and to characterize child development histories (Khalaf et al., 2015; Bornstein et al., 2020), given the difficulty (and even impossibility) of obtaining data from medical or other professional records. Some authors indicate that the validity and reliability of parental recall in data collection are assured when the data are collected within 1–3 years after the relevant event took place (Grace et al., 2017). Other authors extend this time up to 6 years (Keenan et al., 2017), or even up to 20 years, after the event (Natland et al., 2012). According to these authors (Natland et al., 2012; Keenan et al., 2017), we can consider the information provided in this study by the parents to be valid and reliable.

Some authors have indicated that the validity and reliability of parental recall are affected by aspects such as the specificity of the considered event (Bornstein et al., 2020). To facilitate and increase the validity and reliability of the parental recall, as mentioned previously, in the study, parents were asked about general aspects of the delivery, specifically, whether it was vaginal or cesarean, without requesting more detailed information. In the future, it would be interesting to collect as much information as possible about other more specific issues of vaginal/cesarean delivery (for example, instrument use or not during the vaginal delivery), although this implies assuming a greater risk regarding potential parental recall bias.

A similar situation is found for feeding type. As previously mentioned, in our study, no information was collected on the frequency or duration of breastfeeding or the type of feeding used after the first 4 months, aspects which may also affect the children's motor skills (Khan et al., 2019). In the questionnaire administered to the parents, response options did not include the option of providing breast milk in a bottle, another possible feeding type. However, none of the parents indicated this in the "considerations" section of the questionnaire. These limitations may be interesting to consider in future studies.

It should also be considered that the study carried out is a punctual design. Therefore, in the future, it may be interesting to carry out a follow-up study to determine whether changes are found in the influence of the variables studied here regarding the distinct motor skills as the children grow up.

Another aspect to be considered is the small sample size and its non-random nature. It should be noted, however, that observational studies do not seek the representativeness of the sample, but rather its intensive study. There is a greater interest in obtaining a large quantity of detailed information on the natural behavior of a small number of participants than in the representativeness with respect to a larger population (Anguera, 2003). Nevertheless, in the future, it may be interesting to increase the number of participants in the study, which would also assist in the analysis of the influence on motor skills of each of the 3 infant feeding types considered in the questionnaire. However, it should be taken into account that, given the participants are minors, and the assessment of their motor skills is carry out with observational methodology, increasing the sample size may result in great complexity, effort, and dedication

(Salamon, 2017; Maddox, 2019). Therefore, before increasing the sample size, it may be interesting to conduct an analysis of generalizability and an optimization plan to assess costs/benefits (Blanco-Villaseñor and Escolano-Pérez, 2017).

Another limitation of this study is its failure to consider potential confounders. This is a common limitation in this type of studies given the complexity of motor skills and their development (Hernández Luengo et al., 2019). Therefore, in the future, it may be interesting to also consider the effect of potential interactions between the variables analyzed in this study on the motor skills, including other potential variables that have not been considered and which, apart from, or in addition to, the factors considered, may also affect the children's motor skills. These variables may refer to both the child (anthropometric measurements such as weight, body mass index; type of activities –sports and others– carried out in their free time; etc.) and the parents (mother's age at birth, parents' education, smoking during pregnancy, etc.), as well as the family context (quality of home stimulation received, presence of older siblings acting as models for developing motor skills, etc.) and the social context in which the child develops (such as proximity and ease of access to sporting installations). Numerous factors may influence childhood motor skills. Although it was not within the scope of this study to consider every variable in the analyses, they should be carefully considered when interpreting the results of our study and conducting further research on the area, given the complexity. In the future, interdisciplinary collaborations will be necessary to better understand how and why these and other potential factors have specific influences on motor skills.

CONCLUSION

Preschool motor skills are a complex topic. They show distinct degrees of sensitivity to different early environmental and biological variables such as delivery mode, type of feeding during the first 4 months of life, sex, and age. More exactly, vaginal delivery, having been exclusively breastfed for the first 4 months of life, and being older than one's peers (as opposed to being born via C-section, having been formula-fed, and being younger than one's classmates) favor certain (not all) preschool motor skills. No motor skills are negatively influenced by them. Sex influences some (but not all) motor skills, with boys outperforming girls for some skills, and girls outperforming boys for others.

Very important practical implications for teachers, other professionals, and researchers working with children in healthcare, educational, social, or sporting environments are derived from these results. Our results should also be considered by policymakers, given that they suggest the need to implement public health, social and educational strategies aiming to improve children's motor skills and that would, thereby, promote a physically active and healthy lifestyle.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Research Unit of the University of Zaragoza. The research was also approved by the school management team. In accordance with Organic Law 15/1999 of December on the Protection of Personal Data (1999, Official State Gazette no. 298, of December 14), all parents of the participants signed the informed consent authorizing their children's participation in the study and the recording of the children. Furthermore, and following the guidelines of the aforementioned law, observers signed a confidentiality agreement. No special ethical approval was required for this research since the Spanish public education system and national regulations do not require such approval. Each participant received a small reward (two chocolates) in gratitude for their participation. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

EE-P was involved in conceptual and methodological structure, literature review, data collection, systematic observation, manuscript drafting, and discussion. CS-L was involved in methodological structure and data analysis. MH-N was involved in data collection and systematic observation. All of the authors contributed to revising the manuscript and provided final approval of the version to be published.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.725832/full#supplementary-material

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Difference in Personality Traits and Symptom Intensity According to the Trigger-Based Classification of Throwing Yips in Baseball Players

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The triggers of initial onset of yips symptoms can be broadly divided into psychological and non-psychological factors; however, a trigger-based classification of yips has not been established. This study aims to obtain insight into the prevention of yips by clarifying whether there are differences in symptoms and personality traits according to a trigger-based classification of yips in baseball players. A total of 107 college baseball players responded to a questionnaire assessing the presence or absence of yips and its symptoms. They were classified into the psychologically triggered yips group, the non-psychologically triggered yips group, and the non-yips group based on the presence or absence of yips and the triggers of its initial onset. Additionally, we compared whether personality traits examined by the NEO Five-Factor Inventory differed across these three groups. The psychologically triggered yips group had significantly higher agreeableness scores compared with the non-yips group, whereas the non-psychologically triggered yips group had significantly higher neuroticism scores compared with the psychologically triggered yips group. In the non-psychologically triggered yips group, there was a significantly higher frequency of throwing errors than in the psychologically triggered yips group, with a tendency to develop yips symptoms gradually. Since the trigger-based classification of yips is closely related to the strength of the yips symptoms and the players' personality traits, the results of this study contribute to a better understanding of the symptoms of yips and establishment of the prevention of yips. Large prospective studies are necessary to determine the causal relationship between a trigger-based classification of yips and the personality traits and symptoms of athletes with yips.

Keywords: baseball yips, big five personality traits, neuroticism, agreeableness, classification

INTRODUCTION

The "yips" phenomenon is a psycho-neuromuscular disorder characterized by involuntary movements that disrupt the execution of automatic fine motor behavior (Smith et al., 2000; Bawden and Maynard, 2001; Clarke et al., 2015). Yips have been reported to occur in athletes of various sports including golf (McDaniel et al., 1989; Smith et al., 2000; Adler et al., 2005, 2011, 2018; Stinear et al., 2006; Dhungana and Jankovic, 2013; Klämpfl et al., 2013a,b; Ioannou et al., 2018), cricket (Bawden and Maynard, 2001; Roberts et al., 2013), archery (Clarke et al., 2019), baseball (Jones et al., 2017; Smith et al., 2017; Nakane et al., 2018; Aoyama et al., 2021), and darts (Roberts et al., 2013). According to a systematic review by Clarke et al. (2015), 28–54% of low handicap golfers have experienced yips. Smith et al. (2003) proposed classifying yips-affected players into two categories based on their symptoms: Players with physical symptoms such as "jerking" or "freezing" were classified as focal dystonia (type I), whereas players with psychological symptoms such as "anxiety" were classified as choking (Type II). This symptom-based classification is very beneficial when choosing a treatment for yips. For example, in Type I yips, botulinum toxin injection and oral medication are recommended, whereas psychological intervention is proposed as a treatment for Type II yips (Stinear et al., 2006; Adler et al., 2011; Ioannou et al., 2018). Conversely, when aiming to prevent yips, the causes, i.e., the episodes that trigger initial onset of yips, must be evaluated in addition to the symptoms themselves. A previous study indicated that 75% of yips-affected golfers began to exhibit the symptoms during a tournament (McDaniel et al., 1989). Therefore, psychological factors such as extreme pressure or anxiety might strongly influence the initial onset of yips. However, psychological factors are not the only triggers of yips. McDaniel et al. (1989) reported that non-psychological factors such as workload may be involved in the development of yips. Additionally, in focal dystonia patients, non-psychological factors such as workload, changes in technique, and prolonged pain have been reported to be involved in symptom onset (Altenmüller and Jabusch, 2009, 2010). As described above, yips triggers can be broadly divided into psychological and non-psychological factors, but yips have not yet been classified according to their triggers. This type of classification could help develop preventive methods for each type of yips trigger. Therefore, the primary purpose of this study was to establish a classification of yips based on the episode that triggered the first appearance of yips symptoms.

Previous studies have shown that task-specific dystonia, which is a subtype of yips, is related to individual personality. Enders et al. (2011) investigated the big five personality traits in focal dystonia patients using the NEO Five-Factor Inventory (NEO-FFI), which consists of 60 items (Costa and McCare, 1992). They revealed that patients with musician's dystonia have significantly higher neuroticism scores, which is an indicator of emotional instability and includes a tendency to experience negative emotions and vulnerability to stress, than non-musicians or healthy musicians. Therefore, personality traits might be related to yips, which is thought to have a common pathophysiology with task-specific dystonia. Only one study has investigated the relationship between yips and the big five personality traits (Clarke et al., 2019). They did not identify a significant difference in neuroticism scores determined with the Big Five Inventory-10 (BFI-10) between a yips group and non-yips group. However, the BFI-10 only includes two items for each factor. Therefore, although the BFI-10 is suitable for quick and easy investigations (Rammstedt and John, 2007), its reliability is somewhat questionable (Clarke et al., 2019). Furthermore, the relationship between trigger-based classification of yips and big five personality traits has not been clarified. In this context, the secondary purpose of the current study was to investigate whether the big five personality traits differed according to trigger-based classification of yips using NEO-FFI, which is a reliable index consisting of 12 items per dimension (Costa and McCare, 1992). We hypothesized that the personality traits of athletes classified by their triggers of yips would differ.

Symptoms of yips in golfers are more pronounced during short putts of ∼1–4 feet (Smith et al., 2000). In our preliminary report (Aoyama et al., 2021), which investigated throwing yips in baseball players, symptoms appeared to be stronger when throwing at a short distance of ≤20 m. Such task-specific symptoms are found not only in athletes with yips but also in patients with focal dystonia (Altenmüller and Jabusch, 2009, 2010). Furthermore, symptoms of yips fluctuate with psychological state. McDaniel et al. (1989) reported that yips symptoms increase in high-pressure situations, such as tournaments, compared to low-pressure situations such as practice. However, it is unclear whether such context-dependent changes in the symptom intensity of yips, i.e., changes in symptoms due to throwing distance and psychological pressure, differ depending on the triggers of the yips. Therefore, the tertiary purpose of this study was to clarify whether there are differences in the effects of throwing distance and psychological pressure on throwing performance according to trigger-based classification of yips.

The overall aim of the present study was to obtain insights into the mechanisms and prevention of yips by clarifying personality traits and characteristics of the symptoms based on the new classification of yips in baseball athletes.

METHODS

Participants

A total of 107 college baseball players from the First Division of the Tokyo Metropolitan Area Collegiate Baseball League participated in this study. The participants had an average (SD) age of 20.3 (1.3) years and an average of 12.5 (2.1) years of baseball experience. Based on the effect size obtained from a previous study using the NEO-FFI, the sample size was estimated by performing a power analysis using G∗Power with a power of 0.8 and an alpha of 0.05 (Clarke et al., 2019). This study was performed in accordance with the recommendations of the Declaration of Helsinki established by the World Medical Association. The protocol was approved by the local ethics committee of the Ibaraki Prefectural University of Health Sciences (Approved number: 876), and informed consent for participation in this study was obtained from all participants.

Questionnaires

An anonymous self-administered questionnaire was distributed to the participants in August 2019. After completing this questionnaire, the participants submitted it to a researcher who was not affiliated with the players. The questionnaire content was the same as that used in our previous study (Aoyama et al., 2021). The questionnaire was originally developed based on previous reports in yips-affected golfers (McDaniel et al., 1989; Smith et al., 2000) and consultation with the authors, including coaches and a physical therapist who have experience dealing with yips-affected baseball players, a neuroscience researcher (physical therapist) who has physical therapy experience in focal dystonia, and a sports biomechanics researcher who specializes in baseball. The survey data included age, baseball experience, throwing arm, and the presence or absence of yips symptoms; these data were collected from all participants. We classified the players as having yips if they answered "Yes" to a question about the subjective experience of the yips symptoms (Have you ever suddenly or gradually been unable to control the ball as you would like and continued to make throwing errors that your partner would not be able to catch?) and whose symptoms persisted for at least 1 month (Aoyama et al., 2021). We excluded three participants from this study who had a subjective experience of yips symptoms that lasted <1 month. Players who had experienced yips symptoms answered whether there was an episode that triggered initial onset of symptoms. If there was a triggering episode, they selected the most applicable trigger from the following candidates: "pain," "experience of throwing errors," "anxiety about throwing," "reprimand from others," and "change in throwing mechanics." If none of these opinions were applicable, the players described a specific trigger. With respect to symptom progression, the players answered whether the discreet symptoms became gradually more intense (gradual onset) or whether clear symptoms suddenly occurred (acute onset). Additionally, the duration of yips, age at initial onset, and whether symptoms were still present were collected. We also investigated whether the severity of yips symptoms, i.e., the frequency of throwing errors, varied by throwing distance and trigger-based classification of yips. The throwing distance was classified into five categories: <10, 10–20, 20 m to between base distance, between-base distance to 50, and >50 m. Players who had experienced yips selected the frequency of throwing errors at each throwing distance at the time when their symptoms were worst based on the following five-point ordinal scale: 0 = never (no symptoms), 1 = seldom (1–2 out of 10 throws), 3 = occasionally (3–5 out of 10 throws), 4 = frequently (6–8 out of 10 throws), and 5 = almost always (≥9 out of 10 throws).

The big five personality traits were assessed with the NEO-FFI. The following five dimensions were assessed: interpersonal interactions (extraversion); the tendency to seek out new experiences (openness); emotional instability, e.g., anxiety, depression, and self-consciousness (neuroticism); goal-directed behavior and organizations (conscientiousness); and social harmony and concern for cooperation (agreeableness) (Costa and McCare, 1992). The NEO-FFI consists of 12 items per dimension, for a total of 60 items.

Analysis

We divided the participants into four groups based on their episodes that triggered the initial onset of yips symptoms: psychologically triggered yips group, non-psychologically triggered yips group, pain-triggered yips group, and non-yips group. Players were classified into psychologically triggered yips groups when episodes strongly associated with psychological factors such as "experience of throwing error," "anxiety about throwing," and "reprimands from others" triggered initial onset of yips. Players who were triggered by a change in throwing mechanics and who had no specific triggers for initial onset of yips, i.e., psychological factors did not trigger the initial onset of yips symptoms, were classified into the non-psychologically triggered yips group. Players who developed yips due to pain were not included in the statistical analysis because they could not be classified into either the psychological or non-psychological yips groups, and their numbers were small. All statistical analyses were performed using SPSS version 26 statistical software (IBM, Armonk, NY, USA). The level of statistical significance was $p < 0.05$. We performed the Shapiro-Wilk test to examine the null hypothesis stating that the obtained data were normally distributed. Furthermore, Leven's tests were performed to examine the equality of variance. When assumptions of normality or equality of variances were not met, non-parametric tests were used for the statistical analysis. We used generalized linear mixed models (GLMM) to examine the effect of trigger-based classification of yips and throwing distance on the frequency of throwing errors, assuming a multinomial distribution of the dependent variable with a cumulative logit link function. Fixed effects included classification of yips and throwing distance, and the random effects included participants in the model. Sequential Bonferroni correction was used in *post hoc* comparisons. A Fisher-Freeman-Halton test was conducted to examine whether worsening of symptoms in psychologically stressful situations, such as games, differed between two yips groups. The five subscores of NEO-FFI were analyzed using multivariate analysis of variance (MANOVA) with one intersubject factor "group" (psychologically triggered yips group, non-psychologically triggered yip group, and non-yips group). If an overall significant effect was obtained by MANOVA, a separate ANOVA was conducted. Tukey's *post hoc* tests were used for multiple comparisons. The effect size (partial $\eta 2$) was also calculated.

RESULTS

Participants were classified into the psychologically triggered yips group ($n = 19$), the non-psychologically triggered yips group ($n = 25$), the pain-triggered yips group ($n = 5$), and the non-yips group ($n = 55$) based on the trigger of the initial onset of yips. The triggers of the psychologically triggered yips group included "experience of throwing error" ($n = 11$), "anxiety about throwing” ($n = 5$), “reprimand from others” ($n = 2$), and “fear-related throwing experience (the experience of being hit by a batted ball after throwing)” ($n = 1$). The non-psychologically triggered yips group consisted of 3 players triggered by a “change in throwing mechanics” and 22 players with no specific triggers.

The participants’ characteristics are shown in **Table 1**. There were no significant differences in age [$H(2) = 1.193$, $p = 0.551$] and baseball experience [$H(2) = 0.106$, $p = 0.948$] among the psychologically triggered yips, non-psychologically triggered yips, and non-yips groups. The Fisher-Freeman-Halton test revealed no statistically significant difference in throwing arm among these three groups ($p = 0.776$). The Mann-Whitney U test showed that there were no significant differences in age at initial onset ($z = 0.808$, $p = 0.419$) and duration of yips ($z = 0.444$, $p = 0.657$) between the psychologically triggered yips and non-psychologically triggered yips groups. There was no significant difference between the two yips groups regarding whether yips symptoms were still present [$\chi^2_{(1)} = 2.087$, $p = 0.149$]. In the psychologically triggered yips group, nine players displayed acute onset of symptoms while 10 players displayed a gradual onset of symptoms. Conversely, in the non-psychologically triggered yips group, 80% (20 out of 25 players) displayed a gradual onset. Although the p value did not reach statistical significance, the Chi-square test showed that the development of symptoms tended to differ between the psychologically triggered yips group and the non-psychologically triggered yips group [$\chi^2_{(1)} = 3.727$, $p = 0.054$].

The relationship between the frequency of throwing errors and throwing distance in both yips groups is shown in **Table 2**. The GLMM showed that corrected model was statistically significant [$F_{(3, 207)} = 7.294$, $p < 0.001$], and the interaction between the yips classification and throwing distance was not significant [$F_{(4, 207)} = 0.595$, $p = 0.667$] (**Table 3**). There was a significant fixed effect for the yips classification [$F_{(1, 207)} = 5.591$, $p = 0.019$]. The frequency of throwing error was significantly higher in the non-psychologically triggered yips group than in the psychologically triggered yips group. There was a significant fixed effect for the throwing distance [$F_{(4, 207)} = 14.734$, $p < 0.001$]. In addition, the multiple comparison test revealed that frequency of the throwing errors was significantly higher in short-distance throwing (<10 m, from 10 to 20 m and from 20 m to between base distance) compared with long distance (>50 m) throwing ($t = 5.047$, $p < 0.001$, $t = 5.217$, $p < 0.001$, $t = 2.855$, $p = 0.005$, respectively).

There was no significant difference between the two yips groups in the deterioration of throwing errors under stressful conditions such as games ($p = 0.463$, **Table 4**).

The results of MANOVA (**Table 5**) revealed that there was a significant difference in the subscores of NEO-FFI among three groups (Pillai’s trace = 0.193, $p = 0.037$). The separate ANOVA indicated that the agreeableness score and neuroticism score differed significantly among the three groups [agreeableness: $F_{(2, 96)} = 4.305$, $p = 0.016$; neuroticism: $F_{(2, 96)} = 3.420$, $p = 0.037$]. The *post hoc* test showed that the agreeableness score was significantly higher in the psychologically triggered yips group compared with the non-yips group. Conversely, the neuroticism score was significantly higher in the non-psychologically triggered yips group compared with the psychologically triggered yips group. The other three dimensions did not differ significantly among the three groups [extraversion: $F_{(2, 96)} = 0.081$, $p = 0.922$; openness: $F_{(2, 96)} = 0.872$, $p = 0.422$; conscientiousness: $F_{(2, 96)} = 2.225$, $p = 0.114$].

DISCUSSION

The present study focused on triggers of the initial onset of throwing yips in baseball players and divided the triggers into psychological and non-psychological factors. The most striking finding of the present study was the difference in personality traits between the psychologically and non-psychologically triggered yips groups; i.e., the former had significantly higher agreeableness scores compared with the non-yips group, while the latter showed significantly higher neuroticism scores compared with the psychologically triggered yips group. Furthermore, the non-psychologically triggered yips group showed a significantly higher frequency of throwing errors and a tendency toward gradual development of yips symptoms compared with the psychologically-triggered yips group. Thus, the trigger-based classification of yips could potentially contribute to the prevention of yips because it is closely related to the symptoms and personality traits of the players.

In 19 out of 49 (38.8%) yips-affected baseball players, psychological factors such as throwing errors, anxiety about throwing, and reprimand from others led to initial onset of yips. Conversely, 25 out of 49 (51.0%) yips-affected athletes developed yips due to non-psychological factors, including those who had no specific trigger for initial onset and those who developed yips after a change in throwing mechanics. A previous study reported that 75% of yips-affected golfers began to develop symptoms in a tournament in which psychological pressure was assumed to be high, suggesting that psychological factors account for a large proportion of the triggers of golfers’ yips (McDaniel et al., 1989). Therefore, involvement of psychological factors in the initial onset of throwing yips in baseball is likely to be lower than that of golfers’ yips. Although the reason for this difference is unclear from the current study, it may be a result of the different characteristics of the sports, such as required skills (i.e., open skills or closed skills) and regulations (individual or team sports). Regardless, since the initial onset of yips in each sport may differ depending on characteristics of the sport, it is important to investigate them to prevent yips.

10% of the yips-affected baseball players developed yips because of pain. Jankovic et al. reported that some patients develop focal dystonia triggered by pain (Jankovic and Van Der Linden, 1988). Therefore, although infrequent, pain may be one of the triggers for the initial onset of both yips and focal dystonia. Throwing yips that occur after pain can be triggered by both psychological factors, such as anxiety and fear of pain, and non-psychological factors, such as modifying throwing mechanics to avoid pain. Therefore, we could not classify these players into either the psychologically or non-psychologically triggered yips groups, and they were handled as an independent group.

TABLE 1 | Participant characteristics.

	Psychologically triggered yips group	Non-psychologically triggered yips group	Non-yips group	*p*
n	19	25	55	
Age	21 (20–21)	20 (20–21)	20 (19–21)	0.551
Baseball experience (Year)	13 (11–14)	12 (11–14)	12 (11–14)	0.948
Throwing arm (R/L)	17/2	23–2	47/8	0.776
Initial onset (Age)	17 (15–18.5)	17 (16–19)	–	0.419
Duration of yips (Month)	10 (1.5–37)	5.5 (2.25–11.5)	–	0.657
Symptoms at present (+/–)	11/8	9/16	–	0.149
Development of symptoms (Acute/Gradual)	9/10	5/20	–	0.054

The Kruskal-Wallis tests were used for Age and Baseball experience: Median (first quartile-third quartile).
Fisher-Freeman-Halton test was used for Throwing arm: n.
The Mann-Whitney U test were used for Initial onset and Duration of yips: Median (first quartile-third quartile).
The chi-square tests were used for Symptoms at present and Development of symptoms: n.

Although this group comprises a small proportion of yips-affected athletes, repeated painful throwing can trigger yips. Therefore, it is important to avoid throwing in painful conditions and to treat these conditions as soon as possible to prevent the development of yips.

Among the 25 players in the non-psychological triggered yips group, 3 had triggers to throwing yips owing to changes in throwing mechanics. This result indicated that a change in throwing mechanics is a trigger for the initial onset of yips. This finding is consistent with the features reported in patients with focal dystonia. Sadnicka et al. (2016) reported that in patients with musician's dystonia, a slight technical change may trigger the onset of symptoms. In addition, previous studies investigated the relationship between yips and "Reinvestment," which is defined as consciously attempting to control movements by utilizing explicit and rule-based knowledge during skill execution (Masters and Maxwell, 2008). Watanabe et al. (2021) speculate that reinvestment may be involved in yips, based on the fact that alpha-band event-related desynchronization during precision force control task in athletes with yips is different from control individuals. Therefore, results of the present study, in which throwing yips occurred in some players who were in the process of consciously changing their throwing mechanics, would be reasonable in light of previous studies.

We were unable to identify the trigger of the initial onset of yips in the majority of players belonging to the non-psychological triggered yips group. Considering the triggers proposed in focal dystonia (Altenmüller and Jabusch, 2010), it is possible that non-psychological factors such as genetic predisposition and changes in sensory input, which were not investigated in this study, might also be involved in the initial onset of yips.

The results of the personality traits indicate that the agreeableness score was significantly higher in the psychologically triggered yips group compared with the non-yips group. Conversely, there was no significant difference in agreeableness scores between the non-psychologically triggered yips and the non-yips groups. These results suggest that the relationship between agreeableness score and yips differed depending on the trigger of yips. Few reports have evaluated the relationship between yips and agreeableness. Recently, Clarke et al. (2015) investigated the relationship between yips and personality traits examined by the BFI-10, and reported that there was no significant difference in the agreeableness score between the presence and absence of yips. We believe there are two major reasons for this discrepancy between the previous and present studies. The first is the differences in the sports investigated in each study. Clarke et al. (2019) studied the yips in golfers and archers, which are individual sports, whereas we studied the throwing yips in baseball, which is a team sport. Prior works have shown that agreeableness, which is one of the big five personality traits, differs between team sport and individual sport athletes (Nia and Besharat, 2010). Furthermore, unlike individual sports such as golf or archery, throwing errors in baseball affect not only oneself but also the throwing partner and the victory or defeat of the team. Of the 19 players classified into the psychologically triggered yips group in this study, most (16 players) were aware that the symptoms of yips were initially triggered by throwing errors or anxiety about throwing. Moreover, previous studies reported a positive correlation between agreeableness scores and sense of guilt (Einstein and Lanning, 1998; Abe, 2004). These findings suggest that the higher the agreeableness score, the more likely the player is to feel guilty when the team loses or for causing trouble for other players due to their throwing errors. Therefore, we speculate that players with higher agreeableness scores are more likely to experience psychological conflicts due to the guilt and anxiety associated with throwing errors, which may lead to psychologically triggered yips.

The second is the difference in how yips were classified in each study. This study used a trigger-based classification of yips, whereas Clarke et al. (2015) classified golfers and archers into yips and choking groups based on their symptoms and showed no significant differences in agreeableness scores with or without each symptom. Therefore, the difference in the classification of yips may have led to the discrepancy between these results.

The agreeableness score of the psychologically triggered yips group was significantly higher than that of the non-yips group, but not significantly different from that of the non-psychologically triggered yips group. Therefore, it is possible that the non-psychologically triggered yips group also

TABLE 2 | Relationship between frequency of throwing errors and throwing distance.

	Psychologically triggered yips group	Non-psychologically triggered yips group
Under 10 m: Median (first–third quartile)	1 (0–2)	2 (1–3)
0 [Never: *n* (%)]	8 (42.1)	4 (16.0)
1 [Seldom: *n* (%)]	4 (21.1)	6 (24.0)
2 [Occasionally: *n* (%)]	3 (15.8)	8 (32.0)
3 [Frequently: *n* (%)]	4 (21.1)	5 (20.0)
4 [Almost always: *n* (%)]	0 (0)	2 (8.0)
From 10 to 20 m: Median (first–third quartile)	1 (0–2)	2 (1–3)
0 [Never: *n* (%)]	8 (42.1)	5 (20.0)
1 [Seldom: *n* (%)]	4 (21.1)	5 (20.0)
2 [Occasionally: *n* (%)]	3 (15.8)	6 (24.0)
3 [Frequently: *n* (%)]	3 (15.8)	7 (28.0)
4 [Almost always: *n* (%)]	1 (5.3)	2 (8.0)
From 20 m to between base distance: Median (first–third quartile)	0 (0–1)	1 (0–2.5)
0 [Never: *n* (%)]	12 (63.2)	11 (44.0)
1 [Seldom: *n* (%)]	3 (15.8)	5 (20.0)
2 [Occasionally: *n* (%)]	3 (15.8)	3 (12.0)
3 [Frequently: *n* (%)]	1 (5.3)	4 (16.0)
4 [Almost always: *n* (%)]	0 (0)	2 (8.0)
From between base distance to 50 m: Median (first–third quartile)	0 (0–1)	1 (0–2)
0 [Never: *n* (%)]	14 (73.7)	11 (44.0)
1 [Seldom: *n* (%)]	4 (21.1)	7 (28.0)
2 [Occasionally: *n* (%)]	1 (5.3)	5 (20.0)
3 [Frequently: *n* (%)]	0 (0)	1 (4.0)
4 [Almost always: *n* (%)]	0 (0)	1 (4.0)
Over 50 m: Median (first–third quartile)	0 (0–0)	0 (0–1)
0 [Never: *n* (%)]	18 (94.7)	15 (60.0)
1 [Seldom: *n* (%)]	0 (0)	7 (28.0)
2 [Occasionally: *n* (%)]	0 (0)	1 (4.0)
3 [Frequently: *n* (%)]	1 (5.3)	1 (4.0)
4 [Almost always: *n* (%)]	0 (0)	1 (4.0)

TABLE 3 | Statistical results of GLMM for the effect of yips classification and throwing distance on the frequency of the throwing errors.

Fixed effect	*F*-value	Degree of freedom	*p*
Yips classification	7.294	1, 207	0.019*
Throwing distance	14.737	4, 207	< 0.001*
Yips classification × Throwing distance	0.595	4, 207	0.667

The significant difference of the fixed effect was indicated with an asterisk ($p < 0.05$).

included some players with high agreeableness scores. Since the reason for this cannot be mentioned from the results of this study, further investigation with a larger sample size will be necessary.

The neuroticism score was significantly higher in the non-psychologically triggered yips group than in the psychologically triggered yips group. This result suggests that the neuroticism score clearly differs depending on the trigger for the initial onset of yips. Studies on the association between yips (or focal dystonia) and neuroticism have reported conflicting results. Enders et al. (2011) reported that the neuroticism score was significantly higher in patients with musician's dystonia than in healthy musicians or non-musicians. The perfectionism and anxiety scores, which are closely related to neuroticism, are also high in both yips and choking (Stinear et al., 2006; Roberts et al., 2013). However, Clarke et al. (2019) reported that there was no significant difference in neuroticism scores between yips (and choking)-affected athletes and non-affected athletes. Therefore, the results of the present study, in which the neuroticism score varies according to the triggers of the onset of yips, were not inconsistent with these previous studies. Future work is necessary to investigate the relationship between

TABLE 4 | Response to a question assessing whether the yips symptoms are more intense in games than in practice.

	Psychologically triggered yips group	Non-psychologically triggered yips group	p
Median (first–third quartile)	1 (0–2)	1 (0–2)	
0 [Disagree: *n* (%)]	7 (42.1)	6 (24.0)	
1 [Slightly agree: *n* (%)]	4 (15.8)	8 (32.0)	0.463
2 [Agree: *n* (%)]	5 (26.3)	4 (16.0)	
3 [Strongly agree: *n* (%)]	3 (15.8)	5 (20.0)	

p value indicating the results of Fisher-Freeman-Halton test.

TABLE 5 | Results of the NEO-FFI.

	a. Psychologically triggered yips group	b. Non-psychologically triggered yips group	c. Non-yips group	p	ηp^2
Neuroticism	22.5 (6.9)*b	27.9 (6.9)*a	25.3 (6.7)	0.037*	0.067
Extraversion	28.5 (6.6)	28.4 (5.5)	28.0 (6.9)	0.922	0.002
Openness	27.6 (4.0)	29.2 (5.3)	27.3 (6.9)	0.422	0.018
Agreeableness	33.2 (6.4)*c	30.1 (4.5)	28.6 (6.3)*a	0.016*	0.082
Conscientiousness	30.2 (6.0)	26.9 (4.6)	28.9 (5.4)	0.114	0.044

Mean (SD) score of each NEO-FFI sub-scale. The significant differences in the post hoc analysis are indicated with an asterisk (p < 0.05) and different letters (a; vs. Psychologically triggered yips group, b; vs. Non-psychologically triggered yips group, c; vs. Non-yips group).

classification based on the triggers of yips and indicators, including anxiety and perfectionism, which are closely related to neuroticism.

The significantly higher agreeableness score in the psychologically triggered yips group and the higher neuroticism score in the non-psychologically triggered yips group suggest that there may be different triggers for the initial onset of the yips depending on players' personality traits. As mentioned above, yips are classified into Type I and Type II according to their subjective symptoms, which contributes to their treatment selection. However, classification based on the trigger of yips has not been reported thus far. The results of this study, which show for the first time an association between the trigger-based classification of yips and personality traits, have important implications from a preventive perspective because of their potential relevance to the mechanism of development of yips. However, it remains controversial whether these personality traits in yips-affected players are preexistent or a psychoreactive phenomenon (Jabusch and Altenmuller, 2004; Enders et al., 2011). Since all studies that have investigated the relationships between yips (or focal dystonia) and personality traits, including the present study, are cross-sectional studies (Hughes and Mclellan, 1985; Enders et al., 2011; Amouzandeh et al., 2017; Clarke et al., 2019), no clear conclusions can be drawn on this argument. We support the view that the personality traits in yips players are preexistent phenomena rather than psychoreactive, as reported by Altenmüller and Jabusch (2009) and colleagues. This is because if the personality traits observed in players with yips are psychoreactive phenomena, similar personality traits should be obtained regardless of the trigger of the initial onset, whereas the personality traits of the two groups categorized based on the trigger-based classification used in the current study differed. In the future, large prospective studies are necessary to clarify the causality between personality traits and the initial onset of yips.

When assessing the relationship between yips classification and symptom progression, the non-psychologically triggered yips group tended to have a more gradual onset compared with the psychologically triggered yips group. This difference may exist because the psychologically triggered yips group is often triggered by a specific episode such as a throwing error and anxiety about throwing or reprimand from others, while the non-psychologically triggered yips group is often triggered by the absence of a clear episode. These findings support the possibility that psychologically triggered yips and non-psychologically triggered yips are caused by different mechanisms.

Using GLMM, we investigated whether trigger-based classification of yips and throwing distance were associated with symptom severity, i.e., frequency of throwing errors at the time when symptoms of yips were most severe. We found that the frequency of throwing errors was significantly higher for short-distance throwing (< between base distance) than for long-distance throwing (> 50 m). In yips-affected golfers, a previous study reported that the symptoms of yips are more likely to occur in short putts of ∼1–4 feet (McDaniel et al., 1989). These findings suggest that the distance to the target is one of the crucial factors affecting the severity of the symptoms of yips. Although the reason for the paradoxical symptoms of yips, in which symptoms are stronger when the distance to the target is short, is unknown, we speculate that excessive muscle contraction or co-contraction observed in yips-affected athletes (Stinear et al., 2006; Adler et al., 2011, 2018) may contribute to the failure of short-distance throwing or putting, which requires control by relatively weak muscle activity. The frequency of throwing errors was significantly higher in the non-psychologically triggered yips group than in the psychologically triggered yips group. These results suggest that the severity of the symptoms of the yips depends on the trigger for the initial onset of the yips. Because there is often no clear trigger for the initial onset of non-psychologically triggered yips, it is difficult to discuss the prevention of yips based on the present results. However, since excessive practice is thought to have an adverse effect on the onset and progression of task-specific dystonia (Byl et al., 1996; Byl, 2007), it is important to detect symptoms and rest during the early stage of symptoms to prevent symptom progression. Thus, the present finding that the typical symptoms of yips are associated with difficulties in short-distance throwing may be helpful in determining the presence or absence of yips and in considering ways to prevent symptom progression.

Prior work on the relationship between psychological situations and yips symptoms indicated that yips affected golfers were more likely to show yips symptoms under conditions of high psychological stress, such as tournaments (McDaniel et al., 1989; Smith et al., 2000). Therefore, we predicted that the psychologically triggered yips group was more likely to show symptoms, particularly in more stressful psychological situations such as games. However, there were no significant differences between the psychologically and non-psychologically triggered yips groups regarding whether symptoms worsened during games compared with practice. This result suggests that even in yips-affected baseball players triggered by non-psychological factors, psychological pressure such as games can aggravate symptoms. Smith et al. (2003) reported psychological anxiety to be a factor in exacerbating yips symptoms, regardless of the type of yips (choking or dystonia). Therefore, to improve yips symptoms, treatment such as cognitive behavioral therapy for relieving anxiety related to the nervous situation may be required regardless of the triggers or symptoms of yips.

One of the limitations of this study is that we used a trigger-based classification of yips, but it is not clear whether this classification is related to the symptom-based classification (Types I and II yips) (Smith et al., 2003). Symptom-based classification of yips has not been established in baseball. Previous studies in golfers have shown that the classification of yips by subjective symptoms is validated by physiological indicators using electromyography (Stinear et al., 2006; Adler et al., 2018). Therefore, we must establish a symptom-based classification of yips in baseball using both subjective and physiological indices to investigate its relationship with the trigger-based classification of yips. Second, the present study did not obtain standardized measures related to anxiety, fear, or perfectionism. We need to conduct cluster analysis by adding these measures to the NEO-FFI to establish a detailed classification of personality traits. Furthermore, longitudinal studies are required to clarify the causal relationship between classification and initial onset of yips symptoms.

In conclusion, we investigated whether the symptoms of yips and personality traits differed according to the trigger-based classification of yips. We obtained novel findings indicating that the psychologically triggered yips group showed significantly higher agreeableness scores compared with the non-yips group. Additionally, the non-psychologically triggered yips group showed significantly higher neuroticism scores and a higher frequency of throwing errors, particularly in long-distance throwing, compared with the psychologically triggered yips group. Since trigger-based classification of yips is closely related to yips symptom strength and the personality traits of players, the results of this study may contribute to a better understanding of symptoms of throwing yips and the establishment of prevention for yips. In the future, large prospective studies are necessary to investigate the causal relationship between personality traits and the trigger for the initial onset of yips.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Local ethics committee of the Ibaraki Prefectural University of Health Sciences. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TA, KA, HS, and TK designed the study. TA, KK, and TK collected the data. All authors contributed to data analysis, interpretation, and write the manuscript. All authors contributed to the article and approved the submitted version.

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Perceptions of Football Analysts Goal-Scoring Opportunity Predictions: A Qualitative Case Study

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This study aimed to understand the way tactical football analysts perceive the general match analysis issues and to analyze their tactical interpretation of the predictive models of conceded goal-scoring opportunities. Nine tactical analysts responded to the semi-structured interviews that included a general section on the match analysis and a specific one on the results of a study on goal-scoring opportunities conceded by a Spanish La Liga team. Following their transcription, the interviews were codified into categories by the two researchers using Atlas Ti® software. Subsequently, frequency count and co-occurrence analysis were performed based on the encodings. The content analysis reflected that analysts play a crucial role in the analysis of their own team and that of the opponent, the essential skills to exercise as a tactical analyst being "understanding of the game" and "clear observation methodology." Based on the case study of the conceded goal-scoring opportunities, the major causes and/or solutions attributed by analysts in some of the predictive models were the adaptability of the "style of play" itself according to the "opponent" and "pressure after losing."

Keywords: match analysis, coaches, qualitative research, style of play, tactics

INTRODUCTION

In recent years, there are great technological advances in the analysis of football performance (Sarmento et al., 2017). Despite this progress, still there is a gap between the scientific community and the knowledge that the technical bodies of professional clubs actually need to acquire (Carling et al., 2013). A reason for this gap could be the low amount of research that combines both quantitative and qualitative analyses (Sarmento et al., 2020). Though video analysis plays a key role for coaches to improve the performance of their own team and to analyze the opponents (Wright et al., 2012), professional football coaches still encounter problems that have yet to be addressed by research (Wright et al., 2014).

There is one suitable tool that brings data and scientific research closer to answering the tactical questions set out by the technical bodies: the "mixed methods" technique (Sarmento et al., 2013a). This methodology is defined by Johnson and Onwuegbuzie (2007) as a way of conducting research that combines quantitative and qualitative research elements. According to Onwuegbuzie (2012), it can provide added value by giving a more holistic overview of the collected data and by contextualizing the conclusions drawn from the quantitative analysis (Harper and McCunn, 2017). Therefore, the quantitative-qualitative combination is a useful way of identifying not only "what happens in a match," but also "why it happens," based on the interpretations made by the professionals of the sport in question (Halperin, 2018). Based on all the above, and because of the holistic nature that data triangulation brings to a study, *mixed methods* can be described as contributing more than the mere sum of qualitative plus quantitative approaches (Fetters and Freshwater, 2015).

The qualitative research method, such as interviews with the coaches and analysts, could help to develop practical applications of research in game analysis. Despite the extensive literature existing on the match analysis (Hughes, 2008; Carling et al., 2009), few studies have collected the opinions of coaches. The evidence that has been collected, for example, on the game observations of the coaches (Sarmento et al., 2013b), the role of performance analysis (Mackenzie and Cushion, 2013), and their opinions regarding detected game patterns (Sarmento et al., 2016) is still insufficient compared to a large number of quantitative football studies.

Qualitative case studies make it easier for the coaches to actually apply scientific findings. Indeed, the results are related to the real and specific technical-tactical contexts rather than being generalized (Ruddock et al., 2019). In this sense, the present qualitative study used as a reference, the results of a study on the Spanish La Liga team characterized by a high ball-possession profile. The study concluded by advancing a prediction of the conceded goal-scoring opportunities, based on the contextual, defensive, and offensive variables (Aguado-Méndez et al., 2020b). Therefore, the objectives of the present study were as followed:

- First, to understand how the specialists participating in the study perceived the game analysis with respect to their own team and the opponents.
- And second, to examine the tactical interpretation of the analysts of the quantitative data based on a study that focused on conceded goal-scoring opportunities.

MATERIALS AND METHODS

Design

The selected methodology was qualitative using the semi-structured interviews with open-ended responses (Smith and Caddick, 2012).

Participants

The participants were nine football analysts. Of the nine participants, seven were working for the professional teams (Liga Santander, Liga Smartbank), one was part of the Second Division B team of Spain (Segunda División B), and the other was part of the Third Division team (Tercera División) during the 2019–2020 season. They were all in possession of the senior title of football coach and had served as such throughout their career. The study protocol was approved and followed the guidelines stated by the Ethics Committee of the Research Center of Sport Sciences at University Pablo de Olavide, based at Seville (Spain) and conformed to the recommendations of the Declaration of Helsinki.

Instruments

A semi-structured interview comprising of a general section and a specific section was designed by three game analysis research experts (Bardin, 2008). Questions in the general section (**Table 1**) were based on the work of Sarmento et al. (2015). This part of the interview includes general game analysis questions that can be used both for the own team analysis and the opponents.

Questions in the specific section asked the analysts about the results of the study of Aguado-Méndez et al. (2020a). This latter work produced four predictive models of conceded goal-scoring opportunities based on the contextual, defensive, and offensive variables in a 2017/2018 Spanish league case study.

The results of four models were:

- Model 1: the probability of conceding goal-scoring opportunities after "own half losing" was four times greater if this took place between 0′-15′ and 46′-60′ than between 76′ and 90′.
- Model 2: the probability of conceding a goal-scoring opportunity after "own half losing" was almost three times greater if the opponent only gave 0 or 1 pass to finish the move than if it gave five or more passes take place.
- Model 3: the probability of conceding a goal-scoring opportunity in the second half was three times greater if the loss of the ball took place by a "steal" than by a "forced mistake."
- Model 4: the probability of a goal-scoring opportunity conceded being a goal was almost half as likely to result in a draw as in a win.

In the present research, the analysts were asked about the "causes" and "solutions" they would offer as analysts in each of the four models (**Table 2**).

Category System

A category system was first elaborated (González et al., 2020) following the steps established by Braun and Clarke (2006). To test it, three interviews were coded based on the predefined category system. Following this pilot coding, the system was configured based on five distinct parts (one for the general section with four questions, and four others with questions on the cause and solution of each model of the study that they were being asked about). After analyzing the interviews, the most frequent answers were established as categories. **Figure 1** shows the relationship between the questions of the specific section and its categories.

Data Collection

Interviews were conducted and recorded *via* videoconference with experts. Coaches previously received a video summary of the analysis data they were going to be asked about. Each interview lasted for approximately 45 min and recordings were made for the subsequent transcription and analysis in Atlas TI version 8.4.5. The analysts were given time to clarify their thoughts and rewrite their answers.

The authors confirm that the data supporting the findings of this study are available within the article and/or its **Supplementary Material**. This study has followed the Consolidated criteria for reporting qualitative research (COREQ) checklist.

TABLE 1 | Questions and categories in the general section of the interview.

Category: General game analysis

Questions	Categories	
1. Importance of analyzing matches	Importance of own team analysis	
	Fundamental	
2. Analyst features	Ability to synthesize	
	Understanding of the game	
	Clear observation methodology	
	Objectivity	
3. Most important aspects to analyse matches	Adapting to the coach	
	Phases of the opponent game	
	Opponent's strong and weak points	
4. Data provider information	Relevance	Distances
		Contextual factors: minute
		Goal-scoring opportunities
	Problems	Provider heterogeneity
		Overly long reports
	Future	Custom data
		Prediction/probability

Materials

The interviews were recorded *via* videoconference using the official Blackboard Collaborate Ultra platform of the University Pablo de Olavide, Seville, Spain after obtaining the consent from the participants. The NCH Express Scribe® professional software was used to transcribe the recorded interviews. Finally, Atlas.ti 8.4.5® software was used for the content analysis of the data obtained in the study.

Procedure and Analysis

First, the data were briefly analyzed by transcribing, reading, and noting the initial ideas, establishing a code map per question and category. The codes were then classified under possible themes. Third, a thematic map was constructed based on the coded data to visually analyze the themes and the relationships between them. Once all the content of the interviews was encoded, a frequency count, and a co-occurrence analysis technique of the categories were applied in order to determine the associations between the different categories and/or questions.

RESULTS

The first objective was to know the general perceptions of the analysts toward the game analysis of their own team and that of the opponent. To do this, categories were analyzed using the Atlas.ti version 8.4.5 software using the co-occurrences table based on the questions in **Table 1**.

Regarding the first question "what importance do you give to the analysis?," a total of seven of the nine analysts agreed to describe the analysis as a "Fundamental" process (**Figure 1**).

> *The analysis is our point of departure to know what we have and where we are. From this point onwards, we can plan, trainm and re-analyse whether the objectives have been achieved. It is thus essential (participant 4).*

Likewise, when asked about the essential characteristics of an analyst, the answer frequency (**Figure 1**) underscored "Clear observation methodology" and "Understanding of the game" as the most important attributions.

> *A good observational methodology is essential for analysts, it implies appropriate control over the data's quality, avoiding observation biases, understanding what is truly observable, validity, precision, objectivity and reliability (participant 4).*

The aspects that were considered to be most important when analyzing the opponent teams, the participants highlighted the fact of knowing "Phases of the opponent's game" and their "Strengths and weaknesses," and all this "Adapted to the coach's ideas."

> *The first thing is to know the game and one's own team, as well as what the coach wants from his team, to be able to show the game patterns and the opponent's strengths/weaknesses compared to what one's own team can offer (participant 5).*

With regard to the assessment of data provider information by the analysts, participants answered three questions: "relevance", "problems," and "future" (**Figure 2**).

In the case under study, analysts considered "Goal-scoring opportunities" to be the most relevant performance indicator among those offered by the data providers.

> *The most important thing is the way, quantity and quality of the goal-scoring opportunities generated by the team and what happens after. That is what I attach the most importance to when the match*

TABLE 2 | Questions and categories of the specific section of the interview based on the four predictive models of conceded goal-scoring opportunities.

Model 1: Minute and loss zone	
Questions	Categories
Cause	Concentration
	Minute—Loyalty to coach ideas
	Style of play
	Opponent
Solution	Concentration
	Style of play
	Pressure after losing
Model 2: Duration and loss zone	
Questions	Categories
Cause	Physical aspects
	Opponent players participating/counterattack speed
	Team positioning
	Pressure after loss
Solution	Style of play
	Pressure after losing
Model 3: Steal and minute	
Questions	Categories
Cause	Physical aspects
	Concentration
	Style of play
	Opponent
	Concentration
	Pressure after losing
Solution	Style of play
	Pressure after losing
Model 4: Match status	
Questions	Categories
Cause	Concentration
	Style of play
	Opponent
Solution	Style of play
	Opponent
	Scoreboard conditioned tasks

ends, because when you start to improve that aspect, you get closer to achieving results (participant 2).

Regarding the problems, the analysts agreed on the prominence of two issues: "Overly long reports" and "Data heterogeneity."

I am very critical of such long reports because despite the great quantity of data, it does not mean that it provides the information you need (participant 4).

Regarding "Heterogeneity among suppliers" the response of interviewee six was highly illustrative:

We should define the concept of goal opportunity more clearly for data providers. We encountered the problem that for a provider, a move was a clear goal opportunity: a high xG was attributed but not so much in the case of another, the value being lower. Therefore, greater uniformity is needed both for opportunities and in all performance indicators (participant 6).

Answers on the prospective "future" were organized in two dimensions. First, "custom data" adapting it to the characteristics of each team, second, "predict the opponent's behaviors according to the phase of the game."

A great breakthrough would be the adding of probabilities, to predict what can happen in certain situations. I think that means and percentages describe what has already happened and cannot be changed, but ideally, it should anticipate what can happen in certain situations so we can work on it (participant 6).

The second objective of this study was to "examine the analysts' tactical interpretation of a study's quantitative data on conceded goal-scoring opportunities." The questions posed to the analysts concerned the four predictive models about the conceded goal-scoring opportunities. Participants were asked about the "causes" and "solutions" in the case of each model (**Table 2**).

A first descriptive analysis (**Figure 3**) shows that the causes most frequently given in the four predictive models were "Concentration" (14) "Style of play," (8) and "Opponent" (8). Other causes that obtained a lower percentage were "Conditioning factors," "Team positioning," and "Opponents taking part/counterattacking speed." With regard to the "solutions" proposed by analysts in each predictive model, "Style of play" (19), "Pressure after losing" (8), and "Exercise with conditioner score" (6) obtained the highest response rates. The variables "Concentration" (2) and "Opponent" (1) were the lowest mentioned solutions.

Moreover, beyond a quantitative analysis, the co-occurrence analysis technique allowed the design of a network of relationships between "causes" and "solutions" in the four predictive models (**Figure 4**).

The "Style of play" category seems to be the most decisive for analysts as it is included in both the "causes" (in model 1, 3, and 4) and "solutions" (for all four models). A highly representative example is the response of interviewee four when asked about the solution in model 1. This model predicted four times greater chance of receiving a goal-scoring opportunity after losing in his own half at intervals 0′-15′ and 45′-60′ than in 75′-90′) (Aguado-Méndez et al., 2020a).

One form of intervention may be to change the system. In addition, I would do conditional tasks to provoke movements and situations to my advantage. We also modify these rules according to the exercise's outcome (participant 4).

Likewise, according to responses of analysts, the "opponent" category was considered an important cause. The interviewees placed this category as a "cause" for three models (1, 3, and 4), as well as the "solution" in model 4. In this model, it was predicted that it was two times more likely that the conceded opportunity would end in a goal with a favorable result rather

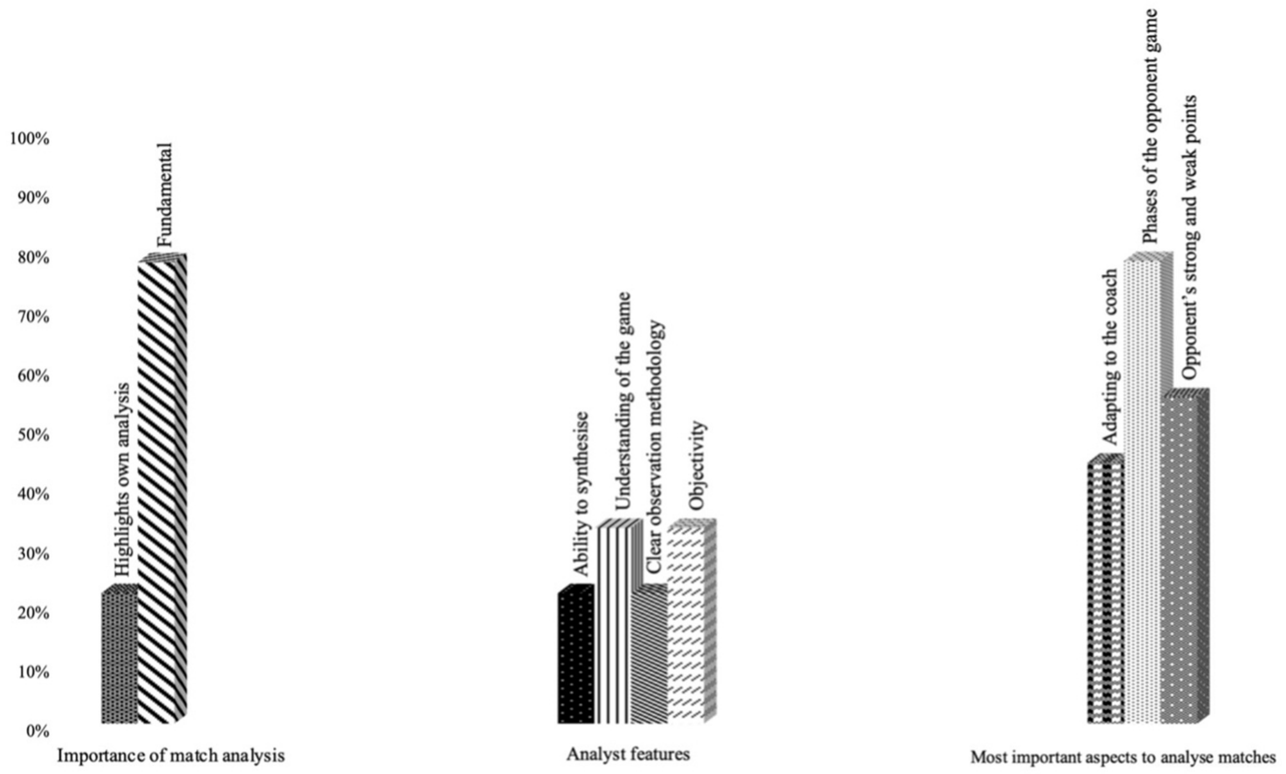

FIGURE 1 | Answer frequency of the categories of the first three questions for Objective 1.

than a tie. An example of how the "opponent" influences this model is exemplified by participants four and six.

Real Betis team, even when leading on the scoreboard, did not changes its idea of play very much, while the opponent was taking steps forward to achieve a tie, and that can lead to receiving more goal-scoring opportunities (participant 6).

On the other hand, the "pressure after losing" category was the "cause" in model 2, but above all, it stands out as a "solution," since it was proposed for this purpose in models 1, 2, and 3. An example of this solution was proposed by analysts two and nine in model 2. This model predicted a higher chance of receiving a goal-scoring opportunity when the ball was lost in own half and, at the same time, few players were involved in the move; therefore, its duration was reduced.

The team should work to achieve the necessary resources and get organized around the ball to rally as much as possible in the face of possible losses (participant 2).

In addition, another major category under which the psychological or emotional aspects could be organized was "concentration." It was cited by the analysts as "cause" for three models (1, 3, and 4) and as a "solution" in two models (1 and 3). The interviewees eight and three interpreted that concentration was a "cause" in model 3 of Aguado-Méndez et al. (2020a). This model predicted that the probability of receiving a goal-scoring opportunity by stealing a ball was two-times as high than by a bad pass due to pressure in the second half.

It may be due to over-relaxation during those minutes. Perhaps the fact of adopting a very horizontal style, pausing a lot when in possession of the ball also led to a lack of energy during the match (participant 8).

Finally, the "physical aspects" category was the "cause" of the opportunities conceded in two models (2 and 3). An example of why this factor was the origin in model 3 (it related form of loss and minute) was given by analyst four.

As fatigue sets in, players make worse decisions, and a typically bad decision they usually make is that the more tired they are, the more they keep the ball, the more they play 1 against one, and the lesser support they get from their teammates—because they are also tired and that is why it causes those losses... (participant 4).

DISCUSSION

The objectives of this study were two-fold: to gather the overall perceptions of the interviewed analysts on the game analysis of their own team and the opponent team, and to analyze the tactical interpretation of the results of a study on goal-scoring opportunities. Regarding the first objective, analysts answered general questions about the analysis of the game of

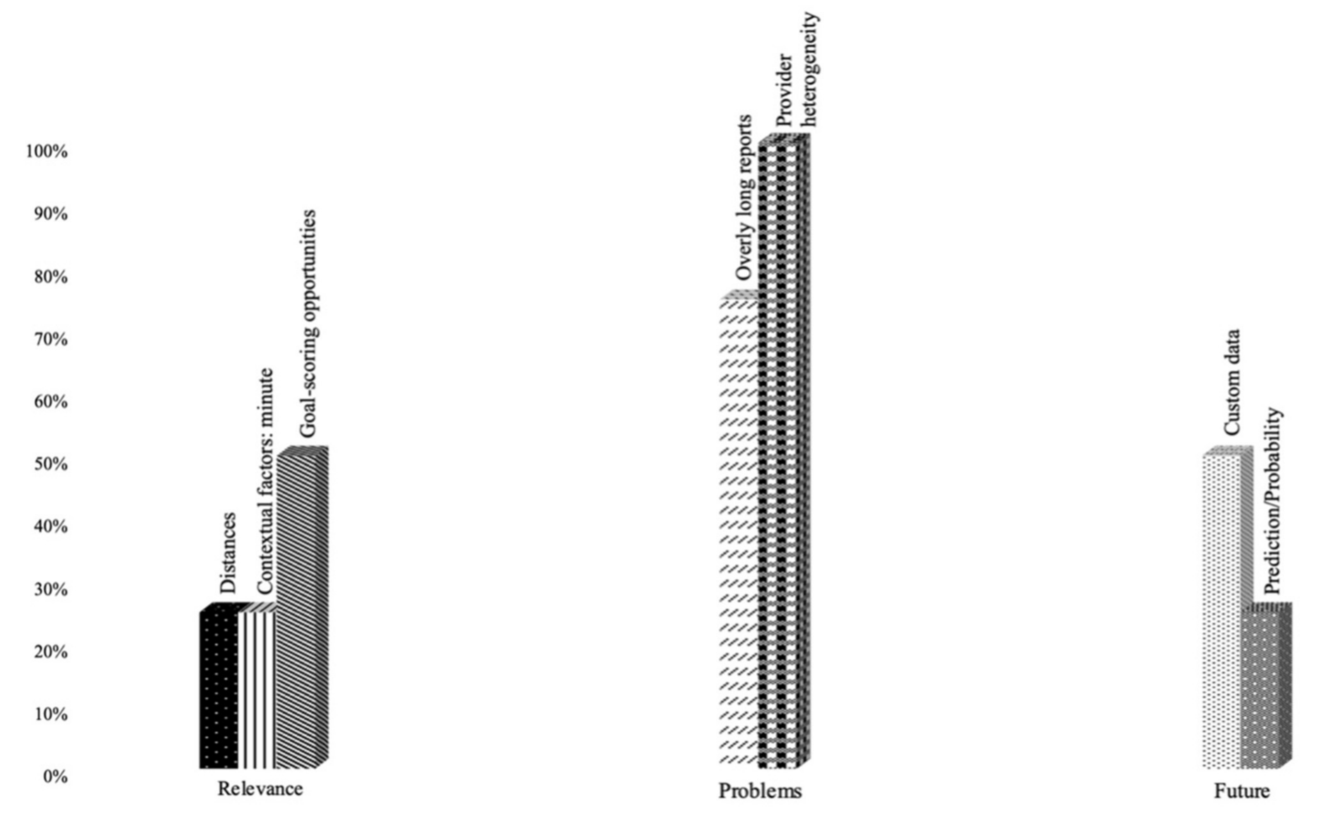

FIGURE 2 | Answer frequency to the question "Data provider information."

their own team and the opponent team. The content analysis of the responses showed that they believed that the analysis of both their own team and the opponent was important. A total of seven of the nine participants all rated the analysis of the game as "fundamental." Supporting this "fundamental" nature of the analysis, in recent years, scientific publications have been highlighting match analysis as a way of optimizing the preparation phase of competitions (Hughes and Franks, 2004) and of building an understanding of the complexity of sports (Brito Souza et al., 2019).

The "Understanding of the game" and a "Clear observation methodology" were considered as essential skills for the tactical analysts. This result is consistent with various works that have underscored the key role of disposing of a good observation tool to collect information in a structured way using the predefined categories (Sarmento et al., 2013b). The "Phases of the game" and the "Strengths and weaknesses" were regarded as the major aspects to study when analyzing the opponent team. These results support the study of Carling et al. (2008). In addition, it has been shown that once the coach obtains this data, using this information in mobile sessions helps players to better know and understand their opponent (Carling et al., 2005).

Moreover, within this first objective of understanding the perceptions of analysts, they considered "Goal-scoring opportunities" as the most relevant indicator of match analysis performance. This opinion is in line with the specialized literature that considers that, due to their greater frequency, goal-scoring opportunities are a better indication of football performance than the number of goals (Reina and Hernández-Mendo, 2012; González-Ródenas et al., 2016; Pratas et al., 2018). Analysts have, however, unanimously considered that no performance indicator is actually useful for coaches if it is included in "overly long reports." In relation to this problem, Castelo (2009) points to the importance that analysts select the most relevant information, adopting a global perspective, so that it can be useful to prepare for the matches.

Regarding the future of game analysis, participants considered it to be the key to "customize the data" in the future, by adapting it to the characteristics of their own team as well as "predicting opponent behaviors" according to the phase of the game. A number of studies have already been carried out in which different variables have been studied to predict the probability of scoring a goal (Tenga et al., 2010), of being conceded a goal-scoring opportunity (Aguado-Méndez et al., 2020a), and the result of the match (Lago-Peñas et al., 2011).

Regarding the second objective, the participants interpreted the predictive models obtained in the study of Aguado-Méndez et al. (2020a). These models were obtained after analyzing the conceded goal-scoring opportunities of the Real Betis in the Spanish league 2017/2018 according to contextual, defensive,

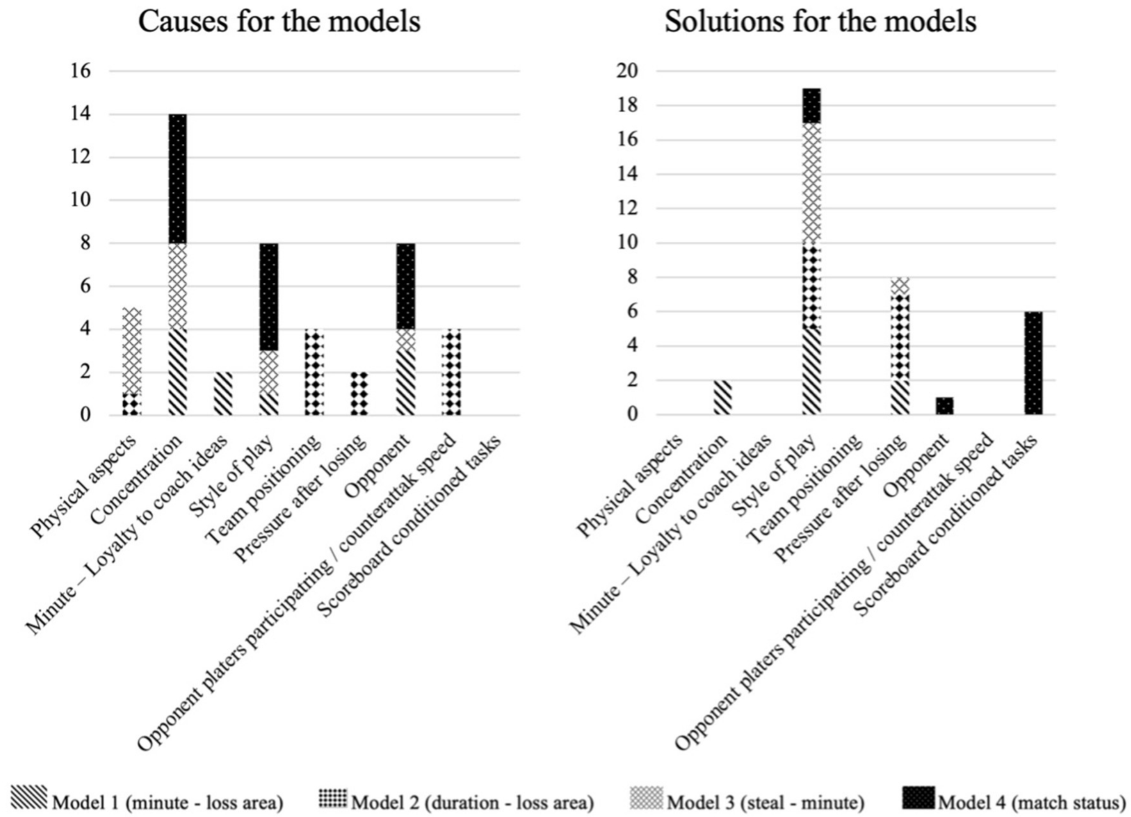

FIGURE 3 | Frequency of causes and solutions in all four predictive models.

and offensive variables through a validated instrument of observational methodology.

The quantitative data of the predictions found in the mentioned study answer the questions: "what is happening" and "what could happen" in the match. On the other hand, understanding the functional logic of the game plays a major role in match analysis. Therefore, the interpretation made by the interviewees of the causes of those predictive models could help to answer the question of "why they happen" within the style of play of a particular football team.

The network of relationships between "causes" and "solutions" indicated that the "Style of play" was the most decisive category across all the models (**Figure 1**). Hewitt et al. (2016) define the style of play as a characteristic pattern of a team cutting across all the five moments of the game (offense, offensive transition, defense, defensive transition, and set pieces). Describing and measuring the different styles of play that soccer teams can adopt during a match is a very important step toward a more predictive and prescriptive performance analysis (Lago-Peñas et al., 2018). According to the patterns shown in these five moments of the game, teams can be defined, and associated with the performance indicators (Fernández-Navarro et al., 2016; Gómez-Ruano et al., 2018). For analysts, the "cause" in models 1, 3, and 4 (**Table 2**) was not adapting the "style of play" of this team—that had an associative style—to the contextual variables of the match. The interaction between the contextual variables as the match status and quality of opposition, and venue and quality of opposition were studied by Fernández-Navarro et al. (2018) determining its influence in styles of play in soccer match play. Further, in a study that analyzed the style of play of the 20 teams of La Liga in Spain in the 2016–2017 season, Castellano and Pic (2019) concluded that the realities of the competition forced the teams to adapt to contextual variables (opponent, location, position in the classification, etc.) in order to succeed. Consequently, it seems advisable to direct the training toward developing the flexible and adaptable styles of play to intra- and inter-match dynamics. It is thus unsurprising that the participants determined the modification of the "style of play" as a "solution" in the four predictive models, adapting to the opponent and the evolution of the outcome of the match to achieve successful results.

Directly related to the above, the analysts considered the "opponent" category as a major "cause," as it was the originator in the three models (1, 3, and 4). This latter finding is in accordance with the study of Lago-Peñas (2009) that found the opponent team does change the way they play the match according to the minute, result, place, etc., thus succeeding in creating difficulties for the team that does not manage to adapt in the same way. The "Pressure after loss" category, i.e., the defensive transition, stood out as a "solution" in models 1, 2, and 3. The importance of properly performing the defensive transitions was reported

FIGURE 4 | Relationship between causes and solutions in the four predictive models.

in a study conducted on the German Bundesliga. This latter work showed that the best teams regained possession faster than lower-level teams (Vogelbein et al., 2014). In addition, the "concentration" category, which encompasses the psychological or emotional aspects, was a "cause" in three models (models 1, 3, and 4) and a "solution" in models 1 and 3. In this line, the specialized literature has previously shown how psychological factors can affect the performance of football teams (Pain and Harwood, 2007).

Finally, the "Physical aspects" category was the "cause" of the goal-scoring opportunities conceded in models 2 and 3. Indeed, this category affects the ball action accuracy as well as decision-making, because it reduces the precision of ball actions and dexterity generally. The review by Alghannam (2012) shows how physical performance decreases throughout the match due to accumulated fatigue. However, a recent study shows that if we consider effective time (i.e., not counting interruptions) rather than total playing time, the differences in terms of distances traveled at different speeds are much smaller between the first and second half of the match (Rey et al., 2020). In addition, the distance traveled at a high intensity (21–24 km/h) and sprint (>24 km/h) between the first and second part of the match depends on the demarcation, with midfielders and attackers decreasing their performance in the second half. Therefore, fatigue could explain the increase in ball inaccuracy as well as the worse decision-making of the players. But it would be incorrect to conclude that a cause-and-effect relationship exists between these factors. In any event, the contributions of qualitative studies based on the opinions of football professionals are essential to build an understanding of the quantitative data, not only regarding the "physical aspects" category, but also the functional logic of the game, globally (Wright et al., 2014, 2016; Sarmento et al., 2015, 2020).

CONCLUSIONS

The objectives of the present study were first, to explore the general perceptions of the analysis of own team as well as of the opponent team, and second, to analyze the tactical interpretation of the quantitative data based on a study on conceded goal-scoring opportunities. The analysts who participated in this study found that it was fundamental to analyze their own team and the opponent team. Indeed, the "Understanding of the game" and a "Clear observation methodology" represented essential skills that tactical analysts need to put into practice. From these results, we emphasize the rigor and systematization that should characterize the observation phase in order to detect patterns of behavior of our own team and of our opponents, with the aim of intervening afterward through the training for the preparation of the match. In addition, the causes and/or solutions that the surveyed analysts attributed to some of the predictive models of the case under study were: adaptability of the "Style of play" itself to the "Opponent"; and "Pressure after loss." Therefore, a style of play that is able to adapt to the opponent, contextual factors, and adequate pressure after losing the ball have been considered key aspects to optimize the performance of a team.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the Research Center of Sport Sciences at University Pablo de Olavide, based at Seville (Spain) and conformed to the recommendations of the Declaration of Helsinki. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RA-M: conceptualization, formal analysis, and visualization. RA-M and FO-S: methodology, investigation, and writing—original draft preparation. JG-J and RA-M: software. ÁR-G and FO-S: validation, resources, writing—review and editing, and data curation. FO-S and JG-J: resources and writing—review and editing. JG-J: supervision. ÁR-G: project administration. All authors have read and agreed to the published version of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.735167/full#supplementary-material

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Downtrends in Offside Offenses Among 'The Big Five' European Football Leagues

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This study examined the evolution of offside offenses and pass performance across a 10-season period in the top five European soccer leagues. Match performance observations (n = 18 259) were analysed for emergent trends. Two-way ANOVA analyses revealed significant league and seasonal differences among the five leagues (medium effect size). The total offside offenses committed during a match experienced a clear decline during the 10 seasons. In contrast, moderate increases were evident for all passing differential variables. Offside offenses per match were higher in the German Bundesliga and Spanish La Liga than in the English Premier League and France Ligue 1. However, the English Premier League had the greatest value in the touch differential, pass differential, successful pass differential, and key pass differential among all leagues. It is important to note that the number of offside offenses fell after the implementation of VAR.

Keywords: soccer, football, offside offenses, European big five leagues, VAR

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INTRODUCTION

The offside rule is a unique feature of soccer matches. It contributes significantly to the dynamism of the game and adds sophistication and creativity to soccer. However, the offside rule is also the source of a large amount of goal-related controversy and has experienced long-term changes (**Table 1**). The offside rule became increasingly liberalised until it was finally amended in 2005. According to FIFA Law 11, a player is in an offside position "if he is nearer to the opponents'(defenders) goal line than both the ball and the second-last opponent (defender). A player in an offside position is only penalised if, at the moment the ball is played by one of his team, he is, in the opinion of the referee, involved in active play by interfering with play, or interfering with an opponent, or gaining advantage being in that position".

The phrase "nearer to his opponents' goal line" refers to those body parts that could be used to score a goal (i.e., all body parts except arms and hands). It follows from the rule that judging offside includes two subtasks. The first subtask requires perceiving the position of the forward from team A in relation to the last defender of team B (who is, in most cases, the second last opponent before the goal keeper) at the moment when another player from team A touches or plays the ball. The second subtask requires judging whether the forward is actively involved in play or gaining an advantage from being in the offside position (Wühr et al., 2015).

The literature about offside derives from two main approaches: offside judgment and comparative analysis on offside.

TABLE 1 | Brief history of the offside rule.

Year	Law change
1863	A player is offside if he is in front of the ball.
1866	Forward passes are made legal, provided that there are 3 defenders between the receiver and the goal. Previously, all attacking players in front of the ball were offside.
1907	A player receiving a pass cannot be offside if he is on his own half.
1920	Impossible to be offside after a throw-in.
1925	The Offside Rule (see 1866) is reduced from three to two defending players.
1990	No longer offside if the receiving player is even with 2nd-to-last defender.
2003	To be offside, a player has to either touch the ball or be in a position to potentially make physical contact with an opponent.
2005	In the definition of an offside position, "nearer to his opponents' goal line" means that any part of his head, body or feet is nearer to his opponents' goal-line than both the ball and the second-to-last opponent. The arms are not included in this definition.

First, greater attention has been paid in the literature to the examination of offside decision-making process in assistant referees and errors associated with it. Baldo et al. (2002) were the first to propose the flash-lag effect as a possible source of incorrect offside judgements. Helsen et al. (2006) and Gilis et al. (2008) examined its validity to explain errors made by assistant referees. Catteeuw et al. (2010) indicated that flag errors can best be explained by the perceptual illusion induced by the flash-lag effect. On the other hand, in line with the optical error hypothesis (Oudejans et al., 2000, 2005) that may explain why incorrect offside decisions may occur, Helsen et al. (2006) revealed that 26.2% of the offside situations were assessed incorrectly during the 2002 World Cup in Japan and Korea, most of which were flag errors (when the assistant referee gave an offside by raising his flag, while the attacker was in an onside position). Furthermore, Oudejans et al. (2007) agreed that scoring incorrect flag decisions is very objective and clear. However, they also suggested examining the non-flag situations in more detail. In this respect, Oudejans et al. (2005, 2007) defined an offside situation as follows: "an offside situation is a situation in which the ball was passed toward the opponents' goal line and in the direction of a receiving attacker who was positioned within a few metres of the offside line".

As regards sportsmen, in soccer (association football), the ability to avoid offside situations has been appointed as a factor that distinguishes players' positional roles, match outcomes, and game location. In terms of players' positional roles, forward commit more offside offenses than fullbacks (Taylor et al., 2004), and winning teams commit significantly more offside offenses than losing teams do (Lago-Peñas et al., 2010; Zhou et al., 2018). Moreover, studies show that home teams commit significantly higher numbers of offside offenses than visiting teams do (Lago-Peñas and Lago-Ballesteros, 2011). However, significant differences across sections of the league table were not found for offside offenses in the Spanish La Liga 2008–2009 season (Lago-Ballesteros and Lago-Peñas, 2010). The offside offenses were similar for winning, drawing and losing teams in 288 matches played at the group stage in the UEFA Champions League in the 2007-2008, 2008-2009, and 2009–2010 seasons (Lago-Peñas et al., 2011). Furthermore, offside offenses during the game have been shown to not be determinant in achieving offensive success (Schauberger et al., 2017).

The most important limitation of previous research concerns the issue of general developments in offside offenses. Scholars have long focused on judgement or flag error with offside offenses rather than longitudinal analysis (Gilis et al., 2009; Catteeuw et al., 2010; Huttermann et al., 2017), which focuses on the evolution of the offside rule. To our knowledge, gaps in the passing and development of offside offenses between the top European leagues during the last decade have not been explored. Accordingly, the aim of this study is to examine the league and seasonal effects on the trends of offside offenses and passing difference.

This study will help us characterise the magnitude of dynamic change of offside offenses and passing difference. Taking into account the introduction of Video assistant referees (VAR) and the widening of the gap in strength between teams, we hypothesised that offside offenses would experience a significant decline. To test this hypothesis we collected offside data for 10 seasons in the top five European leagues and analyzed the seasonal and league effects. And we further try to explain the reason for the downward trend through the analysis of passing difference data.

MATERIALS AND METHODS

Samples

Data from the first divisions in the English Premier League (EPL,3800 matches), French Ligue 1 (Ligue 1,3800 matches), German Bundesliga (Bundesliga,3060 matches), Italian Serie A (Serie A,3799 matches), and Spanish La Liga (Liga,3800 matches) were obtained through online sources (Whoscored.com) with permission. The data resources from Whoscored.com are supported by OPTA Sportsdata Company. The reliability of the tracking system (OPTA Client System) has been verified by Liu et al. (2013). They showed that the data collection system (OPTA Client System) achieved a sufficiently high inter-group consistency (Kappa coefficient between 0.86 and 0.94) when collecting real-time match data. Ethics committee approval of the current study was gained from the local university.

For comparisons between leagues, the most recent ten seasons were analysed, beginning with 2009/2010, when data on all leagues of interest were available. The number of offside offenses, touches, passes and successful passes for home and away teams were obtained for each individual match and were analysed per season for each league. Data for all variables were missing from one match in Serie A (Cagliari vs. Roma in 2012/2013 was forfeited), resulting in a total of 18,259 matches over 10 seasons, beginning with 2009/2010.

The match analysis included the coding of technical indicators based on the criteria defined by OPTA and included the number of offside offenses, touches (a sum of all events where a player touches the ball, which excludes things such as aerial lost or

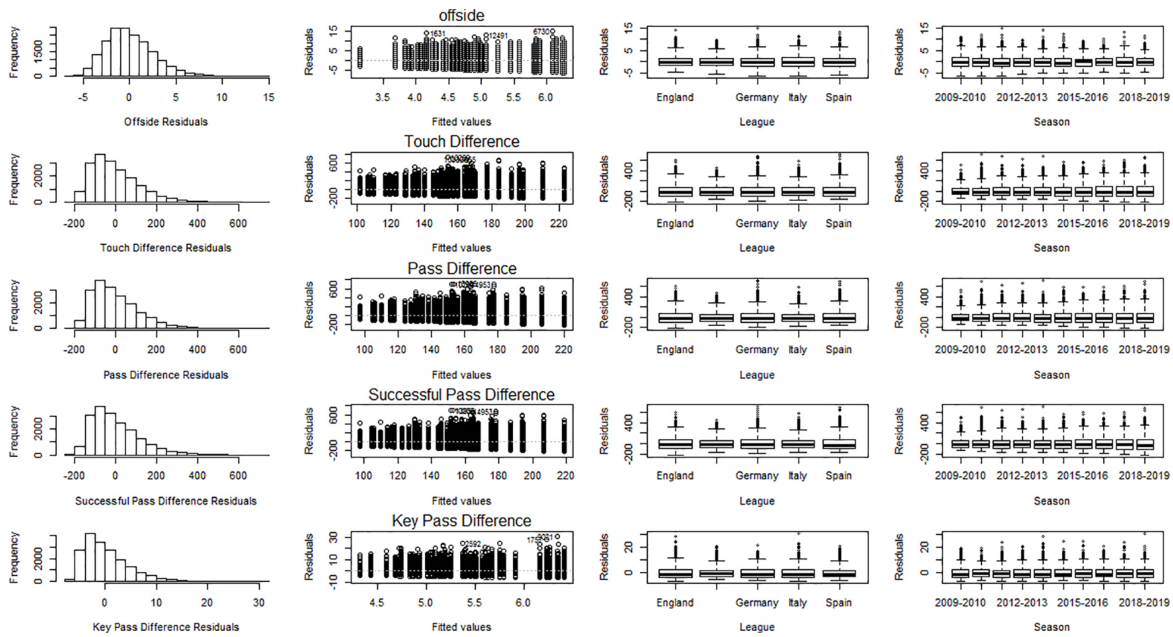

FIGURE 1 | Model validation graphs. Histogram of the residuals (normality). Fitted values versus residuals (independence). Residuals versus league (homogeneity). Residuals versus season (homogeneity).

challenge lost), passes, successful passes, and key passes (the final pass from a teammate leading to a shot on goal). The difference between touches, passes, successful passes, and key passes is the absolute value derived by subtracting the respective value for the home team from that of the away team. Total offside offenses refers to the sum of offside offenses on both sides.

Statistical Analysis

Longitudinal data were analysed using a two-way ANOVA with league and season as independent variables. Even minor deviations from normality can result in data with large sample sizes being classified as not normally distributed. We therefore prefer to assess normality, homogeneity, and independence purely based on a graphical inspection of the residuals (**Figure 1**).

In **Figure 1**, the distribution of the residuals appears skewed, which means the violation of normality. However, several authors argue that violation of normality is not a serious problem (Sokal and Rohlf, 1995, p407; Zar, 2010, p137) as a consequence of the central limit theory. Some authors even argue that the normality assumption is not needed at all provided the sample size is large enough (Fitzmaurice et al., 2012; Ghasemi and Zahediasl, 2012).

For every parameter presented in the present study, a significant interaction between these factors was identified ($p < 0.05$). Effect sizes were calculated using partial eta squared (η_p^2). The following scales were used to classify the effect size of the test (Cohen, 1992): very small, 0–0.02; small, 0.02–0.15; moderate, 0.15–0.35; large, 0.35–1.0. Tukey's *post hoc* tests were used to compare leagues and seasons (**Table 2**). To control for type I error, Bonferroni's correction was applied by dividing the α level by the number of pairwise comparisons being made. Thus, an operational α level of 0.005 ($p < 0.05/10$) was used for league comparisons, and an operational α level of 0.001 ($p < 0.05/45$) was used for season comparisons of each dependent variable.

All analyses were conducted using SPSS Statistics for Windows, version 19.0, and data visualisation was carried out using the R statistical programming language and GraphPad Prism version 7.0.

RESULTS

Offside Offenses

Figure 2A shows the total number of offside offenses called per match for each league over the ten-season span. Two-way ANOVA revealed a significant effect of season [$F(9,18209) = 78.74$, $\eta_p^2 = 0.04$] and league [$F(4,18209) = 99.42$, $\eta_p^2 = 0.02$], with a significant interaction effect [$F(36,18209) = 9.02$, $\eta_p^2 = 0.02$] (all $p < 0.0001$). The number of offside offenses per match consistently declined in all leagues over the ten seasons, and there were significantly more total offside offenses called per match in the first four seasons compared with the last six seasons (all adjusted $p < 0.0001$, **Figure 2B**). From **Figure 2C**, it can be seen that there were significantly fewer offside offenses called in the EPL and League 1 compared to the other three leagues (adjusted $p < 0.0001$).

Simple main effects analysis demonstrated the clear seasonal effect in the EPL [$F(9,18209) = 6.21$, $\eta_p^2 = 0.003$], Ligue 1 [$F(9,18209) = 21.20$, $\eta_p^2 = 0.01$], Bundesliga [$F(9,18209) = 33.55$, $\eta_p^2 = 0.02$], Serie A [$F(9,18209) = 38.21$, $\eta_p^2 = 0.02$] and La Liga [$F(9,18209) = 12.84$, $\eta_p^2 = 0.01$] (all $p < 0.0001$). Pairwise comparison showed that there were significantly fewer offside

TABLE 2 | Offside offenses and passing performance across 10 seasons for European Big five leagues.

	League	Season									
		2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019
Offside offenses	EPL	4.6 ± 2.4	4.7 ± 2.6	4.5 ± 2.7	4.6 ± 2.4	4.2 ± 2.6	3.9 ± 2.2^{ABD}	3.9 ± 2.2^{ABD}	3.8 ± 2.3^{ABCD}	4.1 ± 2.3	4.1 ± 2.3
	Ligue 1	4.3 ± 2.3^{D}	4.4 ± 2.4^{D}	4.6 ± 2.5^{D}	5.6 ± 2.8	4.7 ± 2.4^{D}	4.5 ± 2.2^{D}	4.3 ± 2.5^{D}	4.3 ± 2.3^{D}	4.1 ± 2.3^{ED}	3.1 ± 2.0^{ABCDEFGHI}
	Bundesliga	6.3 ± 3.2	6.2 ± 3	6.1 ± 3.2	5.4 ± 2.7^{AB}	4.8 ± 2.5^{ABC}	4.9 ± 2.6^{ABC}	5 ± 2.4^{ABC}	4.6 ± 2.5^{ABCD}	4.0 ± 2.4^{ABCDEFG}	4.0 ± 2.5^{ABCDEFG}
	Serie A	6.2 ± 3	5.9 ± 2.9	5.8 ± 2.8	5 ± 2.6^{ABC}	4.2 ± 2.1^{ABCD}	4.7 ± 2.7^{ABC}	4.8 ± 2.4^{ABC}	4.6 ± 2.3^{ABC}	4.2 ± 2.4^{ABCD}	3.7 ± 2.4^{ABCDFGH}
	Liga	5.9 ± 2.8	5.8 ± 3.1	5.4 ± 2.6	5.2 ± 2.9^{A}	4.8 ± 2.6^{ABC}	4.9 ± 2.7^{AB}	4.9 ± 2.7^{AB}	4.7 ± 2.5^{ABC}	5.1 ± 2.6^{AB}	4.5 ± 2.6^{ABCD}
Touch	EPL	123.2 ± 93.3	123 ± 92.4	149.8 ± 122.6	148.4 ± 113	170.3 ± 115.4$^{\mathbf{AB}}$	168.1 ± 122.8$^{\mathbf{AB}}$	152.5 ± 112.5$^{\mathbf{AB}}$	191.7 ± 127$^{\mathbf{ABCDG}}$	210 ± 167.9$^{\mathbf{ABCDEFG}}$	223.1 ± 153$^{\mathbf{ABCDEFGH}}$
	Ligue 1	101.6 ± 78.2	106.6 ± 82.8	128.2 ± 92.4	122.8 ± 89.4	136.3 ± 108.9$^{\mathbf{AB}}$	145.4 ± 110.3$^{\mathbf{AB}}$	166.2 ± 131.2$^{\mathbf{ABCDE}}$	166.5 ± 119.3$^{\mathbf{ABCDE}}$	168.2 ± 124.3$^{\mathbf{ABCDE}}$	157.5 ± 113.6$^{\mathbf{ABCD}}$
	Bundesliga	117 ± 92.9	119.6 ± 90.1	140.2 ± 110.3	148.1 ± 111.4	157.1 ± 141.7$^{\mathbf{AB}}$	177 ± 143.3$^{\mathbf{ABC}}$	196.3 ± 163.3$^{\mathbf{ABCDE}}$	198.9 ± 147.3$^{\mathbf{ABCDE}}$	168.5 ± 135.4$^{\mathbf{AB}}$	183.8 ± 149.9$^{\mathbf{ABCD}}$
	Serie A	107.3 ± 79.4	109.8 ± 80	129.2 ± 104.9	119.3 ± 83.4	133 ± 97.6	154.3 ± 108.7$^{\mathbf{ABD}}$	168.4 ± 118.6$^{\mathbf{ABCDE}}$	167.9 ± 125.4$^{\mathbf{ABCDE}}$	177.1 ± 131.5$^{\mathbf{ABCDE}}$	164.9 ± 121.8$^{\mathbf{ABCDE}}$
	Liga	134.3 ± 115.8	153.8 ± 147.3	165 ± 139.4$^{\mathbf{A}}$	166.8 ± 140.4$^{\mathbf{A}}$	159.6 ± 123.6	154.7 ± 125.5	151 ± 115.3	166.2 ± 121.9$^{\mathbf{A}}$	169.5 ± 124$^{\mathbf{A}}$	163.6 ± 138.4$^{\mathbf{A}}$
Pass	EPL	116.7 ± 89	117.7 ± 88.6	145.4 ± 118.6$^{\mathbf{A}}$	142.9 ± 108.9	164.4 ± 111.2$^{\mathbf{AB}}$	166.1 ± 121$^{\mathbf{AB}}$	151.2 ± 112$^{\mathbf{AB}}$	185.1 ± 124.5$^{\mathbf{ABCDGH}}$	206.5 ± 166.7$^{\mathbf{ABCDEFG}}$	220.1 ± 152.2$^{\mathbf{ABCDEFGH}}$
	Ligue 1	96.7 ± 75.6	104.4 ± 81	127.7 ± 91.8$^{\mathbf{A}}$	123.9 ± 89	134.3 ± 106.4$^{\mathbf{AB}}$	141.8 ± 108.2$^{\mathbf{AB}}$	163.9 ± 128.5$^{\mathbf{ABCDE}}$	159.8 ± 117.5$^{\mathbf{ABCD}}$	163 ± 120$^{\mathbf{ABCDE}}$	153.2 ± 111.7$^{\mathbf{AB}}$
	Bundesliga	115 ± 90.8	115.9 ± 88.6	137.8 ± 108.6	144.9 ± 107.7	153.7 ± 143.3$^{\mathbf{AB}}$	177.1 ± 144.2$^{\mathbf{ABCD}}$	194.7 ± 163.1$^{\mathbf{ABCDE}}$	195.6 ± 145$^{\mathbf{ABCDE}}$	165.5 ± 131.7$^{\mathbf{AB}}$	177.8 ± 148$^{\mathbf{ABCD}}$
	Serie A	105.4 ± 77.1	109.8 ± 81.3	131.3 ± 107.4	115.6 ± 82.2	130.7 ± 96.9	149.3 ± 106.4$^{\mathbf{AB}}$	166.1 ± 118.7$^{\mathbf{ABCDE}}$	161.9 ± 121.1$^{\mathbf{ABCDE}}$	174.4 ± 130.1$^{\mathbf{ABCDE}}$	160.8 ± 120.1$^{\mathbf{ABCDE}}$
	Liga	130.5 ± 111.7	152 ± 145.1	163.6 ± 138.6$^{\mathbf{A}}$	162.9 ± 138.8$^{\mathbf{A}}$	155.6 ± 120.7	152.9 ± 124	148.5 ± 115	159.4 ± 117.5$^{\mathbf{A}}$	163.9 ± 119.7$^{\mathbf{A}}$	159.2 ± 135.5$^{\mathbf{A}}$
Successful pass	EPL	118 ± 90.4	118.2 ± 89.4	145.5 ± 120.7	144.2 ± 109.8	167 ± 112.5$^{\mathbf{AB}}$	166.2 ± 122.2$^{\mathbf{AB}}$	151.5 ± 111.6$^{\mathbf{ABH}}$	186.6 ± 124.9$^{\mathbf{ABCDG}}$	206.6 ± 166.1$^{\mathbf{ABCDEFG}}$	218.8 ± 151.5$^{\mathbf{ABCDEFGH}}$
	Ligue 1	97.6 ± 77	104.8 ± 81.2	126.8 ± 91.3	122.6 ± 89.1	132.9 ± 105.6	145 ± 108.7$^{\mathbf{A}}$	163.8 ± 129$^{\mathbf{ABCDE}}$	161.8 ± 118.6$^{\mathbf{ABCDE}}$	163.4 ± 120.8$^{\mathbf{ABCDE}}$	153.5 ± 111.9$^{\mathbf{AD}}$
	Bundesliga	114.1 ± 91.4	116 ± 89.2	138.1 ± 108.5	145.6 ± 107.6	152.8 ± 143.2$^{\mathbf{AB}}$	175.6 ± 143.5$^{\mathbf{ABC}}$	193.7 ± 163.9$^{\mathbf{ABCDE}}$	194.2 ± 143.8$^{\mathbf{ABCDE}}$	164.9 ± 132.8$^{\mathbf{AB}}$	178.1 ± 147.8$^{\mathbf{ABCD}}$
	Serie A	105.6 ± 78.8	110.1 ± 80.1	130.9 ± 105.7	118.1 ± 83.5	132.3 ± 97.5	150.8 ± 107$^{\mathbf{ABD}}$	167.8 ± 119.1$^{\mathbf{ABCDE}}$	163 ± 122.3$^{\mathbf{ABCDE}}$	175.1 ± 130.8$^{\mathbf{ABCDE}}$	161.9 ± 120.5$^{\mathbf{ABCDE}}$
	Liga	130.3 ± 111.9	151.7 ± 146$^{\mathbf{A}}$	165 ± 139.7$^{\mathbf{A}}$	164.1 ± 139.6	157.1 ± 122.3	154.2 ± 124.6	149.4 ± 114.7	159.3 ± 117.5$^{\mathbf{A}}$	163.9 ± 119.3$^{\mathbf{A}}$	158.1 ± 135.6
Key pass	EPL	6.2 ± 5.1	5.7 ± 4.4	6.3 ± 4.6	6.2 ± 4.5	6.2 ± 4.9	5.8 ± 4.3	5.4 ± 4.5	6.4 ± 4.9^{G}	6.2 ± 4.7	5.8 ± 4.7
	Ligue 1	4.9 ± 3.8	4.7 ± 3.7	5.1 ± 4.1	4.9 ± 3.7	4.7 ± 3.7	4.3 ± 3.4	4.6 ± 3.6	4.9 ± 3.7	4.9 ± 3.9	4.9 ± 3.9
	Bundesliga	5.1 ± 4.2	4.9 ± 3.9	5.5 ± 3.8	5.1 ± 4.2	5.4 ± 4.3	5.5 ± 4.2	5.6 ± 4.6	5.1 ± 4.2	5.2 ± 4.1	5.6 ± 4.2
	Serie A	5.2 ± 4.1	4.8 ± 3.7	5.2 ± 4	5.4 ± 4.3	5.2 ± 4.3	5.1 ± 4	5.6 ± 4.5	5.9 ± 4.4^{B}	6.3 ± 4.9^{ABC}	6.3 ± 5^{ABC}
	Liga	5.7 ± 4.5^{G}	5.5 ± 4.3^{G}	5.4 ± 4.4	5.3 ± 4	5.2 ± 4.3	5 ± 3.8	4.4 ± 3.7	5 ± 3.9	4.7 ± 3.8	4.7 ± 4

Data are presented as means and standard deviations. A denotes the difference from the 2009/2010 season (adjusted $p < 0.05$); B denotes the difference from the 2010/2011 season (adjusted $p < 0.05$); C denotes the difference from the 2011/2012 season (adjusted $p < 0.05$); D denotes the difference from the 2012/2013 season (adjusted $p < 0.05$); E denotes the difference from the 2013/2014 season (adjusted $p < 0.05$); F denotes the difference from the 2014/2015 season (adjusted $p < 0.05$); G denotes the difference from the 2015/2016 season (adjusted $p < 0.05$); H denotes the difference from the 2016/2017 season (adjusted $p < 0.05$); I denotes the difference from the 2017/2018 season (adjusted $p < 0.05$).

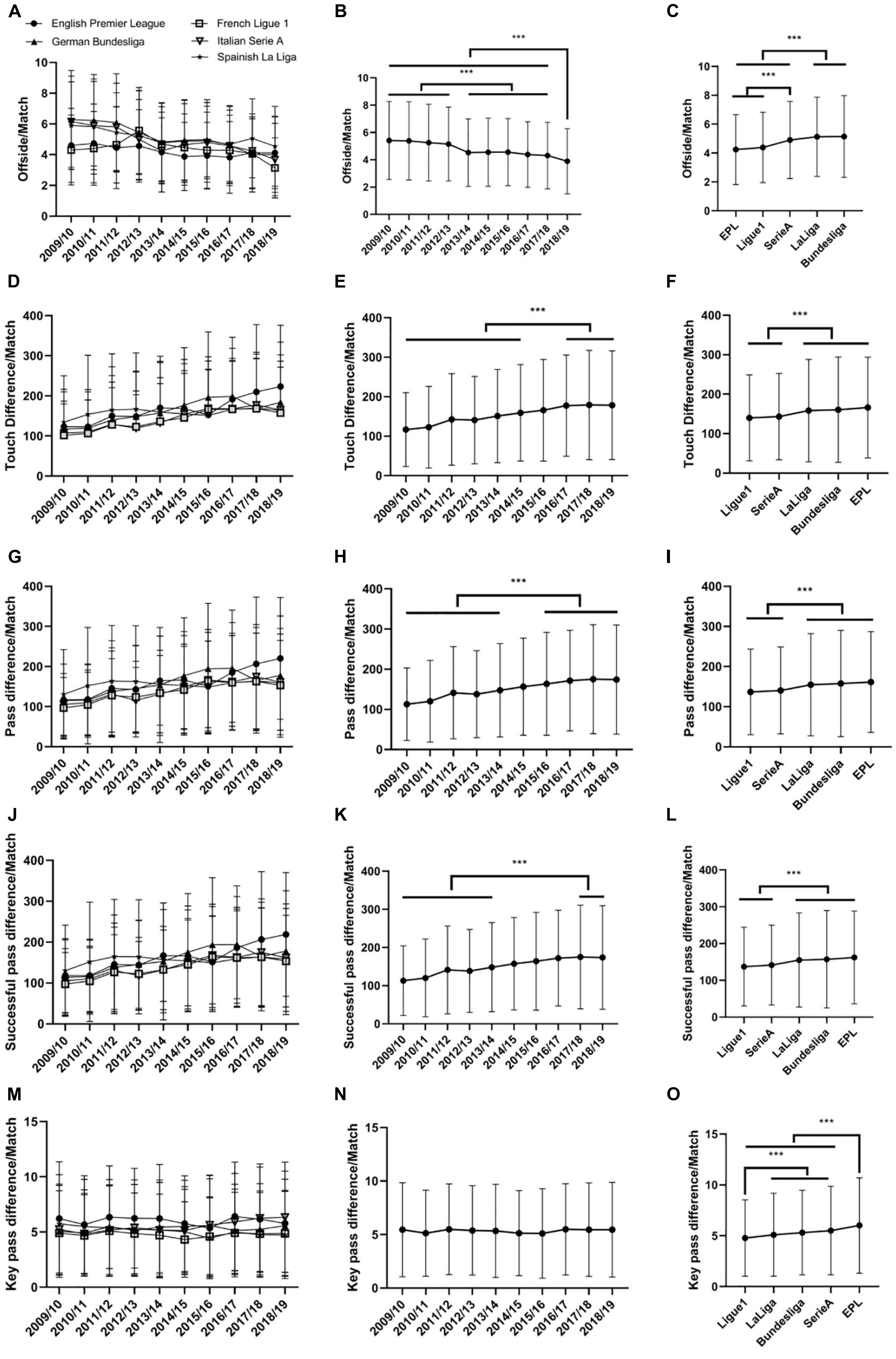

FIGURE 2 | (A) Offsides per match, **(D)** touch difference per match, **(G)** pass difference per match, **(J)** successful pass difference per match, **(M)** and key pass difference per match for each league over the ten seasons span. **(B)** Offsides per match, **(E)** touch difference per match, **(H)** pass difference per match, **(K)** successful pass difference per match, **(N)** and key pass difference per match for each season. **(C)** Offsides per match, **(F)** touch difference per match, **(I)** pass difference per match, **(L)** successful pass difference per match, **(O)** and key pass difference per match for each league. Data are shown as mean ± SD. ***Denotes statistical significance at the 0.1% level.

offenses committed in 2018/2019 than in the other nine seasons for Ligue 1 (adjusted $p < 0.0001$) and significantly fewer offside offenses committed in 2018/2019 than in the first eight seasons for Serie A (adjusted $p < 0.0001$). La Liga committed fewer offside offenses in 2018/2019 compared with the first four seasons, but there were no differences between 2018/2019 and 2017/2018. For Bundesliga, there were significantly fewer mean offside offenses in the most recent two seasons than in the first seven seasons, but there were no differences between the recent two seasons and the other eight seasons for the EPL.

Furthermore, the EPL showed a smaller reduction than the other leagues. The number of offenses in the EPL decreased by 11% from the 2009/2010 season to the 2018/2019 season, while the decreases were 36% for the German Bundesliga, 40% for the Italian Serie A, 23% for the Spanish La Liga, and 27% for the French Ligue 1.

Touches

Two-way ANOVA on touch differential per match revealed significant main effects of season [$F(9,18209) = 66.00, \eta_p^2 = 0.03$] and league [$F(4,18209) = 34.15$, $\eta_p^2 = 0.01$] as well as an interaction effect [$F(36,18209) = 5.33$, $\eta_p^2 = 0.01$] (all $p < 0.0001$). The touch differential per match consistently increased in all leagues over the ten seasons (**Figure 2D**). From **Figure 2E**, it can be seen that the touch differential per match was higher in the last three seasons (2016-2019) than in the first six seasons (all adjusted $p < 0.0001$).

Simple main effects analysis demonstrated the clear seasonal effect in the EPL [$F(9,18209) = 30.48$, $\eta_p^2 = 0.02$, $p < 0.0001$], Ligue 1 [$F(9,18209) = 16.44$, $\eta_p^2 = 0.01$, $p < 0.0001$], Bundesliga [$F(9,18209) = 18.50$, $\eta_p^2 = 0.01$, $p < 0.0001$], Serie A [$F(9,18209) = 18.48$, $\eta_p^2 = 0.01$, $p < 0.0001$] and La Liga [$F(9,18209) = 2.93$, $\eta_p^2 = 0.01$, $p = 0.002$]. Pairwise comparison showed that the touch differential in the most recent six seasons were significantly higher than in the first two seasons for all leagues except for La Liga (adjusted $p < 0.05$) and significantly higher in the most recent four seasons than in the first four seasons for the EPL, Serie A, and Ligue 1 (adjusted $p < 0.05$). La Liga had a higher touch differential in 2018/2019 than in 2009/2010, but there was no differential among the most recent nine seasons.

The EPL showed a larger increase than the other leagues (**Figure 2F**). In the EPL, the touch differential per match increased by 81% from the 2009/2010 to 2018/2019 season, while the increase was 57% for the German Bundesliga, 54% for the Italian Serie A, 22% for the Spanish La Liga, and 55% for the French Ligue 1.

Passes

When leagues are compared by the pass differential per match (**Figure 2I**), Ligue 1 and Serie A are consistently lower than each of the other three leagues (adjusted $p < 0.0001$). The results of the ANOVA showed significant effects of season [$F(9,18209) = 65.13$, $\eta_p^2 = 0.03$], league [$F(4,18209) = 32.25$, $\eta_p^2 = 0.01$], and interaction [$F(36,18209) = 5.78$, $\eta_p^2 = 0.01$] (all $p < 0.0001$). The pass differential per match increased over time for all five leagues and in the ten seasons. In comparison, the most recent four seasons had higher pass differentials for each league than the first five seasons (**Figure 2H**).

Simple main effects analysis demonstrated the clear seasonal effect in the EPL [$F(9,18209) = 32.58$, $\eta_p^2 = 0.02$, $p < 0.0001$], Ligue 1 [$F(9,18209) = 15.74$, $\eta_p^2 = 0.01$, $p < 0.0001$], Bundesliga [$F(9,18209) = 19.13$, $\eta_p^2 = 0.01$, $p < 0.0001$], Serie A [$F(9,18209) = 17.47$, $\eta_p^2 = 0.01$, $p < 0.0001$] and La Liga [$F(9,18209) = 2.77$, $\eta_p^2 = 0.001$, $p = 0.003$].

Pairwise comparison showed that the pass differential was significantly higher in the recent five seasons than in the first two seasons for all leagues except for La Liga (adjusted $p < 0.05$) and a significantly higher pass differential in 2018/2019 than in the first eight seasons for the EPL (adjusted $p < 0.05$). La Liga had a higher pass differential in 2018/2019 than in 2009/2010, but there were no differences among the most recent nine seasons.

The EPL showed a larger increase than the other leagues (**Figure 2G**). The pass differential per match in the EPL increased by 89% from the 2009/2010 season to the 2018/2019 season, while the increase was 55% for the German Bundesliga, 53% for the Italian Serie A, 22% for the Spanish La Liga, and 58% for the French Ligue 1.

Successful Passes

The results were similar, though not as consistent, for the successful pass differential per match **Figure 2J**. Analysis showed a significant effect of season [$F(9,18209) = 64.68$, $\eta_p^2 = 0.03$] and league [$F(4,18209) = 31.03$, $\eta_p^2 = 0.01$], along with a significant interaction effect [$F(36,18209) = 5.64$, $\eta_p^2 = 0.01$] (all $p < 0.0001$). **Figure 2K** shows an increase in the successful pass differential per match over the ten-season span. Ligue 1 and Serie A were lower than all other leagues (adjusted $p < 0.0001$).

Simple main effects analysis demonstrated a clear seasonal effect in the EPL [$F(9,18209) = 31.58$, $\eta_p^2 = 0.02$, $p < 0.0001$], Ligue 1 [$F(9,18209) = 16.03$, $\eta_p^2 = 0.01$, $p < 0.0001$], Bundesliga [$F(9,18209) = 18.59$, $\eta_p^2 = 0.01$, $p < 0.0001$], Serie A [$F(9,18209) = 17.62$, $\eta_p^2 = 0.01$, $p < 0.0001$] and La Liga [$F(9,18209) = 2.87$, $\eta_p^2 = 0.001$, $p = 0.002$]. Pairwise comparison showed that the successful pass differential was significantly higher in the most recent four seasons than in the first two seasons for all leagues except for La Liga (adjusted $p < 0.05$) and a significantly higher successful pass differential in 2018/2019 than in the first eight seasons for the EPL (adjusted $p < 0.05$). La Liga had a higher pass differential in 2017/2018 than in 2009/2010, but there were no differences among the most recent nine seasons.

The EPL showed a larger increase than the other leagues (**Figure 2L**). The successful pass differential per match in the EPL increased by 85% from the 2009/2010 season to the 2018/2019 season, while the increase was 56% for the German Bundesliga, 53% for the Italian Serie A, 21% for the Spanish La Liga, and 57% for the French Ligue 1.

Key Passes

The analysis of key pass differential per match yielded a significant effect of league [$F(4,18209) = 45.81$, $\eta_p^2 = 0.01$,

$p < 0.0001$] (**Figure 2O**). The EPL had a significantly higher differential than all other leagues ($p < 0.0001$). From **Figures 2M,N**, it can be seen that there is no significant difference in the key pass differential per match among the ten seasons.

Simple main effects analysis demonstrated the seasonal effect in the EPL [$F(9,18209) = 2.59$, $\eta_p^2 = 0.001$, $p = 0.01$], Serie A [$F(9,18209) = 5.53$, $\eta_p^2 = 0.003$, $p < 0.0001$] and La Liga [$F(9,18209) = 3.34$, $\eta_p^2 = 0.002, p < 0.0001$]. Pairwise comparison analysis showed that the key pass differential was significantly higher in the most recent two seasons than in the first three seasons for Serie A (adjusted p < 0.05) and significantly lower in 2015/2016 than in 2016/2017 for the EPL (adjusted $p < 0.05$). La Liga had a lower key pass differential in 2015/2016 than in 2009/2010 and 2010/2011, but there were no differences among the most recent eight seasons. However, there were no differences among all seasons in Bundesliga and Ligue 1.

DISCUSSION

The present longitudinal study is the first to map the evolution of offside offenses and pass differential parameters related to the top five European soccer leagues across 10 seasons. It was envisaged that the present study would improve our understanding of evolving patterns of offside offenses and various pass differential parameters during the last 10 seasons. Our data show that the total offside offenses per match declined monotonically in the most recent ten seasons, while three pass differential variables (touch, pass, and successful pass) continued to expand during the same time- period.

Offside offenses are at an historic low and falling. However, now that the game has changed, so has the law. Football has changed faster in the last 10 years than anyone has realised. The old end-to-end game of turning teams, getting in behind players, and trying to catch them offside, is dying at the top level. In modern football, the strategy does not tend to come from a striker gambling from behind the centre-backs. Top-level soccer in Europe is more organised and more technical, with less of the risky ambition that causes offside offenses. For instance, using a high-pressure style of play against a team that utilises a possession style of play could be very effective for regaining the ball and increasing the chances of scoring opportunities (Fernandez-Navarro et al., 2016). And successful teams from European Leagues and World Cups tend to have higher attacking third regains (Garganta et al., 1997; Bell-Walker et al., 2006). And 'maintain possession' strategy may involve more slow play with defensive movements, less risk when passing, and greater emphasis on re-gaining possession relative to teams who might place less importance on this strategy (Jones et al., 2004; Wright et al., 2011). Guardiola' Barcelona, which relied on a sophisticated combination of possession and pressing that, in turn, leaded to the most fruitful period, both in reputation and in the number of titles achieved, including 14 titles during four seasons (Buldu et al., 2018).

As teams change how they attack, they also change how they defend. Modern soccer strategies and tactics are more focused on defensive aspects (Bangsbo and Peitersen, 2002). The 2005 rule change redefined what it means to be "interfering with play" in an offside position, namely, that a player either has to touch the ball or have the "potential for physical contact" with a defender. The rule created a major shift of activity in offside positions. Players could freely run offside and not receive the ball, only to be legally passed the ball by an onside team mate in the next phase. Suddenly, the offside line was no guarantee for defence any more. Attackers could break the line and still hurt their opponents. Therefore, defenders had to think differently. If a defender can now be hurt by attackers from behind, it might be safe to keep attackers in front instead. Defenders have become more flexible and more willing to drop deep. Such style of defending is characterised by a team collectively maintaining a compact shape in a zone nearer to their goal, and only applying pressure on their opponents when the attacking play begins to reach this zone (Bangsbo and Peitersen, 2002).

When compared to successful teams, the most effective scoring pattern for unsuccessful teams is set-play goals (Zhao and Zhang, 2019). Due to the sanctioning of offside positions after a corner kick or throw-in, an unsuccessful team can score without risking an offside call.

Video assistant referee were fully adopted by Bundesliga, Serie A, La Liga, Ligue 1, and the EPL in 2017/2018, 2017/2018, 2018/2019, 2018/2019, and 2019/2020, respectively. Our study suggests that in the three-season interval (2016/2017–2018/2019), there was a decrease in the number of offside calls after the implementation of the VAR in Bundesliga, Serie A, La Liga, and Ligue 1. The VAR effect was significant in Ligue 1 (the number of offside offenses committed per match in 2018/2019 was significantly less than that in 2016/2017 and 2017/2018) and Italy (the number of offside offenses committed in 2018/2019 was significantly less than that in the 2016/2017 season). However, due to not implementing the VAR, the EPL experienced a steady rise in offside calls. Thus, the introduction of VAR technology is one of the reasons for the recent decline of offside calls, and this finding is supported by previous research (Carlos et al., 2019).

Another interesting finding is that in the pre-VAR period, the five major European leagues (except for Ligue 1) also experienced a significant decline in offside offenses. The data demonstrate that all leagues (except for Ligue 1) committed fewer offside offenses during the recent three seasons (2014/2015-2016/2017) compared to the first two seasons (2009/2010–2011/2012).

For all leagues, the most pronounced increases in pass differential performance were for touches, passes and successful passes. Between the 2009/2010 and 2018/2019 seasons, a relative increase in the touch differential was observed for the EPL (45%), followed by Bundesliga, Serie A, Ligue 1, and La Liga (36, 35, 35 and 23%, respectively). A relative increase in the pass differential was observed for the EPL (47%), followed by Ligue 1, Bundesliga, Serie A, and La Liga (37, 35, 34 and 18%, respectively). Similar trends were also observed for successful pass differentials when year-on-year changes were calculated, discounting that a relative increase was observed for the EPL (46%), followed by Bundesliga, Ligue 1, Serie A, and La Liga (36, 36, 35 and 18%, respectively). Thus, it is reasonable to conclude that the gaps in touches, passes and successful passes have evolved for all of the top five leagues, albeit at different rates. Our results are in line with a previous study that reported that the highest ranked teams seem to adopt a more possession-based playing style than the bottom teams in the EPL, who still play a more direct style (Jones et al., 2004; Bloomfield et al., 2005; Taylor et al., 2008; Bradley et al., 2013).

Keeping hold of the ball, completing plays at a higher rate, and not surrendering the ball too often to the opposition means fewer offside offenses. Teams that have a greater share of passes force their oppositions to return to the backcourt, thus reducing offside offenses. The increase in the various pass differential indexes (touch, pass, successful pass) combined with the offside offense reduction illustrates the fact that the disparity in domination of the ball in the five major European leagues has increased significantly during the most recent ten seasons.

Our data demonstrate that whilst the touch, pass, successful pass differentials increased by ∼18–46% between 2009/2010 and 2018/2019, the key pass differential during matches remained relatively constant. Due to the lower key pass and pass conversion rate, we suggest that highly skilled teams are not better at passing than weaker teams. They simply engineer more easy passes in better locations and therefore limit their turnover. For example, the team will use backward passes to secure or support ball possession by passing the ball to a less advanced teammate to create space and new opportunities to attack (Fernandez-Navarro et al., 2016). Logically, the number of passes a team manages to complete in a match and a team's passing quality do not have to go hand in hand.

A global measure of offside evolution of the different leagues noted that Bundesliga and La Liga committed more offside offenses than the EPL and Ligue 1.

Bundesliga had the greatest number of counterattacks in open-play situations than the EPL, La Liga, and Serie A (Mitrotasios et al., 2019). The running distance during the game (Schauberger et al., 2017) and the transitions between the attack and the defence (Vogelbein et al., 2014) have been shown to be the most important premise for a successful match. Thus, the high rhythm and speed of play in Bundesliga lead to more offside offenses committed.

La Liga teams, characterised by ball possession and technical players, favour the aesthetic side of the game and having greater control throughout the game (Sarmento et al., 2013; Castellano and Pic, 2019). The present findings demonstrate that there was no significant difference among the most recent nine seasons of La Liga in the touch, pass, and successful pass differentials. In contrast, due to the low possession rate for underdogs (Gollan et al., 2018), the EPL had significantly higher values of the above three indicators in the 2018/2019 season than in the first eight seasons.

This observation is mirrored by the fact that, over the period of the study, the disparity in ball dominance is more stable in La Liga, but the disparity in the Premier League has increased significantly. Pass volume is related to how often the ball is turned over. Those teams that complete passes at a higher rate are less prone to giving the ball back to the opposition. As no ball means no offside offense, this could be reflective of a reduction in offside offenses and therefore one of the reasons why the La Liga offside value is significantly higher than that of the EPL.

Concerning the limitations of the current study, three aspects should be highlighted. Contextual variables (e.g., opposition level and the score-line) were not taken into consideration and these variables may affect teams' offside strategy. More matches, seasons, variables, and different competitions should be considered to provide conclusive descriptions and measures for playing styles and generalisability of the data. Finally, the combined effects of offensive and defensive tactics and opponent interactions should be included in the future. Thus, one interesting aim for future research is to include information on opposition level and the score-line. This information could further prove meaningful in explaining the decline of offside. And more samples could provide insights into the dynamic development of offside and pass difference.

More variables and matches should be considered to supply conclusive definitions for playing styles and generalisability of the data. Further research should attempt to establish the efficiency and effectiveness of playing styles when measuring performance and outcomes (i.e., scoring probability).

In summary, being offside is not a failure; it is just the price paid for gambles that do not pay out. Top-level soccer has become very tactical and defensive: many unsuccessful teams stopped playing the offside trap and began defending deeper and closer to the penalty box. Teams are not or cannot truly be looking to play an offside trap game as they did in the 1990s. Offside never dies, it just fades away.

CONCLUSION

The most obvious finding to emerge from this study is that there has been a marked decline in the number of offside offenses committed during a match. By contrast, the touch, pass, successful pass differentials increased during the 10 seasons. Offside offenses per match were higher in the German Bundesliga tend to have greater value than the English Premier League and France Ligue 1. And the English Premier League had the greatest value in the touch differential, pass differential, successful pass differential, and key pass differential among all leagues. Furthermore, the number of offside offenses fell after the implementation of VAR.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Quiet Eye and Computerized Precision Tasks in First-Person Shooter Perspective Esport Games

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The gaze behavior in sports and other applied settings has been studied for more than 20 years. A common finding is related to the "quiet eye" (QE), predicting that the duration of the last fixation before a critical event is associated with higher performance. Unlike previous studies conducted in applied settings with mobile eye trackers, we investigate the QE in a context similar to esport, in which participants click the mouse to hit targets presented on a computer screen under different levels of cognitive load. Simultaneously, eye and mouse movements were tracked using a high-end remote eye tracker at 300 Hz. Consistent with previous studies, we found that longer QE fixations were associated with higher performance. Increasing the cognitive load delayed the onset of the QE fixation, but had no significant influence on the QE duration. We discuss the implications of our results in the context of how the QE is defined, the quality of the eye-tracker data, and the type of analysis applied to QE data.

Keywords: e-sport, quiet eye, eye-tracking, FPS-game, cognitive load

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INTRODUCTION

The gaze behavior in various kind of sports and the possibility for novices to enhance performance by trying to mimic experts' gaze behavior has been studied for more than 20 years (for an overview, see Lebeau et al., 2016; Kredel et al., 2017; Hüttermann et al., 2018). This finding is not only limited to sports, however, but is also found in other applied settings such as shooting performance of police officers (Vickers and Lewinski, 2012) and surgical skills of medical personnel (Causer et al., 2014). In this study, we investigate another type of task: a computerized precision task, similar to those found in computerized first-person shooter (FPS) games in which participants aim and shoot at targets, and where accuracy and speed are often essential for success. We also investigate the effects of increased cognitive load on performance. Finally, we investigate and discuss the influence of parameter selection when defining gaze characteristics known as the "quiet eye," which have been shown to correlate with expert performance in a number of applied sport settings.

The Quiet Eye

There are several gaze metrics that can be used as indirect measures of attention and visuomotor behavior. The quiet eye (QE) is the name of a gaze behavior often used as a measure to study the relationship between perceptual behavior and proficiency in various sport-related tasks, e.g., shotgun shooting (trap and double trap), golf putting, and basketball free throws (for an overview, see, e.g., Hüttermann et al., 2018). The term was coined by Vickers (1996) and defined as the duration of the final fixation, in a given task, on the object or location prior to a task-critical action. The final fixation was specified as the last fixation within a three-degree angle for a minimum of 100 msec on the object (see Vickers, 2016 for a background and overview of the phenomena). The QE is considered to start when the performer fixates on the relevant object, and initiates a motor response (QE onset), and ends when the gaze deviates from the object by more than three degrees (QE offset). Both the onset and the duration of the QE have been shown to predict the level of performance, with experts exhibiting an earlier onset and a longer duration of QE than less-skillful performers. This has been found in a variety of sports (e.g., shotgun shooting: Causer et al., 2010; basketball: Rienhoff et al., 2013; biathlon shooting: Vickers and Williams, 2007; dart-throwing: Nibbeling et al., 2012; soccer: Piras and Vickers, 2011), but also in other applied activities (e.g., surgical skills: Causer et al., 2014; visuomotor coordination in children with developmental coordination problems: Miles et al., 2015; decision making within law enforcement: Vickers and Lewinski, 2012).

While an abundance of research has shown a typical QE pattern consistent over a large range of various experimental settings, there is no adequate and generally accepted explanation for the biological underpinnings of this distinct gaze pattern (for an overview and discussion of the causal mechanisms, see Wilson et al., 2015; Rienhoff et al., 2016; Vickers, 2016; Gonzalez et al., 2017). Vickers (2009) suggested that QE reflects the time needed to fine-tune a motor program, where a prolonged QE, with an earlier QE onset, is predictive for executing a successful behavioral response (e.g., a golf putt or a basketball free throw). This is related to functions of attentional control. Vickers (2016) proposed an explanation based on the interaction between the dorsal attentional network (DAN) and the ventral attentional network (VAN) (Corbetta and Shulman, 2002; Corbetta et al., 2008). The two networks have different projection routes and can be considered distinct neural structures, but functionally interactive. The VAN system allocates attentional resources to detect unexpected and intrusive stimuli, while the DAN system tries to maintain a task-relevant focus and thus blocks information from the VAN system (Vickers, 2016). Furthermore, Vickers recently also argued that QE was the reason that the "hot hand" exists in sports[1] (Vickers, 2016). Her interpretation has been questioned, however. Klostermann and Hossner (2018) propose an "inhibition hypothesis," which suggests that experts develop a specific solution to a problem and other less optimal solutions are suppressed during the prolonged QE duration. Based on the research currently available, it is not possible to convincingly dismiss either of the interpretations, but as shown in a recent review by Klostermann and Moeinirad (2020), the prolonged QE typically found in expert performance is a robust phenomenon.

Furthermore, whether the focus of attention is external or internal has shown to be of importance (Moore et al., 2012; Klostermann et al., 2014). The results by Moore et al. (2012) indicate that an external focus is less disruptive and cognitively demanding than an internal focus, something that promotes a more efficient use of the cognitive processes guiding and adjusting the motor program. Basically, this means that a longer QE, in which the cognitive resources are allocated to task-relevant demands, provides a possibility to process the acquired goal information more efficiently and initiate a well-tuned and successful motor response.

Quiet-Eye and Cognitive Load

In sports, elite athletes are often under increased levels of anxiety or mental pressure when competing; for instance, when in the lead at the last shot in a biathlon, or when putting for a win in a golf tournament. Several researchers have shown that a successful performance under pressure is characterized by a longer QE duration compared to those who choked or did not perform at their maximum (see Vickers, 2016 for an overview). According to Vickers (2016), high pressure or anxiety divert cognitive resources from relevant tasks or stimuli, making it harder to maintain an efficient QE pattern. As a consequence, the level of performance is negatively affected (for an overview, see Wilson et al., 2015).

A commonly used induction of cognitive load is the Stroop task (Stroop, 1935). In order to investigate the effects of cognitive load, we used a reverse-Stroop task (Wood et al., 2016) in which the task was to ignore the color that a word was written in, and instead respond to what color the word spelled out. Cognitive load can be introduced in several ways (reduced time frame, ill defined task, increased level of difficulty, etc.). We use the Stroop-task since it is a commonly used and reliable method to increase the cognitive load, but we acknowledge at the same time that there are other forms of cognitive load not covered by the Stroop-manipulation.

Methodological Issues With Defining and Computing Quiet Eye

A fundamental question concerns the definition of QE; the traditionally used definition (Vickers, 1996) is a fixation for at least 100 msec, within an angle of three degrees of the target. This definition is probably linked to the technical capacity of mobile eye trackers at the time (normally a sampling rate of 50–60 Hz, and an accuracy of one degree at best), and the commonly used threshold of 100 ms as a minimum fixation duration. In this study, on the other hand, a high-resolution remote eye tracker (300 Hz sampling rate and accuracy typically < 1 degree) is used. This raises the question of whether Vickers's threshold of three degrees could be lowered, and how this would influence the QE. Furthermore, according to Vickers (1996), the QE period should dichotomously discriminate between "hits" and "misses," That is, a "hit" is when, i.e., a shot is within a designated target area, and a "miss" when it is outside that area. Williams (2016), however, argues that the reason why the QE period should discriminate dichotomously between hits and misses is not obvious. In many settings, there are no distinct borders clearly defining a "hit" area. Rather, the designated "hit area" comprises different sub-areas:

[1]The "hot hand" is the belief that an athlete's performance during a particular period of, i.e., a basketball match is significantly better than the average performance of the athlete (Gilovich et al., 1985).

the center area is a perfect hit, the area outside the center is close-to-perfect, and so on. This is typically the case for target areas seen in, e.g., trap shooting or archery. Accordingly, a more elaborate way could be to analyze performance as a continuous variable, i.e., to test if the gaze patterns related to QE correlate with the distance between the "bullseye" and the actual "hit."

The high-resolution eye trackers also allow us to analyze small eye movements dividing long fixations that may pass unnoticed with less-sensitive eye trackers. As Gonzalez et al. (2017) point out, the eye is seldom "quiet" and during the fixation of an eye, there are low-velocity drifts as well as high-velocity microsaccades. To what extent this affects not only our understanding of QE, but also of physical performance, remains unclear (for an overview of fixational eye movements, see, e.g., Collewijn and Kowler, 2008).

Esport and Quiet Eye

Esport is relatively new, but growing rapidly. Hamari and Sjöblom (2017) describe it as "a form of sports where the primary aspects of the sports are facilitated by electronic systems; the input of players and teams as well as the output of the Esports system are mediated by human–computer interfaces" (p. 211). Parallel to the gaming industry, the number of studies investigating the impact of gaming on different cognitive functions is rapidly increasing (for overview see Dale et al., 2020; Reitman et al., 2020). Many of the popular action video games (AVGs) have a first-person shooter perspective (i.e., *Counter Strike*, *Call of Duty*, *Doom*). AVGs often require focused attention and quick information processing in order to execute very precise and swift movements with the computer mouse combined with clicks, "shots," to hit targets on the screen. When comparing non-gamers with experienced gamers the latter typically show increased proficiency in a number of processing skills. Several studies using a meta-analytic approach (Powers et al., 2013; Wang et al., 2016; Bediou et al., 2018), have shown robust positive effects of AVG training on several cognitive functions. For instance, experienced gamers react faster, with a maintained accuracy level or hit rate (Gorbet and Sergio, 2018; Pardina-Torner et al., 2019). They also exhibit higher hitrate and lower false alarm rate than less experienced gamers, indicating a better ability to accurately ignore interferences, they perform better on perceptual discrimination tasks where the task is to identify small or low-contrast stimuli (Li et al., 2010). Some studies have also used eye trackers to investigate gaze patterns. For instance, Choi and Kim (2015) found a difference in general eye-movement patterns between novices and experts. This was also shown by Koposov et al. (2020), who found that experts responded more quickly to visual stimuli than novices. However, to our knowledge, there are no previous studies in which QE has been measured in relation to esport.

According to Vickers (2016), QE should be, if possible, measured *in situ,* something that imposes practical problems in many settings. The data become noisy or flawed due to artifacts such as rapid head movements and system inertia. Furthermore, the manual approach with predefined areas of interest[2] (AOI) does not always meet the necessary standard for reliable analysis (Kredel et al., 2017). Provided that similar differences in gaze patterns, as found *in situ*, can be reproduced under controlled laboratory settings, the laboratory is preferable, according to Williams (2016), in order to isolate and better understand the basic mechanisms. In the present study, we try to minimize the aforementioned problem, by using a context similar to esport. In esport a participant seated in front of a stationary screen, a setting similar to a computerized laboratory setting used in this study. Thus, it is possible to eliminate some of the problems connected to *in situ* recording of data.

It can be argued that a first-person shooter setting in esport has some similarities with, for instance, clay-pigeon shooting or skeet, in which the goal is to hit a target that suddenly pops up and moves fast. That is, you have to detect the target, aim and shoot in a very limited time frame. The area where the target appears is limited and the shooter is stationary. The dissimilarities are of course the "gun" and the muscular activation needed to aim and to execute a shot. As shown above, the onset and duration of the QE is predictive for the shooting performance (i.e., Causer et al., 2010) in various shooting contexts.

The overall goal of this article is to investigate whether the QE can be replicated in a context similar to esport setting, where participants use the mouse to "shoot" targets appearing on a computer screen. This includes directing, as quickly and accurately as possible, the mouse cursor to the location of the target and "shooting" (clicking on) it. The QE will be considered within and between participants. First, we will address the question of how task performance is associated with QE parameters; are "hits" generally associated with a longer a QE duration and a shorter QE onset? Second, we analyze whether high-performing participants show a more distinct QE behavior compared to low-performing participants. Furthermore, by mimicking a challenging or critical moment during game play, we want to manipulate the player's cognitive load. This is implemented by comparing a standard "shooting" task with a reverse-Stroop task. Finally, we utilize a state-of-the-art remote eye tracker, the Tobii Pro Spectrum, which provides data with higher sampling rates, accuracy, and precision in comparison to the data collected in previous studies of QE. The higher data quality offered by this eye tracker significantly increases the likelihood that participants' "true" oculomotor fixations are measured, thus providing a more valid analysis of QE behavior. This, in combination with the knowledge of the exact locations of the targets on the computer screen, allow us to explore more elaborate analyses of QE parameters.

MATERIALS AND METHODS

Participants

Twenty-three male university students between the ages of 18 and 30 with normal or corrected-to-normal vision volunteered to take part in the study. No data on dexterity were collected and the participants were free to choose which hand to wield the mouse with. All 23 participants were recruited on the campus area of Lund University. To estimate how familiar participants

[2] For a discussion on the problem with AOI, see Hessels et al. (2016).

were with FPS games, they were asked if they played FPS games more than 5 h a month (yes/no). Eleven participants reported playing five or more hours of FPS games per month, whereas the remaining 12 said they played less than 5 h of FPS games per month. Since many of the participants felt it was difficult to quantify their gaming experience this way, we did not take gaming experience into account in the analysis. In accordance with Swedish law regulating research projects involving humans (SFS, 2003:460), no application for ethical approval was needed.

Apparatus, Stimuli, and Procedure

Gaze data were recorded at 300 Hz using the Tobii Pro Spectrum (firmware 1.7.8) eye tracker and the Titta toolbox (Niehorster et al., 2020). Mouse cursor movement was recorded at 60 Hz using PsychoPy (Peirce, 2007, 2009). To synchronize mouse and gaze data, mouse position was sampled during a callback function that was called every time a gaze sample was generated by the eye tracker. The distance between the screen and the participant's eyes was 63 cm, and their heads were stabilized with a custom built chin-and-forehead rest. The test, aiming to simulate an FPS esport environment, was created in PsychoPy (Peirce, 2007, 2009). The test consisted of two blocks with 64 "shots" (mouse clicks) in each block and a 30-s pause between the blocks. Both blocks were preceded by a practice run (8 shots). In the first block, a cross appeared in the middle of the screen, and the participants were instructed to click on the cross. Once clicked, a circular target (0.65° in diameter) appeared on the screen after a delay randomly chosen from the interval 500–2000 ms, and stayed on the screen for 860 ms. The target appeared randomly in one of eight, evenly spaced directions (0, 45, 90, 135, 180, 225, 270, 315 deg) on a perimeter 12° from the cross in the center of the screen. The task was to, as quickly and precisely as possible, "shoot" the target by moving the cursor and clicking the mouse. If the target was hit, it disappeared; if it was missed or if 860 ms elapsed without any click on the target, it disappeared and the cross reappeared in the center of the screen, prompting the participant to initiate the next shot.

In the second block, a reverse-Stroop task was introduced in order to increase the cognitive load, concordant with previous research on cognitive load and the QE (Wood et al., 2016). After the participant clicked on the cross in the center, either the word "blue" or "red" written in either blue or red color was shown in the center of the screen for 1000 ms. After another 500 ms, two targets appeared, one blue and one red. The participants were instructed to ignore the color of the word, and instead shoot the target with the color corresponding to the word itself. Since this task was assumed to be a bit more difficult, the time that the participants were given was increased by 50 ms from 860 ms (subtest one 1) to 910 ms. Gaze behavior and cursor movement were recorded continuously throughout the tests. The first block was designed to work as a baseline in comparison to the second block in terms of cognitive load.

A five-point calibration followed by a four-point validation of the calibration accuracy was performed for each participant prior to each recording. A recording was allowed to start only if the average accuracy across the validation targets was below one degree, and the precision estimated by the root-mean-square (RMS) of inter-sample distances was less than 0.1 degree, for both eyes. All participants met these criteria.

Data Analysis

Quiet eye (QE) *onset* was the time from the appearance of the target until the onset of the last fixation within three degrees from the target before the mouse click. *QE duration* was operationalized as the time from *QE onset* until the end of the fixation that started at QE onset. *Mouse movement latency* was defined as the time from the appearance of the target to initiation of mouse movement, and was considered to happen when the mouse position was further than one degree away from the center of the screen, where the mouse was located at every trial onset. *Time to mouse click* was defined as the time from trial onset to the time when the "shot" was fired (the mouse was clicked).

Performance was quantified in two ways: first, as a binary hit/miss variable, and second, as a continuous variable operationalized as the distance between the center of the target and the position of the mouse cursor at the time of the mouse click. A "hit" was considered to happen if the mouse click was located on the target; otherwise the target was "missed." Trials where the mouse click occurred after the offset of the target were excluded from the analysis.

Fixations were identified using the I2MC algorithm (Hessels et al., 2017). Settings related to screen distance, screen size and recording frequency were adjusted according to our particular setup. For the remaining parameters, default settings were used. The minimum fixation duration was set to 100 ms. Only trials where participants clicked the mouse before target offset, and at least one fixation was located within a three-degree radius from the target prior to mouse click were considered. Moreover, QE onsets and mouse movement latencies shorter than 100 ms were excluded.

Data were analyzed with Python 3.6 and R (v. 1.0.2) using the lme4 package (v. 1.1.21). When using (generalized) linear mixed-effects models, participants were treated as random variables with random intercepts.

RESULTS

In total, 2644 trials were analyzed (23 participants each performing two tasks with 64 trials each). After excluding trials, as explained in the "Data analysis" section, 2311 trials remained. These were used in the remainder of the analysis.

An example of a trial is given in **Figure 1**, which shows how eye and mouse positions typically unfold over time (top row) and in space (bottom row). At trial onset, both mouse and gaze positions were located in the center of the screen. After about 250 ms (all trials: M = 230 ms, SD = 50 ms), a saccade was launched toward the target and shortly after, a mouse movement toward the target was initiated (all trials: M = 301 ms, SD = 55 ms). The QE fixation started directly after the initial saccade had landed on the target. The mouse was clicked before the disappearance of the target (860 ms), and the QE fixation continued for about another 140 ms.

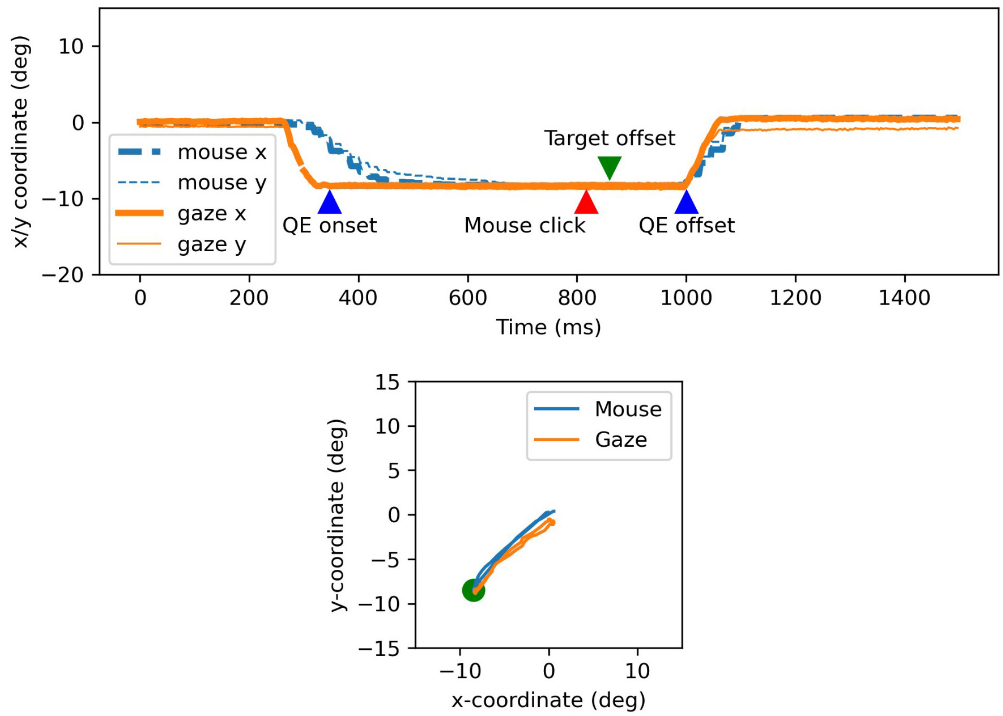

FIGURE 1 | Example of mouse and gaze data collected from one trial over time (top) and space (bottom). The green dot in the bottom subfigure represents the target. Data from the left eye are shown.

Mouse Results

Participants hit the targets in 88.1% (SD = 32.2) of the cases (low cognitive load: M = 88.8%, SD = 31.6%; high cognitive load: M = 87.6%, SD = 32.9%). There was no significant difference between the high and low cognitive load conditions, β = 0.10 (SE = 0.16), z = 0.68, p = 0.53. As the cognitive load increased (**Figure 2**), the mouse movement latency became significantly higher [Low: M = 295.2 ms, SD = 52.3 ms; High: M = 315.0 ms, SD = 57.8 ms; β = 17.2 (SE = 5.7), t = 2.9, $p < 0.01$] and the time to mouse click became significantly longer [Low: M = 785.9 ms, SD = 122.9 ms; High: M = 815.0 ms, SD = 138.5 ms; β = 42.9 (SE = 11.7), t = 3.6, $p < 0.01$]. Moreover, the time to mouse click was significantly longer for hits than for misses [Miss: M = 645.8 ms, SD = 164.1 ms; Hit: M = 821.5 ms, SD = 111.7 ms; β = 60.3 (SE = 10.1), t = 5.9, $p < 0.01$]. For mouse movement latency, there was no significant difference between hits and misses [Miss: M = 312.6 ms, SD = 62.1 ms; Hit: M = 304.4 ms, SD = 55.1 ms; β = −6.0 (SE = 4.98.1), t = −1.2, p = 0.23]. None of the participants clicked on ("hit") the wrong target in the high cognitive load (Stroop) block. The performance between the left (180 deg), right (0 deg), top (90 deg), and bottom (270 deg) directions ranged between 83% (left) to 91% (down) across both blocks. We fit a linear mixed effect model predicting

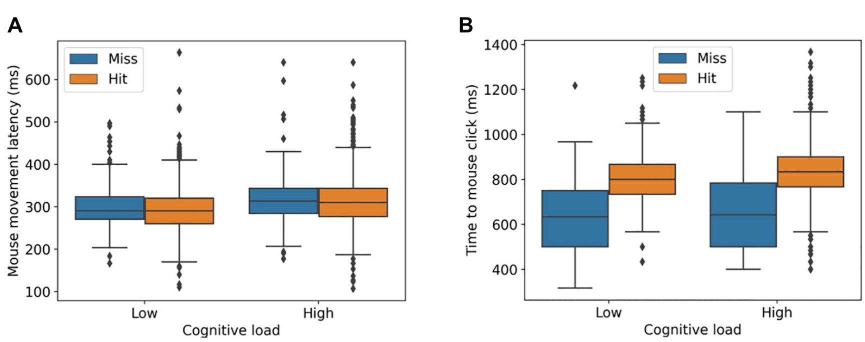

FIGURE 2 | Mouse movement latency **(A)** and time to mouse click **(B)** for different levels of cognitive load. Misses and hits denote when the mouse click is on the target (hit) and outside of the target (miss).

mouse hit accuracy (distance from mouse click to bullseye) from target position (left, right, up, down), using participants as random effects. Pairwise differences in accuracy between the target positions were tested using the emmeans package (v. 1.4.1). None of the pairwise differences was significant (all p-values > 0.33).

Eye Movement Results

There was a significant effect of cognitive load on QE onset (**Figure 3A**), where a higher cognitive load was associated with later QE onsets [Low: M = 379.8 ms, SD = 119.1 ms; High: M = 417.4 ms, SD = 5 131.6 ms; β = 46.1 (SE = 14.4), t = 3.18, $p < 0.01$]. However, there was no significant difference between hits and misses [Miss: M = 365.3 ms, SD = 130.4 ms; Hit: M = 403.6 ms, SD = 125.9 ms; β = 8.9 (SE = 12.3), t = 0.72, p = 0.46]. For QE duration, there was no significant difference between low and high cognitive loads [Low: M = 621.0 ms, SD = 203.3 ms; High: M = 589.3 ms, SD = 202.7 ms; β = −37.1 (SE = 22.0), t = −1.68, p = 0.09], but hits had significantly longer durations in comparison with misses [Miss: M = 464.7 ms, SD = 205.6 ms; Hit: M = 623.6 ms, SD = 195.8 ms; β = 40.5 (SE = 18.9), t = 2.14, p = 0.03].

The alternative way of analyzing the data, and in our opinion more elaborate, is to follow the suggestion by Williams (2016), where performance is regarded as a continuous variable. The center of the target is considered "bullseye" and the distance between the "bullseye" and the actual mouse click defines the accuracy of the mouse click. Also, since QE behavior may be influenced not only by hit accuracy, but also the time until the 'shot' is fired (hit speed), we model QE duration and QE onset as a function of both speed and accuracy. For QE onset, there was a main effect of speed [β = −2.82 (SE = 0.35), t = −8.04, $p < 0.001$), but not accuracy [β = −6.38 (SE = 4.40), t = −1.44, p = 0.15]. The main effect of speed means that the longer it takes to click the mouse, the earlier the QE onset is. For QE duration, both speed [β = 1.70 (SE = 0.53), t = 3.17, p = 0.002], and accuracy [β = −19.1 (SE = 6.84), t = −2.79, p = 0.005] were significant; later and more accurate mouse clicks leads to longer QE durations. There were no significant interactions, neither for QE onset nor QE duration ($p > 0.3$ in both cases).

To assess whether high-performing participants showed a more distinct QE behavior, the relationship between the hit accuracy QE onset and QE duration is plotted in **Figures 4A,B**, respectively, where each dot represents one participant. There was a significant Spearman rank-order correlation between

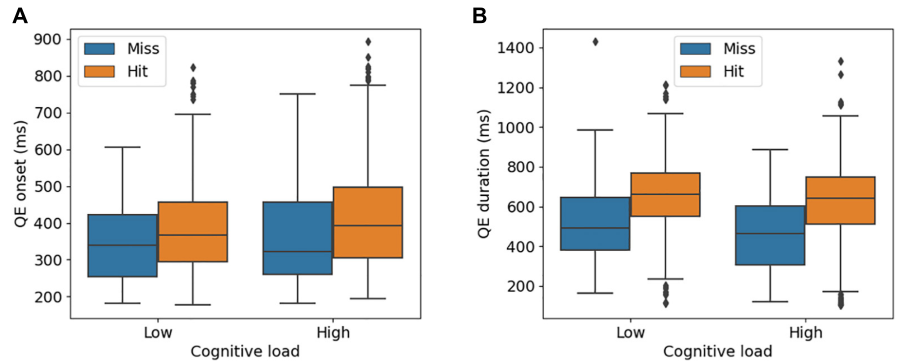

FIGURE 3 | Quiet Eye (QE) onset **(A)** and duration **(B)** for different levels of cognitive load. Misses and hits denote when the mouse click is on the target (hit) and outside of the target (miss).

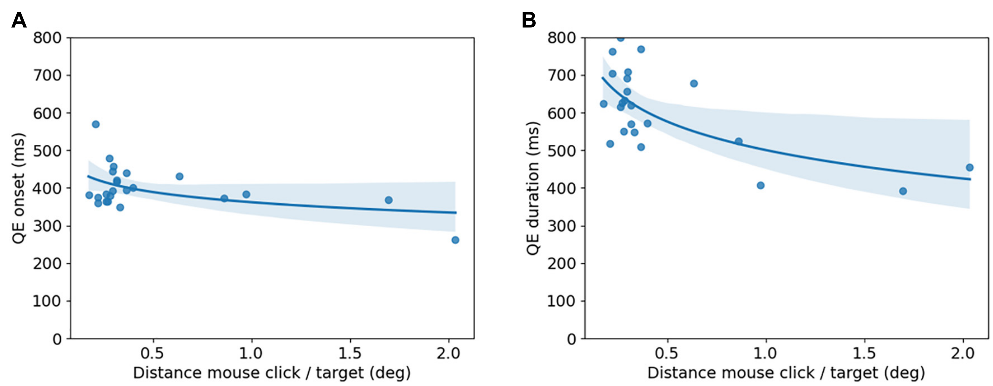

FIGURE 4 | QE onset **(A)** and duration **(B)** as a function of distance to the target at mouse click. Each dot represents one participant. The line shows a logarithmic fit to the data and the shaded area represents a 95% confidence interval. Note that mouse clicks both in (hits) and outside (misses) the target are included.

both D and QE onset (r = −0.46, p = 0.03), and D and QE duration (r = −0.75, $p < 0.01$), indicating a monotonicity of the relationship between the variables.

In the definition by Vickers (1996), a fixation is only classified as a QE fixation if it falls within three degrees of the target. Changing this value to two and four degrees changed the results only marginally. For example, the correlations in **Figure 4** changed from −0.75 (QE duration) and −0.46 (QE onset) when using a threshold of 3 to −0.71 (QE duration) and −0.39 (QE onset) for a threshold of 2, and −0.78 (QE duration) and −0.47 (QE onset) for a threshold of 4.

DISCUSSION

In this study, we have used a computerized precision task in a setup similar to those found in first-person shooter (FPS) e-games, in order to investigate whether findings about the "quiet eye" (QE), traditionally found in other sports-related tasks (e.g., shotgun shooting: Causer et al., 2010; basketball: Rienhoff et al., 2013; biathlon shooting: Vickers and Williams, 2007; dart-throwing: Nibbeling et al., 2012) generalize to a computer setup. Participants were asked to "hit" (click on) briefly appearing targets on a computer screen as quickly and accurately as they could in low and high cognitive load conditions. Most importantly, we could replicate the QE, with longer QE durations for "hits" than for "misses." Consequently, and consistent with previous work, a prolonged QE could be seen as an indicator of successful performance. However, unlike previous studies, we did not find a significant difference between hits and misses with respect to QE onset. Similar results were found when, instead of a binary hit-miss variable, analyzing performance as the relationship between the QE duration (or QE onset) and the distance between the mouse click and the target center ("bullseye"). Also considering the time it took until the mouse was clicked (speed), it became clear that the QE duration was influenced by both the speed and accuracy at which the target was clicked; longer QE durations were associated with both more accurate and later mouse clicks, but shorter QE onsets only with later mouse clicks.

Comparing QE parameters between participants, significant negative correlations were found between hit accuracy and QE duration/onset. **Figure 4B** showed, as expected, a prolonged QE duration for more accurate hits. **Figure 4A** showed, unexpectedly, that less accurate hits were accompanied by earlier QE onsets. This pattern is contrary to what has previously been reported in the QE literature. The reason for this is not clear and needs to be further studied.

One interpretation of the results in **Figure 4** is that different participants may have optimized on different behaviors when conducting the task. The task instruction to "as quickly and accurately as possible, 'shoot' the target" allows participants to optimize on either speed or accuracy. It is conceivable that participants with poorer accuracy (represented by dots in **Figure 4B**) tried to perform the task as quickly as possible while compromising accuracy. At the other extreme (represented by dots in **Figure 4A**), participants tried to use most of the available time on aiming and clicking as accurately as possible, leading to long QE duration on the target. Indeed there was a strong correlation between speed and accuracy, with a Pearson correlation of r = −0.83 ($p < 0.001$).

We argue that it is more informative to analyze performance as a continuous variable rather than as a dichotomous variable. The reason for this is that in many settings, performance is a question of absolute accuracy rather than "all or nothing." This is obvious in sports where the target consists of a graded scale, which is the case in, e.g., target shooting, where a "bullseye" or a "10" reflect a perfect hit, and lower values reflect less-accurate hits. Furthermore, we argue that this is also a more suitable form of analysis in other sports such as soccer, in which there is no static "bullseye." In such cases, you have a designated target (the goal), but in order to score a goal you have to get the ball past the goalkeeper. In one situation, this could mean targeting the area to the lower right, while in another situation it means getting the ball just below the bar to the left. In other words, the "bullseye" moves within the designated target (the goal). Measuring performance as a continuous variable makes it possible to get a more elaborate measure of the precision or skill in a particular task in any given situation, rather than just comparing it dichotomously. In biathlon, for instance, two athletes can have the same numbers of hits, but the hits can vary greatly in proximity to the bullseye. The same is probably true in other settings outside of sports. One example of where detailed analysis of gaze behavior and target hit accuracy could be useful is in the evaluation of police officers' ability to use various forms of countermeasures.

Besides the fact that our study is conducted with a computer setup with a screen and mouse, there are some important differences between many previous QE- studies and the current study First, in previous studies on, e.g., golf and basketball, the tasks are mostly self-paced and performed without a strict time pressure. In these tasks, accuracy is more important than speed, and it is difficult to adjust the movement of the hands/golf club during the actual movement execution. Here, at least for quick participants, there was a chance to correct the initial landing position of the mouse to obtain a more accurate hit.

In this study, we used a screen-based test similar to an FPS action video game. There are obvious technical advantages to using eye trackers in this context, since the experimental setting coincides with the setting used in esport: a relatively static participant in front of the computer screen. There are of course, other differences between the simple and static task used in this experiment and the very complex environment of a modern AVGs (multiple targets, moving targets, stress inducing situations, etc.), aspects that we intend to address in coming studies. Unlike the majority of previous studies investigating the QE using mobile, head-worn eye trackers, we have presented stimuli on a computer screen and used a high-end eye tracker (the Tobii Pro Spectrum) to collect eye movement data. Consequently, the data we have analyzed in this paper typically have higher sample rates, accuracy and precision in comparison with data in the older studies. This has several important implications. First, the original QE definition says that the eye gaze needs to be within three degrees of the target (Vickers, 1996). This probably reflects the (in)-accuracy of mobile eye trackers at that time. The accuracy of our data was below one degree for all participants, meaning that Vickers's threshold of three degrees is probably unnecessarily high. However, changing this threshold to two or four degrees did not change our results significantly. Second, and perhaps even more important, the higher sample rates and precision of the data make it easier to detect smaller saccades. Thus, the exact same oculomotor fixation of the eye may end up having a different (QE) duration when computed from data recorded with different eye trackers. More generally, the duration of the QE depends critically on a number of factors, including (1) the sample rate and precision of the data, (2) the particular algorithm used to detect it, and (3) the theoretical criteria that are used to separate larger voluntary saccades from microsaccades (*cf.* Poletti and Rucci, 2016). Consequently, the definition of the QE is intimately connected to data quality, data processing, and definitions of what fixations and saccades are (for a more detailed discussion on this topic, see Hessels et al., 2018).

From the first esport event held in 1972 at Stanford University, mainly for local students, esport has grown to a multi-billion-dollar industry, where the number of spectators of the most popular events, such as the world championship final of *League of Legends*, equals or surpasses "traditional" events such as Super Bowl, and the prognosis says that popularity is still rapidly increasing (NewZoo.com, 2020). The same can be said about the hardware and the programming behind the interface of the games, where the technical performance of computers powering the games has increased by several million percent over the two last decades. Research in the area of esports, however, has not experienced a similar increase. While it has grown from being practically non-existent in the early 2000s to now being spread across several academic fields (for a review of esport research, see Dale et al., 2020; Reitman et al., 2020), the number of published articles remains surprisingly low. This will probably change in the future, however. The results presented in this paper show that QE may also be beneficial in an esport context, and that esport practitioners should therefore be aware of its existence.

A difference in performance related to cognitive load has typically been found in various types of tasks (i.e., Wilson et al., 2015; Vickers, 2016). In this paper, higher levels of cognitive load led to a generally slower performance, indicated by a slower mouse movement initiation, a later mouse click on the target, and a later onset of the QE fixation. This likely reflects the additional time required to process both the possible mismatch between the color of the text and the meaning of the text, and visually discriminate between two possible targets instead of one. However, cognitive load did not significantly influence the duration of the QE. One particular challenge associated with manipulating cognitive load is its dynamic nature (e.g., Hanslmayr et al., 2008), and it is uncertain whether the Stroop manipulation used in this paper actually led to a higher degree of cognitive load at the moment of the critical event, the mouse click, and would thus influence QE duration. In order to further test the impact of cognitive load other types of manipulations than Stroop need to be investigated.

The participant sample consisted of university students who had not been pre-screened about their gaming habits. About half of the participants reported playing less than 5 h of FPS games per month, and the other half played more or equal to 5 h per month. Thus, it is unclear how the results in this paper would generalize to those from professional gamers, routinely playing FPS games several hours a week.

CONCLUSION

We have replicated the "quiet eye" (QE) effect, found in a variety of sports, using a high-end eye tracker in a computerized task similar to FPS computer games. QE, the duration of the last fixation before a motor action (in our case clicking the mouse on a target), predicts the performance outcome. We argue that a more elaborate way of analyzing the data is to treat them as continuous variables, that is, to look at the distance between the center of the target and the actual hit, rather than dichotomously looking at "hits" versus "misses." Both QE duration and QE onset were significantly negatively correlated with the distance between the mouse click on the target and the center of the target ("bullseye"). This latter correlation, however, was unexpected and needs to be further investigated.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MD, MT, AH, and MN contributed to conception and design of the study and wrote sections of the manuscript. MN performed the statistical analysis. MD wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.676591/full#supplementary-material

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