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Multidisciplinary aspects and performance in racket sports

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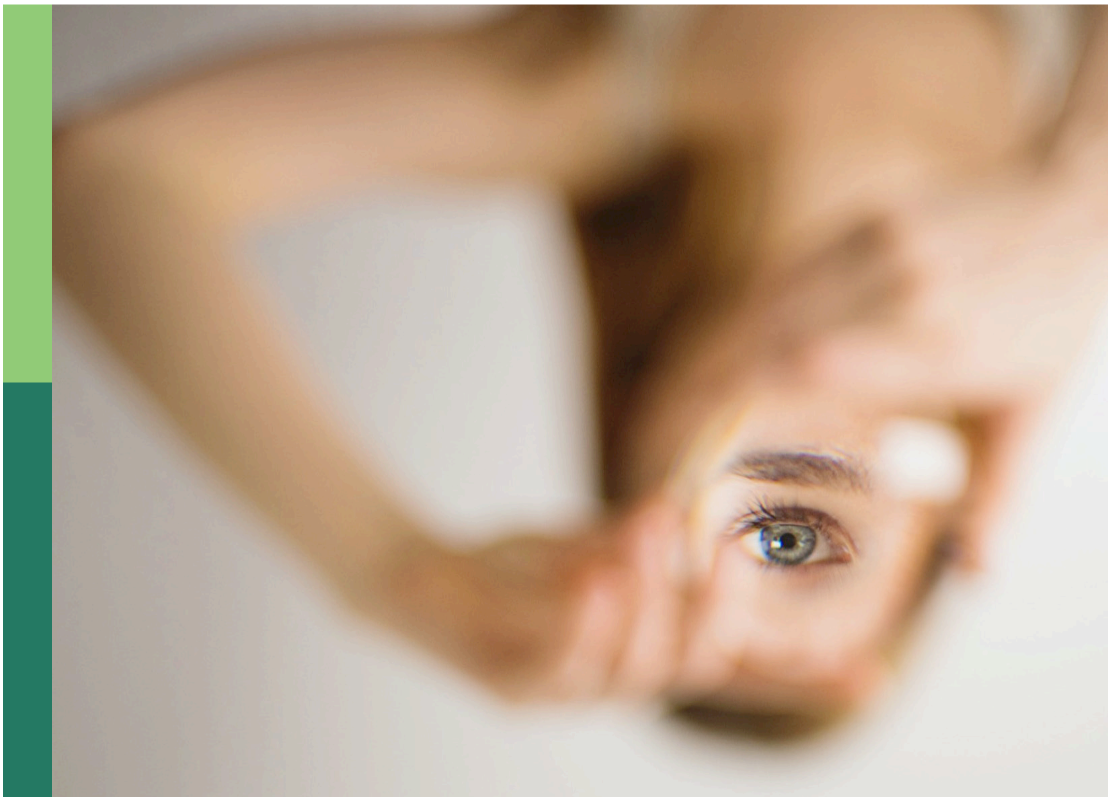

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Multidisciplinary aspects and performance in racket sports

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Editorial: Multidisciplinary aspects and performance in racket sports

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Editorial on the Research Topic
Multidisciplinary aspects and performance in racket sports

The convergence of disciplines such as exercise physiology, sport psychology, biomechanics, and nutrition has proven to be fundamental in enhancing sport performance (Hanton, 2006; Jeukendrup and Gleeson, 2019). By integrating knowledge and techniques from different fields, a deeper understanding of the factors that influence sporting success is achieved, allowing for the design of comprehensive strategies that maximize performance and prevent injury (Kraemer and Fleck, 2007). This interdisciplinary approach not only improves physical variables such as strength and endurance (Baechle and Earle, 2008), but also affects psychological aspects such as motivation and stress management, thus promoting sporting excellence in a holistic and sustainable manner (Williams, 1993).

Thus, in this Research Topic of Frontiers in Psychology, titled "*Multidisciplinary Aspects and Performance in Racket Sports*" we explore a comprehensive range of studies that elucidate the complex balance of physical fitness, psychological dynamics, physiological demands, and technical skills across various racket sports. This editorial aims to connect together the findings from these diverse studies, highlighting their unified implications for athletes, coaches, and sports science professionals.

Physiological demands across different racket sports are systematically reviewed by Cádiz Gallardo et al., emphasizing sport-specific training needs and health benefits. This study serves as a crucial reference for tailoring athlete training regimens according to the unique demands of each sport. Following the topic of physical and physiological aspects, an innovative study by Pradas de la Fuente et al., provides a detailed assessment of physical fitness in young high-level table tennis players. This research not only outlines differences based on sex, age, and playing style but also sets a precedent for how such data can guide targeted training programs, potentially developing performance and career longevity in table tennis. Related with these aspects, the innovative work by Zhou et al. in the field of training methodology examines the effects of combined balance and plyometric training on knee function and proprioception in elite badminton players. This study not only expands the understanding of effective training techniques but also highlights the importance of comprehensive training regimens that address multiple aspects of athlete development.

Parallel to physical fitness, psychological readiness plays a pivotal role in sports. Conde-Ripoll et al. investigate precompetitive anxiety and self-confidence among high-level men's padel players. Their findings underscore the importance of psychological management in achieving peak performance, particularly how anxiety levels fluctuate with competition stages and outcomes, while self-confidence remains comparatively stable. In a related manner, Castillo-Rodriguez et al. expand on the psychological aspects by examining how playing category, BMI, and experience influence precompetitive anxiety and self-confidence in padel players. Their study reveals that higher categories are associated with higher self-confidence and lower somatic anxiety, indicating that psychological traits could be as critical as physical skills in determining sports performance.

From a technical perspective, Pradas et al. provide interesting insights into the sex differences in serve strategies and returns among elite table tennis players. Their work suggests that these differences may reflect broader physiological and psychological variations, which could inform more personalized coaching strategies. Also, on the technical side of youth training, Touzard et al. investigate the effects of racket scaling on serve biomechanics in young tennis players. Their findings support for a cautious approach to equipment scaling, which is vital for optimizing development and minimizing injury risks. The development of young athletes was also explored by He et al., investigating how family background influences self-efficacy in adolescent table tennis players, with technical learning engagement playing a mediating role. This study suggests that early interventions aimed at enhancing engagement can be particularly beneficial.

Turning the focus to the officiating side of sports, Li and Li's study on tennis officials in China addresses job satisfaction and turnover intentions, pointing to the critical need for supportive structures that promote a sense of community and motivation. This highlights an often-overlooked aspect of sports ecosystems, where the wellbeing of officials can indirectly influence the quality of the sport itself.

Together, these studies offer a rich understanding of insights that reinforce the multidimensional nature of racket sports. They collectively advance our understanding of how physical and psychological factors interact to structure athlete performance in these dynamic sports. As we continue to uncover these complex interactions, our strategies for training, competition, and management in racket sports will undoubtedly evolve, promising enriched outcomes for athletes at all levels.

Author contributions

RM-G: Writing – original draft, Writing – review and editing. BS-A: Writing – original draft, Writing – review and editing. GV: Writing – original draft, Writing – review and editing. JR-L: Writing – original draft, Writing – review and editing.

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Level of Precompetitive Anxiety and Self-Confidence in High Level Padel Players

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The objectives of the present study were firstly to evaluate precompetitive anxiety and self-confidence (SC) in padel players according to their playing level; and secondly, to study the factors that influence the levels of precompetitive anxiety and SC. One hundred padel players, all of whom were federated men (age: M = 27.6, SD = 7.5 years; weight: M = 73.4, SD = 9.8 kg; height: M = 175.6, SD = 7.5 cm) participated in the research. The CSAI-2 (*Competitive State Anxiety Inventory-2*) questionnaire was used and a one-way ANOVA and a two- and three-ways MANOVA were conducted. The results show that the players from a better category had higher scores in SC and lower scores in somatic anxiety (SA) (η^2 = 0.10 and η^2 = 0.12, respectively). Moreover, the factors of category, body mass index (BMI) and experience, predicted 82% of the variance explained by the SC of the player. As a conclusion, this study has made it possible to ascertain that the playing category, understood as the level of the padel players, determines the levels of anxiety and SC and represents a key factor for the prediction of sports performance.

Keywords: anxiety, self-confidence, category, competition, raquet sports, padel

INTRODUCTION

Padel is a sport racket, that uses tennis rules (García-Benítez et al., 2018), played in pairs on a 20 m × 10 m court divided in two areas by a net where the enclosing walls are a part of the game (Rivilla-García et al., 2019). Matches are the best of three sets using tennis scoring (Ramón-Llin et al., 2019). Torres-Luque et al. (2015) found in elite players a mean of 9.30 s per point and 9.38 shots per point, in matches lasting 57 min. The development of these shots continuously and with such a short duration could cause a stress situation that can occur permanently prior to official competition matches (Jiménez et al., 2012).

The study of psychological factors can be of great importance for an athlete's performance (Giske et al., 2016). Different qualities and psychological skills, like stress and anxiety control, self-confidence (SC), communication, team cohesion, motivation, mood states and, concentration, could fluctuate over time as they are not fixed and innate states, and are susceptible to improvement in time, thanks to the training of psychological skills (Guillen and Feltz, 2011) and thus, can improve sports performance (Mathers and Brodie, 2011; Slack et al., 2015; Díaz et al., 2019).

Racket sports present different physical, physiological and psychological demands, among others, due basically to the nature of play, i.e., intermittent sprints with incomplete recovery

(Alvero-Cruz et al., 2009; Courel-Ibáñez et al., 2017) and constant decision-making which implies processing a large quantity of information in a short interval of time (Castillo-Rodríguez et al., 2014a), which generates high responses of anxiety and stress due to the cognitive and emotional pressure experienced.

On the one hand, anxiety in the moments prior to sports competition refers to the temporary emotional state characterized by subjective sensations of apprehension and tension, accompanied by activation of the autonomous nervous system (Martens et al., 1990). On the other hand, stress defined as a psychophysiological response of the athlete to threatening events (Jiménez et al., 2012), is triggered by the absence of adequate coping strategies that permit the redefinition of the situation as non-threatening on the part of the athlete (Alonso-Arbiol et al., 2005). These levels of anxiety and stress generated by athletes have increased due to the number of competitions that are currently organized and the high level of physical preparation thus required by the athletes to face them (Ruiz and Lorenzo, 2008), resulting in performance problems if this high level of activation is maintained.

Similarly, the SC of the athlete, which is the belief that he or she can act successfully (Robazza and Bortoli, 2007), has a positive relation with sports performance (Díaz et al., 2008), although up to an optimal point, as an excess of SC decreases these levels of performance (Weinberg and Gould, 1996). The relations between anxiety and SC and sports performance have been an object of study for decades. Thus, there is a clear consensus that indicates an inverse relation between anxiety and sports performance and SC (León-Prados et al., 2011), specifically, low levels of SC suggest higher levels of cognitive anxiety (CA) (Pinto and Vázquez, 2013) and a high level of anxiety suggests a lower sports performance (García-Mas et al., 2011; Ries et al., 2012), which leads us to consider the initial hypothesis that athletes with a better sports performance, who play in higher categories, possess lower levels of anxiety and higher ones of SC than athletes in lower categories.

Martens et al. (1990) developed an instrument to analyze the constructs related to anxiety and SC called the Competitive State Anxiety Inventory-2 (CSAI-2), which was identified as one of the most commonly used tools for analyzing these constructs (Morillo Baro et al., 2016). CA is characterized by an understanding of the negative expectations and cognitive worries that a person has about him or herself and their environment; and somatic anxiety (SA) is manifested through signs of physiological activation, e.g., degree of muscle tension, and increase in heart rate, among others (Andrade Fernández et al., 2007).

In racket sports, it was found that tennis players from a higher category showed a strong inverse relation with precompetitive anxiety (Ryska, 1998), and moreover, the tennis players that won official competitions, had presented lower levels of CA and SA than those who eventually lost (Covassin and Pero, 2004). However, in spite of these investigations, there is no scientific evidence from the study of the responses of anxiety and SC prior to sports competition in padel players. Recently, a study has described stress control in padel players between 20 and 35 years of age without specifying their category or skill level (Almendros-Pacheco et al., 2022). Therefore, the objectives of the present study were first to assess the states of anxiety and SC prior to competition in padel players, bearing in mind their playing category; and secondly to study the factors that influence the levels of precompetitive anxiety and SC.

MATERIALS AND METHODS

Participants

One hundred athletes participated in this study. Their characteristics can be seen in **Table 1**. They belonged to different playing categories (C1, C2, and C3), according to the structural composition of teams proposed by the Spanish Padel Federation. Most of the participants were Spanish, except 4 who were Argentinian. All the championships evaluated were of a national nature. Different categories were added according to the category usually played by the subjects during the last year. All players were informed about the characteristics and objectives of the study and signed an informed consent form. The research was conducted according to the indications established in the Declaration of Helsinki (2013) and the Ethics Committee of the University of Granada gave its approval (Ref. n° 471/CEIH/2018).

Instruments

Weight and height were assessed through a wall-mounted stadiometer (Seca 220, Hamburg, Germany), and a calibrated electronic digital scale (Seca 769, Hamburg, Germany), respectively. Players were analyzed on the match day because they came from different Spanish cities, corresponding to their usual place of residence. Therefore, all of them did not come fasting, but all of them had eaten juice and bread at least 2 h before the competition.

The CSAI-2 (*Competitive State Anxiety Inventory-2*) questionnaire by Martens et al. (1990) comprising 27 items with a Likert scale of 1–4, was administered. This questionnaire assesses the two basic components of anxiety. The first is the state of CA or worry about a possible failure and the adverse consequences that derive from it, which manifest as negative thoughts, restlessness and doubt, negative expectations and loss of concentration. The second component refers to the state of SA or elevation of the level of activation of physiological functions (heart rate, respiration, and muscle tension, among other symptoms) which produce nervousness and tension. As well as the cognitive and somatic components, a third component is identified, SC, which is conceptually similar to perceived self-sufficiency. In this study, Cronbach's alpha has been analyzed in the psychological variables (CA: 0.702; SA: 0.771; SC: 0.839).

Procedure

The participants in this research were selected in an intentional and stratified manner, i.e., the possible participants were divided into categories and a small number of cases were selected to be studied in depth in each competition. These championships were held in Spanish cities with altitudes varying between 15 and 106 m above sea level. The environmental conditions were very similar in all the matches analyzed, with a temperature of between 19–23°C and between 40 and 56% humidity. The questionnaire was

TABLE 1 | Characteristics of padel players depending on the category.

		C1 (*N* = 26)	C2 (*N* = 16)	C3 (*N* = 20)	*P*	η^2
Age	(years)	27.96 ± 6.16	27.11 ± 9.39	27.97 ± 6.98	0.768	0.05
Weight	(kg)	78.62 ± 10.0[2]	68.10 ± 8.02[1]	73.44 ± 11.5	0.001	0.27
Height	(cm)	176.0 ± 7.45	174.0 ± 7.65	176.7 ± 7.24	0.465	0.09
BMI	($kg \cdot m^{-2}$)	25.35 ± 2.49[2,3]	22.48 ± 2.08[1]	23.48 ± 2.89[1]	0.001	0.31
GT	(hours/week)	2.60 ± 3.05	1.78 ± 3.17	1.21 ± 1.65	0.068	0.16
ST	(hours/week)	14.44 ± 13.4[3]	13.33 ± 13.1	7.15 ± 8.81[1]	0.025	0.19
TT	(hours/week)	17.04 ± 14.3[3]	15.11 ± 12.2	8.36 ± 9.00[1]	0.008	0.22
Experience	(years)	6.52 ± 4.04[3]	6.78 ± 5.03[3]	4.00 ± 2.47[1,2]	0.007	0.22

C1: players of highest category; C2: players of moderate category 2; C3: players of lowest category. ANOVA test ($P < 0.05$); Bonferroni Post hoc test: [1]Differences with C1; [2]Differences with C2; [3]Differences with C3; GT, General training; ST, Specific training; TT, Total training; Experience: Experience of padel.

administered to the players 60 min before the start of the match. Moreover, demographical data was also recorded like years of experience, general training hours per week, padel training hours per week and playing category. Measurements were subsequently obtained for weight, height and age, and body mass index (BMI) was calculated.

Statistical Analysis

The statistical analyses were performed with *SPSS for Windows v.20.0* (*SPSS Inc*., Chicago, IL, United States). The normality of the variables was assessed with the Kolmogorov-Smirnov test and the size of the sample was calculated with an α value of 0.05. Descriptive and comparative analyses were then conducted with the category factor with 3 levels (ANOVA and Kruskal Wallis for non-normal variables) and correlations (Pearson's coefficient and Spearman's Rho for non-normal variables). Additionally, a two-way (category-experience and experience-BMI) MANOVA (multiple analysis of variance) and a three-way (category-experience-BMI) MANOVA were performed. Effect size ($\eta 2$) was also analyzed which quantified the size of the difference that exists between both groups. According to this, we could say that this is a true measure of the importance of the said difference (Coe and Merino, 2003). The threshold values for the Cohen effects sizes in the ANOVA test were small: 0.10; moderate, 0.25; and large, 0.40 (Cohen, 1988). The *post hoc* analysis was adjusted with the Bonferroni test and the accepted significance level was $P < 0.05$.

RESULTS

The results found using the one-way ANOVA indicated significant differences between C1 and C3 in the responses to SA and SC (**Figure 1**). A lineal decrease in SA can be observed according to the playing category [$F_{(1,97)} = 7.888$; $P < 0.01$; $\eta^2 = 0.12$]. With regard to SC, the players at the C3 level scored 31.29 ± 5.6 points and those at the C1 level 35.25 ± 4.9 points [$F_{(1,97)} = 5.474$; $P < 0.01$; $\eta^2 = 0.10$].

The correlations between the psychological variables according to the playing category were then analyzed (**Table 2**). These correlations differ among the categories, although SA and SC showed mean negative relations in all the categories ($r = -0.34$ and -0.54; $P < 0.05$).

With respect to the relation between the psychological variables and the category and training, an inverse relation was found between experience and category (rho = –0.26, $P < 0.01$) and SC was found to relate to this experience and category ($r = 0.21$ and -0.30; $P < 0.05$; respectively; **Table 3**).

Finally, CA was influenced by the experience and category of the player [$F_{(1,23)} = 2.189$, $P = 0.02$, $\eta^2{}_p = 0.42$], so that it was greater in more experienced players. Moreover, SC was influenced by a significant interaction between the factors Category-Experience-IMC [$F_{(1,22)} = 11.170$, $P = 0.001$, $\eta^2{}_p = 0.60$]. The *post hoc* Bonferroni comparison indicated high values of SC in C1 with regard to C3 ($P < 0.001$). Finally, SA was influenced by the factors experience-BMI [$F_{(1,22)} = 3.600$, $P = 0.01$, $\eta^2{}_p = 0.45$], in which SA was lower when BMI was higher.

DISCUSSION

The objectives of this study were firstly, to assess CA, SA, and SC prior to sports competition in padel players according to playing category; and secondly, to analyze the factors that influence the levels of precompetitive anxiety and SC. As an initial hypothesis it was established that the players from a higher level or category would score higher values in SC and lower values in CA and SA. This hypothesis was accepted in part, as the results indicated that the levels of SA were lower and those of SC higher in the padel players who participate in the highest category. This may be due to the fact that the SC of an athlete increases as they accumulated victories in competition, as determined by Weinberg and Gould (1996). Thus, the higher the number of wins, the greater the probability of playing in a higher category the following season. The 80% of the points scored in padel were carried-out at the net (Torres-Luque et al., 2015), using the volley technique. This fact allows us to know that these players increase their SC during the game and after it (Muñoz et al., 2017).

These results between the playing categories could be compared with other studies in the sport of tennis, as until now, there have been no studies on this topic in padel. Lundqvist and Hassmén (2005) indicated that high level tennis players scored lower values of SC with 31.1 ± 7.6 points, compared

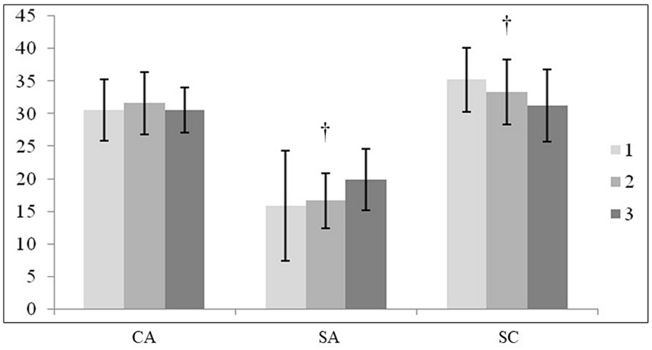

FIGURE 1 | Differences in the anxiety and self-confidence variables between the 3 game categories. †: Indicates differences between categories 1 and 3. 1: Category 1; 2: Category 2; 3: Category 3; CA, cognitive anxiety; SA, somatic anxiety; SC: self-confidence.

to the padel players. However, they confirmed their superiority with respect to players from C3 with 28.4 ± 7.5 points, they were also considerably below those found in padel, also showing significant differences between these categories. Although the CSAI-2 test was administered at the same time before the competition (60 min), the difference in scores could be due to the lesser experience of these tennis players. It has been shown that SC is affected by the category, experience, and BMI factors. Moreover, in this same sport of tennis, studies both in players from C1 by Cervelló et al. (2002) and Letelier (2007), and in players from C3 by Ryska (1998) showed a clear difference in SC compared to those of padel (26.0 ± 8.0; 27.9 ± 4.5, and 24.69 ± 6.6, respectively). Only in the study by Covassin and Pero (2004) had a similarity been confirmed in the responses on SC, in tennis players from C2 (32.0 ± 3.6 points), using in all cases the same instrument (CSAI-2). Finally, we could state that SC may be an important factor for differentiating elite and non-elite athletes, as also indicated in the study by Li et al. (1999). This SC was explained in up to 82% of the variance through the category, experience, and BMI factors.

With regard to anxiety, the playing category more than experience has a strong inverse relation with precompetitive anxiety (Ryska, 1998). This study showed a clear difference between the players from C1 and C3 ($P < 0.05$; **Figure 1**). However, both CA and SA were influenced by experience and BMI. On the one hand, CA was higher in experienced players. The player's experience is proportional to the expectation of success and thus corresponds to a greater manifestation of concern (response of CA). Thus, it is recommended to include a program for training psychological skills to attenuate this high level of CA (Mathers and Brodie, 2011; Slack et al., 2015). On the other hand, SA was lower when the BMI is higher, basically because the players with more muscle mass are those with a greater BMI and thus, less anxiety. An inverse relation has been found between specific training and SA, which denotes more muscle mass.

Playing category was related to SA which was lower in higher categories ($P < 0.05$), confirming that the players from C1 showed less SA than those from C3. These results were similar to those found in the study by García et al. (2009), who observed that the scores for precompetitive anxiety gradually diminish ($P < 0.05$), as the playing level or category increases (regional, national, and international). This difference in SA may be due to different factors like for example the player's self-concept, age, experience, and morphology, in which a greater mesomorphic component stood out in players from C1 (Castillo-Rodríguez et al., 2014b). Furthermore, the higher the player's level, the more distance was covered at lower speeds that may be due to efficiency in the first category players' movements (Mellado-Arbelo and Baiget, 2022). This efficiency in highest level players, could be the cause of having the

TABLE 2 | Correlation coefficient between psychological variables.

	SA	SC
High level (C1)		
CA	0.72**	−0.26
SA		−0.34*
Moderate level (C2)		
CA	0.10	0.21
SA		−0.54**
Low level (C3)		
CA	0.27	−0.10
SA		−0.45**

*$P < 0.05$; **$P < 0.01$; CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence.*

TABLE 3 | Relationship between psychological variables and category, experience, BMI and specific training.

	Cat	CA	SA	SC
Experience	−0.26**	0.05*	0.01**	0.21**
Cat		−0.01*	0.38**	−0.30**
BMI		−0.21*	−0.34**	0.17**
ST		−0.12*	−0.19**	0.02**

*$P < 0.05$; **$P < 0.01$; Cat, Category; CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; ST, specific training (raquet).*

lowest SA showed in this study. In contrast, in golf, an inverse progressive increase was evident, that is, the higher the playing level, the greater the levels of anxiety, due to the physiological and psychological requirements characteristic of this sport (Chamberlain and Hale, 2007).

This study has some strengths. First, it is the first study to analyze anxiety in padel players prior to official competition. Secondly, it has been shown that the padel players of higher category or expertise, are those who have less anxiety and greater SC before a padel match. Finally, it has been shown that age, experience and BMI are factors that predict 80% of the variance explained, the SC of the padel player. However, the present study has several limitations. Due to the decrease in statistical power (effect size) the women players were excluded from the initial database. For future studies, researchers are encouraged to assess if behavior regarding anxiety and SC is similar in both genders. Moreover, it is recommended to record the final result of the matches, to analyze if in the end precompetitive anxiety influences the victory or defeat of the players. In the present study, the fat and muscle mass of the players have not been analyzed, which would be interesting to contrast that the players with the highest BMI are those with the greatest muscle mass, and even be able to make more rigorous statements regarding to these anthropometric variables. The authors consider that the BMI value in performance should not be treated in isolation.

To conclude, levels of anxiety and SC prior to sports competition have been described in padel players according to playing category. The main findings show that the levels of SC increase linearly as the player progresses to a higher category and this construct is predicted by the factors of category-BMI-experience in 82% of the explained variance. Specifically, category represents 28.4% of the explained variance in precompetitive SC in padel players. Lastly SA decreases linearly the higher the category of the padel player, confirming that players from lower categories could include intervention programs to improve psychological skills with the aim of facing competition with fewer psychological states related to anxiety, in the same way as they are recommended for players in the highest category to avoid dropping to a lower one.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

AC-R, JF-G, AH-M, and JA-C contributed to the conception and design of the study. AC-R and WO-O organized the database. AC-R, JF-G, and JA-C performed the statistical analysis. AC-R, WO-O, and JA-G wrote the first draft of the manuscript. All authors wrote sections of the manuscript, and contributed to manuscript revision, read, and approved the submitted version.

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Combined balance and plyometric training enhances knee function, but not proprioception of elite male badminton players: A pilot randomized controlled study

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Objectives: To investigate the effect of combined balance and plyometric training on knee function and proprioception of elite badminton athletes.

Methods: Sixteen elite male badminton players (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) volunteered to participate and were randomly assigned to a combined balance and plyometric training (CT) ($n = 8$) and plyometric (PT) group ($n = 8$). The CT group performed balance combined with plyometric training three times a week over 6 weeks (40 min of plyometrics and 20 min of balance training); while the PT group undertook only plyometric training for the same period (3–4 sets × 8–12 reps for each exercise). Both groups had the same technical training of badminton.

Results: The knee function and proprioception were assessed at baseline and after the intervention by measuring the performance of single-legged hop tests (LSI_O, LSI_T, LSI_C, LSI_S), standing postural sway (COP_{AP}, COP_{ML}), and LSI of dominant leg and non-dominant leg. The results showed that as compared to PT, CT induced significantly greater improvements in LSI_T and LSI_S ($p < 0.001$) and significant greater percent increase in N_{AP} ($p = 0.011$). The changes in LSI_O, LSI_C, D_{AP}, N_{AP}, LSI_{AP}, D_{ML}, N_{ML}, and LSI_{ML} induced by CT did not differ from that induced by PT ($p > 0.213$).

Conclusion: In elite badminton players, intervention using CT holds great promise to augment the benefits for knee function compared to the intervention using PT only, and at the same time, with at least comparable benefits for proprioception. Future studies are needed to examine and confirm the results of this study.

KEYWORDS

plyometric exercise, physical conditioning, knee, postural balance, badminton

Introduction

Badminton is considered as one of the fastest racket sports (Phomsoupha and Laffaye, 2015; Abdullahi and Coetzee, 2017; Gómez et al., 2021), requiring frequent quick starts, stops, lunges, and changes of direction (Shariff et al., 2009; Hong et al., 2014). These high-intensity and quick movements and reactions in badminton significantly increased the risks of injuries to lower extremities, such as anterior cruciate ligament (ACL) injury of knees, one type of injury that frequently occurs in badminton athletes (Kimura et al., 2012; Alikhani et al., 2019; Zhao and Gu, 2019). In addition, badminton matches require players to adjust their body position continuously throughout the game, in which their capacity of dynamic balance to maintain their center of gravity within the base of support to react to the moving shuttlecock (Faude et al., 2007; Chang et al., 2013). Strategies aiming to improve knee function and proprioception are thus beneficial for the on-court performance of badminton players and can help reduce the risk of injuries (White et al., 2013).

One such strategy is plyometric training (PT), of which the goal is to improve lower limb strength, knee function (e.g., isokinetic muscle strength test and single-legged hop tests), and movement pattern of landing (e.g., depth jump and continuous jump) (Hewett et al., 2010) by shortening muscle eccentric-concentric contraction cycle [also termed as a stretch-shortening cycle (SSC)] (Markovic and Mikulic, 2010; Ramírez-delaCruz et al., 2022). Studies have shown that PT can enhance the sport performance of athletes, such as strength (Asadi, 2012), running economy (do Carmo et al., 2022), agility (Maciejczyk et al., 2021), and sprint ability (Markovic and Mikulic, 2010), as well as reducing ACL injury risk. Alikhani et al. (2019) observed that, for example, 6-week PT significantly improved dynamic balance and knee proprioception in female badminton players by enhancing their functional adaptations and neural recruitment of motor units that activate appropriate muscles before landing and the proprioceptive inputs.

More recently, studies have emerged to combine PT with other training programs and observed that this combined training (CT) can significantly augment the benefits of using PT only for knee function and proprioception (Nessler et al., 2017). These kinds of CT can simultaneously enhance multiple aspects contributing to knee function and proprioception, target reflexive response and proprioception, and help adjust the body positioning while landing with correct knee and hip position (Hewett et al., 2006). The study of Wedderkopp et al. (2003) for example, showed that combined training of balance and strength is of great promise to reduce the incidence of injuries in young female handball players. Additionally, several of our previous studies showed that combined training of balance and PT significantly improved the capacity to adjust the direction of movements and dynamic balance, which are essential for athletic performance and the prevention of injury risk (Guo et al., 2021; Lu et al., 2022). These findings suggest that compared to PT only, CT may induce greater benefits for athletes of badminton by simultaneously augmenting their knee function and proprioception, which, however, have not been examined.

Therefore, this pilot randomized controlled study aims to characterize the effects of a 6-week CT with balance training and plyometric training on knee function and proprioception in a group of elite badminton players and examine if this kind of CT can induce greater benefits as compared to PT. Participants completed the CT and PT of the same training protocol as validated in our previous studies (Guo et al., 2021; Lu et al., 2022). Specifically, we hypothesize that the CT protocol would induce a significant increase in performance (e.g., single-legged hop tests and center of pressure) pertaining to knee function and proprioception compared to PT.

Materials and methods

Participants

Sixteen healthy elite male badminton players were recruited in the study. The inclusion criteria were: (1) Elite players who had won the top four of national youth games and provincial games, or higher-level games; (2) The dominant arm or leg is the right side; and (3) the ability and willingness to complete the 6-week programs of tests and intervention. The exclusion criteria were: (1) Participants had ACL, hamstring, meniscus, ankle, or any other lower-extremity injuries during the last 3 years, and (2) Limb Symmetry Index (LSI) of single-legged hop tests were < 85%. Eight players entered the quarterfinalists of national youth games and the rest entered the finals at the provincial level. All the participants were from the same club, all right-handed, and undertook three training sessions per week each of which consisted of 2–3 h of technical and physical training sections. The study protocol was approved by the Research Ethics Committee of Beijing Sport University (Approval number: 2020008H), and all procedures were conducted in accordance with the Declaration of Helsinki. 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.

Procedures

All experimental training programs were conducted along with a weekly technical training routine. Participants were randomized into the group of CT (n = 8) and the group of PT (n = 8) (**Table 1**). Before the initiation of the study, all participants completed a 2-week familiarization (three sessions per week) with the same training protocols as used in the following intervention in this study. During the intervention period, participants in CT group completed the intervention that combining the balance training and PT. Specifically, they completed three sessions of CT per week for 6 weeks (i.e., 18 sessions). Within each session of CT, they were asked to complete 40 min of PT (e.g., depth jump and lateral barrier jump) and then 20 min of balance training that was performed on an unstable support (e.g., BOSU ball, Swiss ball, and Balance pad). In PT group, participants also completed three sessions of PT per week for 6 weeks. To ensure a similar training load between CT and PT group, in each session the participants in PT group first completed 40 min of PT and then 20 min of balance training that was the same as CT group, but on the stable support (i.e., solid floor). The recovery period of 24–48 h was provided between each training session. The details of the protocols of balance training and PT were included in **Supplementary Material**.

Single-legged hop tests hold potential as predictive factors of knee function in individuals to evaluate the risk of ACL injury and discriminate between those individuals who return to previous activity level after ACL injury or reconstruction (**Figure 1**; Noyes et al., 1991). The single hop for distance, triple hop for distance, cross-over hop for distance and timed for 6 meters hop were measured, respectively. Smart Speed device (Fusion Sport, Coopers Plains, Australia) was set for Time for six meters hop to record the time. After hopping, participants needed to stand with a single leg for 2 s to make results effective. Participants were asked to jump three times every leg in each test, and the longest distance and the shortest time in the three tests were taken as the final data when the four tests' lower LSI was calculated. LSI was counted as the ratio between the non-dominant leg and dominant leg while timed for 6 meters hop was calculated by dominant and non-dominant in the division. Four kinds of LSI were defined as LSI_O (Single Hop for Distance), LSI_T (Triple Hop for distance), LSI_C (Cross-over for distance), LSI_S (Time for 6 meters Hop) in this study. When LSI $\geq$ 85%, there is no risk of ACL injury; and LSI < 85%, ACL is at risk of injury (Noyes et al., 1991).

The proprioception test was used to assess the balance performance of players by the center of pressure (COP) (Sell, 2012), which evaluate the proprioception of players to observe the injury risk of knee or ankle (Thompson et al., 2017). Participants stood on an in-ground force plate (Kistler 9281CA, KISTLER, Winterthur, Switzerland, 1,000 Hz) and stood with a dominant or non-dominant leg for 10 s. MATLAB software (r2014b, MathWorks, Natick, Massachusetts, United States) was used to calculate COP. All data were smoothed through low-pass filtering, and the truncation frequency was set to 13.33 Hz.

COP was calculated from the time series within 10 s after standing, and anterior-posterior (AP) displacement difference, and medial-lateral (ML) displacement difference of both legs (D_{AP}, N_{AP}, D_{ML}, N_{ML}) (Ziv and Lidor, 2010). X_T and Y_T are the anterior-posterior (AP), medial-lateral (ML) displacements at t seconds and the value of t are 1–10 s. LSI of COP was counted as the ratio between non-dominant leg and dominant leg while timed for 6 meters hop was calculated by dominant and non-dominant in the division.

$$\text{AP} = \sum_{1}^{10} \left(X_t - \overline{X}\right)^2 \quad (1)$$

$$\text{ML} = \sum_{1}^{10} \left(Y_t - \overline{Y}\right)^2 \quad (2)$$

Statistical analysis

Experimental data were processed by IBM SPSS statistical software package (version 25.0, IBM, Chicago, IL, United States). All data were presented as means and SD. The level of significance was set at $p < 0.05$ for all tests. To examine the effects of the combined training on the performance of single-legged hop tests and proprioception tests, we firstly performed two-way repeated-measure ANOVA (group × time). The dependent variable for each model was LSI_O, LSI_T, LSI_C, LSI_S, D-(AP, ML, LSI), and N-(AP, ML, LSI). The model factors were group, time, and their interaction. When a significant interaction was observed, LSD post-hoc correction was performed to identify the location of the

TABLE 1 The descriptive characteristics of the participants.

	Age (years)	Height (cm)	Weight (kg)	Training experience (years)
PT (*n* = 8)	19.13 ± 2.23	179.13 ± 6.06	69.88 ± 8.94	10.63 ± 1.06
CT (*n* = 8)	20.50 ± 1.07	177.75 ± 5.06	68.13 ± 7.22	11.38 ± 1.41

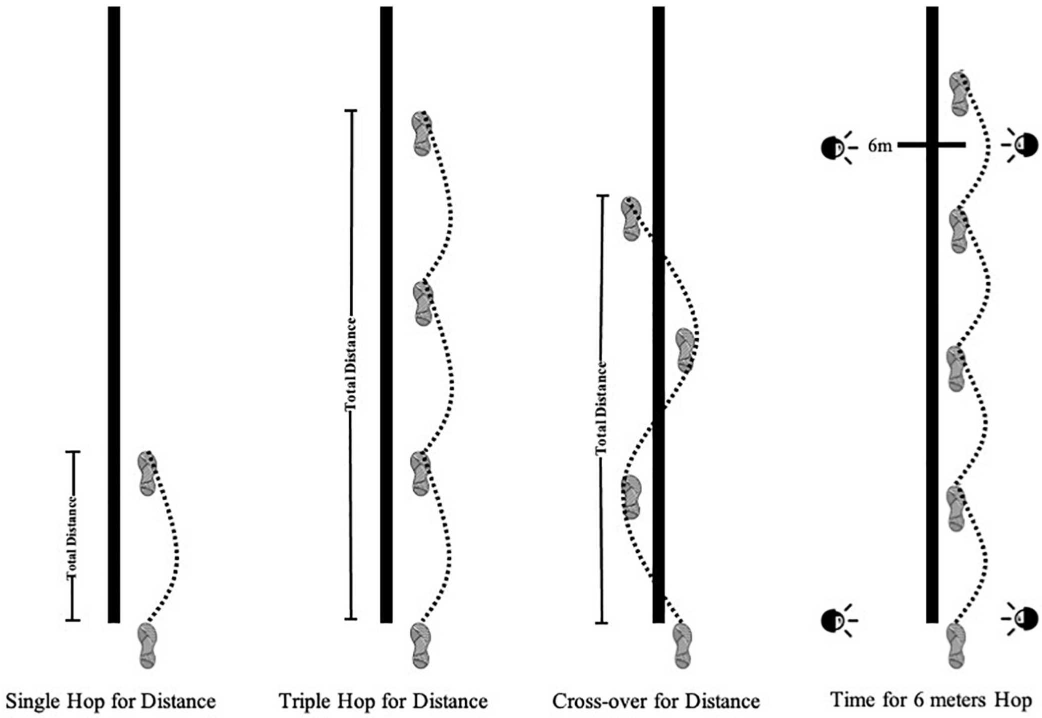

FIGURE 1
Single-legged hop tests.

significance. Secondly, we examined the effects of CT on the performance within each group, and the percent changes from pre- to post-intervention between CT and PT by using separate one-way ANOVA models. The model factor was time. Partial η^2 was used to assess the effect size (ES) where the significance was observed, with its strength being interpreted as the following: < 0.06 as small, < 0.14 as moderate, and ≥ 0.14 as large (Cohen, 2013).

Results

The primary two-way repeated-measures ANOVA models showed significant interactions between group and time on LSI_T ($p = 0.008$) and LSI_S ($p = 0.019$) but not on LSI_O and LSI_C ($p > 0.507$). The *post-hoc* analysis revealed that the LSI_T [$F_{(1, 28)} = 7.535$, $p = 0.010$, partial $\eta^2 = 0.212$] and LSI_S [$F_{(1, 28)} = 14.402$, $p = 0.001$, partial $\eta^2 = 0.340$] in CT group were significant greater after the intervention as compared to all the other pre- and post-interventions (Table 2).

For LSI_O and LSI_C, the secondary one-way ANOVA models showed that the LSI_O was significantly improved as compared to pre-intervention within either CT and PT group ($p < 0.048$), while no significant effect and percent change in LSI_C of both groups was observed ($p > 0.719$). Additionally, the percent changes in LSI_T ($p = 0.007$) and LSI_S ($p = 0.023$) within the CT group was significantly improved compared to PT group, indicating greater benefits was induced by CT.

The primary two-way repeated-measures ANOVA models revealed no significant interaction of group and time on D_{AP} ($p = 0.460$), N_{AP} ($p = 0.146$), LSI_{AP} ($p = 0.472$), D_{ML} ($p = 0.933$), N_{ML} ($p = 0.605$) or LSI_{ML} ($p = 0.508$). Only significant effects of time on D_{AP}, LSI_{AP}, N_{AP}, N_{ML}, and LSI_{ML} (but not on D_{ML}) were observed (D_{AP}: $p < 0.001$; N_{AP}: $p < 0.001$; LSI_{AP}: $p = 0.006$; N_{ML}: $p < 0.001$; LSI_{ML}: $p = 0.019$).

Secondarily, one-way ANOVA models showed that compared to pre-intervention, D_{AP}, D_{ML}, N_{AP}, and N_{ML} were significantly decreased after the intervention

TABLE 2 The assessment results for CT group and PT group before and after the 6-week training.

	CT ($N = 8$)				PT ($N = 8$)				The effects of time, group and their interaction (p-value)		
Variable	Pre	Post	△	Partial η2	Pre	Post	△	Partial η2	Time	Group	Time × group
LSI_O (%)	90.74 ± 4.15	95.43 ± 3.21*	5.33 ± 5.25	0.208	88.25 ± 2.51	91.97 ± 3.74*	4.31 ± 5.86	0.141	0.002	0.022	0.691
LSI_T (%)	87.13 ± 1.71	96.55 ± 4.46*#	10.8 ± 5.63#	0.548	89.30 ± 3.72	92.16 ± 2.78*	3.30 ± 3.66	0.100	<0.001	0.340	0.008
LSI_C (%)	91.04 ± 4.56	94.28 ± 2.21	3.74 ± 4.73	0.079	91.77 ± 4.78	93.02 ± 4.57	1.52 ± 5.55	0.013	0.138	0.857	0.507
LSI_S (%)	87.51 ± 1.63	99.68 ± 2.69*#	13.93 ± 2.90#	0.813	87.20 ± 1.46	95.49 ± 2.73*	9.55 ± 3.87	0.668	<0.001	0.007	0.019
D_{AP} (cm)	90.79 ± 7.67	71.50 ± 10.31*	20.88 ± 12.38	0.327	93.33 ± 14.36	79.58 ± 8.11*	13.80 ± 9.07	0.198	<0.001	0.167	0.460
N_{AP} (cm)	102.67 ± 8.33	72.20 ± 10.81*	29.75 ± 7.52#	0.585	103.95 ± 11.18	83.72 ± 8.05*	19.11 ± 7.09	0.383	<0.001	0.072	0.146
LSI_{AP} (%)	89.28 ± 3.79	98.15 ± 7.28*	11.27 ± 11.49	0.197	90.99 ± 5.21	95.37 ± 9.45	6.84 ± 10.48	0.056	0.006	0.826	0.472
D_{ML} (cm)	88.37 ± 8.22	80.44 ± 10.60	9.00 ± 8.09	0.039	89.54 ± 11.94	82.11 ± 11.60	8.29 ± 4.59	0.031	0.165	0.485	0.933
N_{ML} (cm)	99.65 ± 8.77	80.76 ± 7.22*	18.75 ± 6.53	0.174	102.08 ± 15.85	87.81 ± 15.60*	13.87 ± 8.91	0.036	<0.001	0.233	0.605
LSI_{ML} (%)	88.77 ± 4.68	100.19 ± 15.09*	12.47 ± 12.01	0.139	88.08 ± 4.77	94.66 ± 12.03	7.55 ± 13.32	0.050	0.019	0.371	0.508

LSI, limb symmetry index; D, dominant leg; N, non-dominant leg; △, percentage changes between pre- and post- test; Partial η^2, effect size of between-group comparisons.
*Statistically significant difference between pre- and post-test, $p < 0.05$.
#Statistically significant difference between CT group and PT group, $p < 0.05$.

within both CT and PT groups ($p < 0.014$) and within CT, LSI_{AP}, and LSI_{ML} were significantly improved after intervention (LSI_{AP}: $p = 0.014$; LSI_{ML}: $p = 0.033$), while no significant difference was observed within PT group. Additionally, the percent changes in N_{AP} within the CT group were significantly improved compared to PT group ($p = 0.011$), indicating greater benefits was induced by CT.

Discussion

This pilot study demonstrated that combined training (CT) of balance and plyometric training (PT) is of great promise to enhance knee function and proprioception. Multiple aspects of knee function and proprioception (e.g., LSI_O, D_{AP}, LSI_{AP}, N_{ML}, LSI_{ML}) were improved after the intervention. Though as compared PT, significantly greater benefits of CT were observed only for LSI_T and LSI_S, the results of this pilot study suggest that CT can at least induce comparable benefits to that by PT-only intervention, providing critical knowledge of study design, sample size estimation for future large-scale randomized trials.

We observed that compared to PT, CT significantly improved LSI_T and LSIs but not on LSI_C and LSI_O. LSI_T, and LSIs mainly reflect knee functions and limb symmetry for the continuous hopping process of the stretch-shortening cycle (SSC) (Fitzgerald et al., 2000). For example, Zwolski et al. (2016) has shown that LSI_S can be used to identify dynamic stability of knees in ACL injury rehabilitation.

LSI_O only reflects muscle strength of single-leg and limb symmetry between legs, and LSI_C reflects the capacity of imposing forces in frontal and transverse planes with multiple hops in the sagittal plane, which is a more technique-demanding condition (Logerstedt et al., 2012). The traditional PT focuses only on enhancing the musculoskeletal function and consolidating the movement pattern of landing, which may thus particularly benefit the LSI_C and LSI_O. The balance training of CT protocol focuses on multiple abilities of balance and stability including the posterior thigh muscles, the abdominal muscles, and the hip muscles, especially improving the stability of ankle during the process of landing and take-off (Hewett et al., 2010). Hariri and Sadeghi (2018) found that it was necessary to increase the speed of the knee in order to achieve maximum foot speed toward the target in the performance of the Karate. Improving muscle performance and joint movement is thus of great importance in quick movement during badminton matches, especially in enhancing knee function. CT intervention thus can simultaneously target lower limb strength, knee function, and movement pattern of landing, and can improve both power and agility of badminton players (Fischetti et al., 2018; Guo et al., 2021). It may thus induce significantly greater improvements specifically in LSI_T and LSIs (but not LSI_C and LSI_O) by targeting SSC and dynamic stability of knees, suggesting particular benefits from CT on dynamic stability of knees.

However, as compared to PT, no significant improvements in proprioception as assessed by COP outcomes induced by CT were observed, suggesting CT induced benefits for proprioception which are only comparable to PT. The proprioception and stability of postural control require the integration of the visual, vestibular information and coordination across those systems, among which the strength of the lower limb is extremely important (Wrisley and Stephens, 2011; Zhao and Gu, 2019). Alikhani et al., observed that 6-week of PT improved dynamic balance and knee proprioception in female badminton players (Alikhani et al., 2019). Additionally, Nepocatych et al. (2018) observed that balance training can increase ankle stability by augmenting neuromuscular function and proprioception as well as the dynamic balance by optimizing the postural control system to more efficiently utilize multiple kinds of sensory inputs (e.g., visual, proprioceptive) (Söderman et al., 2000; Guo et al., 2021; Lu et al., 2022). However, no significant difference in COP outcomes between CT and PT is observed here, though a greater percentage change in these outcomes was induced by CT compared to PT, which thus needs to be further explored in future studies.

Meanwhile, one potential reason for non-significant results may be the ceiling effects that only elite professional players were included, and using PT may be sufficient to induce maximum improvements in proprioception. Taken together, our results show that CT may uniquely augment knee function, suggesting that this type of CT would be a helpful strategy that can be included in the training routines of elite badminton players with adaptive protocols to maximize the benefits for athletes (e.g., using balance training as a passive rest method between different sets of exercises).

Several limitations of this pilot study should be noted. First, only sixteen male elite badminton players were included, so the generalizability of the study findings was limited. Studies with larger sample size and consisting of both male and female participants, as well as of other cohorts (e.g., adolescent players), are highly demanded to further examine and confirm the observations in this study. Second, we here only examined the short-term/immediate effects of CT, studies consisting of longer-term follow-up assessments and the record of athletic injury incidence are needed to examine how such benefits can sustain and if CT can help reduce the incidence of injuries in athletes. Additionally, we here implemented the CT following our previous work, it is worthwhile to examine the effects of other types of CT protocol, and to explore the appropriate training intensity and number of sessions that can help maximize the benefits of CT. Third, future studies can implement assessments which are more closely linked to on-court performance (e.g., badminton-field reaction test and three-dimensional motion capture technique) to examine the benefits of CT for badminton performance, in addition to the knee function. Additionally, future studies are needed to examine the effects of CT on other psychological and physiological aspects related to badminton, such as cognitive function, and mood, to comprehensively assess the benefits of CT on this cohort.

Conclusion

This pilot study showed that balance training combined with plyometric training program may induce a significant effect on knee function and at least comparable positive effects on proprioception of elite badminton players as compared to plyometric training only. The knowledge obtained from this pilot study will ultimately help inform the design of future larger-scale studies to confirm the findings here.

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 study protocol was approved by the Research Ethics Committee of Beijing Sport University (Approval number: 2020008H), and all procedures were conducted in accordance with the Declaration of Helsinki. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LZ, WG, SW, ZG, and DB: research concept and study design. LZ, WG, SC, DB, and JZ: literature review and writing of the manuscript. LZ, WG, and DB: conceptualization and methodology. SW, ZG, and ML: formal analysis, investigation, and resources. ZG, ML, and JZ: data collection, data analysis and interpretation, and statistical analyses. LZ and WG: writing—original draft preparation. LZ, SC, DB and JZ: writing—review and editing. 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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.947877/full#supplementary-material

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There is no rush to upgrade the tennis racket in young intermediate competitive players: The effects of scaling racket on serve biomechanics and performance

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Introduction: Scaling the equipment of young athletes is justified by the constraints-led approach introduced in motor learning. The aim of the present study is to analyze the effect of racket scaling on the serve biomechanics and performance parameters for young tennis players (between 8 and 11 years-old).

Methods: Nine young intermediate competitive tennis players (age: 9.9 ± 1.0 years) performed maximal effort flat serves with three different rackets (scaled 23 inches, scaled 25 inches and full-size 27 inches) in a randomized order. A radar measured ball speed while shoulder and elbow kinetics and upper and lower limb kinematics were calculated with a 20-camera optical motion capture system. Repeated measures ANOVAs were used to analyze the effect of the three rackets on ball speed, percentage of serve in, serve kinematics and kinetics.

Results: No significant differences in ball speed, maximal racket head velocity and percentage of serve in were observed between the three rackets. The lowest maximal upper limb kinetics and the highest upper limb maximal angular velocities were obtained with the scaled 23 inches racket.

Discussion: Using scaled rackets has the advantage to decrease shoulder and elbow loadings without reducing serve performance. Consequently, the present results incite tennis coaches and parents to not upgrade too soon the size of the racket in young intermediate tennis players to avoid overuse injury risks in the long term. Our results showed that the full-size 27 inches racket induced higher lower limb kinematics. As a consequence, occasionally serving with a fullsize racket can be a sparingly interesting intervention to help young tennis players to intuitively and immediately increase their leg drive action, allowing a more functional representation of the elite junior serve.

KEYWORDS
modified sport, scaling equipment, ecological dynamic approach, children's sport, constraints-led approach, performance analysis, injury risks, joint loadings

1. Introduction

Improving sport performance, increasing motivation and preventing injuries constitute ones of the main concerns and responsibilities for sport coaches of young athletes. To this end, coaches are encouraged to scale the equipment in children's sport to improve motor patterns acquisition and to favor the emergence of efficient and safe technical skills in a fun and exciting environment (Buszard et al., 2016). Scaling the equipment of young athletes is justified by the constraints-led approach introduced in motor learning (Buszard et al., 2016). This approach is based on the theory of ecological dynamics that considers humans as complex, nonlinear, neurobiological systems that interact with an unstable, unpredictable and evolving environment to produce movement patterns in a given situation (Newell, 1986; Davids et al., 2008). Three types of constraints can facilitate the emergence of self-organized movement patterns: individual characteristics, environmental and task-related constraints (Newell, 1986). In accordance with the theory of ecological dynamics in motor learning, international and national tennis organizations have proposed tennis programs with adaptations of task-related constraints in recent years [“Tennis 10s Program” (International Tennis Federation, 2012), “Galaxie Tennis” (Pestre, 2017), “Tennis Hot Shots” (McInerney et al., 2017)] based on different stages with different ball colors, racket lengths, court dimensions and net heights to facilitate the long-term technical and tactical development of tennis players. Beyond these long-term development programs, coaches can also deliberately scale equipment during training sessions to manipulate tasks constraints in the short-term hope of destabilizing the biomechanics of the existing movement pattern, encouraging exploration and self-organization towards more efficient and safer motor patterns that increase performance and reduce injury risks (Elliott et al., 2009; Reid and Giblin, 2015; Gray, 2021; Fadier et al., 2022). Among all the possible interventions on equipment, scientists encourage coaches to ask young tennis players to play with different racket size (and consequently, different mass, length, balance, swingweight and twistweight) in the theoretical hope of facilitating racket handling ability, decreasing upper limb joint loadings, promoting more variability, increasing impact performance (speed and accuracy), releasing degrees of freedom, increasing segmental and joint angular velocities (Elliott et al., 2009). Only a few of these intentions and practical interventions have been validated from a scientific point of view. Indeed, scientific studies supported the positive effects of scaled rackets on immediate tennis performance improvements. In a previous study, from 4 to 10 years old beginner children were asked to “swing as hard as possible and hit the ball as closely to the center of the racket” during a forehand hitting task with four different rackets (21 inches: 0.533 m and 0.201 kg, 23 inches: 0.584 m and 0.247 kg, 25 inches: 0.635 m and 0.293 kg, and 27 inches: 0.685 m and 0.339 kg; Gagen et al., 2005). Results showed that, for each participant, there was one specific racket that allowed better racket speed and ball impact accuracy than the other three but this “optimal” racket was not statistically related to any of the individual player’s anthropometrical data (weight, arm length, hand size, height, and leg length) or strength measures studied (shoulder strength and grip strength) or their interactions. As a consequence, the prediction of the characteristics of an optimal racket for young tennis players remains unclear.

Moreover, two other studies reported better immediate improvements in forehand performance when young beginners (6–9 years and 9–11 years) used a scaled racket (19 inches–0.483 m or 23 inches–0.584 m) with low compression balls in comparison with a standard racket (27 inches–0.685 m) and standard balls (Buszard et al., 2014a,b). However, if all these previous studies confirm that scaling racket allows to increase tennis performance in young beginners, the tennis motor skill improvements were only evaluated from a general technical point of view using video replay and technical fundamentals checklists. In these studies, biomechanical data based on full-body kinematics and upper limb joint loadings that underpin and objectify the emergence of more efficient and safer motor patterns as a consequence of the scale equipment are missing. Only two studies assessed the biomechanical effects of equipment scaling in young tennis players. In outstanding works, Buszard et al., (2020a,b) showed that a scaled racket (21 inches) and low compression balls promoted functional movement variability, whereas standard, full-size racket (27 inches) and balls resulted in the freezing of mechanical degrees of freedom during a forehand stroke task performed by beginner children (Buszard et al., 2020a). They also reported that scaled equipment promoting a more distal control of the shoulder-racket distance than full-sized equipment (Buszard et al., 2020b).

However, the biomechanical analysis of these studies was limited to the kinematics of the upper-arm, forearm and racket, but neglected the trunk, the lower limbs and the wrist. In the literature, there is also a lack of evidence that scaling equipment (i.e., tennis racket) may decrease the risk of injury by constraining children’s biomechanics to safer movement patterns inducing limited joint loadings. Moreover, all these previous studies have assessed children with limited tennis skills and experience. According to the systematic review by Buszard et al. (2016), there is a real need to examine children with a certain degree of skill regarding the task in order to explore the non-linear nature of learning within this specific population (Buszard et al., 2016).

Considered as the most important stroke in adult skilled tennis players (Johnson et al., 2006), the serve involves a proximo-distal sequence that allows the transfer of energy from the lower to the upper body (Martin et al., 2013a, 2014a) and may induce excessive joint loadings leading to overuse injuries (Martin et al., 2014b; Touzard et al., 2019). Tennis coaches spend considerable time designing specific interventions or testing different equipment constraints to improve serve biomechanics (Whiteside et al., 2014; Reid and Giblin, 2015; Fadier et al., 2022) because it is a complex and hard to control stroke, especially for young players. However, the short-term effects of the racket scaling constraint on serving performance, upper and lower body kinematics, joint loadings, and injury risks are largely unknown in young intermediate tennis players and need to be considered. As a consequence, this study aimed to assess the effect of racket scaling on the serve biomechanics and performance parameters for young intermediate tennis players. We hypothesized that racket velocity, percentage of serves in, upper limb joint kinematics to increase and upper limb joint kinetics to decrease with scaled rackets compared to full-size one. We hypothesized that scaling racket has no effect on lower limb joint kinematics and percentage of serve in.

2. Materials and methods

2.1. Participants

Nine young intermediate competitive tennis players (five boys and four girls, age: 9.9 ± 1.0 years, height: 1.39 ± 0.07 m, mass: 30.3 ± 5.1 kg), with an International Tennis Number between 6 and 9 and at least 3 years of practice, participated voluntarily in this study. Seven were right-handed and two were left-handed. All players were involved in a local training program coordinated by the Ille-et-Vilaine departmental Committee of the French Tennis Federation. At the time of testing, all the players were considered healthy, with no history of surgery on the dominant arm. Testing was conducted in an indoor tennis court at the M2S Laboratory.

Abbreviations: R23: scaled 23 inches racket.; R25: scaled 25 inches racket.; R27: full-size 27 inches racket.

Before experimentation, the players and their parents provided informed consent, medical history and were fully informed about the procedures. The study was approved by the local ethics committee and conducted in accordance with the 1975 Declaration of Helsinki.

2.2. Experimental protocol

Forty-three retro-reflective markers were placed on the player's bony landmarks and five markers were located on the racket as described in a previous study (Martin et al., 2014b). After a warm-up of at least 15 min, including general warm-up led by a tennis coach and serve repetitions (as many repetitions as needed to familiarize with the testing equipment), each player performed three successful flat serves (Mullineaux et al., 2001) with three different rackets (scaled 23 inches, scaled 25 inches and full-size 27 inches, respectively called R23, R25, R27) in a randomized order. The choice of these three racket sizes is in accordance with the recommendations of the national tennis federations for young tennis players between 8 and 12 years old. For each trial, two experimented tennis coaches assessed the type of serve performed and checked that the participants performed only flat serves.

For each racket condition, the players served with "green" low compression balls and from the baseline of the "green" tennis court (9.00 m from the net) to the deuce service box. The characteristics of each racket are described in Table 1. R27 corresponds to a full-size adult racket but with a weight (unstrung mass < 0.250 kg) recommended for young players who are looking for their first adult racket. The "swingweight" of each racket corresponds to the racket moment of inertia about its transverse axis. Racket moment of inertia about the long axis, called twistweight was calculated as reported in the literature (Brody, 1985):

$$\text{twistweight}\left(\text{kg}\cdot\text{m}^{-2}\right)=\left(\text{mass}\times\text{head width}^{2}\right)/17.75$$

Players were asked to hit the ball as fast as possible and to serve into the deuce service box. A motion capture system with 20 cameras sampling at 200 Hz (Oqus, Qualisys AB., Göteborg, Sweden) was used to record the trajectories of the 3-dimensional (3-D) anatomical landmarks. Players were shirtless or wore a bra and a tight short to limit movement of the markers. Post-impact ball speed was measured for each trial with a radar (Stalker Professional Sports Radar, Applied Concepts, Plano, TX, United States) fixed on a tripod and placed 2 m behind the players in the direction of the serve. For each player, the radar's height on the tripod was adjusted according to the impact height. After the capture, 3-D coordinates of the landmarks were reconstructed with QTM software Qualisys AB., Göteborg, Sweden with a residual error of less than 1 mm. The 3-D motions of each player were expressed in a right-handed inertial reference frame R1 whose origin was at the center of the baseline. X represented the baseline, Y pointed forward, and Z was vertical and pointed upward. The markers 3-D coordinates were filtered with a Butterworth low-pass filter with a cutoff frequency of 12 Hz as determined by residual analysis (Winter, 1990).

Different serve kinematic variables were calculated as previously described in the literature (Martin et al., 2016). An inverse dynamics approach was used to calculate maximal joint torques (Martin et al., 2014b, 2016). The serving arm was modeled as a three-link kinetic chain composed of the racket/hand segment, forearm, and upper arm. For the purpose of the study, shoulder internal rotation, abduction and horizontal abduction torques and elbow varus torque were analyzed. The joint torques obtained were first computed in the reference frame R1 and were later transformed to a series of anatomically relevant, righthanded orthogonal local reference frames at each joint. Mean kinetic peak values were normalized: torques were divided by the product of body mass by height, and then multiplied by 100 (Martin et al., 2014b).

TABLE 1 Characteristics of the three racquets used in the study.

	R23	R25	R27
Brand and model	Wilson Burn 23	Wilson Clash 25	Wilson Six One Lite 102
Length (m)	0.584	0.635	0.685
Unstrung mass (kg)	0.190	0.239	0.249
Unstrung balance (m)	0.275	0.305	0.340
Head size (cm²)	613	645	658
Swingweight (kg.m²)	0.0159	0.0219	0.0308
Twistweight (kg.m²)	0.0007	0.0009	0.0010
Grip size (cm)	9.21	10.16	10.16

2.3. Statistical analyses

For each of the three racket conditions, the magnitudes of ball speed, kinematic and kinetic parameters were averaged for each player. One-way analysis of variance with repeated measures was used to analyze the effect of the three rackets on ball speed, serve kinematics and torques. When significant main effects were present, *post hoc* pairwise comparisons were undertaken using a Holm correction to determine the source of difference. Where data were not normally distributed, significance was determined using a Friedman analysis of variance with repeated measures on ranks and a *post hoc* Durbin-Conover test. *Post-hoc* analysis with Durbin-Conover tests was conducted with a Bonferroni correction for multiple comparisons. The level of significance was set at $p \leq 0.05$. Furthermore, we also calculated effect sizes using partial eta squared (η^2p), defined as small (0.10–0.24), moderate (0.25–0.39), or large (≥ 0.40), Kendall's W, defined as small (0.10–0.29), moderate (0.30–0.49) and large (≥ 0.50), and Cohen's *r*, defined as trivial (< 0.10), small (0.10–0.30), moderate (0.31–0.50), or large (≥ 0.50) (Cohen, 1992).

3. Results

3.1. Ball speed and racket head velocity

Ball speed ($\chi^2(2) = 3.35$; $p = 0.187$; $W = 0.186$), maximal racket head velocity ($\chi^2(2) = 2.00$; $p = 0.368$; $W = 0.111$) and percentage of serve ($F(2,18) = 0.35$, $p = 0.713$, $\eta^2_p = 0.041$) in were not significantly modified between the three rackets (Table 2).

3.2. Shoulder and elbow kinetics

A significant and large main effect of the racket type on maximal shoulder internal rotation torque was observed ($F(2,18) = 11.90$, $p < 0.001$, $\eta^2_p = 0.598$; Table 3). The maximal shoulder internal rotation torque was largely higher for R27 compared to R23 ($p = 0.011$; $r = 0.800$, large effect) and R25 ($p = 0.005$; $r = 0.856$, large effect) and for R25 compared to R23 ($p = 0.027$; $r = 0.690$, large effect). The racket type significantly and moderately influenced the shoulder abduction torque ($F(2,18) = 4.52$, $p = 0.028$, $\eta^2_p = 0.362$) that is significantly higher for R27 than for R23 ($p = 0.019$; $r = 0.722$, large effect). The racket type significantly and largely influenced the maximal elbow varus torque ($\chi^2(2) = 18.00$; $p < 0.001$; $W = 1.000$) that is significantly higher for R27 than for R23 ($p < 0.001$; $r = 0.629$, large effect) and in R25 ($p < 0.001$; $r = 0.629$, large effect), and for R25 compared to R23 ($p < 0.001$; $r = 0.630$, large effect; Table 3).

3.3. Upper body kinematics

The results showed a significant and large main effect of the racket type on maximal velocity of forearm pronation ($F(2,18) = 5.50$, $p = 0.015$, $\eta^2_p = 0.407$). The maximal velocity of forearm pronation was largely higher for R23 compared to R27 ($p = 0.028$; $r = 0.688$, large effect). The racket type significantly and moderately influenced the maximal velocity of elbow extension ($\chi^2(2) = 6.89$; $p = 0.032$; $W = 0.383$) that is significantly lower for R27 than for R25 ($p = 0.007$; $r = 0.628$, large effect). The racket type significantly and largely influenced the maximal velocity of wrist flexion ($\chi^2(2) = 11.56$; $p = 0.003$; $W = 0.642$) that is significantly lower for R27 than for R25 ($p = 0.002$; $r = -0.628$, large effect) and in R23 ($p < 0.001$; $r = -0.489$, moderate effect; Table 4).

3.4. Lower body kinematics

The racket type significantly affected the angles of maximal front knee flexion ($F(2,16) = 7.36$, $p = 0.005$, $\eta^2_p = 0.479$) and back ankle flexion ($F(2,16) = 4.27$, $p = 0.033$, $\eta^2_p = 0.348$). Maximal front knee flexion was significantly lower for R23 than for R25 ($p = 0.044$; $r = 0.547$, large effect) and in R27 ($p = 0.044$; $r = 0.736$, large effect; Table 2). The results showed a significant and large main effect of the racket type on maximal extension velocities of the back knee ($F(2,16) = 8.08$, $p = 0.004$, $\eta^2_p = 0.502$) and the back ankle ($F(2,16) = 6.61$, $p = 0.008$, $\eta^2_p = 0.452$). The maximal velocity of back knee extension was significantly lower for R23 compared to R25 ($p = 0.032$; $r = 0.760$, large effect) and R27 ($p = 0.033$; $r = 0.729$, large effect). The maximal velocity of back ankle extension was significantly lower for R23 compared to R27 ($p = 0.047$; $r = 0.734$, large effect). The racket type significantly and moderately influenced the maximal front hip vertical velocity ($\chi^2(2) = 6.89$; $p = 0.032$; $W = 0.383$) that is significantly lower for R23 than for R27 ($p = 0.007$; $r = -0.544$, large effect; Table 5).

TABLE 2 Serve performance for the different racket conditions (mean±SD).

	R23	R25	R27	Main effect *p* value
Ball speed (km.h^{-1})	94.2 ± 13.7	96.2 ± 11.7	95.3 ± 8.4	0.187
Maximal racquet head velocity (km.h^{-1})	99.9 ± 13.9	98.7 ± 10.3	97.0 ± 8.2	0.368
% of serves in	49.1 ± 25.2	51.3 ± 23.8	44.2 ± 11.5	0.713

4. Discussion

This study provides an evidence-based insight into the constraint-led approach by evaluating a contemporary coaching intervention and task constraint in tennis. Our results demonstrate that, at the same time, scaling tennis racket can both positively and negatively affect the joint and segment biomechanics of different body parts.

The results obtained in this study for young intermediate tennis players seem to show that scaling racket from 23 to 27 inches would not have immediate effect on performance and percentage of serves in. As expected, upper limb joint kinetics increased with the length, the mass and the moments of inertia of the racket. It appears that serving with a light full-size racket altered several upper limb kinematics but simultaneously and surprisingly improved several lower limb kinematics for young tennis players.

As expected, our results showed that when racket size, mass, swingweight and twistweight increased from R23 to R27, the maximal shoulder and elbow torques were significantly higher in the young tennis players involved in our study. Our findings are in agreement with a previous study in expert adult players who performed sets of serves using two rackets identical in mass, balance, and swingweight but with different twistweights (0.00152 vs. 0.00197 kg.m^2; Rogowski et al., 2014). Significant increases in maximal shoulder and torques were associated with the increase in racket twistweight. These findings suggest that when racket characteristics (mass, length, swingweight and twistweight) increase, the dominant upper limb joints are required to produce more torque to swing the R27 rather than the two other rackets. Increasing maximal joint torques during the tennis serve is associated with higher

TABLE 3 Maximal joint loadings for the different racket conditions (mean±SD).

Maximal joint loadings (% BW*H)	R23	R25	R27	Main effect *p* value	*Post-hoc* difference and effect size
Shoulder internal rotation torque***	41.9 ± 8.3	47.5 ± 7.9	51.1 ± 8.5	< 0.001	R27 > R23 (large effect) R25 > R23 (large effect) R27 > R25 (large effect)
Shoulder abduction torque*	60.6 ± 24.1	69.6 ± 21.8	79.3 ± 30.9	0.028	R27 > R23 (large effect)
Shoulder horizontal abduction torque	41.9 ± 25.2	41.3 ± 17.0	48.0 ± 14.8	0.050	/
Elbow varus torque***	43.7 ± 8.8	49.6 ± 7.4	54.7 ± 7.9	< 0.001	R27 > R23 (large effect) R25 > R23 (large effect) R27 > R25 (large effect)

Significant main effect between racket conditions: *$p < 0.05$; ***$p < 0.001$. BW: bodyweight, H: height.

TABLE 4 Maximal upper body kinematics for the different racket conditions (mean±SD).

	R23	R25	R27	Main effect *p* value	*Post Hoc* Difference and effect size
Upper trunk longitudinal rotation velocity (°.s⁻¹)	672 ± 205	675 ± 158	642 ± 151	0.522	/
Trunk flexion velocity (°.s⁻¹)	263 ± 79	266 ± 59	275 ± 58	0.695	/
Pelvis longitudinal rotation velocity (°.s⁻¹)	555 ± 192	567 ± 149	495 ± 207	0.717	/
Shoulder-over-shoulder rotation velocity (°.s⁻¹)	255 ± 83	259 ± 65	268 ± 61	0.643	/
Shoulder internal rotation velocity (°.s⁻¹)	2016 ± 725	1772 ± 600	1,656 ± 540	0.062	/
Forearm pronation velocity (°.s⁻¹) *	1,644 ± 794	1,442 ± 740	1,345 ± 661	0.015	R27 < R23 (large effect)
Elbow extension velocity (°.s⁻¹) *	1,126 ± 392	1,128 ± 299	1,050 ± 283	0.031	R27 < R25 (large effect)
Wrist flexion velocity (°.s⁻¹) **	1748 ± 299	1,644 ± 242	1,483 ± 235	0.003	R27 < R23 (moderate effect) R27 < R25 (large effect)

Significant main effect between racket conditions: $*p < 0.05$; $**p < 0.01$.

risks of overuse upper limb injuries (Martin et al., 2013b, 2014b). Consequently, our results confirm our initial hypothesis as well as those of medicine practitioners and researchers, who have suggested that task-related constraints and especially a full-size racket could overload the upper limb joints (Miller, 2006; Hennig, 2007; Gray, 2021) and, potentially increase the risks of upper limb injuries in young tennis players. In a recent study, incidence proportion revealed that 13.0% of U10 and 61.0% of U12 players in a tennis academy sustained an injury over 2 years of tennis practice (O'Connor et al., 2020). In young tennis players, the shoulder and elbow showed the highest frequency in the upper limb (Kibler and Safran, 2005; O'Connor et al., 2020). The higher shoulder horizontal abduction and internal rotation torques generated from R23 to R27 may induce a greater risk of rotator cuff overuse injuries and shoulder tendinopathies that are common in young tennis players (Bylak and Hutchinson, 1998). The higher maximal elbow varus torque generated from R23 to R27 may increase the risk of elbow tension injuries, such as lateral epicondylitis (tennis elbow), medial epicondylitis, and injury to the medial epicondylar apophyseal growth plate that are common in skeletally immature tennis players (Bylak and Hutchinson, 1998).

In our study, the highest upper limb maximal angular velocities were obtained with R23. This result is in agreement with a previous work reporting that when the racket swingweight was increased for adolescent tennis players, the maximal shoulder internal rotation and wrist flexion velocities during the serve both decreased and even regressed towards the values documented for pre-pubescent players (Whiteside et al., 2014). These kinematical changes prove that the degrees of freedom are reorganized and that the movement system is constrained by equipment characteristics. The immediate decreased angular velocities were probably measured because the young intermediate tennis players involved in our study lacked the upper limb strength to overcome the higher characteristics of the full-size racket (R27). While the shoulder internal rotation, the wrist flexion and the elbow extension velocities are crucial contributors to the serve speed (Gordon and Dapena, 2006) and decreased from R23 to R27, our results showed no significant immediate difference in ball speed between R23, R25, and R27. Maximal racket head velocity ranged from 99.9 to 97.0 km.h⁻¹ (−2.9 km.h⁻¹) between R23 and R27, but this decrease was not statistically significant. Whiteside et al. (2014) increased the racket swingweight by 10% for a population of adolescent tennis players and found a significant but very small decrease in the resultant velocity of the racket at impact (−3.2 km.h⁻¹) although not in ball speed (Whiteside et al., 2014). Creveaux et al. (2013) investigated the influence of three rackets with distinct mass, balance, swingweight, twistweight and transverse moment of inertia on serve biomechanics in adult expert players. They reported similar ball speeds for the three racket conditions (Creveaux et al., 2013). Söğüt (2017) showed that adding extra mass (+ 10 and + 20 grams) to the tip of a racket has no acute effect on serve ball speed for a population of junior tennis players (Söğüt, 2017). Based on the study of Whiteside et al. (2014), we suggest that the decreases in upper limb angular velocities observed with R27 and R25 were offset by the increase in racket mass, a more efficient impact, or both and could explain why we did not observe a significant decrease in ball speed and racket head velocity from R23 to R27.

Contrary to our hypothesis, our results showed that serving with a full-size racket (R27) promoted a more dynamic engagement of the leg drive from the players. This outcome is deduced from the increase in maximal back knee and ankle extension velocities (respectively + 73°.s⁻¹ and + 78°.s⁻¹ with R27 than with R23), the higher front knee flexion angle (+5° with R27 than with R23) and the higher maximal front hip vertical velocity (+0.1 m.s⁻¹ with R27 compared to R23). Our results suggest that the R27 releases the degrees of freedom of the front knee. With R27, the back knee and ankle extension velocities and the front knee flexion angle were closer to previous published data obtained in older and more skilled players (elite juniors; Whiteside et al., 2013; Fett et al., 2021) and therefore point towards a more mature and efficient leg drive. Indeed, in order to hit a proficient serve, tennis players need to produce an efficient leg drive based on first an effective ankles and knees flexion and then a vigorous ankles and knees extension (Girard et al., 2007; Reid et al., 2008). The constraint-led approach stipulates that the constraints imposed by sport (e.g., court size, net height, balls and racket characteristics in tennis) both determine the boundaries of what actions are possible and provide opportunities for action called "affordances" (Newell, 1986; Davids et al., 2008). Our results support this approach because they suggest that a heavier, bigger and higher inertia racket provides an affordance to young intermediate tennis players by forcing them to intuitively increase their leg drive during serve, permitting a more functional representation of the elite junior serve. According to previous studies (Withagen et al., 2012, 2017), certain information sources (visual, acoustic, haptic and proprioceptive) in a performance environment "invite" actions. Proficient tennis players are able to distinguish differences as small as 2.5% in the swingweight of a racket

TABLE 5 Maximal lower body kinematics for the different racket conditions (mean±SD).

	R23	R25	R27	Main effect *p* value	*Post-hoc* Difference and effect size
Internal angle of maximal back ankle flexion (°) *	81 ± 6	79 ± 8	79 ± 7	0.033	NS
Internal angle of maximal front ankle flexion (°)	81 ± 7	79 ± 8	81 ± 8	0.052	/
Internal angle of maximal back knee flexion (°)	128 ± 15	126 ± 16	127 ± 16	0.874	/
Internal angle of maximal front knee flexion (°) **	125 ± 11	121 ± 9	120 ± 9	0.005	R27 < R23 (large effect) R25 < R23 (large effect)
Back knee extension velocity (°.s^{-1}) **	343 ± 201	407 ± 205	416 ± 203	0.004	R27 > R23 (large effect) R25 > R23 (large effect)
Front knee extension velocity (°.s^{-1})	381 ± 154	421 ± 138	454 ± 111	0.059	/
Back ankle extension velocity (°.s^{-1}) **	452 ± 120	503 ± 135	530 ± 110	0.008	R27 > R23 (large effect)
Front ankle extension velocity (°.s^{-1})	407 ± 148	500 ± 97	485 ± 119	0.097	/
Back hip vertical velocity (m.s^{-1})	1.3 ± 0.4	1.4 ± 0.3	1.4 ± 0.3	0.097	/
Front hip vertical velocity (m.s^{-1}) *	0.9 ± 0.3	1.0 ± 0.2	1.0 ± 0.2	0.031	R27 > R23 (large effect)

Significant main effect between racket conditions: *$p < 0.05$; **$p < 0.01$. NS: *post-hoc* tests revealed no significant difference between the three racquet conditions.

(Brody, 2000). Inexperienced tennis children are also sensible to different rackets' swing weight (Beak et al., 2000). We hypothesize that the young intermediate tennis players in our study perceived the higher mass, length and swing weight of R27 which "invited" them to produce immediate better leg drive kinematics, perhaps in an attempt to compensate for their immature upper limb musculature. By increasing the action of their leg drive, we would expect that young tennis players could be able to transfer a little bit more force to their trunk and their dominant upper limb. However, even if the leg drive kinematics were moderately to largely improved with R27, we did not see any immediate repercussions on the trunk and the dominant upper limb. Indeed, our results showed no significant differences in trunk kinematics between the three racket conditions and even highlighted a significant decrease in several upper limb angular velocities (forearm pronation, elbow extension and wrist flexion, tendency for the shoulder internal rotation) with R27. The lack of energy and force transfer between the leg drive and the trunk can be explained by the immature serve technique of the young (pre-pubescent) tennis players (Whiteside et al., 2013; Fadier et al., 2022).

4.1. Practical implications

Our results allow to propose practical applications for tennis coaches and parents. Using scaled rackets (R23) has the advantage to decrease shoulder and elbow loadings without reducing serve performance (ball speed and maximal racket head velocity). Consequently, the present results incite tennis coaches and parents to not upgrade too soon the size of the racket in young intermediate tennis players to avoid overuse injury risks in the long term. Our findings also encourage coaches to incorporate deliberate perturbations of the service action with different rackets to induce immediate and more appropriate coordinative joint rotations in young intermediate tennis players. Using scaled rackets (R23) has the advantage to increase the maximal angular velocities of the most distal joints and segments (forearm pronation, elbow extension and wrist flexion) that are generally restrained or sacrificed in prepubescent tennis players to simplify the serve motion. This intervention can be regular since our results showed significant decreases of shoulder and elbow loadings with this type of racket. On the contrary, serving with a full-size (R27) but light mass racket (<0.250 kg) can be an interesting intervention to help them to intuitively and immediately increase their leg drive action, allowing a more functional representation of the elite junior serve. Obviously, this intervention needs to be occasional and used with a lot of moderation and caution since our results showed significant increases of shoulder and elbow loadings with this type of racket.

4.2. Limitations and future directions

This study has some limitations. First, our sample size is limited because we only included young intermediate tennis players and their participation was voluntary and submitted to their parents' consent. Some results (shoulder horizontal abduction torque, maximal shoulder internal rotation velocity, front knee and ankle extension velocities, back hip vertical velocity) tend to show differences between the three rackets. It seems reasonable to assume that nonsignificant results are due to lack of power caused by the small number of subjects involved in the study and the small number of successful serves (only three) used for the statistical analysis. One may assume that with more trials and fatigue related to differences in racket characteristics (mass and length), other significant statistical differences would appear. Similarly, given the small sample size, the current study lacks generalization and thus serves to encourage future work to examine and confirm the immediate effects of racket scaling on serve biomechanics on larger or different tennis playing cohorts. Moreover, it would be interesting to conduct future studies about the immediate effects of racket scaling on groundstrokes (forehand and backhand) kinematics and kinetics. Our study did not take into account the individual characteristics of the young players involved (age, body height, mass, upper and lower limb strength) and we did not know which scaled racket was the most appropriate for each child. Consequently, in an attempt to discover the most optimal scaling ratio, future studies should consider applying concepts from the body-scaling literature, namely pi ratios that offers a practical and seemingly new means to quantify the most beneficial scaling ratio on the basis of individual characteristics. Moreover, in the literature, it has been reported that the age and the maturation have an effect on serve biomechanics in elite female tennis players (Whiteside et al., 2013). Indeed, several racket and ball kinematics are different between elite pre-pubescent, pubescent and post-pubescent female tennis players. In our work, we did not take into account the maturity status of the players involved in the experimentation. This is a limitation of our study. To go even further, future longitudinal investigations should also examine the influence of equipment modification in relationship with the players' maturity status and strength on serve learning over a certain period of time to better understand the motor learning process.

5. Conclusion

In conclusion, the current results seem to show that scaling racket from 23 to 27 inches would not have immediate effect on ball speed, maximal racket head velocity and percentage of serves in but would decrease shoulder and elbow loadings. Moreover, the manner in which the body produced joint angular velocities differed between the three racket conditions, with scaled rackets promoting more distal angular velocities and the full-size racket facilitating more proximal angular velocities from the lower limbs. Our results suggest that serving with a full-size racket provides beneficial biomechanical opportunities for the lower limbs but detrimental boundaries for the dominant upper limb in young intermediate tennis players (between 8 and 11 years old). Finally, our study shows that modifying racket characteristics constitutes a short-term and relevant practical intervention that provides immediate new learning opportunities for young intermediate tennis 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 University of Rennes 2. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

CL, PT, MF, BB, RK, LF, NC, and CM: conceptualization. CL, PT, MF, NC, and CM: data curation and methodology. CL, MF, and CM: formal analysis. CL, PT, and CM: writing—original draft. PT, LF, and CM: writing—review and editing. 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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Physiological demands of racket sports: a systematic review

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The practice of racket sports has had an exponential growth in the last decade, along with it, the scientific interest in researching the different disciplines: badminton, padel, table tennis, tennis, and squash. However, most research has focused on the technical and tactical field. Therefore, the aim of this review is to analyze and compare the indicators of the internal load of each sport: heart rate (HR), maximum oxygen consumption (VO_{2max}), oxygen consumption (VO_2), and lactate (LA) in order to reset physiological references to adjust the training of the players and also use these references to propose the practice of these sports for healthy purposes to the general population. PRISMA Guidelines for Systematic Review were used to search for articles that met the inclusion criteria in three databases: Web of Science, Pubmed, and Sportdiscus. The search was performed between January 2010, and September 2022. Finally, a total 27 records were included for analysis in this study. The main findings were related to the differences in the intensity rates between sports. The highest lactate concentrations and heart values were found in badminton in the intensity of effort values (whose highest values were found in badminton) 10.11 (±4.99) mmol/L and 182.6 (±2.7) bpm respectively, whereas table tennis showed the lowest ones 1.2 (± 0.4) mmol/L, and 103.99 (±15.09) bpm, respectively. The highest mean VO_2 was found in table tennis with a value of 36.8 (±13.2) ml/kg/min and the lowest in tennis with a value of 26.6 (±2.7) ml/kg/min. The highest VO_{2max} was found in tennis players 58.0 (±4.6) ml/kg/min, and the lowest value was in table tennis with a value of 42.9 (±4.2) ml/kg/min. Since most of the studies were carried out on elite men players, future research should focus on amateur and women level players.

KEYWORDS
heart rate, maximum oxygen consumption, lactate, padel, badminton, table tennis, tennis

1. Introduction

The so-called racket sports include a variety of disciplines such as: badminton, racquetball, padel, tennis, table tennis, squash, etc., which are competed individually or in pairs. Racket sports are characterized by being acyclical disciplines, which combine very intense physical load cycles with short breaks, allowing incomplete recovery from the efforts performed (Martínez, 2014).

In the last decade, racket sports have become an important alternative to traditionally practiced sports, considerably increasing the number of people who practice them. One of the main factors that differentiates each of the racket sports is the court on which the game takes place. Some of them are developed in spaces divided by a net (badminton, tennis, and table tennis); in others it is mandatory to use a wall or fence (squash and racquetball); and in the case of padel, a mixed sport developed in a space enclosed by side and back walls and divided by a net where it is allowed to play with some side wall areas and with the back walls.

Despite the importance that technical-tactical variables undoubtedly have in racket sports, since all the decisions made during the game determine performance and victory (Stare et al., 2015; Varas Caro and Gómez-Ruano, 2016; Cui et al., 2017), it is also interesting to analyze other aspects that have a direct influence on sports performance, such as the physiological response or the metabolic impact, indicators that inform us about the internal load, that it is to say variables of great relevance to know the intensity of the effort in a match.

These metabolic demands depend, mainly on the type of effort required in each sports specialty and the distribution of the periods of effort and rest established in each case. In this sense, considering the game elements of each discipline, such as scoring, as indicated by International Tennis Federation (2022) matches can be played to the best of three or five sets, whose duration can fluctuate between 1 to 5 h; although most matches are played to the best of three sets, with an average duration of 60 to 90 min (Bergeron et al., 1991; Torres-Luque et al., 2014). According to the rules of the International Padel Federation (2021), padel matches are played to the best of three sets whose duration according to the study carried out by Sánchez-Alcaraz (2014) was 35 min in men, and 36 min in women. As described above, padel and tennis have similar elements that are manifested through the type of scoring and rest times: 20 s between points, 90 s between side changes and 120 s between sets (Spanish Padel Federation, 2022), but they differ in the dimensions of the court (Amieba and Salinero, 2013) and absence of walls. Badminton has similar scoring characteristics to tennis and padel; in addition, the matches are developed to the best of three sets, according to the Badminton World Federation (2022), whose duration fluctuates between 17 and 40 min (Ming et al., 2008; Abian-Vicen et al., 2013). Squash matches usually take place over five sets, but sometimes also over three sets (World Squash Federation, 2020). Whereas in table tennis the score is different from the sports mentioned, since the matches are developed to the best of any odd number of games (Royal Spanish Table Tennis Federation, 2021–2022), and the duration of a match fluctuates between 10 to 25 min (Lees, 2003).

About resting times during racket sports competition, we can point out that in padel between each set are 2 min, 20 s maximum between each game, when changing side by game the maximum time is 1 min and 30 s, and in the case of tie-break the player has 20 s for the change of side (International Padel Federation, 2021). In tennis, the players have a maximum rest of 25 s between points. When players switch sides at the end of a game a maximum break of 1 min and 30 s allowed. However, after the first game of each set and during a tie-break game, the game is continuous, and players will switch sides without any rest. At the end of each set there is rest of a maximum of 2 min (International Tennis Federation, 2022). In table tennis the game is continuous throughout the match, except that every player is entitled to a break of up to 1 min between successive games of a match; short breaks to use the towel after every 6 points from the beginning of each game and in the change of side in the last possible game of a match. Moreover, a player or partner may request a timeout period of up to 1 min during a match (RFETM, 2021–2022). In badminton matches there is a break that should not exceed 1 min during each game when one side reaches 11 points; in addition, a break that should not exceed 2 min between the 1st and 2nd game, and between the 2nd and 3rd game in all matches (Spanish Badminton Federation, 2019). In squash the allowed rest time should not exceed 1 min and 30 s between the end of the warm-up and between each game (Badminton World Federation, 2022).

According to these resting, we can say that table tennis and squash are the sports that have less recovery time, unlike tennis, padel and badminton. This could impact the values of physiological markers used to analyze internal load.

Another factor that could intervene in the internal load are the types, amount, and frequency of strokes. In tennis, strokes such as serve, lobs, deep groundstrokes, are characterized by explosive and fast movements with high energy consumption in a short time (Kovacs, 2007). It also occurs in table tennis, with the difference that the speed and explosiveness with which the game is developed is much greater, finding differences between sexes being the number of strokes made by women than men (Torre et al., 2022). In badminton the strokes that are made during the game are also very fast, likewise, the speed of the technique with minimum preparation, the thinking speed and the risk they take in attacking blows (Stovba et al., 2020). Similarly, the strokes in padel resemble those of tennis since they share some rules. The difference relies in the alternating hits that can be made between both players in addition to being able to slow down the game using both the background walls and the side walls (García-Benítez et al., 2018). On the other hand, according to the description above, the punctuation systems are similar, but in the case of padel, a new rule incorporated in 2020, which is that if both teams have won three points, the score will be deemed "equal" and a single decisive point will be played, called "Golden Point." The pair that wins the decisive point will win the game (World Padel Tour, 2022).

Additionally, the anthropometric characteristics of the players of each sport is another variable to considered. In badminton, according to the study conducted by Ramos Álvarez et al. (2016) women are ectomorphs and men mesoform. In padel, as stated by Pradas de la Fuente et al. (2015a) the anthropometric profile in women is endosomesomemorphic, because they present a greater development of skeletal muscle than fat. Endomorphic somatotypes were negatively related to performance, while ectomorphic profiles seems more effective. In table tennis, as reported by Pluta et al. (2021) and Pradas et al. (2021a) the predominant somatotype in men is mesomorphic, while ectomorphic in women. The study of Pradas et al. (2021a) showed that mototype was predominatly mesomorphic in men and endomorphic in woman. Higher leans-mass in the upper limbs appeared to be associated with better performance in table tennis player.

The court and the type of movements made are other aspects that might intervene in the physiological response and suggest some difference between each sport because of the difference in court sizes. Padel is played on a rectangular court of 20 × 1 0m with 10 m bottom walls, and side walls of 20 m (Pradas de la Fuente et al., 2015a). In the study conducted by García-Benítez et al. (2018) this size generates an improved pace of play and greater frequency of actions without increasing physical intensity compared to other sports, such as tennis where the playing field is a rectangle measuring 23.77 × 8.23 m, for singles. For doubles the court has the same sizes as singles, but the width is 10.97 m (International Tennis Federation, 2022). Table tennis is played in a rectangle measuring 2.74 × 1.525 m (ITTF, 2020), badminton is played in a rectangle too, that measures 13.40 × 5.18 for singles, and 13.40 × 6.10 (Badminton World Federation, 2022) for doubles.

The dimensions of the playing court of each sport have a direct relationship with the physiological and metabolic response since the path of these are different in each sport. For example, in padel, 52.32% of the total number of strokes are lateral displacements and 42.29% are frontal (Priego et al., 2013), while in the case of table tennis a playing surface of such small dimensions causes short and fast very explosive high intensity movements although the final distance traveled is short but its intensity is very high (Torre et al., 2022). Similarly occurs with badminton, but on a court of larger dimensions as in tennis (Kovacs, 2007; Stovba et al., 2020). This aspect has a direct relationship with the density of play (activity time//rest time).

About the temporal structure game, according to the study of Pradas et al. (2021a) table tennis with other racket sports, the playing times are longer in badminton with values of 6.8 s in men competition and 2.3 s in women competition (Fernandez-Fernandez et al., 2007). In tennis, the duration of points is longer than in table tennis, with playing times 5.2, s for men and 7.1 s for women (O'Donoghue and Ingram, 2001). In padel the duration is also more than in table tennis with effort values 9.3 and 17.7 s 9.06 and 13.03 in women (Pradas de la Fuente et al., 2015a).

As described above, here are multiple factors involved in the physiological response, such as the dynamics of the game, the type of surface, the dimensions of the court, the distances traveled, the breaks in each match and the type of effort made, which in some game actions will predominate the efforts of resistance, strength, and speed (Montoya et al., 2020). This variability of efforts will cause different metabolic and physiological responses in athletes, due to the interval nature of these sports (Sánchez-Alcaraz, 2014). To evaluate these responses, different markers have been assessed, being blood lactate concentrations (LA), heart rate (HR) and oxygen consumption (VO_2) the most used (Carrasco et al., 2011; Kondrič et al., 2013).

Available research in racket sports mainly refers to the structure of the game and how the different technical-tactical factors are involved in performance (Courel-Ibañez et al., 2017; Fernández-García et al., 2020; Navas et al., 2020; Ramón-Llin et al., 2020). However, in relation to physiological responses we can find a diversity of results in studies of performance in rackets sports, considering all the elements of the game involved in sports performance and how they determine the response of the player's body during a match. According to the above and considering the growth that racket sports have had in recent years, the aim of this review is to analyze and compare the indicators of the internal load of each sport: HR, VO_{2max}, VO_2, and LA in order to reset physiological references better adjust the training of the players and also use these references in order to propose the practice of these sports for healthy purposes to the general population.

2. Materials and methods

For the performance of this review, the protocol was registered in PROSPERO 2022 CRD42022354791, and the PRISMA Guidelines for Systematic Reviews was used (Page et al., 2021). The search was carried out in the following databases: Web of Science, Sportdiscus and Pubmed, in all fields, using MeSH and Thesauri terms derived from the rackets sports.

The search strategy used the following terms:

- Racket sports:" racquet sports" OR "racket sports" OR "racket players" OR Badminton OR "Badminton players" OR squash OR "squash sport" OR padel OR "paddle tennis" OR paddle OR "padel players" OR tennis OR "Tennis player" OR "Table Tennis" OR "ping pong" OR "table tennis players."
- Exercise intensity: "exercise physiology" OR "exercise intensity" OR "clinical exercise physiology."
- Physiological markers: "Lactic Acid" OR "Lactate" OR "Lactates" OR "BLOOD lactate" OR "heart rate" OR "Heart rates" OR "Cardiac Rate" OR "rate heart" OR "heart rate monitoring" OR "heart rate monitors" OR "oxygen consumption" OR "VO_2 peak" OR "VO_{2max}" OR "exercise physiology" OR "exercise intensity" OR "clinical exercise physiology."
- Sintax: ("racquet sports" OR "racket sports" OR "racket players" OR Badminton OR "Badminton players" OR squash OR "squash sport" OR padel OR "paddle tennis" OR paddle OR "padel players" OR tennis OR "Tennis player" OR "Table Tennis" OR "ping pong" OR "table tennis players") AND ("Lactic Acid" OR "Lactate" OR "Lactates" OR "blood lactate" OR "heart rate" OR "Heart rates" OR "Cardiac Rate" OR "rate heart" OR "heart rate monitoring" OR "heart rate monitors" OR "oxygen consumption" OR "VO_2 peak" OR "VO_{2max}" OR "exercise physiology" OR "exercise intensity" OR "clinical exercise physiology")

For the selection of studies, the following criteria were considered: articles published between 2010 and September 2022, articles in English and Spanish, studies in which adult male and female players (18 years or older) were analyzed in real competition or in simulated situations, and studies that assessed the following physiological variables: maximum oxygen consumption, heart rate, lactate and others derived from the above and articles published in full-text academic journals.

On the other hand, the exclusion criteria were the following: systematic reviews, narrative reviews meta-analysis, scoping reviews, articles that analyzed the adapted sport, articles that analyzed subjects with different pathologies, abstracts, conferences and/or communications to congress.

Once the search strategy was applied in the databases the selection bias was controlled for by the two researchers who used the Endnote web manager (available online at https://www.myendnoteweb.com/EndNoteWeb.html) bibliographic manager. This software was also used to identify duplicates once the main search was conducted. For quality bias, each investigator independently applied the National Heart, Lung, and Blood Institute (NHLBI) Quality Assessment Tool for Short, Cross-Sectional Observational Studies available online https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools; and for the case studies the tool available online was applied https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools. The document is organized by number of questions to assess the quality of the studies, registering three indicators, as appropriate: "Yes" (Y), "No" (N), or "Other" (O): "cannot determine" (CD); "not applicable" (NA); "not reported" (NR).

The application of this tool was based on the study design, and it was used for the general measuring of the quality of the studies:

"good," "fair" and "poor." Two researchers applied this tool independently and in case of disagreement, a consensus was reached through discussion, or the opinion of a third researcher was requested.

The Supplementary Table 1 have the results of the evaluation.

3. Results

The initial search yielded a total of 1,110 articles. After removing duplicates, a total of 840 articles were reviewed. Once the inclusion and exclusion were applied criteria 27 articles were selected for the final analysis (Figure 1).

According to the results obtained in the evaluation of the quality of the studies, the risk of bias is negative, since most of the studies respond to good quality.

The selected studies were organized by sport to present the results of each physiological marker. In table tennis 8 studies were found, 6 in tennis, 6 in padel and 7 in badminton. Surprisingly, no studies in squash.

The most used parameter to analyze the internal load was HR, since all studies selected 27 studies analyzed this variable. In relation to concentration LA, this variable was analyzed in 14 studies, VO_{2max} was analyzed in 12 studies and VO_2 in 6 studies.

The studies found involved female and male subjects, and there were some studies whose sample was mixed.

The selected studies analyzed variables in a diversity of subjects with different levels of play. Below are the levels found.

The values found in each study were organized by each sport to present the number of subjects, age, intervention, mean LA, VO_{2max}, VO_2, and HR.

4. Discussion

The main objective of this review was to analyze the indicators of internal load to reset physiological references to adjust the training of the players and suggest the practice of the general population.

According to the search strategy and the inclusion and exclusion criteria applied, the sports selected for this review were tennis, table tennis, padel and badminton. The findings found in the studies of these sports refer to the analysis of internal load using four main physiological markers: HR, VO_{2max}, VO_2 and LA, being HR the most used.

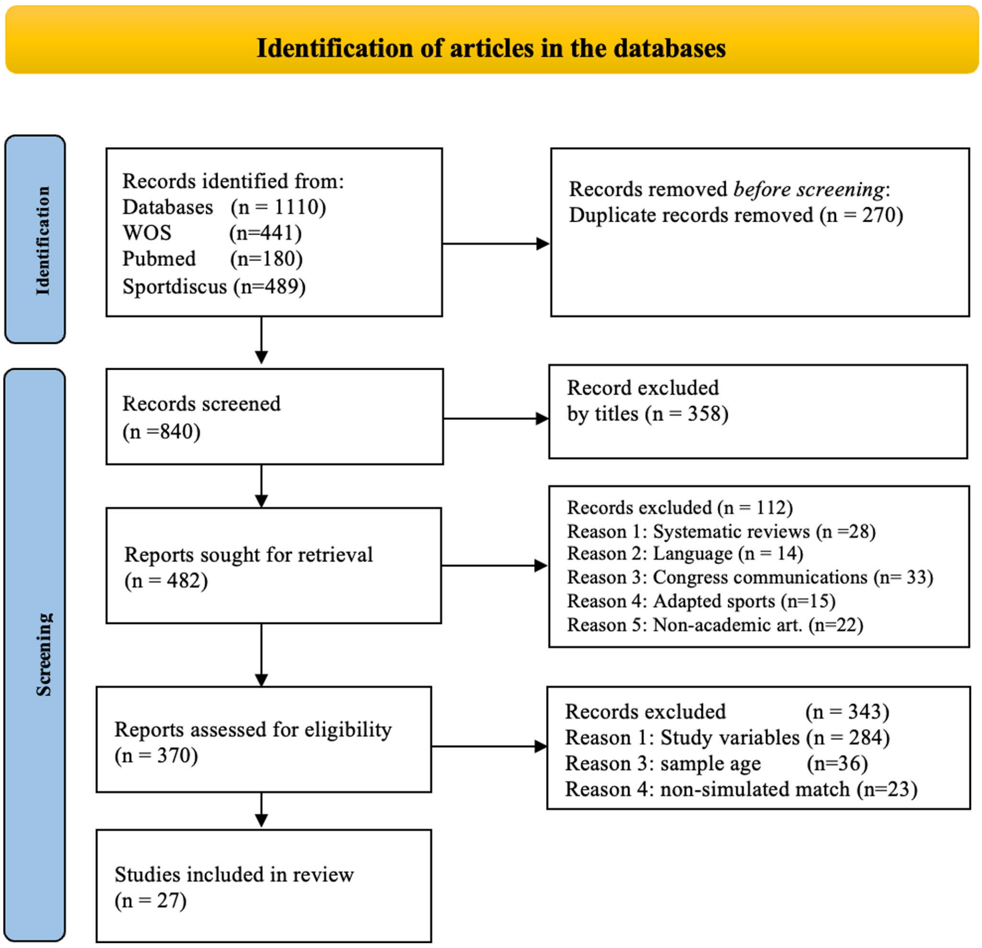

FIGURE 1
Flow chart of the search process the selection of article.

4.1. Maximum oxygen consumption (VO_{2max}) and oxygen consumption (VO_2)

VO_{2max} is the ability to transport and consume oxygen during strenuous work; it is associated with cardiorespiratory fitness and is used as an indicator in this field; it measures aerobic capacity and, therefore, defines the limits of cardiovascular function (Koutlianos et al., 2013; Sánchez-Otero et al., 2014).

In table tennis of the 7 included studies, 5 evaluated VO_{2max} (Shieh et al., 2010; Zagatto et al., 2016; Milioni et al., 2018; Pradas et al., 2021b; Torre et al., 2022) these analyses correspond to the study carried out on a men sample, whose values fluctuated between 42.1 (±6.4) and 53.2 (±0.6) ml/kg/min.

The variable VO_2 was analyzed by only 3 studies (Shieh et al., 2010; Zagatto et al., 2016; Milioni et al., 2018), whose values fluctuated between 28.5 (±3.02) and 35.6 (±18.4) ml/kg/min. The cause of shortages of analysis of this variable could be associated with the complexity involved in carrying a device when playing a simulated match, and even more so in an official match.

In tennis, of the 6 included studies, only 3 evaluated VO_{2max} (Baiget et al., 2015; Kilit et al., 2016; Hoppe et al., 2020) the values fluctuated between 40.9 (±4.3) and 58.0 (±4.6) ml/kg/min, in women and men, respectively. The mean value the VO_2 in play fluctuated between 26.6 (±2.7) and 29.9 (±3.7) ml/kg/min. These values correspond to the group of men. These values are similar to those presented in other studies (Smekal et al., 2001; Ferrauti et al., 2003) using game simulation and real competition situations.

In badminton, one study analyzed the VO_{2max} in a sample whose level of play was recreational (Deka et al., 2017), the value was found to be 45.2 (±8.7) ml/kg/min, while the meanVO_2 recorded during the game was 34.4 (±5.8) ml/kg/min, values very similar to those found in another study (46.0 ± 4.5 ml/kg/min; Faude et al., 2007), but the sample analyzed was an elite level group.

In the case of padel 2 studies recorded the VO_{2max} (Pradas de la Fuente et al. 2015a; García et al., 2017), where the values fluctuated between 47.33 (±4.57) and 51.15 (±5.73) ml/kg/min. The VO_2 during a match was not recorded by any studies of this sport. However, in one study (Carrasco et al., 2011) the variable analyzed in young players the $VO_{2máx}$ was 55.64 (±8.84) ml/kg/min, and the mean value of VO_2 in matches was 24.06 (±6.95) ml/kg/min.

The highest VO_{2max} values reported was 58 (±4.06) ml/kg/min (Baiget et al., 2015) corresponding to tennis and the lowest value was 42.1 (±6.4) ml/kg/min (Shieh et al., 2010) corresponding to table tennis. In a study we found an intermediate value (Deka et al., 2017), whose value was 45.2 (±8.7) ml/kg/min in a recreational sample. These values are similar to the results obtained in a study in national game players (Milioni et al., 2018). Although, there are similar values among national and recreational players in badminton and table tennis the difference is that players of national category can tolerate much greater physical efforts (Fernandez-Rodriguez et al., 2019).

The maximum VO_2 during a match was 36.8 (±13.2) ml/kg/min registered in one study (Shieh et al., 2010), focused on table tennis, whereas the minimum value recorded in matches was 26.6 (±2.7) ml/kg/min registered in tennis (Kilit et al., 2016).

However, and according to the above results we could say that VO_2 does not seem to be a limitation for racket sports practice (Mellado-Arbelo and Baiget, 2022).

4.2. Heart rate

Of the totality of the studies selected for this review, this physiological marker was analyzed by 25 studies, which shows that it is one of the most used markers to measure the intensity of effort (Kondrič et al., 2013). This could be due to the easy access to heart monitors, and the low interference generated by the device in the performance of the players in match.

In table tennis, 7 studies analyzed the HR as variable (Martin et al., 2015; Pradas de la Fuente et al., 2015a; Zagatto et al., 2016; Milioni et al., 2018; Picabea et al., 2021; Pradas et al., 2021b; Torre et al., 2022) whose mean values fluctuated between 103.9 (±15.09) and 146 (±5.9) bpm. In a study conducted in a group of young players of competitive level (Sperlich et al., 2011), the mean HR in a simulated match was 125 (±22) bpm.

In tennis, of the 6 studies found, 5 analyzed this variable (Gomes et al., 2011; Martin et al., 2011; Baiget et al., 2015; Kilit et al., 2016; Hoppe et al., 2020), where the values fluctuated between 128 bpm and 154 bpm.

The values found in this sport were found in elite levels of players, however this data could be a reference for recreational players.

In badminton all selected studies analyzed HR, whose values fluctuated between 157 (±13.9) and 182 (±9.4) bpm these results indicate that the intensity of this type of sports is moderate to vigorous, because of the high averages recorded during the match (Cabello Manrique and González-Badillo, 2003; Faude et al., 2007).

The highest value was found in the study conducted in a sample of competitive national level players, mean HR was the 182.6 (±2.7) bpm (Chen et al., 2011). These results may be associated with the characteristics of this sport, since it is considered one of the three most competitive, intense and fastest racket sports (Stovba et al., 2020).

In padel, this variable was analyzed in all studies, fluctuating between 126.7 and 159.1 bpm. Two studies (Castillo-Rodríguez et al., 2014; Roldán-Márquez et al., 2022) analyzed this variable in national level players, reporting values between 135 (±7.9) and 149.1 (±18.2) bpm, respectively. The last value is similar to that recorded in the research by Carrasco et al. (2011), who found a mean HR of 148.3 (±13.63) bpm in a sample of first-level juniors players. The highest mean value found was in badminton with a value of 182.6 (±2.7) bmp registered in one study (Chen et al., 2011), and the lowest value was found in table tennis (mean HR of 103.99 (±15.09) bpm; Picabea et al., 2021). It is well known that racket sports are characterized by being sports of variable intensity. HR values reported suggest that tennis, table tennis and padel dominate the aerobic pathway, with very short high intensity intervals. In the case of badminton, the values found suggest that the dominant route is anaerobic.

4.3. Lactic acid concentrations

In table tennis, of the 8 studies found, 6 analyzed this variable (Martin et al., 2015; Pradas de la Fuente et al., 2015b; Zagatto et al., 2016; Milioni et al., 2018; Pradas et al., 2021b; Torre et al., 2022), LA concentrations ranged between fluctuated 1.2 (±0.4) and 4.7 (±2.2) mmol/L. The highest value found in the one study (Martin et al., 2015) was because the blood sample taken was 1 min after the end of each set and 3 min after the end of the matches to respect International Table Tennis Federation timing rules. However, in the others studies blood sample was taken after the end of each set, and in the 3er, 5th, and 7th min after the match; this explains the differences found.

Concentrations found in table tennis are less than 2 mmol/L, so it could be said that the dominant metabolic pathway is aerobic, with little participation of the anaerobic lactic pathway (Zagatto et al., 2018).

In tennis, of the 6 selected studies, 4 analyzed this marker, 2 studies were performed on men and two studies on women (Mendez-Villanueva et al., 2007; Gomes et al., 2011; Martin et al., 2011; Hoppe et al., 2020). The values recorded in these studies fluctuated between 1.5 and 5.7 (±1.8) mmol/L, being similar to those found in other studies (Fernandez-Fernandez et al., 2007).

In the study where the values in women and men were analyzed, and compared according to the type of court (Martin et al., 2011), the highest value was found in women whose game was developed in clay courts. In addition to the differences between gender, it seems that the type of court could interfere with the dynamics of the game and consequently in the metabolic response, an aspect that should be considered in future research for the analysis of the internal load. In the studies conducted in women, the highest value found was 5.7 (±1.8) mmol/L recorded in a clay court, whereas the lower value was 1.5–2.3 mmol/L. This difference could be associated with the players at competitive level since the highest value corresponds to elite players and the lowest to national players. In more demanding game situations LA concentrations could rise between 6 and 8 mmol/L (Fernandez-Fernandez et al., 2007; Mendez-Villanueva et al., 2007; Christmass et al., 2010).

In badminton, of the 7 studies found, 2 analyzed circulating levels of LA, whose recorded values fluctuated between 4.3 (±0.4) and 10.1 (±4.9) mmol/L, although the highest value corresponds to the analysis in a recreational male player; this value is like that recorded in other study (Mendez-Villanueva et al., 2007), whose values are related to long-lasting matches. According to the studies found, we can say that most focus on elite level players (Patterson et al., 2017). However, the values found suggest that the dominant metabolic pathway is glycolytic anaerobic.

In padel, of the 6 studies found, only 3 analyzed the LA concentrations (Castillo-Rodríguez et al., 2014; Pradas de la Fuente et al., 2015a; Roldán-Márquez et al., 2022). The recorded values fluctuated between 1.83 and 2.87 mmol/L. Blood LA levels were ower than those found in studies of badminton and tennis, therefore, it could be estimated and according to the characteristics of this sport (Pradas et al., 2021a) that the metabolic pathway is aerobic due to the long duration of the matches, and at the same time anaerobic due to the actions that take place in the game, such as changes of direction and accelerations (Courel-Ibáñez and Herrera-Gálvez, 2020). Racket sports are characterized by being cyclical in nature, but for training to have positive effects on the game, technical characteristics, tactics, age, sex, level of play must also be considered, and in the case of tennis, the type of court. It is important to consider all the factors mentioned above since they are involved in the physiological response.

According to the variables analyzed in this systematic review, we could say that badminton is the most physiologically demanding sport, this could be due to the important technical demand during the game that is characterized by jumping, changes of direction and acceleration (Cabello Manrique and González-Badillo, 2003). This could also be due to the duration of a game point, technical characteristics, or rest periods between one game and another. The value found in LA concentration in this review is far from the study carried out before the last decade (Majumdar, 1997) whose LA concentrations were 4.7 mmol/L in real match conditions. The high values of the FC may be characteristics of the game. It requires efforts of high intensity and short duration that generate a high level of stress, with the consequent stimulation of the sympathetic nervous system and as a consequence the increase of HR (Ramos Álvarez et al., 2016) In addition, all the load is distributed in the different muscle groups and in all body systems, therefore, they create an important biological reserve in high performance (Stovba et al., 2020). In table tennis, the values found in this study suggest could be related to the characteristics of the game, explosive and very fast (Torre et al., 2022). In response to these characteristics it seems that the main energy pathways are aerobic and anaerobic, because is a sport characterized by skill rather than VO_2, were fast and intense actions predominant. The mean values of VO_2 are lower than badminton; his could be due to the high technical demand, the short duration of the points and the shorter routes that characterize badminton. This could be explained the metabolic and cardiorespiratory demands are moderate throughout the match. Moreover, as explained by Sperlich et al. (2011) metabolic and cardiorespiratory demands are moderate throughout the match. In t the mean values of VO_2 are lower than badminton; his could be due to the high technical demand, the short duration of the points and the shorter routes that characterize badminton.

In the case of padel according to the results analyzed it could be suggested that the most used metabolic pathway is glycolytic aerobic, lactate values show that the energy coming from the lactic anaerobic system is not predominant. In this sense, we found similar results in another study (Pradas de la Fuente et al., 2015a) where the maximum value obtained was close to 2.4 mmol/L, indicating that the glycolytic anaerobic pathway is the least determining. Another study shows that mean values transit from aerobic-anaerobic zone. This occurs because it is an intermittent sport, whose highest HR occurs in games and the lowest in breaks (Muñoz et al., 2018). In tennis, according to the results obtained, it could be said to be a sport with lower physiological demands than badminton. This could be explained by the recovery phases (Edel et al., 2019), and the speed of gaming actions. According to the study of Kovacs, (2007) the main contributor is the anaerobic ATP-PC, since it is a source of immediate energy that is used mainly in some hits, such as in serves at more than 200 km/h. However, in the study by Bergeron et al. (1991) it was found that the overall metabolic response is prolonged exercise of moderate intensity. It appears that oxidative metabolism restores ATP for the duration of a full match due to recovery periods (Kerr, 2015). It seems that the energy systems for to racket sports are the aerobic and anaerobic (Simpson et al., 2017).

According to the findings, it is necessary to assess whether badminton is a recommended discipline for the general population, given the characteristics of the intensity of the effort manifested in the values found.

The limitations of this review were the scarcity of research conducted on women, since most focused on men, also the type of sample since the most studies were carried out in elite o competitive players. There are very few studies conducted at amateur or recreational levels of play. And additionally, the lack of observational studies.

Likewise, we did not find any studies of squash in the period that this research was carried out, except for before the last decade (Vučković et al., 2013). This highlights the need to generate more studies on the female gender, at different levels of play, considering, in the case of tennis, the type of court. In addition, generate studies on the effects of a physical exercise program based on one or more racket sports on the health status of different populations of interest. Given that the practice of these sports has been growing in recent years, both at a competitive and recreational level, it is necessary to know the physiological requirements.

5. Conclusion

Racket sports are disciplines characterized by being intermittent, however according to the results found in this review we find some differences between one sport and another. It can be said that badminton is the sport with the highest cardiovascular and metabolic demand, since we find the highest values in HR and LA; the latter exceeds the limit of the established aerobic and anaerobic threshold (2–4 mmol/L). In table tennis the values of HR and LA are lower than those of badminton, but the average value of VO_2 is the highest of all the sports analyzed; this could be because specific skills are the most determining factor for the performance of this racket sports. In tennis, VO_2 was the lowest value found, it seems that cardiovascular capacity would not be a limitation to practice this sport. In padel the values are lower than badminton, tennis and table tennis; the results suggest the dominant pathway could be aerobic with very short high intensity intervals.

The analysis of the physiological markers was made in samples with different levels of play (elite, professional, amateur, recreational) despite the well-known differences, it could be that padel, table tennis, tennis and badminton are recommended for general practice for healthy purposes, the latter being the most demanding of all.

Future research should focus on women, as most studies are conducted on men. Also, considering the growth of the practice of these sports, future research should include amateur or recreational level players with the purpose of knowing the effects on health.

Author contributions

MC, FP, LC, and AM-A: research concept and study design. MC, FP, and LC: literature and review and write of the manuscript and conceptualization and methodology, formal analysis investigation, and resources data analysis. All authors contributed to the article and approved the submitted version.

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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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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1149295/full#supplementary-material

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Relationship between family background and self-efficacy in adolescent table tennis players: a moderated mediation model

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Introduction: A moderated mediation model was constructed in this study to clarify the relationship between family background and self-efficacy of adolescent table tennis players, focusing on the mediating effect of technical learning engagement in the relationship as well as the moderating role of factors such as gender and training years.

Methods: 189 adolescent table tennis players (age: 13.69±1.28 years) were investigated as subjects using a questionnaire method.

Results: (1) Family background, technical learning engagement, and self-efficacy were significantly and positively correlated (p<0.01), with girls' technical learning engagement (M_{female}=5.81, M_{male}=5.19, p<0.01) and self-efficacy (M_{female}=3.34, M_{male}=2.66, p<0.01) significantly higher than boys'; (2) Technical learning engagement partially mediated the effect of family background on self-efficacy (ab=0.10, boot SE=0.02,95% CI=[0.07, 0.14]); (3) The first half of technical learning engagement's mediating role was moderated by gender (B=0.05, p<0.01), with a more significant influence of family background on boys' (B=0.24, p<0.001, 95% CI=[0.22, 0.26]) technical learning engagement than girls' (B=0.19, p<0.001, 95% CI=[0.17, 0.21]); (4) The second half of technical learning engagement's mediating role was moderated by training years (B=−0.21, p<0.001), with a more significant influence of technical learning engagement on the self-efficacy of adolescents with fewer training years (B=0.54, p<0.001, 95% CI=[0.39, 0.68]). The positive effect of technical learning engagement on self-efficacy gradually diminished with increasing training years, and the moderating effect of training years disappeared when the training years reached 8.94 years.

Conclusion: (1) More attention should be paid to adolescent table tennis players with poor family backgrounds, who are more likely to have low self-efficacy. (2) Parents should never neglect their initiative in providing guidance and support to adolescent players involved in long-term professional table tennis training, especially for boys. (3) Coaches should pay close attention to the level of technical learning engagement of players with long training years, who are more likely to have lower self-efficacy as a result of their own emotional experiences, stagnant performance, etc.

KEYWORDS

adolescent table tennis players, family background, self-efficacy, gender, training years

1. Introduction

Competitive sports are at the core of global sports development, and China's competitive sports are currently rising in the world with rapid development and impressive accomplishments. Table tennis has dominated the international arena for over half a century as the most popular sport in China (Xu et al., 2016; Zhang and Zhou, 2019). These achievements would not have been possible without the support of China's national sports system and the cultivation of generations of young table tennis talents. Given the country's unique historical context and national conditions, China's competitive sports reserve talents primarily follow a tradition of intense training under the trinitarian principles of difficulty, rigor, and practicality. Athletes are constantly exposed to overload training and the challenge of physiological limits, especially adolescent players who undergo a period of psychological and physiological development and personality formation. As a result, adolescent players are prone to injury and disease, tend to passively accept the training contents assigned by coaches, and may even develop a dislike for and resistance to training, eventually lowering their sense of efficacy in training and jeopardizing athletic performance. As the most fundamental unit of human life, the family is a crucial setting that impacts an individual's growth and development. Adolescents are at a critical juncture in their formation of self-awareness and thinking maturity, and supportive family background has a significant impact on their physical and mental well-being (Kleszczewska et al., 2019) as well as their cognitive development (Belen Barreto et al., 2017). Therefore, it is crucial to consider how self-efficacy can be safeguarded and enhanced in adolescent athletes from the perspective of family background.

Self-efficacy is a core concept of social cognitive theory, which refers to how confident individuals feel in their ability to use the skills they possess to perform a task (Bandura, 1986). It can affect the way individuals attribute things (Yeo and Tan, 2012) and motivate individuals to adopt positive behaviors (Carron et al., 1996; Ouweneel et al., 2011) and attitudes (Graydon, 1997; Judge and Bono, 2001) in a given task. Additionally, self-efficacy plays a positive role in goal setting (Cheng and Chiou, 2010), action orientation (Wolf et al., 2018), task performance (Barling and Abel, 1983; Pajares and Miller, 1994), academic achievement (Hwang et al., 2016), work engagement (Chase et al., 1994; Tan and Chou, 2018), and career exploration (Scott and Ciani, 2008). Most existing studies have explored the mediating effects of self-efficacy on the behavioral performance of the whole group of adolescents from the perspectives of family environment (Davis-Kean, 2005) and family socioeconomic status (Hsieh and Huang, 2014; Wiederkehr et al., 2015). The level of commitment and self-discipline in learning varies by gender due to family economic status, home environment, and parental educational intentions (Zimmerman and Martinez-Pons, 1990). Skill acquisition in table tennis is a practical process of mind–body unity that fosters the co-development of physical and cognitive activities. Adolescents go through complex mental activities at the same time when training and learning, including a constant state of competition, collaboration, overcoming, and performance change. The longer a student trains, the more their sense of experience with learning to train varies, which has varied degrees of impact on their self-efficacy (Richardson and Newby, 2006). In addition, in terms of economic capital, social capital, and the family environment, families with poor backgrounds are more likely to experience stress and uncertainty, which increases the likelihood of issues such as powerlessness, learned helplessness, and low self-esteem for adolescents (McLoyd, 1998) and diminishes their self-efficacy.

In terms of self-efficacy theory, this study focuses on the processes and mechanisms that influence the self-efficacy of adolescent table tennis players in terms of their family background, analyzes the mediating role of technical learning inputs and the moderating role of gender and training years, and makes two major theoretical contributions. First, this study sheds light on the mechanisms that influence self-efficacy in the training process of adolescent table tennis players from the perspective of family background, which enriches the theory of self-efficacy in the training process of adolescent table tennis players. Second, taking China, the world's dominant table tennis player, as an example, the study of this group of Chinese adolescent table tennis players is of great relevance for future adolescent table tennis training in China and abroad. Therefore, the following objectives were set for this study: (1) to investigate the relationship between family background and self-efficacy of youth table tennis players, as well as the influencing mechanisms; (2) to investigate the mediating role of technical learning engagement of youth table tennis players; (3) to explore the moderating effects of gender and years of training factors in the various segments of the mediating role of technological learning inputs.

2. Literature review

2.1. Family background and self-efficacy

Recent research has revealed that family background characteristics, such as family structure, socioeconomic status, parental relationship quality, and parental desires, have an impact on the development of self-efficacy (Astone and McLanahan, 1991; Hsieh and Huang, 2014; Weisskirch, 2018). As early as the 1980s, Whitbeck (1987) put forth the hypothesis that adolescents' self-efficacy would be directly or indirectly influenced by parental behaviors in the family context. Subsequently, scholars have argued about the effects of factors such as family economic status, family environment, and parental educational intentions on adolescent self-efficacy. For instance, Matthews and Gallo (2011) argued that families with a high socioeconomic level were more likely to offer their children better academic and material conditions, which had a positive impact on their children's thinking, academic performance, and sense of efficacy. Adolescents were inspired to engage in similar habits and foster their sense of efficacy by observing their parents' success in specific areas (Bandura, 2012). Furthermore, adolescents' academic self-perceptions, expectations, and perceptions of task difficulty were found to be related to their parents' expectations (Parsons et al., 1982). Parents can help children grow up with high expectations of themselves by being willing to act and verbally expressing their expectations. Based on the above findings, the first hypothesis proposed in this study is as follows:

> *H1*: Family background positively predicts the self-efficacy in Chinese adolescent table tennis players.

2.2. Mediating role of technical learning engagement

Family background is closely related to learning engagement. It is found that adolescents with poor family backgrounds frequently experience more intra-family conflicts and less family warmth as a result of their parents' lower socioeconomic status and less favorable family environment, which makes it more difficult for them to have a positive attitude toward learning (Terenzini et al., 2001; Randolph et al., 2006). This phenomenon is further corroborated by empirical studies demonstrating that parents with lower socioeconomic status have more negative parenting styles, such as paying less attention and showing insufficient affection and understanding to their children (Bae and Wickrama, 2015). In contrast, families with stronger parental educational aspirations are more likely to produce children with more educational attainments and academic achievements (Catsambis, 2001). Thus, family background is an important factor affecting adolescents' technical learning engagement.

At the same time, technical learning engagement has a positive effect on individuals' self-efficacy. According to social cognitive theory, learning is regulated and influenced by individual behavioral and situational factors (Shute, 2008). Students regulate their learning process based on cognition, learning engagement, and internal motivation (Panadero et al., 2018). Learning engagement is an important variable in the learning process, which assesses students' engagement in learning activities during their studies (Jurik et al., 2014). A higher level of learning engagement has a positive impact on students' academic achievements (Dresel and Haugwitz, 2008; Pat-El et al., 2012). Accordingly, the second hypothesis proposed in this study is as follows:

> *H2*: Family background influences the self-efficacy of Chinese adolescent table tennis players through technical learning engagement.

2.3. Moderating effect of gender

The impact of different family backgrounds on children exhibits gender differences in many aspects. For example, families with lower socioeconomic status see investing in their children's education as an important strategy for family well-being. The resource dilution model presupposes that there is a cap on the resources available to the family and that the resources allotted to each child decline as the birth rate rises (Blake, 1981). However, the degree of this loss differs significantly between boys and girls. From the perspective of Western academics, families should invest more in daughters when they are in less fortunate circumstances (Trivers and Willard, 1973), while there is still a "preference for sons over daughters" in some Chinese families due to China's patriarchal culture. Boys' education is more important to parents in rural China (Hannum, 2003), where the family's declining economic status is more likely to have a detrimental impact on girls' education (Hannum, 2005). Gender inequality in education tends to decline as the socioeconomic status of families increases (Yeung, 2013).

Previous studies have demonstrated that girls exhibit higher levels of engagement and self-regulation in learning compared to boys and that girls outperform boys in planning, goal setting, structuring, and self-monitoring in learning (Zimmerman and Martinez-Pons, 1990). Studies have revealed that when it comes to learning tactics and usage, girls tend to be more organized, allocate their study time appropriately, and are able to devote more metacognition to their learning (Ruffing et al., 2015). Girls tend to be more engaged and self-regulated in their learning than boys, especially as they enter adolescence (Klimstra et al., 2009). Due to these gender differences, boys may be more dependent than girls on the influence of factors and structures within the family for learning engagement. Accordingly, the third hypothesis proposed in this study is as follows:

> *H3*: The mediating role of the first half of the technical learning engagement is moderated by gender, with family background having a more significant impact on technical learning engagement in boys.

2.4. Moderating effect of training years

In academic settings, students' learning engagement refers to the quality of effort they put into achieving desired outcomes, such as good grades (Hu and Kuh, 2002; Richardson et al., 2004). Previous research has illustrated a positive correlation between students' learning engagement and motivational factors (Kanuka, 2005), learning factors (Whipp and Chiarelli, 2004), and emotional experiences (Usan Supervia and Quilez Robres, 2021). However, limited research has been conducted to empirically investigate the relationship between students' learning engagement and motivational and learning variables (interest, self-efficacy, and self-regulation). For instance, Bates and Khasawneh (2007) found that higher computer self-efficacy can be observed in students who spent more time using online learning technologies and were more engaged in the learning process. Sporting skill acquisition is a long-term process, and students' emotional experiences decrease as they train for a longer time (Richardson and Newby, 2006). Long-term follow-up studies in schools have shown that positive emotional experiences lead to higher levels of learning engagement and promote positive changes in coping styles, which in turn promotes students' self-efficacy (Dong et al., 2020). Accordingly, the fourth hypothesis proposed in this study is as follows:

> *H4*: The mediating role of the second half of the technical learning engagement is moderated by training years. The positive effect of technical learning engagement on self-efficacy decreases as the number of training years increases.

In summary, this study proposed that the technical learning engagement of adolescent table tennis players might play a mediating role in the relationship between family background and self-efficacy, and that the factors of gender and training years have moderating effects on the first and second halves of the mediation model, respectively. The proposed model is shown in Figure 1.

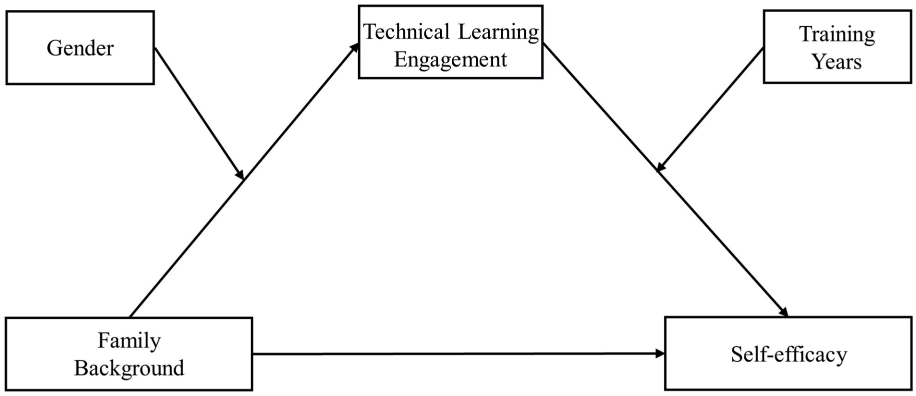

FIGURE 1
Hypothetical model of the mediating role of technological learning engagement and the moderating role of gender and training years.

3. Methods

3.1. Data collection

The cluster sampling method was utilized in this study to conduct a group administration on adolescent table tennis players from Shichahai and Haidian sports schools in Beijing. Our study was approved by the ethical committee of the Capital University of Physical Education And Sports (2022A75). The questionnaires were completed and collected on the spot. 189 questionnaires were distributed successfully according to the inclusion criteria of more than 5 years of participation in table tennis training with a frequency of more than 3 times a week. Additionally, questionnaires with unanswered questions or the same answers to 8 or more consecutive questions were considered invalid and excluded. 181 valid questionnaires were finally collected with an efficiency of 95.77%. The subjects ranged in age between 11 and 16 years old ($M = 13.69$, SD = 1.28), with the majority of training years lasting between 5 and 10 years ($M = 7.83$, SD = 1.54). There was no significant difference in the gender distribution in terms of school type ($\chi^2 = 2.88$, $p = 0.09$); there was no gender difference in the age distribution ($M_{female} = 13.72$, $M_{male} = 13.65$, $t = -3.44$, $p = 0.73$) and school type ($M_{Shichahai} = 13.59$, $M_{Haidian} = 13.75$, $t = -0.83$, $p = 0.41$).

3.2. Data measurement

3.2.1. Family background

This study measures family background in terms of two dimensions: family socioeconomic background and family cultural environment. The family socioeconomic background dimension was synthesized using two variables: "family income" and "parents' education level" (Bradley and Corwyn, 2002; Marks and Mooi-Reci, 2015). The academic accomplishment of earlier generations (Bourdieu and Passeron, 1977) and the supportive attitudes of family members (Zimdars et al., 2009; Jæger, 2011) are commonly used to assess the family cultural environment dimension. Since this study was conducted in a professional-technical setting, the level of family cultural environment was synthesized using three variables: "number of sports-related jobs in the family," "parents' attitudes toward their children's long-term table tennis training," and "parents' attitudes toward their children becoming professional table tennis players" (Guo and Min, 2006).

The family income was denoted by numbers 1 to 5 for less than 5,000 yuan, 5,000 ~ 15,000 yuan, 15,000 ~ 30,000 yuan, 30,000 ~ 60,000 yuan, and more than 60,000 yuan, respectively (Xia, 2022). The education level of parents was denoted by numbers 1 to 5 for the groups of elementary school and below, junior high school (including junior high school without a degree), high school or junior college (including high school without a degree), college (including night college and electric college), undergraduate and above, respectively. The number of persons engaged in sports-related work in the household was denoted by numbers 1 to 5 for the groups of 1 or less, 2 ,3, 4, 5 or more, respectively. The numbers 1 to 5 were used to represent parents' attitudes toward their children's long-term table tennis training and becoming professional table tennis players, including very opposed, opposed, average, very supportive, and somewhat supportive, respectively. The questionnaire consisted of 5 items and was scored on a 5-point Likert scale. The scores were synthesized by first standardizing and summing the scores for each dimension variable to obtain scores for both the family socioeconomic background dimension and the family cultural environment dimension. Finally, the standardized scores of both dimensions were summed to obtain the family background score. The higher the score, the higher the family background. The Cronbach's α coefficient of the questionnaire in the actual test was 0.76.

3.2.2. Technical learning engagement

The UtrechtWork Engagement Scale-student (UWES-S) developed by Schaufeli et al. (2002) was used to measure students' engagement in technical learning. The UWES-S has been widely used by researchers and demonstrates desirable reliability and validity (Moon and Ke, 2020; Wang et al., 2021; Li et al., 2022). In particular, the questionnaire has been translated and adapted to use among Chinese populations (Fong and Ng, 2012). Since this study was conducted in a professional-technical setting, the original scale was partially revised by including a sample question like "I can recover quickly from mental fatigue during technical learning." The Learning Engagement Scale consisted of 17 items and was graded on a 7-point Likert scale, ranging from 1 denoting "never" to 7 denoting "always." The total scale was established from 3 dimensions: motivation, energy, and concentration. Higher scores indicate a greater commitment to

TABLE 1 Results of descriptive statistics, correlation analysis between study variables.

Variable (N=181)	M	SD	1	2	3	4
1. Training years (years)	7.83	1.54	1			
2. Family background	0.00	4.26	0.79**	1		
3. Technical learning engagement	5.51	0.67	0.76**	0.93**	1	
4. Self-efficacy	3.00	0.66	0.67**	0.91**	0.91**	1

**p < 0.01.

learning. The factors and overall Cronbach's α coefficients for this scale in the actual test were 0.79, 0.81, 0.72, and 0.91, respectively. The corresponding results of confirmatory factor analysis were: χ^2/df = 1.14 (df = 116), RMSEA = 0.03, IFI = 0.99, TLI = 0.98, and CFI = 0.98.

3.2.3. Self-efficacy

The General Self-Efficacy Scale (GSES) developed by Schwarzer et al. (1997) was used to measure students' self-efficacy. The GSES has been widely used by researchers and demonstrates desirable reliability and validity (Luszczynska et al., 2005; Azizli et al., 2015; Lazić et al., 2021). The questionnaire has been culturally appropriate for the Chinese context (Sun et al., 2021). This 10-item scale is scored on a 4-point Likert scale to measure the individual's self-efficacy in the face of frustration or difficulty, ranging from 1 denoting "not at all true" to 4 denoting "completely true," with higher scores representing higher self-efficacy. The Cronbach's α coefficient of the scale in the actual test was 0.94, and the corresponding results of validation factor analysis were: χ^2/df = 0.67 (df = 35), RMSEA = 0, NFI = 0.98, RFI = 0. 98, and CFI = 1.

3.3. Data processing

SPSS 27.0 was used for data processing, and GraphPad Prism 9 was used for producing moderating effect plots in this study. First, Harman's single-factor test was employed for common method bias. Second, descriptive statistics were used to demonstrate the current status of various variables in adolescent table tennis players; Pearson correlation was used to reflect the relationship between the variables. Third, the mediating role of technical learning inputs was investigated using Model 4 in the SPSS macroprogram PROCESS (PROCESS is a computational aid in the form of a freely available macro for SPSS and SAS) (Hayes, 2018). Finally, Model 21 in PROCESS was used to test the moderating effects of the gender and training years in the first and second halves of the mediation model, respectively. A bootstrap method (5,000 bootstrap samples) with 95% confidence intervals (CI) was used to test the significance of the effects during the study (MacKinnon et al., 2004; Fritz and MacKinnon, 2007). To avoid multiple correlations, all observed variables were standardized for z-scores before analyzing Model 4 and Model 21.

4. Results

4.1. Control and test of common method bias

In this study, anonymous questionnaire survey and reverse presentation were used for some items to procedurally control any potential common bias. The collected data were tested for common method bias using Harman's single-factor test. The results of the unrotated exploratory factor analysis extracted a total of five factors with characteristic roots greater than one, with a maximum factor variance explained as 38.83% (less than 40%), indicating that there was no significant common method bias.

4.2. Descriptive statistics and correlation analysis

Table 1 displays the means, standard deviations, and correlation coefficients for each variable. The results of the correlation analysis revealed that there were highly positive correlations between training years, family background, technical learning engagement, and self-efficacy, all of which reached an extremely significant level (p < 0.01). Female athletes scored considerably higher than male athletes on the overall family background score (M_{female} = 2.88, M_{male} = −1.50, t = −8.00, p < 0.01), technical learning engagement (M_{female} = 5.81, M_{male} = 5.19, t = −6.97, p < 0.01), and self-efficacy (M_{female} = 3.34, M_{male} = 2.66, t = −7.99, p < 0.01).

4.3. Direct effect of technical learning engagement on self-efficacy

The mediation effect of technical learning engagement between family background and self-efficacy was examined using Model 4 in PROCESS developed by Hayes (2013), with age, gender, and training years controlled. As shown in Tables 2, 3, family background significantly and positively predicted self-efficacy (B = 0.15, t = 19.37, p < 0.001). Moreover, technical learning engagement significantly and positively predicted self-efficacy (B = 0.33, t = 6.43, p < 0.001). The bias-corrected Bootstrap test indicated a significant mediating effect of technical learning engagement with an indirect effect value of 0.10, a 95% confidence interval of [0.07, 0.14], and a mediating effect of 43.48% of the total effect (0.23). This implies that family background can have both a direct effect and a partial mediating effect on self-efficacy through technical learning engagement.

4.4. Test of moderated mediating effect

Model 21 in PROCESS was used to test the moderated mediation model with age controlled to examine the moderating effects of factors such as gender and training years in the first and second halves of the mediation model for analyzing the impact of family background on adolescent table tennis players' self-efficacy through technical learning engagement (Model 21 assumes that the first and second halves of the

TABLE 2 Mediation model test for technical learning engagement.

Regression (*N*=181)		Overall fitted index			Significance of regression coefficients	
Result variables	Predictive variables	*R*	R^2	*F (df)*	*B*	*t*
Self-efficacy		0.92	0.84	236.36***		
	Age				0.07	3.26**
	Gender				−0.10	−2.24*
	Training years				−0.10	−3.19**
	Family background				0.15	19.37***
Technical learning engagement		0.94	0.88	314.00***		
	Age				0.04	2.19*
	Gender				0.03	0.81
	Training years				0.03	1.07
	Family background				0.14	20.15***
Self-efficacy		0.93	0.87	240.62***		
	Age				0.05	2.52*
	Gender				−0.12	−2.86**
	Training years				−0.12	−4.04***
	Technical learning engagement				0.33	6.43***
	Family background				0.08	6.44***

Gender was dummy coded in the model: 1 = male, 0 = female; each continuous variable was standardized and brought into the regression equation; $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

TABLE 3 Decomposition of total effect, direct effect and mediating effect.

	Effect	Boot SE	Boot LLCI	Boot ULCI	Relative effect value
Total effect	0.23	0.08	0.14	0.17	
Direct effect	0.13	0.02	0.08	0.16	56.52%
Mediating effect	0.10	0.02	0.07	0.14	43.48%

Boot SE, Boot LLCI, and Boot ULCI refer to the standard error, lower and upper limits of the 95% confidence interval of the indirect effects estimated by the bias-corrected percentile Bootstrap method, respectively; all values are rounded to two decimal places.

mediation model are moderated, consistent with the theoretical model in this study). The results in Table 4 illustrated that after introducing factors of gender and training years to the model, the product term of family background and gender was a significant predictor of technical learning engagement ($B = 0.05$, $t = 3.28$, $p < 0.01$), and the product term of technical learning engagement and training years was a significant predictor of self-efficacy ($B = -0.21$, $t = -5.57$, $p < 0.001$). Based on this, it can be inferred that gender moderates the prediction of technical learning engagement by family background, and training years moderate the prediction of self-efficacy by technical learning engagement.

Family background exhibited a greater effect on boys' technical learning engagement compared to girls, with a judgment index of −0.01 and a confidence interval of [−0.017,-0.004] (excluding 0), indicating a significant moderating effect of gender on family background and technical learning engagement. Separate analyses were conducted for male and female subjects to better understand the essence of the interaction between family background and gender. The results illustrated that the values of the mediating effect and the 95% Bootstrap confidence intervals were significantly different for the two groups, as shown in Table 5. According to Figure 2, further simple slope analysis revealed that family background had a significant positive predictive effect on technical learning engagement for both male and female adolescents, which was higher for male adolescents (simple slope = 0.24, $t = 26.72$, $p < 0.001$) than for female adolescents (simple slope = 0.19, $t = 16.66$, $p < 0.001$).

Based on the findings above, it is evident that different training years have a moderating effect in the second half of the model for analyzing the impact of family background on self-efficacy through technical learning engagement. To further understand the interaction between technical learning engagement and training years, data from different training years were divided into the high training years group (M + 1SD) and the low training years group (M-1SD) for analysis, as shown in Table 6. There was a significant difference in the impact of technical learning engagement on self-efficacy in the group with low training years and no significant difference in the group with high training years. Further visualization is shown in Figure 3, where the moderating effect is always greater than 0, implying that technical learning engagement has a positive mediation effect on self-efficacy regardless of the moderating effect of training years. As training years

TABLE 4 Mediated model tests with moderation.

Regression (N=181)		Overall fitted index			Significance of regression coefficients	
Result variables	Predictive variables	R	R^2	F (df)	B	t
Technical learning engagement		0.94	0.88	333.47***		
	Age				0.06	2.39*
	Gender				−0.02	−0.24
	Family background				0.19	16.66***
	Family background*gender				0.05	3.28**
Self-efficacy		0.94	0.89	274.91***		
	Age				0.04	1.85
	Family background				0.16	8.78***
	Training years				−0.19	−4.41***
	Technical learning engagement				0.33	4.26***
	Technical learning engagement*training years				−0.21	−5.57***

Gender was dummy coded in the model: 1 = male, 0 = female; each continuous variable was standardized and brought into the regression equation； $*p<0.05$, $**p<0.01$, $***p<0.001$.

TABLE 5 Mediating effects of technical learning engagement for subjects of different genders.

Mediator variables	Gender	Effect	Boot SE	Boot LLCI	Boot ULCI
Technical learning engagement	Male	0.24	0.01	0.22	0.26
	Female	0.19	0.01	0.17	0.21

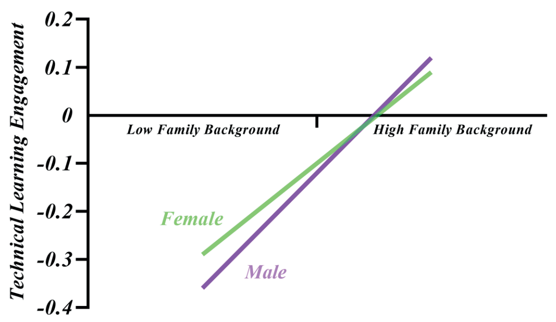

FIGURE 2
The moderating role of gender in the relationship between family background and technology learning engagement.

TABLE 6 Mediating effects of technical learning engagement of subjects with different training years.

Mediator variables	Training Years (years)	Effect	Boot SE	Boot LLCI	Boot ULCI
Technical learning engagement	6.29 (M-1SD)	0.54	0.07	0.39	0.68
	7.83 (M)	0.33	0.08	0.18	0.48
	9.37 (M + 1SD)	0.12	0.10	−0.07	0.31

increase, the positive moderating effect of technical learning engagement on self-efficacy gradually decreases. There is no significant effect of technical learning engagement on self-efficacy until the training years reach the critical value of 0.72 (obtained by standardizing the value of 8.94 years, at which the moderating effect of training years disappeared). According to Figure 4, the regression coefficient was significantly larger in the low training years group (simple slope = 0.54, t = 7.37, p < 0.001) than in the high training years group (simple slope = 0.12, t = 1.24, p = 0.22), according to a simple slope analysis (Figure 4). That is, the effect of technical learning engagement on self-efficacy was higher when training years were short. When training years were long, the impact factor of technical learning engagement on self-efficacy decreased as training years increased. Furthermore, training years had a significant negative moderating effect on the relationship between technical learning engagement and self-efficacy, diminishing the positive effect of technical learning engagement on self-efficacy until the moderating effect disappeared.

5. Discussions

A moderated mediation model was constructed in this study to clarify the relationship between family background and self-efficacy of adolescent table tennis players, focusing on the mediating effect of technical learning engagement in the relationship, as well as the moderating role of factors such as gender and training years. The results revealed that (1) family background, technical learning engagement, and self-efficacy were significantly and positively correlated (p < 0.01), with girls' technical learning engagement

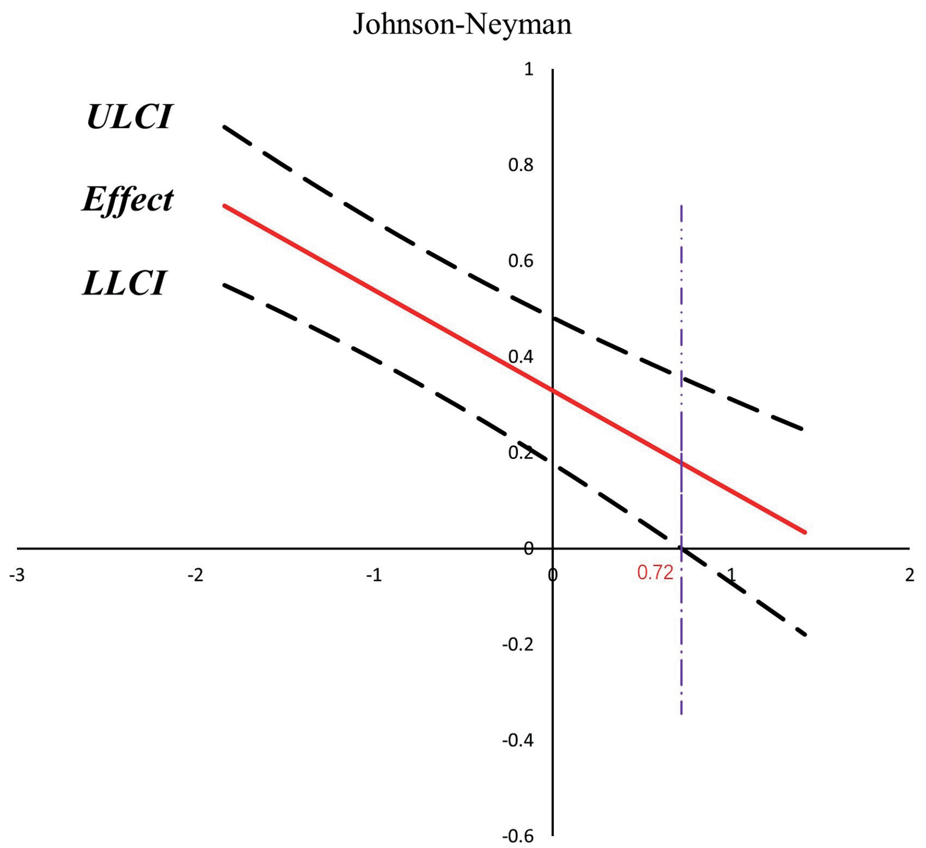

FIGURE 3
Johnson-Neyman diagram of the moderating effect of training years. ULCI refers to upper limit of the 95% confidence interval; LLCI refers to the lower limit of the 95% confidence interval.

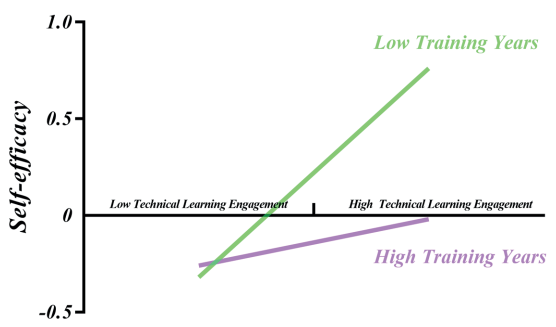

FIGURE 4
Moderating role of training years in the relationship between technical learning engagement and self-efficacy.

(M_{female} = 5.81, M_{male} = 5.19, p < 0.01) and self-efficacy (M_{female} = 3.34, M_{male} = 2.66, p < 0.01) significantly higher than boys'; (2) technical learning engagement partially mediated the effect of family background on self-efficacy [ab = 0.10, boot SE = 0.02,95% CI = (0.07, 0.14)]; (3) the first half of technical learning engagement's mediating role was moderated by gender (B = 0.05, p < 0.01), with a more significant influence of family background on boys' [B = 0.24, p < 0.001, 95% CI = (0.22, 0.26)] technical learning engagement than girls' [B = 0.19, p < 0.001, 95% CI = (0.17, 0.21)]; (4) the second half of technical learning engagement's mediating role was moderated by training years (B = -0.21, p < 0.001), with a more significant influence of technical learning engagement on the self-efficacy of adolescents with fewer training years [B = 0.54, p < 0.001, 95% CI = (0.39, 0.68)]. The positive effect of technical learning engagement on self-efficacy gradually diminished with increasing training years, and the moderating effect of training years disappeared when the training years reached 8.94 years.

The correlation analysis revealed a significant positive relationship between family background and self-efficacy of adolescent table tennis players. The higher the overall score of adolescent players' family background, the higher their self-efficacy. This outcome reaffirms that factors related to family backgrounds, such as family economic status, family environment, and parental educational intentions, have a direct and indirect impact on adolescent players' self-efficacy (Astone and McLanahan, 1991; Hsieh and Huang, 2014; Weisskirch, 2018). Furthermore, there is a positive correlation between family background and adolescents' technical learning engagement, with better family backgrounds associated with higher technical learning engagement, which is consistent with theoretical predictions. Adolescents with high-level family backgrounds are more likely to have better academic and material conditions due to their family's higher socioeconomic status (Matthews and Gallo, 2011). They may also be motivated to engage in similar behaviors by their parents' role modeling in their field of expertise and their willingness to set high expectations for their technical learning achievements and language (Catsambis, 2001; Bandura, 2012). Additionally, this study discovered a substantial positive association between self-efficacy and technical learning engagement. Adolescent players' technical learning in table tennis is greatly influenced by factors such as training, competition, and external motivational support such as family support, recognition from others, and athletic achievement. They gradually lose their ability to experience and evaluate themselves if their commitment to technical learning decreases, which will lower their self-efficacy (Siu et al., 2014).

Further mediation analysis revealed that technical learning engagement mediated the relationship between family background and self-efficacy, and that family background influenced the technical learning engagement and self-efficacy of adolescent table tennis players. The results support previous research that adolescents with poor family backgrounds are more likely to experience increased intra-family conflicts and reduced family warmth due to their parents' lower socioeconomic status and less favorable family environment, making it more difficult for them to engage in learning with a positive attitude and ultimately leading to their lower self-efficacy (Randolph et al., 2006; Pat-El et al., 2012). This finding allows us to refocus on family factors and technical learning engagement, rather than the earlier focus on aspects such as youth technical training and competitiveness, providing fresh ideas for improving the technical level and training efficacy of disadvantaged adolescent players. Specifically, parents with poor family backgrounds can enhance the technical learning engagement and self-efficacy of these adolescent table tennis players by adopting a more positive parenting style, such as showing more warmth and understanding to their children (Masarik and Conger, 2016). Second, youth training is regulated and influenced by the own behavioral and situational factors of adolescent table tennis players (Martin and Gill, 1991; Seidel, 2006; Shute, 2008). Therefore, coaches must focus not only on training and game performance but also on the development of contextual factors such as a positive training atmosphere and healthy competition (Psychountaki and Zervas, 2000) among players in order to enhance their sense of efficacy. As for future research, on the one hand, more importance should be attached to identifying additional mediators that may bridge the gap between family background and efficacy to fully reveal the pathways through which family background affects self-efficacy in adolescent table tennis players; on the other hand, research on other sports can be conducted to investigate the common patterns of family background influencing self-efficacy in the context of various sports characteristics.

Additionally, the effect of family background on the technical learning engagement of adolescent table tennis players was moderated by gender, with a more significant influence of family background on boys' technical learning engagement and a stronger indirect effect of technical learning engagement on self-efficacy. This finding is a reflection of China's distinctive patriarchal culture with a preference for boys (Chu et al., 2007), which differs from the findings of Trivers and Willard (1973) and others in a Western cultural context. Previous research has shown that the pattern of gender differences in academic self-efficacy varies across domains (Huang, 2013). Boys showed higher self-efficacy than girls in math, computers and social sciences (Chou, 2001; Peng et al., 2006). In contrast, girls had significantly higher levels of self-efficacy in self-regulated learning (Britner and Pajares, 2001), engagement in learning and self-regulation (Zimmerman and Martinez-Pons, 1990) than boys, which is consistent with the theoretical prediction of this study: male adolescent table tennis players perform poorly than female adolescent players in terms of planning, goal setting, and self-monitoring during training, thus with a lower level of learning engagement. As family backgrounds improve, boys tend to have better development and academic accomplishment due to more parental attention (Terenzini et al., 2001), more positive parenting (Randolph et al., 2006), and higher educational expectations (Bae and Wickrama, 2015). Therefore, it can be concluded that family background has a greater impact on the technical learning engagement of male adolescent table tennis players.

Finally, the effect of technical learning engagement on the self-efficacy of adolescent table tennis players was moderated by training years, with a more significant influence of technical learning engagement on the self-efficacy of players with fewer training years. The positive effect of technical learning engagement on self-efficacy gradually diminished as training years increased. This finding differs from that of Bates and Khasawneh (2007) in that the effort level of adolescents with fewer training years tended to be higher, leading to more noticeable performance gains, especially in less difficult technical tasks, which resulted in lower gains in self-efficacy (Treasure et al., 1996; Linnenbrink and Pintrich, 2003). However, the positive effect of technical learning engagement decreased with training years due to increased learning pressure and factors such as win-loss and competition among players. Players' emotional experience will decline and ultimately lead to a decrease in self-efficacy (Richardson and Newby, 2006). Therefore, it can be concluded that technical learning engagement has a greater effect on self-efficacy in adolescent players with fewer training years, and this positive effect will gradually diminish as their training years increase.

6. Conclusion

This study analyzed the processes and mechanisms of the impact of family background on the self-efficacy of adolescent table tennis players, as well as the mediating role of technical learning engagement and the moderating effects of gender and training years. We found that family background had a predictive effect on the self-efficacy of adolescent table tennis players. The path was partially mediated by technical learning engagement. The mediating effect of technical learning engagement in the first half was moderated by gender, with a more significant influence of family background on boys' technical learning engagement. The mediating effect of technical learning engagement in the second half was moderated by training years, with a more significant influence of technical learning engagement on the self-efficacy of adolescent players with fewer training years. The positive effect of technical learning engagement on self-efficacy gradually diminished as training years increased, and the moderating effect of training years disappeared at 8.94 years. This study still has some implications for enhancing the self-efficacy of adolescent table tennis players and promoting their skill acquisition and healthy development, both physically and mentally. First, more attention should be paid to adolescent table tennis players with poor family backgrounds, who are more likely to have low self-efficacy. Second, parents should never neglect their initiative in providing guidance and support to adolescent players involved in long-term professional table tennis training, especially for boys. Third, coaches should pay close attention to the level of technical learning engagement of players with long training years, who are more likely to have lower self-efficacy as a result of their own emotional experiences, stagnant performance, etc.

7. Limitations

It is essential to recognize the several limitations of the current study. First, the sample size of this study was relatively small, and the objects were all selected from Haidian and Shichahai Gymnasium in Beijing, China. A larger sample of adolescent table tennis players engaged in long-term professional training in more cities should be examined in future studies, taking into account the unique environment and cultural context of table tennis talent development in China. Second, the disparity in levels of competitiveness among adolescents from different sports schools was not considered when analyzing the effect of family background on the self-efficacy of adolescent table tennis players in this study. This factor may have different effects on adolescents involved in long-term professional training. Therefore, multilevel models should be employed in future studies to simulate the effects of different training levels. Third, the effects of various sub-dimensions of family background, which serve as composite variables in this study, can be further investigated, such as family economic status, family support, parental educational intentions, and parental praise and criticism.

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

The studies involving human participants were reviewed and approved by the Capital University of Physical Education and Sports. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

KH and ZL contributed to the conception and design of the study. WL organized the database. KH and WL performed the statistical analysis. KH wrote the first draft of the manuscript. WL and ZL wrote sections of the manuscript. All authors contributed to the manuscript revision, read, and approved the submitted version.

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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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1125493/full#supplementary-material

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Analysis of the spatial distribution of the serve and the type of serve-return in elite table tennis. Sex differences

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Serve and return of the serve are among the most critical technical-tactical factors influencing performance in table tennis (TT). The present study aimed to analyse sex differences in the spatial distribution of serve and serve-return in elite TT players. A total of 48 elite TT players (men: n=24; women: n=24) participated in the investigation. A total of 24 matches were recorded and examined, analysing 1,177 plays and 5,319 strokes in the men's competition and 950 games and 5,097 strokes in the women's competition. Technical actions were analysed using an observation tool validated by two expert TT coach with a high level of agreement (K>0.80). Men distributed their serves over zones 1 and 2 of the table, while women more frequently selected zone 5 (p<0.05). In men, 30.1% of the serves were near the net, 63.6% in the middle zone of the table and 6.2% in the end zone of the table, while in women, these values were 10.9%, 67.2%, and 21.8%, respectively. As for the technique of the serve-return depending on the zone of the service, in men the action of the cut from zone 1 and 2 predominated, while in women this technique was more frequent from zone 5 (p<0.05). On the other hand, the serve-return with the flip technique in zone 1, 3 and 4 was more frequent in men (p<0.05). As for the return of the serve with the topspin technique, there were differences in zone 3, being more frequent in men (p<0.05). Finally, the serve return with cut and defensive serve-return techniques in zones 3, 4, 5, and 6 were more frequent in women (p<0.05). There are differences between sexes in service and return of serve actions during a match in elite players.

KEYWORDS

racket sports, technique, strokes, game analysis, server, receiver

1. Introduction

Table tennis (TT) has significantly transformed the rules and playing materials in the last two decades. These modifications have led to a more modern and dynamic TT (Pradas et al., 2021; De la Torre et al., 2022). The TT game is played on a rectangular table 2.74 m long by 1.52 m wide, 76 cm above the ground and separated in the middle by a net 15.25 cm high (Kawazoe and Suzuki, 2004). Considering the reduced dimensions of the playing surface, TT is characterised by developing a high-speed game dynamic, where intermittent physical efforts predominate, alternating short periods of rest with short but very high intensity and explosive efforts (Zagatto et al., 2010). In this sense, TT is considered one of the fastest sports in speed of play (Pradas et al., 2022).

In racket sports, the analysis of the game actions performed during competition has been the subject of essential studies as they are considered one of the most relevant aspects of performance (Kolman et al., 2019; Ramón-Llin et al., 2020; Sánchez-Alcaraz et al., 2020; Valldecabres et al., 2020). However, more research is needed in TT to describe the indicators involved during play and their relationship to performance (Djokić, 2006; Munivrana et al., 2015), and research involving women is practically non-existent. Undoubtedly, the results in TT competitions will be affected by physical fitness, physiological response, the metabolism involved or different psychological variables. However, technique and tactics can be considered in TT as one of the key aspects of performance, without underestimating others of great interest such as perception and decision, as they seem to have a direct effect on the results obtained during the competition (Huang et al., 2021).

In TT, each game starts with a serve or service and then the opponent immediately performs a motor response called serve-return. The serve and serve-return action is followed by a sequence of alternating strokes between the two players, ending when either player commits a fault (Wang, 2019). However, a play can also end with a direct service point (Reid et al., 2010), either because it is not returned correctly by the receiver or because of an error in the execution of the serve.

The service technique is considered one of the most critical performance indicators in racket sports (Ramón-Llin et al., 2021) as it is the action that starts each game (Katsikadelis et al., 2010). In the case of TT, the serve has evolved from being simply how the ball was put into space over a particular area, thus allowing game to begin, to become today a fundamental technical-tactical element that is essential to obtain a direct point (Pradas et al., 2009), as the serve is considered a technical action that can provide a tactical advantage.

The serve in TT is the only unforced technique during play (Yu et al., 2007). The TT serve action has infinite possibilities of execution, depending on the player's level of skill and mastery of this technique, always within the legal limits allowed by the game's rules. TT players specialise in this technical element as a basis for developing their own game, automating certain tactics depending on the type of serve. An infinite number of serves depends on the different characteristics of the playing materials and the player's creativity in combining the different rotations that can be applied to the ball. In this sense, the serves in TT can be classified according to: (1) the distance of the bounce of the ball (close to the net, intermediate and close to the baseline); (2) the bounce zone of the ball (centre of the table, backhand zone and forehand zone); (3) the type of spin or rotation involved (slice, topspin, lateral or combined); and (4) the speed of the ball (fast or slow) (Pradas and Herrero, 2015).

Undoubtedly, a serve can greatly affect the opponent's return and allow the player to gain an advantage to attack (Malagoli Lanzoni et al., 2014). In fact, it has been shown that in TT successful serves can lead to victory in a match (Katsikadelis et al., 2013). On the other hand, previous research has shown that the server's tactical advantage is most significant in relatively short plays, up to the third stroke. In contrast, the probability of winning a play for the receiver increases after the fourth to sixth stroke (Malagoli Lanzoni et al., 2014). Thus, the serve advantage is lost as the length of the play increases. Although this pattern differs slightly between the sexes, the trend is very similar (Tamaki et al., 2017).

Another important game situation to consider in the sport of TT is the technical action of the return of the serve. An effective reception and return of the service allows the player to score a point outright or to enable the player to prepare well for game action to dominate subsequent attacks. Therefore, an effective serve and a successful reception and return are essential factors influencing the performance of a high-level TT player (Munivrana et al., 2015; Wang, 2019). Returning a serve correctly is undoubtedly the most difficult part of today's TT technique. The return of the service is conditioned by the type of serve (spin, direction, speed, and location on the table), which makes it very difficult for the receiver to return. The correct reception and return of the serve is as important a technique as the serve itself, and a fundamental element in the development of tactics in this sport, as depending on the level of skill, it can allow a direct score to be obtained, prevent the opponent from taking the initiative in the game or provide an advantageous situation (Pradas et al., 2009). Among the most predominant techniques in serve and serve-return actions are the following: (a) Push, an interlocutory stroke imparting a back-spin effect to the ball; (b) Flip, an attacking stroke performed when the ball bounces close to the net; (c) Topspin, an attacking stroke actually imparting a topspin effect to the ball; (d) Block, a defensive stroke performed in response to a top in a passive fashion; (e) Lob, a defensive stroke performed when the player is far from the table, consisting of lifting the ball to a considerable height; (f) Smash, an attacking stroke characterised by a linear trajectory and no spin of the ball; and (g) Drive, an interlocutory stroke imparting no effect on the ball (Molodzoff, 2008).

Previous studies have qualified the importance of serving technique (Katsikadelis et al., 2013; Malagoli Lanzoni et al., 2014; Munivrana et al., 2015). However, studies that analyse the serve or return of the serve are scarce (Munivrana et al., 2015; Gómez et al., 2017; Wang et al., 2022), and even more so in high-level TT (Li and Li, 2008; Wang, 2019). Similarly, the serve and return of the serve analysis is practically non-existent in elite women TT players (Gómez et al., 2017). The differences between sexes in game dynamics have yet to be analysed in depth, and in this sense there is a great lack of knowledge about the technical-tactical situations of serve and return of the serve between men and women (Pradas et al., 2021). Therefore, the present study aimed to analyse the differences between sexes in the serve and return in elite TT players.

2. Materials and methods

2.1. Participants

In the present study, 24 men players (age: 25.3 ± 4.0 years; experience: 16.0 ± 4.1 years) and 24 women players (age: 22.3 ± 3.8 years; experiences: 13.2 ± 3.8 years) of different nationalities participated voluntarily.

Abbreviation: TT - table tennis.

The research was approved by the Clinical Research Ethics Committee of the Department of Health and Consumption of the Government of Aragon with file number 19/2010. All participants were informed of the procedures to be followed during the research and signed the consent form.

In order to participate in the research, subjects had to meet the following criteria: (a) belong to the senior category; (b) hold a federative licence from the Royal Spanish Table Tennis Federation; (c) play in the men's or women's first division of TT; (d) have at least 10 years' experience; and (e) occupy at least 30th place in the men's or women's ranking in the Royal Spanish Table Tennis Federation senior category.

2.2. Study design

The present study was conducted in Seville (Spain) during the development of the matches corresponding to the final phases of two competitions, the Spanish Absolute Championship and the Spanish International Open. A total of 24 matches were studied ($n = 12$ males and $n = 12$ females). A total of 1,177 plays and 5,319 strokes in the men's competition and 950 plays and 5,097 strokes in the women's competition were analysed.

2.3. Analysis of technical-tactical actions

The matches were recorded using four Sony HDR-CX300E video cameras (Sony, Japan), placed on the sides of the tables at a minimum distance of 3 m and raised to a height of 2.5 m on telescopic supports (Manfrotto, 007 U, Italy). The games were recorded with a shutter speed of 1/500 s. Each camera filmed half a table from an elevated side view (Figure 1), obtaining two records of the game actions performed by each player.

The playing surface was divided into six zones (each side), with a reference system placed on it, recorded by the cameras before the start of the match (Figure 2).

After the recordings, a process of synchronisation of both cameras was carried out. The recorded matches were analysed using an observation tool validated for TT (Pradas et al., 2012), using the Match Vision Studio© v. 3.0 programme (Perea et al., 2004), organised employing an *ad hoc* notational system that made it possible to study the times of game and break, as well as the different technical and tactical actions of the game (Figure 3).

Two TT coaches with level III of the maximum category of RFETM, experts in this sport, analysed the matches. The concordance analysis of the technical, tactical and time data obtained showed a Kappa index above 0.80 in all the variables analysed, considering the degree of agreement to be very high (Altman, 1991).

2.4. Statistical analysis

IBM® SPSS® Statistics Version 22 (IBM Corp., Armonk, NY, United States) was used for the analysis. Qualitative variables were expressed as percentages. The comparison between both sexes was made through contingency tables using the chi-square test.

Quantitative variables were expressed as mean and standard deviation and range. Normality was assessed using the Kolmogorov–Smirnov test and Levene's test to evaluate homoscedasticity. For comparisons between sexes, the student's t-test or the Mann–Whitney U test was used (according to normality and homoscedasticity). A value of $p \leqq 0.05$ was considered statistically significant.

3. Results

Table 1 presents the study participants' technical characteristics (dominant hand, playing style, players grip and specific rubbers) according to sex. Differences between sexes were found in defensive style, grip style and backhand style ($p < 0.05$).

Table 2 shows the zone of serve on the table. Zones 1 and 2 were the most used by male players, while zone 5 was the predominant zone for female players ($p < 0.05$).

Tables 3, 4 shows the return of the serve overall and by ball placement zone in the table. In Table 3 there were differences between sexes in the total number of strokes. In Table 4, firstly, the return of the serve with push in zones 1 and 2 were predominant in male, while the return of the serve in zone 5 was more frequent in female ($p < 0.05$). On the other hand, concerning the return of the serve with the flip

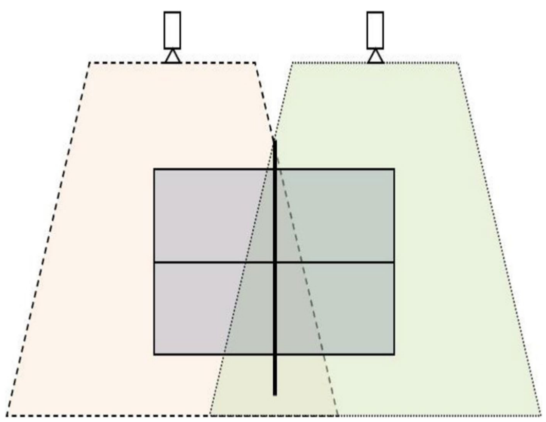

FIGURE 1
Competition recording protocol from an elevated side view (Pradas et al., 2021).

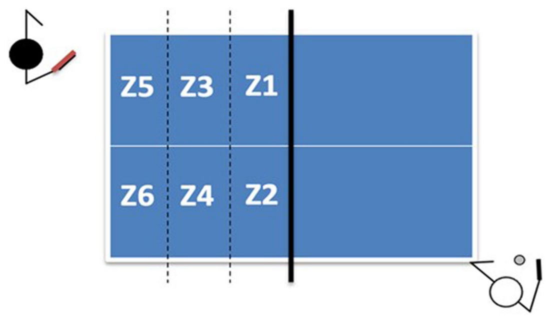

FIGURE 2
Distribution of the playing table into six zones. Zenithally view of the playing areas.

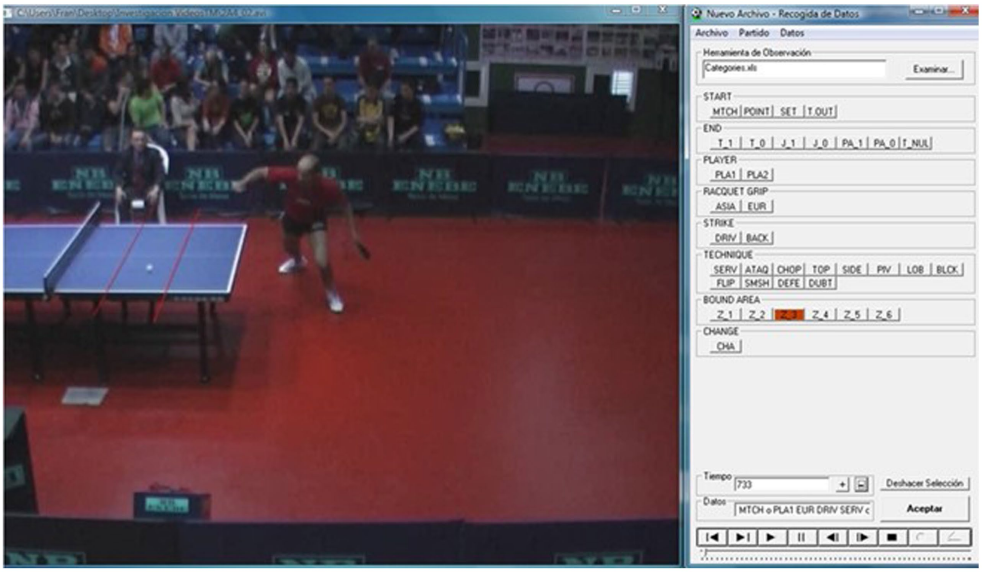

FIGURE 3
Example of data collection with the observation programme (Pradas et al., 2012).

TABLE 1 Technical characteristics of the participants.

	Male (*n*)	%	Female (*n*)	%	χ^2	*p*
Right-handed	17	70.8	20	83.3	1.061	0.300
Left-handed	7	20.2	4	16.7		
Defensive style	1	4.2	5	20.8	3.448	0.043
Offensive style	23	95.8	19	79.2		
Shake-hand grip	18	75	23	95.8	4.181	0.032
Pen-hold grip	6	25	1	4.2		
Pimples-in rubber (F)	21	87.5	23	95.8	1.091	0.296
Short pimples-out rubber (F)	3	12.5	1	4.2		
Pimples-in rubber (B)	22	91.8	18	75	5.567	0.039
Short pimples-out rubber (B)	1	4.1	1	4.1		
Long pimples-out rubber (B)	1	4.1	5	20.9		

Pearson's Chi-square test. Values expressed in percentage F: forehand; B: backhand.

technique, zones 1, 3, and 4 were more frequent in male ($p < 0.05$). As for the return of the service with the topspin technique, there were differences in zone 3, being more frequent in male ($p < 0.05$). Finally, in the return of the serve push or chop in zones 3, 4, 5, and 6 were more frequent in female players ($p < 0.05$).

4. Discussion

In TT, the technical actions of the serve and return of the service are two of the most significant factors that can affect the result of TT match (Katsikadelis et al., 2013). The tactical implication of these two technical elements of the game is very important as they will define the development of game. Considering the critical relevance of these technical-tactical aspects in TT competition, the present study aimed to analyse the differences between sexes in the location of the service zone and the serve-return performed in elite players.

The results obtained in different investigations indicate that in order to win a TT match it is necessary to master two variables with great mastery and perfection, an excellent serving technique, and to possess the ability to execute a good technique for receiving and returning the ball, which is considered to be the game actions that make the difference between winners and losers in this sport (Djoković et al., 2020). On the other hand, as has been reported in previous studies (Munivrana et al., 2015; Pradas et al., 2021, 2022), there are sex differences in game structure, playing time and physical, physiological and metabolic demands. These factors cause differences in the development and application of technical-tactical actions.

Regarding the technical action of the serve, the results obtained in this research indicate to the existence of important differences between sexes in terms of preferences for the zone of the serve.

TABLE 2 Table serve zone.

	Male	Range	Female	Range
Zone 1 (*n*) +	9.17 ± 5.34	0–18	1.92 ± 3.06**	0–13
Zone 2 (*n*) –	12.17 ± 11.91	1–45	2.17 ± 2.12**	0–5
Zone 3 (*n*) –	38.42 ± 15.36	12–62	33.67 ± 17.35	17–70
Zone 4 (*n*) –	32.42 ± 20.71	5–71	28.17 ± 9.26	12–41
Zone 5 (*n*) +	4.25 ± 2.37	0–8	9.08 ± 3.89**	3–16
Zone 6 (*n*) +	1.67 ± 1.43	0–5	4.17 ± 5.42	0–20

**$p < 0.01$ male vs female differences; –: student's *t*-test; +: non-parametric Mann–Whitney U test; values expressed as means ± standard deviation.

TABLE 3 Total serve-return types by sex.

	Male	%	Female	%	χ^2	*p*
Push (*n*)	623	57.16	569	67.18	200.73	<0.001
Flip (*n*)	226	20.73	73	8.62		
Topspin (*n*)	207	18.99	105	12.40		
Block (*n*)	4	0.37	1	0.12		
Lob (*n*)	1	0.09	0	0.00		
Drive (*n*)	28	2.57	36	3.42		
Smash (*n*)	1	0.09	0	0.00		
Chop (*n*)	0	0.00	66	8.26		

Pearson's Chi-square test. Values expressed in total strokes and percentage.

Malagoli Lanzoni et al. (2014) reported that the serve plays a key role from a tactical point of view: (i) avoiding the opponent's attack and (ii) allowing the server to attack the ball from the rest. Men mostly use the zones closer to the net while women do the opposite, using the areas closer to the baseline of the table, especially the opponent's backhand area. This behaviour indicates that at a tactical level the men try to make their serve difficult or cancel out the opponent's attack, while the women, on the contrary, prefer the opponent to initiate offensive actions immediately in order to develop a more counter-offensive game. These results are similar to those described for international cadet and junior (Mulloy et al., 2014) and senior top-level (Malagoli Lanzoni et al., 2014), with no data available for senior elite female players. However, in a study conducted on cadet greek female players, the young players chose as their main option serves over areas far from the net (Nikolakakis et al., 2021), and these results coincide with those obtained in this study for the female players. As can be seen, in both sexes the players avoid sending the ball to the right corner of the opponent's table, i.e., zone 6 (for right-handed players), from which the attack for the receiver is easier to make and more dangerous for the server, thus preventing the receiver from taking the initiative to attack (Katsikadelis et al., 2013).

Players who win matches score more points when serving compared to losing players (Djokic, 2002; Katsikadelis et al., 2013). In this sense, according to Yu et al. (2007) when a player serves and then attacks they obtain a higher rate of points compared to the case when they attack after receiving the opponent's serve.

Previous research has compared the server and return service characteristics of TT at the London (2012) and Rio (2016) Olympic Games, with significant changes observed in the percentage of the type of stroke used, in particular with the topspin and flip technique (Wang, 2019). The first decreased from 42.6% to 24.3%, while the latter increased from 5.1% to 16.6%. These data indicate that the players, when performing the serve technique, direct them towards areas close to the net, thus forcing the return of the service to perform

TABLE 4 Return of the service according ball placement zone.

	Male	Range	Female	Range
Reception with push				
Zone 1 (*n*)	6.58 ± 3.19	0–13	1.67 ± 3.11**	0–11
Zone 2 (*n*)	7.17 ± 4.95	1–18	1.92 ± 1.78**	0–4
Zone 3 (*n*)	19.83 ± 12.96	2–37	23.58 ± 14.13	7–50
Zone 4 (*n*)	18.08 ± 11.85	2–37	19.42 ± 8.43	9–30
Zone 5 (*n*)	0.25 ± 0.62	0–2	2.58 ± 2.61**	0–8
Zone 6 (*n*)	0.00 ± 0.00	0–0	1.25 ± 3.13	0–11
Reception with flip				
Zone 1 (*n*)	2.25 ± 1.42	0–4	0.17 ± 0.57**	0–2
Zone 2 (*n*)	4.25 ± 7.32	0–26	0.25 ± 0.45	0–1
Zone 3 (*n*)	9.08 ± 4.75	3–16	3.25 ± 3.72**	0–12
Zone 4 (*n*)	7.50 ± 5.05	2–19	2.08 ± 2.27**	0–8
Zone 5 (*n*)	0.08 ± 0.28	0–1	0.00 ± 0.00	0–0
Zone 6 (*n*)	0.00 ± 0.00	0–0	0.25 ± 0.62	0–2
Reception with topspin				
Zone 1 (*n*)	0.25 ± 0.86	0–3	0.00 ± 0.00	0–0
Zone 2 (*n*)	0.58 ± 0.79	0–2	0.00 ± 0.00	0–0
Zone 3 (*n*)	8.50 ± 3.82	3–18	2.83 ± 3.29**	0–12
Zone 4 (*n*)	6.25 ± 5.81	0–19	4.17 ± 3.51	1–13
Zone 5 (*n*)	2.17 ± 1.58	0–4	3.25 ± 3.19	0–12
Zone 6 (*n*)	1.08 ± 0.90	0–3	1.67 ± 1.92	0–6
Reception with block				
Zone 4 (*n*)	0.00 ± 0.00	0–0	0.08 ± 0.28	0–1
Zone 5 (*n*)	0.17 ± 0.57	0–2	0.00 ± 0.00	0–0
Zone 6 (*n*)	0.17 ± 0.38	0–2	0.00 ± 0.00	0–0
Reception with lob				
Zone 6 (*n*)	0.08 ± 0.28	0–1	0.00 ± 0.00	0–0
Reception with drive				
Zone 3 (*n*)	0.75 ± 1.21	0–9	0.50 ± 1.24	0–6
Zone 4 (*n*)	0.25 ± 0.62	0–3	1.08 ± 2.31	0–13
Zone 5 (*n*)	1.17 ± 1.74	0–14	0.58 ± 0.99	0–7
Zone 6 (*n*)	0.17 ± 0.38	0–2	0.25 ± 0.62	0–3
Reception with smash				
Zone 6 (*n*)	0.08 ± 0.28	0–1	0.00 ± 0.00	0–0
Reception with chop				
Zone 3 (*n*)	0.00 ± 0.00	0–0	2.75 ± 4.59**	0–33
Zone 4 (*n*)	0.00 ± 0.00	0–0	0.33 ± 0.88*	0–4
Zone 5 (*n*)	0.00 ± 0.00	0–0	2.00 ± 2.79**	0–24
Zone 6 (*n*)	0.00 ± 0.00	0–0	0.75 ± 1.28*	0–9

*$p < 0.05$; **$p < 0.01$ male and female differences. Student's *t*-test. Values expressed as means ± standard deviation.

either a defensive push or offensive flip technique, avoiding the service close to the baseline and preventing the return of the service from using the topspin technique, considered in this sport as the most offensive.

Different studies indicate that the push technique and the flip are the most frequent return of the serve actions in men's competition (Malagoli Lanzoni et al., 2014), in line with the findings of this research. No current research has been found with which to compare the tactical indicators corresponding to the direction and zone of play, as the researchers applied different notational systems to the one used in this study (Kahn et al., 2004; Wu and Escobar-Vargas, 2007), so the results obtained for these tactical actions cannot be discussed. Recent studies on the location of the serve in elite players show that men direct their serves towards the central areas of the table, similar to that found in this study (Djokić et al., 2020).

Regarding the type of technical action by return of service and the area of game in which this tactical action is located, (Djokić, 2006) indicates out that it is very diverse, and that it depends on different variables, such as the area where the serve bounces, the style of play developed by the player, and the type of coating used on the racket. In this research, only the serve-return zone has been considered, so it cannot be compared with other reference studies. No current research has been found that describes these tactical indicators in the women's game.

The present study is not without limitations: (i) the small number of participants; (ii) the style of play developed was not taken into consideration; (iii) the type of playing materials used was not taken into consideration; (iv) the lateral dominance of the players was not considered; and (v) psychological factors were not considered in this study. It is true that the stress generated during competition can affect the technical and tactical actions studied. Likewise, the need for more information on this topic makes it difficult to discuss the results. However, this fact allows the present manuscript to be novel in the area. For future research it could be interesting to analyse the above technical-tactical aspects in men's, women's and mixed doubles where there is a limitation and obligation to serve diagonally to the right.

In conclusion, there are sex differences in serve and return of the service actions during a match in elite TT players. Regarding the serve, male players preferentially use zones 1 and 2, while female players select zone 5 to a greater extent. Regarding the return of the service, there are differences between sexes according to the zone and the serve-return technique used. The results of this research provide valuable information on the predominant actions according to sex to choose the most appropriate system of play for TT players.

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

The research was approved by the Clinical Research Ethics Committee of the Department of Health and Consumption of the Government of Aragon with file number 19/2010. All participants were informed of the procedures to be followed during the research and signed the consent form.

Author contributions

FP and CC: conceptualization. FP and LC: methodology and writing—review and editing. VT-R: formal analysis and data curation. FP, CC, and LC: investigation. VT-R and FP: writing—original draft preparation. FP: funding. All authors contributed to the article and approved the submitted version.

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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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Physical fitness in young top level table tennis players: differences between sex, age and playing style

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Understanding the physical fitness of table tennis (TT) players could be interesting in improving the training process and evaluating talent. This study aimed to assess the physical fitness of U14 TT players and differentiate between sex, age and playing style. A total of 352 players (203 males and 149 females) aged between 9 and 13 years participated in the present study. Furthermore, the sample was divided according to playing style: offensive (OFF) and mixed + defensive (M + D). A battery of tests was carried out to assess cardiorespiratory capacity, speed, strength, flexibility and power. Both sexes reported significant differences in cardiorespiratory capacity and speed ($p < 0.05$). Concerning age, there were substantial differences in cardiorespiratory capacity, speed, strength and power, with older players obtaining better results ($p < 0.05$). Finally, concerning playing style, differences were reported in cardiorespiratory capacity, higher in OFF style group, and flexibility, higher in the M + D style group. Finally, there were relationships between playing style and cardiorespiratory fitness and flexibility. Physical fitness evolves with increasing age as a function of sex. This is the first study to assess fitness in a large sample of TT players as a function of playing style.

KEYWORDS
racket sports, youth, elite, defensive, offensive

1. Introduction

Table tennis (TT) is a sport where highly complex motor tasks are performed. The efforts made during a game in TT are acyclic, intermittent, of short duration, high intensity, with constant changes of rhythm and direction, where players must continuously react, move and hit a ball that moves at high speed (1, 2). The activity of a TT player is not only determined by the complexity of its technical and tactical actions but also by the cumulative-explosive nature of the physical effort caused by the high precision required by the movements to be executed (2) and the continuous repetitiveness of interactions between the neuromuscular system and the ball as a moving stimulus (3).

At the technical level, the dynamics of TT playing demands are characterized by the continuous and fast execution of different types of strokes and displacements that involve significant physical stress for players. Movements at high velocity and endurance are two critical physical qualities in this sport (4, 5). Short and intense efforts during the game require essential training in reaction speed and anaerobic endurance (5, 6), At the same time, the duration of the matches makes it necessary to maintain an adequate aerobic endurance base (7, 8).

Abbreviations
TT, table tennis; MIX, mixed style; DEF, defensive style; OFF, offensive style; VO_{2max}, maximum oxygen uptake.

The resistance to be overcome by the upper extremity when impacting on the ball is relatively small (6). However, this type of action involves a significant muscular effort for the lower extremities due to the degree of acceleration and deceleration required to hit each ball in a properly position (9, 10). In this sense, the manifestations of the lower extremities' explosive and reactive strength are considered one of the sport's main physical qualities (11, 12). On the other hand, flexibility in TT performance is of little relevance. However, the range of motion of the lower body is an essential physical aspect because if it is insufficient, there is a reduction of the gestural content and a deterioration of neuromuscular coordination (13).

In terms of tactical skills, TT is a demanding sport as athletes have to plan different and precise technical-tactical actions (14), depending on the style of play and the opponent, making decisions in very short periods of time, also enduring situations of physical fatigue (15). TT players mainly use two styles of play: offensive (OFF) and defensive (DEF) (16). Although less known, there is also a style of play called mixed (MIX), intermediate between the two previous styles. The development of each type of play is directly related to the use of specific materials in the table tennis blades (17).

The OFF style of play is one in which the players are positioned at a very close or far distance from the table, using techniques to initiate the attack, either through lift-type strokes such as flip and topspin or with blocks to accelerate the game's pace (1, 18). On the other hand, the DEF playing style is performed at a medium distance or even far away from the table. In a defensive game, the player tries to nullify the opponent's attacking strokes by defensive techniques (push or chop), producing a recoil effect on the ball. These players tend to slow down the game's speed, lengthening the play and trying to win the point by forcing their opponent to make mistakes (1, 18). Finally, the MIX playing style can be performed very close to the table or at a middle distance. This style of play is very varied and aims to confuse the opponent with different types of slice or lift effects, especially in a defensive phase (1, 18).

In the scientific literature, some studies show differences in the physical load depending on the style of play (19). Differences have been reported in physiological parameters (heart rate and maximum oxygen consumption), the duration of games and matches, and the type and number of total strokes performed (7, 19, 20). However, no research has been found that analyzes and compares the levels of physical fitness as a function of the style of play developed (OFF vs. MIX + DEF), especially in young top level players, and in particular studies that include the female sex. Consequently, the study aimed to analyze the influence of playing styles (OFF vs. MIX + DEF) in young high-level TT players' physical fitness levels according to age and sex.

2. Materials and methods

2.1. Participants

Three hundred fifty-two children aged from 9 to 13 years volunteered to participate in the study (203 males and 149 females). The sample size is larger for a population of 1981 players of U14 categories (based on the number of licenses of the Royal Spanish Table Tennis Federation) for a confidence interval of 95% and a margin of error of 5% ($n = 322$). The TT players were recruited from the National Sports Technification Program developed by the Royal Spanish Table Tennis Federation. All players were ranked in the top positions of their respective categories and sex. The playing style data were obtained by reviewing the types of racquets and coverings used by the players, in addition to observing the use given by the players during training and competitions. Also, the players and their coaches were asked about the type of game they intended to develop with the playing equipment used.

After an extensive verbal and written explanation of the study, written informed consent was obtained from the parents or legal guardians. The research protocol was reviewed and approved by the Clinical Research Ethics Committee of Aragon (Spain) (code: 19/2010) following the guidelines of the Helsinki Ethical Declaration for research in humans.

For inclusion in the study, participants had to achieve the following criteria: (i) practice only TT as a sport modality; (ii) have at least one year's experience; (iii) be federated; (iv) not having any pathology; (v) not ingest of medication. The playing characteristics of the participants were provided by the coaches of the study participants (**Table 1**).

2.2. Procedures

The study was carried out during the summer months, coinciding with the vacation period of the participants. No training was required for a more objective assessment the day before the evaluations.

Before the assessments, participants performed a 10-minute warm-up based on general mobility and jogging. All participants were familiarized with the different tests. The physical fitness assessments were performed in two different phases in the following order: anthropometry, flexion, vertical jump, upper limb strength and running speed. In the second phase, carried out 60 min after the first phase, the test to assess maximum cardiorespiratory capacity was performed.

TABLE 1 General characteristics of the sample.

Variables		n	%
Sex	Male	203	57.6
	Female	149	42.4
Playing style	Defensive	5	1.4
	Mixed	12	3.4
	Offensive	335	95.2
Laterality	Right-handed	318	90.3
	Left-handed	34	9.7
	9	32	9.1
	10	80	22.7
	11	94	26.7
	12	109	31.0
	13	37	10.5

2.3. Anthropometric

Body weight, height and body mass index (BMI) were evaluated. A scale (Seca 769, Seca, Hamburg, Germany) and a measuring rod (Seca 220, Seca, Hamburg, Germany) were used. All participants were evaluated with as minimal clothing as possible and without footwear.

2.4. Flexibility

The sit-and-reach test was used to measure the range of motion of the lumbar region and the hamstring muscle, according to standardized procedures (21) using the sit-and-reach flexibility tester (Baseline®, New York, USA). From a seated position on the floor with legs fully extended, participants extended the arm along the measurement scale as far as possible without bending the knee, placing one hand on the other with palms down. The best of two repetitions was chosen for further analysis.

2.5. Vertical jump

To evaluate the vertical jump, the squat jump (SJ), counter-movement jump (CMJ) and Abalakov jump (ABK) tests were established (22). A jump mat system (Newtest Powertimer®, Oulu, Finland) was used to measure height and flight time during the jumps. During the test, the guidelines proposed by Bosco et al. (23), were followed.

For the SJ, participants initiated the movement from a squat position (knee angle 90°) and arms resting on the hips. After 2 s of holding the position, a jump was performed without countermovement at maximum intensity. For the CMJ, participants started the execution from an upright position and hands resting on the hips. Subjects performed a knee flexion-extension followed by a jump at maximum possible intensity. For the ABK, participants could propel their arms by swinging.

Recovery was 30 s between jumps. The best jump of three attempts was selected for further analysis.

2.6. Upper limb strength

The handgrip strength and medicine ball throw tests were performed to assess upper body strength.

A Takei 5,101 dynamometer (Takei Instruments Ltd., Tokyo, Japan) was used to determine handgrip strength. Participants completed two maximal voluntary contractions with the dominant and non-dominant hand. At all times, the arm was extended. The grip of the dynamometer was adjusted to the participant's hands. The best of two alternative repetitions was chosen. The asymmetry of grip strength (difference between the dominant and non-dominant hand) was evaluated.

The overhead medicine ball throw tests upper body strength and explosive power, which consists of throwing the ball forward over the head. It consists of performing a quick downward motion, bending the knees and hips, before quickly extending the hips, knees and arms to throw the medicine ball as far as possible. A 3 kg medicine ball was used for both sexes. Two attempts were made, and the most significant distance obtained was chosen for analysis.

2.7. Flying 30 meter sprint test

Flying 30-meter sprint test is a physical test used to measure the maximum sprint speed of an individual. On a 70-meter straight line, the subject sprints to reach the maximum speed upon reaching a photocell located at 20 m and holding it until passing the photocell at the finish line located at 50 m (Newtest Powertimer®, Oulu, Finland). Two attempts were performed with a 2-minute rest between attempts. The best of the two repetitions was chosen.

2.8. Cardiovascular fitness

Cardiovascular fitness was examined by a maximal multistage 20 m shuttle run test (Course Navette Test; CN) (24). Sound signals were emitted from a pre-recorded tape that increased 0.5 km·h^{-1} each minute from a starting speed of 8.5 km·h^{-1}. When the subject could no longer follow the pace, the last stage number announced was used to estimate the maximal oxygen uptake (VO_{2max}) by formula (24). Distance, periods, and speed were noted.

2.9. Statistical analysis

The data were processed in IBM SPSS 25.0 Statistics (IBM Corp., Armonk, NY, USA) and were expressed as mean ± standard deviation, except for the data on the characteristics of the participants, which were described as frequencies and percentages. The normality of the distribution of the variables was analyzed using the Kolmogorov-Smirnov test and the homogeneity of variances using the Levene test. A two-way ANOVA (sex and age effect) was used to show any differences in the variables studied. The effect size was calculated using partial eta squared. Effect size values were classified as 0.01–0.06 small effect size; 0.06–0.14 moderate effect size; >0.14 large effect size (25). A *t*-test for independent samples was used to analyze differences between play styles. Finally, Pearson's correlation coefficient *r* was used to establish relationships between playing style and sex with the physical fitness parameters analyzed. Differences of $p < 0.05$ were considered statistically significant.

3. Results

The data obtained in the present study are presented below. **Table 2** shows the anthropometric characteristics. Significant

TABLE 2 Anthropometric characteristics.

Variables	Age (years)	Male	Female	Sex effect	Age effect	Sex × Age
Height (m)	9	1.39 ± 0.05	1.38 ± 0.06	0.301	<0.001^##	0.510
	10	1.42 ± 0.07	1.43 ± 0.05			
	11^^	1.47 ± 0.06	1.50 ± 0.07			
	12^^,$$	1.52 ± 0.06	1.54 ± 0.06			
	13^^,$$,&&	1.57 ± 0.08	1.56 ± 0.06			
Weight (kg)	9	33.61 ± 4.15	34.02 ± 7.87	0.443	<0.001^##	0.496
	10	37.02 ± 7.10	38.15 ± 6.28			
	11^^	41.08 ± 9.04	42.92 ± 8.93			
	12^^	44.28 ± 7.72	44.59 ± 6.35			
	13^^,$$,&&	50.72 ± 9.71	47.00 ± 6.89			
BMI (kg/m^2)	9	17.26 ± 1.85	17.73 ± 3.68	0.515	0.019^##	0.510
	10	18.22 ± 2.59	18.57 ± 2.83			
	11	18.68 ± 3.20	18.81 ± 3.15			
	12	19.04 ± 2.50	18.62 ± 1.94			
	13	20.34 ± 2.79	19.13 ± 2.28			

^^$p < 0.01$ differences vs. 9.
$$$p < 0.01$ differences vs. 10.
&&$p < 0.01$ differences vs. 11.
##Large effect size.

differences were observed in height, weight and BMI ($p < 0.05$) being higher in older players.

The results related to the upper body strength and flexibility are presented in Table 3. There were significant differences between sexes in medicine ball throwing and flexibility ($p < 0.001$). On the other hand, with respect to age, there were differences in hand grip and medicine ball throwing, being higher in older players ($p < 0.001$).

The results related to the vertical jump are presented in Table 4. No significant differences were observed between sexes. However, there were significant differences between the ages of the participants where the jump height was higher with increasing age ($p < 0.001$).

Table 5 shows the results obtained in velocity and cardiorespiratory test. There were significant differences and large effect sizes between sexes and between ages in all parameters analyzed ($p < 0.05$).

Table 6 shows the differences in the physical fitness parameters analyzed previously comparing between playing styles. Differences between playing styles were observed in weight ($p = 0.012$), CN period ($p = 0.017$), CN distance ($p = 0.033$), CN speed ($p = 0.033$), maximum oxygen consumption ($p = 0.033$) and flexibility ($p < 0.001$).

Table 7 shows the differences in physical fitness parameters as a function of playing style and sex. Regarding playing style, significant differences were observed in BMI ($p = 0.025$). In relation to sex, no significant differences were reported.

Finally, Table 8 shows the correlations between physical condition parameters and playing style as a function of sex. There were negative correlations in male players and the CN period ($p = 0.045$). That is, OFF players performed longer periods in the CN. Regarding female players, there were positive correlations between female players and maximal oxygen consumption ($p = 0.037$), as well as flexibility ($p = 0.030$). That is, players with MIX and DEF playing styles obtained higher values of maximal oxygen consumption and flexibility.

4. Discussion

The objective of the present study was to analyze the differences of sex, age and style of play on the physical fitness of young high-level TT players. The present study reported significant differences between sexes and ages in the physical fitness parameters. In addition, as a novelty of the current investigation, it is shown that there could also be differences in the physical fitness parameters according to the style of play, as well as correlations. However, it should be noted that the participants in each playing style group (OFF and MIX + DEF) were very heterogeneous. The different playing styles result in specific and different spatiotemporal activity patterns in terms of stroke length, stroke speed, tactics, techniques and effects on the ball, as well as using other specific materials on the table tennis blades (rubbers and wood), factors that alter the pattern of playing activity (26). Consequently, the development of one or the other style of play is related to specific physical and physiological demands associated with the performance of more explosive game actions as in the OFF style (27).

The results of the sex differences observed in the current study are similar to those reported by other authors (28–30), who reported that men have higher performance in strength, vertical jump, running speed and aerobic endurance tests. In comparison, women are significantly more flexible than men (31).

The evaluation of physical fitness using test batteries allows monitoring the evolution of the athlete to create individual training programs (6). In TT, high speed, agility, coordination, reaction time, strength and flexibility are fundamental to performing the different techniques and tactics correctly (32, 33).

TABLE 3 Upper body strength and lower body posterior flexibility.

Variables	Age (years)	Male	Female	Sex effect	Age effect	Sex × Age
HG Dominant (kg)	9	17.78 ± 2.69	15.01 ± 2.27	0.490	<0.001##	0.018##
	10	17.03 ± 3.68	17.14 ± 3.18			
	11^^,$$	20.27 ± 4.32	18.04 ± 2.38			
	12	23.84 ± 5.21	23.81 ± 3.65			
	13	25.48 ± 6.76	24.78 ± 5.13			
HG Non-Dominant (kg)	9	16.88 ± 2.51	13.84 ± 2.24	0.181#	<0.001##	0.014##
	10	15.10 ± 3.14	15.54 ± 3.30			
	11^^,$$	17.70 ± 4.48	16.32 ± 2.60			
	12	21.14 ± 5.46	21.84 ± 5.13			
	13	24.44 ± 5.43	22.10 ± 3.17			
Asymmetry HG (%)	9	3.47 ± 11.71	12.29 ± 4.90			
	10	9.23 ± 8.62	15.54 ± 9.75	0.312	0.542	0.601
	11	8.62 ± 9.38	14.14 ± 4.87			
	12	9.61 ± 10.65	12.71 ± 9.36			
	13	10.61 ± 12.47	12.78 ± 10.20			
Medicine ball throw (m)	9	3.01 ± 0.39	2.18 ± 0.18	<0.001##	<0.001##	0.037##
	10	3.20 ± 0.41	2.62 ± 0.52			
	11^^	3.64 ± 0.44	3.12 ± 0.46			
	12^^,$$,&&	4.33 ± 0.84	3.66 ± 0.74			
	13^^,$$,&&,«»	5.45 ± 1.00	4.42 ± 0.37			
Flexibility (cm)	9	16.28 ± 4.19	21.33 ± 8.03	<0.001##	0.121#	0.043##
	10	14.18 ± 3.21	21.50 ± 6.27			
	11	17.10 ± 5.09	23.50 ± 6.03			
	12	18.84 ± 5.16	23.71 ± 8.44			
	13	19.67 ± 4.16	20.16 ± 6.43			

HG, hand grip.
^^$p < 0.01$ differences vs. 9.
$ $p < 0.05$ differences vs. 10.
& $p < 0.05$ differences vs. 11.
«» $p < 0.01$ differences vs. 12.
##Large effect size.
#Moderate effect size.

Previous studies have analyzed physical fitness in adult high-level TT players (6, 33) and in children practicing TT (34). However, this is the first study to assess fitness as a function of playing style.

Physical fitness is an essential marker of health and sports performance in youth (35). Proper physical fitness monitoring can be an excellent strategy to promote health and identify

TABLE 4 Vertical jump.

Variables	Age (years)	Male	Female	Sex effect	Age effect	Sex × Age
SJ (cm)	9	17.67 ± 2.41	17.55 ± 3.21	0.434	<0.001##	0.911
	10	19.02 ± 3.91	18.53 ± 4.43			
	11	21.01 ± 4.37	20.15 ± 4.01			
	12^^,$$	22.81 ± 4.67	22.52 ± 4.26			
	13^^,$$	24.18 ± 4.99	22.59 ± 3.48			
CMJ (cm)	9	20.80 ± 2.76	21.66 ± 4.17	0.382	<0.001##	0.932
	10	21.64 ± 4.02	20.87 ± 5.09			
	11	24.29 ± 4.59	23.70 ± 4.20			
	12^^,$$	26.07 ± 5.64	25.40 ± 5.04			
	13^^$$	27.60 ± 5.38	25.55 ± 3.02			
ABK (cm)	9	23.58 ± 3.69	23.13 ± 4.11	0.670	<0.001##	0.714
	10	23.80 ± 4.88	23.82 ± 6.58			
	11	27.48 ± 5.09	27.58 ± 4.72			
	12^^,$$	29.79 ± 6.00	28.81 ± 6.07			
	13^^,$$	31.66 ± 5.5	29.50 ± 4.75			

SJ, squat jump; CMJ, countermovement jump; ABK, abalakov jump.
^^$p < 0.01$ differences vs. 9.
$$ $p < 0.05$ differences vs. 10.
##Large effect size.

TABLE 5 Cardiorespiratory capacity and speed assessment.

Variables	Age (years)	Male	Female	Sex effect	Age effect	Sex × Age
Periods CN (n)	9	4.21 ± 1.40	3.28 ± 0.84	<0.001##	<0.001##	0.516
	10	4.93 ± 1.56	3.53 ± 1.09			
	11^^,$$	6.35 ± 1.58	4.37 ± 1.25			
	12^^,$$	6.19 ± 1.53	4.89 ± 1.56			
	13^^	7.00 ± 1.98	5.30 ± 1.29			
Speed CN (km/h)	9	10.12 ± 0.69	9.67 ± 0.42	<0.001##	<0.001##	0.421
	10	10.55 ± 0.79	9.85 ± 0.55			
	11^^	11.24 ± 0.81	10.26 ± 0.62			
	12^^,$$	11.15 ± 0.77	10.51 ± 0.80			
	13^^	11.55 ± 1.02	10.76 ± 0.66			
Distance CN (m)	9	658.4 ± 241.8	502.5 ± 139.6	<0.001##	<0.001##	0.561
	10	812.7 ± 291.1	564.4 ± 191.3			
	11^^	1,068.3 ± 311.6	706.0 ± 221.6			
	12^^,$$	1,033.4 ± 297.1	798.1 ± 288.8			
	13^^	1,178.3 ± 379.5	887.3 ± 246.1			
VO_{2max} (mL/min/kg)	9	39.85 ± 4.07	37.23 ± 2.46	<0.001##	<0.001##	0.481
	10	42.36 ± 4.67	38.28 ± 3.27			
	11^^	46.38 ± 4.78	40.67 ± 3.64			
	12^^,$$	45.86 ± 4.56	42.12 ± 4.69			
	13^^	48.19 ± 6.00	43.62 ± 3.89			
Speed 20 + 30 m (s)	9	5.48 ± 0.70	6.14 ± 1.07	0.019##	<0.001##	0.463
	10	5.60 ± 1.01	5.81 ± 0.99			
	11	5.03 ± 0.56	5.29 ± 0.65			
	12^^,$$	4.85 ± 0.39	5.03 ± 0.31			
	13^^,$$	4.53 ± 0.42	4.96 ± 0.39			

VO_{2max}, maximal oxygen uptake; CN, course navette.
^^$p < 0.01$ differences vs. 9.
$$$p < 0.01$ differences vs. 10.
&&$p < 0.01$ differences vs. 11.
##Large effect size.

young athletic talent for all types of sports (35). It is common practice to analyze the physical profile of young athletes and compare them with adult athletes when aiming to predict potential success (36). However, this type of methodology is strongly rooted in assumptions (35). Adolescence is a dynamic period characterized by the growth and development of different organ systems (e.g., bone tissue, muscle tissue), which rarely progresses at the same time (37). The development of physical fitness in children and the effects of moderating variables, such as age and sex, are well documented (38, 39). Girls have more advanced skeletal and sexual maturity relative to chronological age, entering puberty and reaching peak growth velocity earlier than male (an average of 12 years in female and 14 years in male) (40).

The present study observed age differences in anthropometric parameters (weight, height, and BMI). Previous studies reported that the onset of accelerated height growth is around 10–12 years of age (41). The data on height and weight coincide with other studies performed on soccer (42), padel (43) and TT (33) players. These differences are directly related to sexual dimorphism between males and females (44, 45).

Regarding upper body strength, in the present study, differences between ages were observed in grip strength, being higher in older players. With respect to medicine ball throwing, males threw the ball a longer distance than females. These results coincide with general populations (46), young padel (47) and tennis (48) players. Sex differences in strength could be due to differences in muscle mass. It is well known that males tend to have more lean mass than females, influencing strength levels

TABLE 6 Differences in physical fitness in all participants according to playing style.

Variables	Ofensive	Mixed-Defensive	*t*	*p*
Height (m)	1.47 ± 0.070	1.51 ± 0.07	1.7	0.09
Weight (kg)	41.05 ± 7.11	46.71 ± 6.08	2.5	0.01
BMI (kg/m^2)	18.71 ± 2.19	20.21 ± 1.34	2.3	0.01
Periods CN (n)	5.24 ± 1.73	4.11 ± 1.49	2.3	0.01
Distance CN (m)	861.02 ± 320.51	677.47 ± 270.45	2.1	0.03
Speed CN (km/h)	10.86 ± 0.93	10.17 ± 0.74	2.1	0.03
VO_{2max} (mL/min/kg)	44.1 ± 5.21	40.15 ± 4.38	2.1	0.03
Speed 20 + 30 (s)	5.28 ± 0.71	5.19 ± 0.67	0.2	0.81
HG Dominant (kg)	21.16 ± 5.41	24.08 ± 7.05	1.9	0.05
HG Non-Dominant (kg)	19.07 ± 4.15	20.63 ± 6.12	1.3	0.17
Asymmetry HG (%)	10.87 ± 8.10	13.97 ± 9.67	1.0	0.29
Medicine ball throw (m)	3.85 ± 0.83	3.78 ± 0.97	0.3	0.70
Flexibility (cm)	18.43 ± 4.42	24.20 ± 9.73	3.8	<0.01
SJ (cm)	21.06 ± 4.59	20.87 ± 5.15	0.0	0.99
CMJ (cm)	24.21 ± 6.06	24.17 ± 5.44	0.2	0.84
ABK (cm)	28.01 ± 5.13	26.32 ± 6.83	0.5	0.60

BMI, body mass index; CN, course navette; VO_{2max}, maximal oxygen uptake; HD, hand grip; SJ, squat jump; CMJ, countermovement jump; ABK, abalakov jump.

TABLE 7 Anthropometry and physical fitness according to sex and playing style.

	Style	Male	Female	Sex effect	Style effect	Style × Age
Height (m)	OFF	1.46 ± 0.05	1.45 ± 0.04	0.812	0.710	0.910
	MIX + DEF	1.48 ± 0.02	1.47 ± 0.11			
Weight (kg)	OFF	41.14 ± 8.81	38.61 ± 7.34	0.317	0.081##	0.615
	MIX + DEF	49.10 ± 2.12	44.38 ± 7.98			
BMI (kg/m^2)	OFF	19.10 ± 4.12	18.51 ± 3.09	0.276	0.022##	0.498
	MIX + DEF	22.26 ± 0.32	20.19 ± 0.82			
Periods CN (n)	OFF	5.64 ± 1.61	4.21 ± 1.19	0.691	0.114#	0.101#
	MIX + DEF	3.50 ± 0.00	4.30 ± 1.30			
Distance CN (m)	OFF	958.5 ± 351.9	710.5 ± 231.8	0.495	0.131#	0.211
	MIX + DEF	608.0 ± 0.0	681.2 ± 199.9			
Speed CN (km/h)	OFF	11.09 ± 0.61	10.51 ± 0.61	0.412	0.181#	0.191
	MIX + DEF	10.0 ± 0.0	10.20 ± 0.57			
VO_{2max} (ml/min/kg)	OFF	45.12 ± 4.18	41.01 ± 3.91	0.517	0.161#	0.191
	MIX + DEF	39.12 ± 0.00	40.29 ± 3.33			
Speed 20 + 30 (s)	OFF	5.21 ± 0.79	5.45 ± 0.61	0.415	0.463	0.911
	MIX + DEF	5.43 ± 0.19	5.63 ± 0.85			
HG Dominant (kg)	OFF	19.41 ± 4.91	23.36 ± 4.92	0.101#	0.681	0.517
	MIX + DEF	20.35 ± 7.42	23.14 ± 6.57			
HG Non Dominant (kg)	OFF	17.42 ± 4.76	19.99 ± 5.42	0.253	0.955	0.966
	MIX + DEF	17.40 ± 5.09	19.78 ± 6.74			
Asymmetry HG (%)	OFF	8.19 ± 9.11	12.17 ± 7.55	0.321	0.411	0.691
	MIX + DEF	13.29 ± 6.61	14.94 ± 11.53			
Medicine ball throw (m)	OFF	3.91 ± 0.91	3.41 ± 0.95	0.085##	0.714	0.615
	MIX + DEF	4.03 ± 0.80	3.26 ± 0.87			
Flexibility (cm)	OFF	17.15 ± 3.11	20.15 ± 7.18	0.055##	0.796	0.618
	MIX + DEF	16.00 ± 1.41	21.50 ± 10.01			
SJ (cm)	OFF	22.18 ± 5.81	20.81 ± 4.27	0.312	0.219	0.610
	MIX + DEF	19.50 ± 0.70	16.76 ± 2.56			
CMJ (cm)	OFF	24.69 ± 6.94	22.91 ± 6.11	0.415	0.131	0.619
	MIX + DEF	21.85 ± 0.49	19.88 ± 3.47			
ABK (cm)	OFF	28.12 ± 7.49	27.39 ± 6.12	0.421	0.181	0.487
	MIX + DEF	25.50 ± 0.70	21.60 ± 4.27			

BMI, body mass index; CN, course navette; VO_{2max}, maximal oxygen uptake; HD, hand grip; SJ, squat jump; CMJ, countermovement jump; ABK, abalakov jump; IE, elastic index.
[##]Large effect size.
[#]Moderate effect size.

(49, 50). Sex differences in strength could be due to differences in muscle mass. It is well known that males tend to have more lean mass than females, influencing strength levels (39).

In relation to the flexibility of the lower back and hamstring muscles, the present study reported differences between sexes, with females obtaining higher values. These results coincide with other racket sports, such as padel and tennis (5, 51). The anatomical structure of the hip and pelvis could explain these differences (52), and the greater muscle mass that characterizes the male sex (41, 53). On the other hand, the differences found according to the style of play could be explained by the physical requirements of each style. The OFF style requires greater muscle mass to generate high levels of explosiveness that could be related to lower values in the sit and reach test. In this sense, a lower muscle mass in MIX + DEF players would directly impact higher flexibility values as this style of play requires less power than OFF.

As for the data obtained in the vertical jump, differences between ages were reported, with the height of the jumps being greater as age advanced. Pradas de la Fuente et al. (11), showed similar results in vertical jump performance, where significant differences were found in table tennis players from under 11 years to 17 years of age. Other authors reported similar results in school populations (54). The differences between ages could be related to higher plasma testosterone levels in males (55), as well as the development of muscle mass and anatomical changes in both sexes (38). On the other hand, the sex difference in jumps that involved a countermovement might indicate that males were slightly more effective in using the stretch-shortening cycle (56) and/or involving the hip extensor muscles (57). In the CMJ, men appear to apply greater concentric momentum and, therefore, achieve greater velocity during most of the concentric phase, including the take-off (28). When comparing jump height as a function of gender and playing style, a higher jump height, although not significant, is observed in players who play an OFF game. These data point to a tendency in the OFF style of play from an early age to generate higher levels of strength in the active (impulsive) and reactive (elastic-impulsive) manifestations as has been demonstrated in similar research (6, 58, 59).

Regarding the speed test, differences in displacement time between sexes and age were reported. Previous authors observed

TABLE 8 Correlations, according to sex, in the parameters of physical fitness and style of play.

			Playing style (0 = OFF; 1 = MIX + DEF)
Periods CN (n)	Male	*r*	−0.144
		p	0.043
	Female	*r*	−0.004
		p	0.961
Distance CN (m)	Male	*r*	−0.110
		p	0.117
	Female	*r*	0.007
		p	0.930
Speed CN (km/h)	Male	*r*	−0.110
		p	0.111
	Female	*r*	0.006
		p	0.941
VO_{2max} (mL/min/kg)	Male	*r*	−0.105
		p	0.131
	Female	*r*	0.005
		p	0.961
Speed 20 + 30 (s)	Male	*r*	0.042
		p	0.541
	Female	*r*	−0.101
		p	0.225
HG Dominant (kg)	Male	*r*	0.041
		p	0.681
	Female	*r*	0.115
		p	0.351
HG Non-Dominant (kg)	Male	*r*	0.004
		p	0.961
	Female	*r*	0.099
		p	0.411
Medicine ball throw (m)	Male	*r*	0.010
		p	0.891
	Female	*r*	0.712
		p	0.128
Flexibility (cm)	Male	*r*	−0.004
		p	0.951
	Female	*r*	0.171
		p	0.034
SJ (cm)	Male	*r*	−0.031
		p	0.631
	Female	*r*	0.041
		p	0.591
CMJ (cm)	Male	*r*	−0.043
		p	0.551
	Female	*r*	0.072
		p	0.381
ABK (cm)	Male	*r*	−0.034
		p	0.612
	Female	*r*	−0.015
		p	0.836

BMI, body mass index; CN, course navette; VO_{2max}, maximal oxygen uptake; HD, hand grip; SJ, squat jump; CMJ, countermovement jump; ABK, abalakov jump.

similar results in distances of 5 and 10 meters in TT players (33), as well as reaction times and lateral displacement times (6). The differences in times in the tests between sex and age could be related to hormonal characteristics. Higher levels of circulating testosterone, characteristic of men, result in increased muscle weight and more significant muscle cross-sectional area, translating into greater applications of reaction forces, which generates superior running performance for men (60). On the other hand, the differences found in speed as a function of playing style could be explained by the physical requirements of each playing style. The OFF style requires more muscle mass to generate high levels of reactivity and explosiveness as opposed to the more conservative and less powerful MIX + DEF style of play (6, 27).

Finally, concerning the cardiorespiratory capacity, differences were observed between sexes and ages, with greater distance and maximum oxygen consumption (VO_{2max}), estimated in males and at older ages. These data align with those reported Pradas et al. (34), Pradas et al. (43), in TT and padel players. Generally, higher VO_{2max} values have been observed in males (61) and sex differences increase as they progress through adolescence. These could be attributed to males' greater muscle mass and hemoglobin concentration (61). In addition, it could also be explained by a slight increase in body fat in children aged 7–12 years, as well as a reduction in body fat at puberty (62). OFF styles of play, characterized by short and very explosive actions, show lower values of oxygen consumption compared to players who develop MIX or DEF styles of play, characterized by the development of game actions of longer duration and with a higher volume of hits and displacements, requiring a more significant contribution of the aerobic pathway (6, 26).

Concerning the differences found according to playing styles, one of the most exciting findings, considering the results obtained for both sexes, is that those players with a greater body weight tend to develop MIX + DEF playing styles, which require less explosiveness in their playing actions compared to OFF players, who need a more significant development of strength and speed. The MIX – DEF style of play at early ages is an essential technical-tactical resource to improve performance. In young TT players, the MIX – DEF style of play can be linked to different limitations, which can be physical because they have a greater body weight, cognitive because they have not yet consolidated the learning of such vital aspects in this sport as reading and analyzing quickly and effectively the effects produced on the ball; or of a technical-technical-tactical type, by covering one side of the racquet with a defensive covering (e.g., long pimples-out rubber), which prevents the opponent from benefiting from a weakness on one side of the game (1).

According to sex, no significant differences were found, but co-relationships were found. Male players with an OFF style of play were negatively correlated with the CN period ($p < 0.05$). These results could be explained as a consequence of the needs of the OFF style of play, characterized by the development of short, fast and explosive game actions, where the anaerobic metabolic pathway is essential to obtain optimal performance in this type of players (6, 19).

In the female sex, players who developed a MIX + DEF style of play were correlated with higher values of flexibility ($p < 0.05$). The MIX + DEF style of play is characterized by the performance of game actions of longer duration but at a slow pace. This type of game, in which low-intensity aerobic actions predominate, produces adaptations in the biotype, particularly in women with MIX – DEF playing styles, characterized by lower power and speed of play, and as a consequence, makes it possible to acquire and maintain higher levels of flexibility (6, 12, 33).

This study also has certain limitations: (i) the rubber materials used in the table tennis blade were not taken into consideration; (ii) the lateral dominance of the players was not considered; (iii) the years of experience not been considered; (iv) this study did not consider biological maturation; and (v) the play style and age groups were very heterogeneous in terms of the number of participants.

5. Conclusions

There are differences in physical fitness parameters between playing styles, sex and age. Generally, male and older players perform better in physical fitness tests.

Flexibility and cardiorespiratory capacity are related to playing style and sex. Players practising the MIX – DEF style of play have higher levels of flexibility, while those of the OFF style are characterized by developing a greater aerobic capacity.

The MIX – DEF style of play is developed in both sexes by players who have a greater body weight, so using this style of play could be considered as a technical-tactical resource to improve the performance of young athletes with certain deficiencies such as low physical fitness.

It is necessary to carry out new studies to confirm the results obtained in this study, especially at early ages, since, in some cases, the players have a short sporting experience in table tennis.

The existing differences in the levels of physical fitness could help coaches develop specific training programs according to the style of play of their players and sex.

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 humans were approved by Clinical Research Ethics Committee of Aragon (Spain) (code: 19/2010). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

FP: Conceptualization, Investigation, Visualization, Writing – original draft, Writing – review & editing. VT-R: Writing – original draft, Writing – review & editing. MO: Data curation, Methodology, Writing – review & editing. AM: Conceptualization, Investigation, Writing – original draft.

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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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Precompetitive anxiety and self-confidence during the 2023 Finnish Padel championship in high level men's players

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The aim of the current study was to assess precompetitive anxiety and self-confidence in high level men's padel players from Finland. Twenty eight men's padel players from the highest category participated in the research (87.5% of the target population). The CSAI-2R (Competitive State Anxiety Inventory-2 Revised) and STAI-S (State–Trait Anxiety Inventory – State) questionnaires were used and descriptive and inferential analyzes were performed, including the Kruskal Wallis's H and Mann–Whitney's U tests. The results show that seeded players presented lower levels of cognitive anxiety ($\eta^2 = 0.111$). Moreover, losers of first round presented more state anxiety than winners ($\eta^2 = 0.302$). Before the first match, state anxiety was higher than prior to the second match ($\eta^2 = 0.148$). Furthermore, lower ranked players of first round, compared to second, presented more state anxiety and somatic anxiety ($\eta^2 = 0.487$ and $\eta^2 = 0.277$, respectively). However, according to the results obtained, self-confidence was not affected by any of the variables analyzed (ranking, seed, result or round). These findings may be of great interest to players, coaches and sports psychologists, as they allow an enhanced comprehension of the player's level of anxiety and self-confidence.

KEYWORDS

psychophysiology, confidence, anxiety, competition, racquet sports, Padel, CSAI-2R, STAI-S

1 Introduction

Padel is a doubles racquet sport played on a court measuring 20 × 10 meters, divided by a central net, and enclosed by glass or fencing that is four o three meters in height along the court's sides and bottom, against which the ball can be hit during play (PadelFip: Federación Internacional de Pádel, 2023). Padel has experienced remarkable growth in recent decades, as indicated by Courel Ibáñez et al. (2017). Its popularity is due to the simplicity of its rules and its adaptability in terms of physical and technical-tactical demands, allowing individuals of varying ages and skill levels to take part in the sport (Coruel-Ibáñez et al., 2018; García-Benítez et al., 2018). Presently, this sport boasts a presence in over 70 countries, resulting in a substantial surge in facilities, commercial agreements such as sponsorships and employment contracts, as well as sports licenses in recent years (Muñoz et al., 2016; PadelFip: Federación Internacional de Pádel, 2023). Within this context, the quantity of scientific studies pertaining to padel has seen an uptick in recent years (García-Giménez et al., 2022; Martín-Miguel et al., 2023; Sánchez-Alcaraz et al., 2023). Among the various topics under investigation, the analysis of performance stands out as the most frequently studied aspect. Research carried out on performance analysis seeks to determine the differences that exist between players based on their level of play (Muñoz et al., 2017a,b), gender (Escudero-Tena et al., 2021a, 2022b) or result (Escudero-Tena et al., 2021b, 2022a).

Mental toughness is essential for attaining success in sports (Crust and Keegan, 2010) and sustaining and enhancing performance in competition (Gucciardi et al., 2015). Moments right before the actual competition begins, players tend to experience anxiety (Dosil, 2004). Such anxiety, commonly recognized as precompetitive anxiety (Cox, 2012), has been extensively studied in the recent past (Cuesta-Vargas and Vertedor Corpas, 2016; Correia and Rosado, 2019; Pineda-Espejel et al., 2021; Ren et al., 2022). This mental factor is widely acknowledged to have a profound impact on performance in sports competition, in addition to self-confidence (León-Prados et al., 2014; Pineda-Espejel et al., 2019). Sport-related research has demonstrated that athletes displaying greater amounts of anxiety typically perform worse in competitions compared to those with less anxiety (León-Prados et al., 2011; López-Torrers et al., 2011; Ngo et al., 2017; Sánchez et al., 2017). However, the classic assertion that anxiety invariably has a detrimental impact on sports performance has come under scrutiny. Elite athletes often perceive anxiety symptoms as performance-enhancing, while those with less expertise tend to view anxiety as hindering their performance. In fact, experiencing competitive anxiety can be advantageous for performance, as long as the athlete maintains control (Jones and Hanton, 2001; Demarie et al., 2013). In any case, it may seem important to manage and control that precompetitive anxiety to achieve optimal sport performance. Furthermore, the player's self-confidence, that is, the player's conviction in their potential for successful competition (Robazza and Bortoli, 2007), is positively correlated with sporting success (Santos-Rosa et al., 2007; Díaz et al., 2008; Martínez-Romero et al., 2016; Zurita-Ortega et al., 2017). Nevertheless, an excessive level of self-confidence is capable of decreasing the ideal performance level (Weinberg and Gould, 2010). The correlation between an athlete's self-confidence and their competitive performance stands out as one of the most relevant aspects in the realm of sports performance (Vodičar et al., 2012).

Several factors, such as the sex and type of sport, can potentially influence precompetitive anxiety (Martens et al., 1990). It is worth noting that, in racquet sports, players have to constantly make decisions in short periods of time (Castillo-Rodríguez et al., 2014) and coping with high-pressure situations is intrinsically linked to performance (González-Díaz et al., 2012; Knight et al., 2016; Martínez-Gallego et al., 2022). In general, in individual sports, compared to team sports where responsibility is shared among all team members, athletes present an increased amount of precompetitive anxiety (Koronas et al., 2020). However, according to Rodríguez-Cayetano et al. (2022), when comparing tennis (singles format) to padel (doubles format), the results are not like this in every case, differing depending on the sex. These authors found that women's tennis players, compared to padel players of the same sex, have a significantly higher level of cognitive anxiety and a significantly lower level of self-confidence, but no differences were found in the somatic anxiety. In addition, the same authors indicate that men's padel players, compared to tennis players of the same sex, present significantly higher level of somatic anxiety but no differences have been found in cognitive anxiety and self-confidence. It is also worth highlighting that senior padel players, compared to junior padel players, show significantly higher levels of cognitive and somatic anxiety and a significantly lower level of self-confidence.

After analyzing the scientific literature, as indicated above, in padel there has been an increase in scientific publications in recent times (García-Giménez et al., 2022; Martín-Miguel et al., 2023). However, mental preparation and performance have been scarcely studied, with only a small number of studies that have analyzed the level of pre-competitive anxiety (Almendros-Pacheco et al., 2022; Castillo-Rodriguez et al., 2022; Rodríguez-Cayetano et al., 2022). Gaining a better understanding of the player's level of anxiety and self-confidence can be of great interest for players, coaches and sports psychologists. The former can adapt their lifestyle and game style, while the latter can tailor feedback and training sessions accordingly. The aim of the present investigation was to analyze the pre-competitive anxiety and self-confidence during the competition in high-level padel players from Finland according to the ranking, the seed, the result and the round. Therefore, the following hypotheses were put forward: (1) Finnish padel players, compared to players from other nations, will display lower levels of self-confidence and higher levels of anxiety, (2) seeded players, compared to non-seeded, will show less anxiety and more self-confidence; (3) higher ranked players, compared to lower ranked, will show more self-confidence and less anxiety; (4) winners of the matches, compared to losers, will have a higher level of self-confidence and a lower level of anxiety; (5) in first round, lower ranked players and losers will present more anxiety and less self-confidence than higher ranked players and winners, respectively; (6) first round matches, compared to second, will bring more anxiety for the players and the players will have less self-confidence; (7) as rounds go by, players with lower ranking will present more anxiety and less self-confidence.

2 Materials and methods

2.1 Participants

A total of 28 men's high level padel players from Finland (87.5% of the target population) voluntarily participated in the present study, which took place during the main draw of the 2023 Finnish Padel Championship. The obtained points of this competition counted for the ranking of the Finnish Federation. 23 (71.9%), 12 (75.0%), 8 (100%), and 4 (100%) players completed the questionnaires in round of 16 (first round), quarter finals, semifinals and final, respectively. Participants completed the questionnaires in English, as it is the only language that both researchers and athletes are fluent in. All participants were ranked top 103 in Finland. At the time of the measurements, none of the athletes had physical injuries, nor were they using any medication. Furthermore, none of the participants had any hindrance to their involvement in the study. The study was in accordance with the Helsinki Declaration (World Medical Association, 2013). Participants were treated ethically under the American Psychological Association code of ethics regarding consent, anonymity and responses. Previously, the current investigation had been approved by the Ethics Committee of the European University of Madrid with the code CIPI/22.303. To obtain permission to administer the questionnaires to the players before the competition, the researchers first contacted the Finnish Padel Federation and the championship organizer. So as to respect the principles of voluntariness and confidentiality, each player was required to sign an informed consent form that clearly explained the objectives of the research and their voluntary participation in it.

2.2 Instruments

2.2.1 Competitive anxiety

CSAI-2R was used to measure precompetitive anxiety and self-confidence of padel players. This inventory was originally developed by Martens et al. (1990) to measure the intensity of cognitive and somatic responses and self-confidence before training and before competition. It was adapted and validated years later by Cox (2012). The CSAI-2R consists of 17 items (using a 4-point Likert scale). These items make up a total of three subscales: cognitive anxiety, somatic anxiety and self-confidence. Higher values represented higher cognitive anxiety, somatic anxiety, and self-confidence levels. In the analysis of the instrument, Cronbach's alpha coefficients were obtained, showing reliability scores of 0.72 for cognitive anxiety, 0.66 for somatic anxiety, and 0.85 for self-confidence, all meeting acceptable standards (Cortina, 1993; Nunnally and Bernstein, 1994; DeVellis, 2003; Vaske, 2008).

2.2.2 State anxiety

STAI-S was used to measure state anxiety. This inventory was developed by Spielberger et al. (1970). This questionnaire has been used in previous research in racquet sports (García-Gonzálvez et al., 2022; Villafaina et al., 2022).

2.2.3 Procedure

The questionnaires were administered to the players between 30 and 45 min prior to the start of each match, following similar criteria to that used by Andrade Fernández et al. (2007), who administered their questionnaires between 15 and 45 min before the start of the competition. All questionnaires were completed in a quiet room with a controlled temperature of 20°C. Participants were not allowed to speak during the assessments.

2.3 Statistical analysis

All data were analyzed using the statistical package SPSS for Macintosh v.25.0 (SPSS Inc., Chicago, IL, United States). A Kolgomorov-Smirnov test was used to test the normality of the distribution of the data and it indicated that it is non-parametric. Then, a descriptive analysis was performed to obtain information on the number of times the categories of each study variable occurred (mean, standard deviation, median, maximum, and minimum).

Next, inferential analyzes were carried out to analyze the differences between the anxiety factors and the self-confidence with the independent variables result (winner/loser), ranking (higher/lower), seed (seeded/non-seeded), round (first round, quarter-final, semi-final, final). Mann–Whitney's U and Kruskal Wallis's H tests were used. A p value of less than 0.05 was considered to be statistically significant.

3 Results

Table 1 shows the descriptive analysis of the psychological variables regarding precompetitive anxiety and self-confidence.

Table 2 shows the level of precompetitive anxiety and self-confidence as a function of the players being seeded or not in the draw. Significant differences ($p = 0.018$; $\eta^2 = 0.111$) were found in cognitive anxiety.

Table 3 shows the level of precompetitive anxiety and self-confidence as a function of the ranking (higher/lower) of the pairs confronted in each match. No significant differences were found.

Table 4 shows the level of precompetitive anxiety and self-confidence as a function of the result (winner/loser) of each match. No significant differences were found.

Table 5 shows the level of precompetitive anxiety and self-confidence as a function of the result in round of 16 (first round) of the championship. Significant differences ($p = 0.006$; $\eta^2 = 0.302$) were found in state anxiety.

Table 6 shows the level of precompetitive anxiety and self-confidence between the round of 16 (first round) and quarter finals. Significant differences were found in state anxiety ($p = 0.022$; $\eta^2 = 0.148$).

When comparing other rounds, significant differences ($p = 0.020$; $\eta^2 = 0.332$) were only found between quarter finals and final in state anxiety.

Table 7 shows the level of precompetitive anxiety and self-confidence as a function of the round for the lower ranked players of each match. Significant differences were found in somatic anxiety ($p = 0.032$; $\eta^2 = 0.277$) and state anxiety ($p = 0.004$; $\eta^2 = 0.487$).

The differences were found between round of 16 (first round) and quarter finals in somatic anxiety ($p = 0.009$; $\eta^2 = 0.329$) and state anxiety ($p = 0.002$; $\eta^2 = 0.428$). Also, there were significant differences between round of 16 (first round) and semifinals in state anxiety ($p = 0.010$; $\eta^2 = 0.349$).

4 Discussion

The aim of the present study was to evaluate anxiety and self-confidence prior to sports competition in high level men's padel players from Finland. As an initial hypothesis it was established that Finnish padel players would have lower self-confidence values and higher anxiety levels. This hypothesis was accepted in part, since Finnish padel players showed lower values of self-confidence compared to Spanish padel players from the same category (Castillo-Rodriguez et al., 2022). However, Finnish padel players also presented lower values of cognitive anxiety, and similar values of somatic anxiety. This could be since padel in Finland is a relatively new sport. Thus,

TABLE 1 Descriptive analysis of the precompetitive anxiety and self-confidence.

Variable	Mean	SD	Median	Max.	Min.
CA	1.37	0.39	1.20	2.40	1.00
SA	1.59	0.37	1.57	2.71	1.00
SC	3.21	0.59	3.20	4.00	1.40
STA	7.23	3.41	6.00	16.00	2.00

CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; STA, state anxiety; SD, standard deviation; Max., maximum; Min., minimum.

TABLE 2 Precompetitive anxiety and self-confidence between seeded and non-seeded players.

	Seeded players (n = 25)	Non seeded players (n = 22)		
Variable	Median (IQR)	Median (IQR)	p	η^2
CA	1.20 (0.10)	1.50 (0.85)	0.018*	0.111
SA	1.57 (0.57)	1.71 (0.36)	0.337	0.019
SC	3.40 (0.80)	3.20 (0.60)	0.091	0.060
STA	6.00 (2.50)	7.00 (6.00)	0.095	0.058

CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; STA, state anxiety; n, number; IQR, interquartile range; p, value of p; *$p < 0.05$; η^2, eta squared.

TABLE 3 Precompetitive anxiety and self-confidence according to the ranking.

	Higher ranked (n = 22)	Lower ranked (n = 25)		
Variable	Median (IQR)	Median (IQR)	p	η^2
CA	1.20 (0.25)	1.20 (0.70)	0.938	0.000
SA	1.64 (0.71)	1.57 (0.29)	0.650	0.004
SC	3.40 (0.80)	3.20 (0.70)	0.485	0.010
STA	6.00 (2.25)	7.00 (6.00)	0.174	0.038

CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; STA, state anxiety; n, number; IQR, interquartile range; p, value of p; *$p < 0.05$; η^2, eta squared.

TABLE 4 Precompetitive anxiety and self-confidence according to the result.

	Match winner (n = 22)	Match loser (n = 25)		
Variable	Median (IQR)	Median (IQR)	p	η^2
CA	1.20 (0.30)	1.20 (0.70)	0.588	0.006
SA	1.57 (0.61)	1.71 (0.36)	0.222	0.031
SC	3.40 (0.80)	3.20 (0.90)	0.150	0.043
STA	6.00 (1.25)	8.00 (6.00)	0.054	0.077

CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; STA, state anxiety; n, number; IQR, interquartile range; p, value of p; *$p < 0.05$; η^2, eta squared.

TABLE 5 Precompetitive anxiety and self-confidence according to the result in round of 16.

	Match winner (n = 10)	Match loser (n = 13)		
Variable	Median (IQR)	Median (IQR)	p	η^2
CA	1.20 (0.60)	1.40 (1.00)	0.313	0.046
SA	1.50 (0.61)	1.71 (0.36)	0.148	0.092
SC	3.10 (1.05)	3.00 (0.60)	0.648	0.009
STA	6.00 (2.25)	11.00 (5.00)	0.006*	0.302

CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; STA, state anxiety; n, number; IQR, interquartile range; p, value of p; *$p < 0.05$; η^2, eta squared.

TABLE 6 Precompetitive anxiety and self-confidence between round of 16 and quarter finals.

	R16 (n = 23)	QF (n = 12)		
Variable	Median (IQR)	Median (IQR)	p	η^2
CA	1.20 (1.00)	1.20 (0.30)	0.290	0.030
SA	1.71 (0.57)	1.43 (0.43)	0.071	0.092
SC	3.00 (0.60)	3.40 (0.70)	0.082	0.085
STA	7.00 (5.00)	5.50 (2.50)	0.022*	0.148

CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; STA, state anxiety; R16, round of 16; QF, quarter finals; n, number; IQR, interquartile range; p, value of p; *$p < 0.05$; η^2, eta squared.

padel players from Spain may have more experience, and cognitive anxiety and self-confidence are directly and positively influenced by experience (Castillo-Rodriguez et al., 2022).

Another hypothesis was that seeded players, compared to non-seeded, would present less anxiety and more self-confidence. This hypothesis was accepted in part, since seeded players showed significantly lower levels of cognitive anxiety. This may be attributed to the fact that by having a higher ranking, seeded players have more competitive experience and technical-tactical abilities, which could contribute to present less cognitive anxiety. In view of the results, it is advisable for non-seeded players to incorporate a psychological skills training program to reduce this elevated level of cognitive anxiety (Mathers and Brodie, 2011; Slack et al., 2015). It is also recommended to include pressure during training through the implementation of psychological demands and consequences that leave a sustained mark on athletes (Stoker et al., 2016; Low et al., 2023). Nevertheless, contrary to our findings, Castillo-Rodriguez et al. (2022) found that the higher the level of the padel players, the higher the values of self-confidence and the lower the values of somatic anxiety. It is important to note that in the cited study, this comparison was made among 3 level of categories and there was no comparison intra-category, as it is the case in our study.

It was also hypothesized that players with higher ranking would display more self-confidence and lower anxiety than players with lower ranking. This hypothesis was not accepted at all. There were no significant differences despite being the values as expected. This could be due to the lack of experience of the participants since, as previously indicated, padel is a new sport in Finland. And it has been shown that self-confidence is affected by the experience (Castillo-Rodriguez et al., 2022).

Another hypothesis was that winners of the match would present higher level of self-confidence and lower level of anxiety compared to losers before matches. This hypothesis was not accepted at all. Despite the differences were as expected, these were not significant. This could be partly explained since the padel players increase their self-confidence during and after the game (Rodríguez-Cayetano et al., 2017).

Additionally, it was hypothesized that in first round, losers would present more pre-competitive anxiety than winners, and less self-confidence. This hypothesis was accepted in part. Significant differences were found in the level of state anxiety. This result could be explained by the fact that a high level of anxiety indicates a decrease in sports performance (Garcia-Mas et al., 2011; Ries et al., 2012).

TABLE 7 Precompetitive anxiety and self-confidence as a function of the round in lower ranked players.

	R16 (*n* = 13)	QF (*n* = 6)	SF (*n* = 4)	*F* (*n* = 2)		
Variable	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	*p*	η^2
CA	1.40 (1.00)	1.20 (0.65)	1.10 (0.35)	1.20 (0.00)	0.438	0.014
SA	1.71 (0.36)	1.43 (0.32)	1.50 (0.46)	1.64 (0.07)	0.032*	0.277
SC	3.00 (0.60)	3.30 (0.50)	3.20 (0.50)	3.60 (0.40)	0.363	0.009
STA	11.00 (5.00)	5.00 (2.00)	5.00 (0.75)	8.50 (0.50)	0.004*	0.487

CA, cognitive anxiety; SA, somatic anxiety; SC, self-confidence; STA, state anxiety; R16, round of 16; QF, quarter finals; SF, semifinals; F, final; n, number; IQR, interquartile range; *p*, value of *p*; $*p < 0.05$; η^2, eta squared.

Furthermore, there was a hypothesis suggesting that first round matches (round of 16), compared to second (quarterfinals), would involve more anxiety and less self-confidence for the players. This hypothesis was accepted in part. Significant differences were found in state anxiety. To the best of our knowledge, there are no other studies in padel regarding this particular topic. Nevertheless, these results are partially in line with the study of Villafaina et al. (2022), in which it was found that elite international junior tennis players had lower state anxiety levels before the second match than before the first match of the same competition. Besides, prior to the first match, compared to the second, the level of cognitive anxiety was also higher in these tennis players. Concordantly, BMX cyclists experienced significant decreases in both somatic and cognitive anxiety levels as they transitioned from the first round to the second round (Mateo et al., 2012). The authors proposed that these findings might be attributed to the repeated exposure to precompetitive pressure, leading to a diminished fear of failure during competition. Consequently, this reduced the anxiety response among the athletes. Furthermore, a prior study demonstrated that athletes' prior exposure to a particular competitive environment had an impact on their precompetitive anxiety levels (Cerin et al., 2000).

As a final hypothesis, it was established that, as rounds go by, players with lower ranking would present more anxiety and less self-confidence. This hypothesis was accepted in part. Significant differences were found in the level of somatic anxiety and state anxiety. Ranking is directly associated to the level meaning that low ranked players do not usually reach final rounds in tournaments. And a strong consensus exists, affirming an inverse correlation between anxiety levels and sports performance (León-Prados et al., 2011).

This study boasts various strengths. To begin with, it is the first study carried out with Finnish players. Secondly, it is the first study that compares the level of precompetitive anxiety and self-confidence as a function of the ranking of the players, and the round and outcome of the matches. Thirdly, the findings carry significant practical implications for coaches and sport psychologists, particularly considering the differences in rounds, ranking and outcome of the matches. The results must be taken into account to design effective training programs for each individual athlete, as well as for the design of specific training tasks. For example, exercises that simulate real competition situations that imply a higher degree of anxiety and a lower degree of self-confidence should be an important part of training sessions, such as tie-breaks, golden points, conditional rules of the game, score against, etc.

While this study adopts a similar methodology to recent research in the field, it is essential to underscore certain limitations inherent in this investigation. In future studies, researchers are encouraged to examine whether anxiety and self-confidence responses manifest similarly in both sexes. To measure precompetitive anxiety and self-confidence, it would be advisable to use other tools such as pulsometers which measure heart rate variability, and not only questionnaires. Future research should take into account both precompetitive anxiety and self-confidence and post-competitive anxiety and self-confidence, and relate it to sports performance, at elite and amateur level.

5 Conclusion

The levels of anxiety and self-confidence before the sports competition have been described in high-level men's padel players from Finland according to classification, match result and round.

Anxiety was affected by the variables analyzed (ranking, seed, result, and round). The seeded athletes presented lower levels of cognitive anxiety than the unseeded ones, the losers presented more state anxiety than the winners in the first round and, the state anxiety was also higher before the first round (round of 16) than before the second round (quarterfinals). Finally, the lower ranked players in the first round (round of 16), compared to those in the second (quarterfinals), presented a higher degree of state anxiety and somatic anxiety.

On the other hand, self-confidence was not affected by any of the variables analyzed (ranking, seed, result and round).

As a practical application, based on these results, players are encouraged to develop their mental skills to enhance their performance. Thus, padel coaches should consider undergoing psychological training to provide more effective support to their athletes, as well as the latter could benefit significantly from having a sport psychologist within their teams.

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 humans were approved by the Ethics Committee of the European University of Madrid with the code CIPI/22.303. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

RC-R: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Writing – original – draft, Writing – review – & – editing. AE-T: Software, Supervision, Validation, Writing – review & editing. VS-C: Funding acquisition, Supervision, Validation, Writing – review & editing. ÁB-S: Conceptualization, Funding acquisition, Project administration, Supervision, Validation, Writing – review & editing.

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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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Community and motivation among tennis officials: a cross-cultural multilevel analysis

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Sport officials are pivotal to the development of the game at every level. Yet, the exploration of these officials' job satisfaction and turnover intentions, especially within tennis, remains largely neglected. This study undertakes a cross-cultural adaptation and validation of the Referee Retention Scale (RRS) in a Chinese context (RRS-CN) and uses multilevel models (MLM) to explore the influence of perceived administrator consideration, mentoring, continuing education opportunities, remuneration, stress, and ecological factors on tennis officials' sense of community and officiating motivation. Data from 523 tennis officials across 26 provinces in China were gathered via an online survey. Through exploratory and confirmatory factor analyses, the RRS-CN was validated as a culturally adaptive 25-item scale. In the following, MLM results revealed that officiating levels, socioeconomic status, perceived administrator consideration, mentoring, and levels of continuing education significantly predict officials' sense of community. Additionally, we identified that continuing education, mentoring, and remuneration significantly influences officiating motivation. These findings underscore the importance of fair assignments, mentorship, and ongoing professional development in enhancing job satisfaction and retention. Future explorations are encouraged to extend the analysis to more ecological variables and further investigate their potential effects on systematic partial nesting, enhancing the generalizability and precision of measurement in job satisfaction and turnover studies across diverse cultural landscapes.

KEYWORDS

sport, officiating, scale validation, satisfaction, hierarchical model

Community and motivation among tennis officials: a cross-cultural multilevel analysis

Organized sports are heavily reliant on officials; however, the number of qualified personnel continues to decline, posing a significant challenge to the sports industry (Kim, 2016; Ridinger et al., 2017). The shortage of officials in various sports can negatively impact both the quantity and quality of game competitions and spectator experiences. In many instances, games must be rescheduled or canceled due to the unavailability of officials (Zvosec et al., 2021). Overworked official teams and inexperienced officials thrust into situations beyond their skill level contribute to a toxic environment within the industry (Read, 2000; Cuskelly and Hoye, 2004). Previous research has highlighted the increasing difficulty of recruiting new referees, necessitating actions to expand the officiating community (Ridinger et al., 2017). To more effectively recruit and retain sports officials, it is crucial for sports administrators to understand the factors influencing job satisfaction (Warner et al., 2013; Ridinger et al., 2017). A growing body of literature addresses various issues related to this community, examining the entire process from entering to leaving officiating roles (Purdy and Snyder, 1985; Kellett and Shilbury, 2007; Warner et al., 2013; Ridinger, 2015; Livingston et al., 2017; Ridinger et al., 2017). With attrition rates of nearly 30%, sport officials are leaving their positions due to many reasons, for instance, abuse (Radziszewski et al., 2023); lack of respect and recognition (Hancock et al., 2015); and gendered aggressions (Webb et al., 2021; Tingle et al., 2022).

Meanwhile, several contributors were found that should consider ways of enhancing sport officials' engagement and retention; a sense of community was known as a strong predictor (Zvosec et al., 2021; Kim et al., 2022). Sport brings together people of diverse backgrounds into many common communities where they can feel a sense of belonging (Kellett and Warner, 2011). A community that seems to provide more opportunities for meaningful social interactions has been shown to be important to sport officials where they can feel safety, belonging, and attachment (Kim et al., 2022). A strong sense of community led to greater psychological wellbeing, positive officiating experiences, and better officiating persistence (Zvosec et al., 2021; Kim et al., 2022). In addition, Hancock et al. (2015) demonstrated that sport officials were motivated to begin officiating for intrinsic reasons and cited intrinsic and social motivations for continuing officiating. Furthermore, mentorship, perceived organizational support, and financial remuneration were found as contributors to retaining sport officials (Cuskelly and Hoye, 2013; Kim, 2016; Livingston et al., 2017; Kim et al., 2022).

As vital facilitators of match competitions and integral components of tennis culture, tennis officials play an irreplaceable role in the game (Lake and Osborne, 2019). A tennis official is a person who "helps ensure that any given tennis match is conducted under the fairest possible conditions" (United States Tennis Association, 2016, p. 1). Tennis officials encompass various roles, including referee, chief umpire, chair umpire, and line umpire, with differing responsibilities on and off the court. In Asia, and particularly in China, the tennis community has experienced dramatic growth over the past decade (Rick and Li, 2023). Although tennis is considered a minority sport in China, the country's large population makes a significant contribution to global participation rates (Rick and Li, 2023). According to the International Tennis Federation (2021), an estimated 20 million Chinese play tennis, almost one-fourth of the world's total. Meanwhile, the expansion of tennis events in China has been instrumental in the sport's development (Mangan and Dong, 2009). In collaboration with the Women's Tennis Association (WTA), Association of Tennis Professionals (ATP), and International Tennis Federation (ITF), China hosted more than 70 international tournaments in 2019, comprising 80% of all professional tennis events held in Asia (General Administration of Sport of China, 2019). This growth in events marks a significant milestone in the development of tennis officials in China. As of 2016, approximately 60 white badge or higher ranking officials, 300 national-level officials,[1] and thousands of junior-level officials have worked in over 21,000 domestic and international tournaments (Xinhua News Agency, 2016). Despite the growing official community, the number of officials has not grown at the same rate as the number of participants and events in China.

Noteworthily, existing research has primarily examined sports officials within a Western context. Only a limited amount of sport officials related studies were found from Africa (Mkumbuzi et al., 2023); the Middle East (Qader, 2023); and Asia (Kim and Hong, 2016; Kim, 2016). Thus, studies focusing on a globally symbolic sport like tennis, and its rapidly growing officiating community in China, could provide valuable insights for understanding this unique stakeholder group as part of the sport ecosystem and has practical implications related to officiating sense of community and motivation. Additionally, multilevel modeling (MLM) should be employed more frequently in sport management research to ensure appropriate data analysis and interpretation as data are often nested (Swierzy et al., 2019). Consequently, this study considers both individual-level factors and macro-level factors, such as the province where a tennis official is registered, in relation to job satisfaction.

A two-fold study was conducted to address this gap in literature. First, given the absence of relevant measurements in Chinese, we translated the Referee Retention Scale (RRS) developed by Ridinger et al. (2017) and established a validated Chinese version (RRS-CN). The RRS-CN was then utilized in the main study, which aimed to answer two primary research questions within the context of tennis officials in China:

1. To what extent do individual and provincial factors, such as administrator consideration, mentoring, continuing education, remuneration, stress, and the number of events hosted, influence tennis officials' sense of community in officiating? Are these effects moderated by officials' officiating level, age, gender, and socioeconomic status (SES)?
2. Furthermore, how do individual and provincial factors, including administrator consideration, mentoring, continuing education, remuneration, stress, and the number of events hosted, affect tennis officials' motivation to continue officiating? Are these effects moderated by officials' officiating level, age, gender, and SES?

Methods

Participants

Tennis officials ($N = 523$, female = 143, male = 380) were recruited online from 26 provinces in China. Participants were a convenience sample of varying categories of tennis officials included white badge or higher level ($n = 32$), national-level ($n = 154$), and junior-level officials who were not yet promoted to the national level ($n = 337$), albeit with a ratio of official levels mirroring national estimates of the population (Xinhua News Agency, 2016). The majority (95%) of the participants reported bachelor's or post-graduate degrees, and 39% of them were employees in higher education institutions. Approximately half of the participants were recruited from the central and southeastern coastal regions (see Appendix A Table 1).

1 According to International Tennis Federation (2023), there are four levels of officiating: (1) National; (2) Level 1, denoted as ITF Green Badge officials; (3) Level 2, known as White Badge; (4) Level 3, which includes Bronze, Silver, and Gold Badges.

Procedures

Participants were collected in two waves of data collection via an anonymous online survey on Tencent Survey (Tencent Inc.). In November 2019, 31 provincial-level tennis administration agencies were contacted by the corresponding author and 26 of them consented to take part in facilitating the data collection (response rate: 84%). In the first wave of data collection, an online survey link with recruiting message was distributed by provincial-level agencies to individual tennis officials who registered in their provinces via WeChat, a mainstream social media platform in the mainland (Tencent Inc.). The background of the study, purpose, and voluntary participation information were introduced on the first page of the survey. Participants E-signed an online informed consent form before enrollment in the study. In the second wave, a reminder message with the same survey link was sent 2 weeks after the first wave. In total, 1,152 cases were recorded, after the exclusion of incomplete and inconsistent cases, 523 participants remained in the convenience sample (first wave $n = 180$, second wave $n = 343$, overall completed response rate: 45.2%). To note, the first and second wave samples were used in the RRS-CN validation and reliability testing process (see Appendix A), and the combined sample ($n = 523$) was analyzed in the main study. The procedure used in the current study was approved by the institutional ethics committee and adhered to the ethical principles of the Declaration of Helsinki.

Measures

Measurement validation and internal reliability

The RRS was first translated into Chinese simplified by the authors and evaluated by two bilingual expert consultants in a related field (Ridinger et al., 2017; Li et al., 2022). Following the methodological steps described by Mimura and Griffiths (2007), we adopted the forward–backward translation method due to its established efficacy in ensuring fidelity during cross-cultural scale translation. In alignment with these steps, the preliminary RRS-CN, once achieving satisfactory agreement, was translated back to English for a comprehensive accuracy check. This was followed by a re-translation to simplified Chinese. Before commencing data collection, the final RRS-CN was scrutinized by authors and expert consultants to validate its precision and consistency. Demographic data, including geographic location, age, gender, official level, educational background, occupation, and income, were self-reported. An overview of RRS-CN is in Appendix A Table 2.

Main study

Participant demographic characteristics questions were identical to the measurement validation sample, and all information was self-reported. Participants' socioeconomic status (SES) scores were first calculated based on income, educational background, and occupation responses and then categorized into three levels, high, medium, and low (Chen et al., 2018; Wani, 2019). Events hosted data were calculated based on the 2019 China Tennis Association event schedule (General Administration of Sport of China, 2019). Two outcome variables, sense of community and intrinsic motives (hereafter motivation) related to officiating, were measured using three and six Likert items on the RRS-CN, respectively. Five level 1 predictors, administrator consideration, mentoring, continuing education, lack of stress (hereafter stress), and remuneration, were measured using five subscales of RRS-CN, respectively. Participants indicated their degree of agreement on a 7-point Likert scale from 1 (strongly disagree) to 7 (strongly agree) where RRS-CN applied. Unweighted average scores of each outcome variable and predictor were calculated for data analyses. Internal consistency of the measurement was evaluated through Cronbach's alpha (in the current study, α ranged from 0.72 to 0.92. which were consistently above the acceptable threshold of 0.70, see Appendix Table 2). Furthermore, an overview of the predictors and outcome variables in the main study is illustrated in Table 1.

Data analysis

Measurement validation and internal reliability

To validate RRS-CN, an exploratory factor analysis (EFA) was used to provide initial internal structural evidence for the items. EFA was based on the first wave of collected data. In the following, to verify the factor structure extracted from the EFA, we conducted a confirmatory factor analysis (CFA) to validate the model fit of the measurement. The data analysis procedure and criteria are introduced in Appendix A.

Main study

A two-level linear model was used to test the main research questions and control for non-independence in the data due to provincial-level clusters of individual-level tennis officials. Given tennis officials primarily work under the administration of provincial-level tennis governing body, recognizing the individual–provincial hierarchy in the data was appropriate and necessary. Specifically, a series of models were specified with tennis officials nested within 26 provinces, beginning with an intercept-only model (M0) to evaluate the intraclass correlation (ICC). For ease of interpretation of model results, age, gender, officiating levels, SES, and event hosted were effect coded, and psychometrical measured variables were standardized as z-scores, with level 1 predictors cluster-mean centered and level 2 predictors grand-mean centered (see Table 1). The final model (M3) with random intercept was as follows:

$$
\begin{aligned}
Community_{ij} = {} & \gamma_{0.0} + \gamma_{1.0} * FemEff_{i.j} + \gamma_{0.1} * L2Fem_{1.j} + \gamma_{2.0} * OffW_{i.j} \\
& + \gamma_{0.2} * L2OffW_{2.j} + \gamma_{3.0} * OffN_{i.j} + \gamma_{0.3} * L2OffN_{3.j} \\
& + \gamma_{4.0} * AgeEff_{i.j} + \gamma_{0.4} * L2Age_{4.j} + \gamma_{5.0} * SESHigh_{i.j} \\
& + \gamma_{0.5} * L2SESHigh_{5.j} + \gamma_{6.0} * SESLow_{i.j} \\
& + \gamma_{0.6} * L2SESLow_{6.j} + \gamma_{0.7} * EventEff_{7.j} \\
& + \gamma_{7.0} * Admin_{i.j} + \gamma_{0.8} * L2Admin_{8.j} + \gamma_{8.0} * Stress_{i.j} \\
& + \gamma_{0.9} * L2Stress_{9.j} + \gamma_{9.0} * ConEducation_{i.j} \\
& + \gamma_{0.10} * L2ConEducation_{10.j} + \gamma_{10.0} * Mentoring_{i.j} \\
& + \gamma_{0.11} * L2Mentoring_{11.j} + \gamma_{11.0} * Remuneration_{i.j} \\
& + \gamma_{0.12} * L2Remuneration_{12.j} + \gamma_{12.11} * L1Mentoring_{i.j} \\
& * L2Mentoring_{11.j} + \gamma_{0.13} * L2Admin_{8.j} \\
& * Event\_Eff_{7.j} + U_{0.j} + r_{i.j}
\end{aligned}
$$

In the model above, the i^{th} perceived sense of community of the j^{th} provinces is equal to the sum of the conditional mean ($\gamma_{0.0}$), the unique effects of female status, official levels, age, SES, administrator

TABLE 1 Overview of variables.

Variable name	Brief description	Predictor level	Analytic function
L2_Site	Provinces identifier where tennis officials were recruited from: 1, 2, 3, …, 26	Level 2	
L1_ID	Participant identifier ID: 1, 2, 3, …, 523	Level 1	
Community	*Sense of community*	Level 1	Outcome
	Rating scale (1 = strongly disagree; 7 = strongly agree); average score of three Likert items in RRS-CN (V18-V20);		
	Brief definition[a]: Perceived sense of belonging to a supportive community of officials		
Motivation	*Intrinsic motives*	Level 1	Outcome
	Rating scale (1 = strongly disagree; 7 = strongly agree); average score of six Likert items in RRS-CN (V01-V06);		
	Brief definition: Reasons related to enjoyment of competition and staying involved with a sport that attract someone to the role of officiating		
FemEff	Effect-coded female status, 1 = female, −1 = male	Level 1	Predictor
L2_Fem	Level 2 standardized mean province-level female officials recruited aggregate, grand-mean centered, in *SD*s	Level 2	Predictor
Off_Level_W	Effect-coded referee level, international level (white badge and/or higher) = 1, lower than national level = −1, else = 0	Level 1	Predictor
L2_Off_Level_W	Level 2 standardized mean province-level white-card level officials recruited aggregate, grand-mean centered, in *SD*s	Level 2	Predictor
Level_N	Effect-coded referee level, national level = 1, lower than national level = −1, else = 0	Level 1	Predictor
L2_Off_Level_N	Level 2 standardized mean province-level national-level officials recruited aggregate, grand-mean centered, in *SD*s	Level 2	Predictor
Age	Effect-coded age, 1 = 30 or younger (yrs), −1 = above 30 (yrs)	Level 1	Predictor
L2_Age	Level 2 standardized mean province-level officials age 30 and younger recruited aggregate, grand-mean centered, in *SD*s	Level 2	Predictor
SES_H	Effect-coded socioeconomic status, high category 1 = 1, middle category 2 = −1, else = 0	Level 1	Predictor
L2_SES_H	Level 2 standardized mean province-level upper-level socioeconomic status recruited aggregate, grand-mean centered, in *SD*s	Level 2	Predictor
SES_L	Effect-coded socioeconomic status, low category 3 = 1, middle category 2 = −1, else = 0	Level 1	Predictor
L2_SES_L	Level 2 standardized mean province-level lower-level socioeconomic status recruited aggregate, grand-mean centered, in *SD*s	Level 2	Predictor
Event_Eff	The total amount of national and/or international tennis events hosted in provinces, one or more events hosted category 1 = 1, no event hosted category 0 = −1	Level 2	Predictor
Admin	*Administrator consideration*	Level 1	Predictor
	Rating scale (1 = strongly disagree; 7 = strongly agree); average score of three Likert items in RRS-CN (V25, V27, V28);		
	Brief definition: Level of perceived fairness and consideration from assigners and administrators		
L2_Admin	Level 2 standardized mean province-level administrator consideration aggregate, grand-mean centered, in *SD*s	Level 2	Predictor
Stress	*Lack of stress*	Level 1	Predictor
	Rating scale (1 = strongly disagree; 7 = strongly agree); average score of three Likert items in RRS-CN (V15-V17);		
	Brief definition: Infrequent encounters with stressful situations related to officiating		
L2_Stress	Level 2 standardized mean province-level lack of stress aggregate, grand-mean centered, in *SD*s	Level 2	Predictor

(Continued)

TABLE 1 (Continued)

Variable name	Brief description	Predictor level	Analytic function
ConEducation	*Continuing education*	Level 1	Predictor
	Rating scale (1 = strongly disagree; 7 = strongly agree); average score of three Likert items in RRS-CN (V21-V23);		
	Brief definition: Preparation from ongoing education and training to deal with various aspects of officiating		
L2_ConEducation	Level 2 standardized mean province-level continuing education aggregate, grand-mean centered, in *SDs*	Level 2	Predictor
Mentoring	*Mentoring*	Level 1	Predictor
	Rating scale (1 = strongly disagree; 7 = strongly agree); average score of four Likert items in RRS-CN (V11-V14);		
	Brief definition: Support and encouragement from a mentor or a friend to become involved with officiating		
L2_Mentoring	Level 2 standardized mean province-level mentoring aggregate, grand-mean centered, in *SDs*	Level 2	Predictor
Remuneration	*Remuneration*	Level 1	Predictor
	Rating scale (1 = strongly disagree; 7 = strongly agree); average score of three Likert items in RRS-CN (V07, V09, V10);		
	Brief definition: Financial payment for officiating sporting events		
L2_Remuneration	Level 2 standardized mean province-level remuneration aggregate, grand-mean centered, in *SDs*	Level 2	Predictor

N = 523 participants within 26 provinces; event data were extracted from the China Tennis Association (CTA) 2019 event schedule. [a]Brief definitions of level 1 psychometrical predictors were extracted from Table 2 (p. 518) from Ridinger et al. (2017); to note, V01-V28 (except V08, V24, AND V26) were used in the main study, and items are illustrated in Appendix A Table 2.

consideration, stress, continuing education, mentoring, remuneration, two interactions ($\gamma_{1.0} - \gamma_{0.13}$), and the residual error due to provincial membership ($U_{0.j}$), and tennis officials ($r_{i.j}$).

$$\begin{aligned} Motivation_{ij} = {} & \gamma_{0.0} + \gamma_{1.0} * FemEff_{i,j} + \gamma_{0.1} * L2Fem_{1,j} + \gamma_{2.0} * OffW_{i,j} \\ & + \gamma_{0.2} * L2OffW_{2,j} + \gamma_{3.0} * OffN_{i,j} + \gamma_{0.3} * L2OffN_{3,j} \\ & + \gamma_{4.0} * AgeEff_{i,j} + \gamma_{0.4} * L2Age_{4,j} + \gamma_{5.0} * SESHigh_{i,j} \\ & + \gamma_{0.5} * L2SESHigh_{5,j} + \gamma_{6.0} * SESLow_{i,j} \\ & + \gamma_{0.6} * L2SESLow_{6,j} + \gamma_{0.7} * EventEff_{7,j} \\ & + \gamma_{7.0} * Admin_{i,j} + \gamma_{0.8} * L2Admin_{8,j} \\ & + \gamma_{8.0} * Stress_{i,j} + \gamma_{0.9} * L2Stress_{9,j} \\ & + \gamma_{9.0} * ConEducation_{i,j} + \gamma_{0.10} * L2ConEducation_{10,j} \\ & + \gamma_{10.0} * Mentoring_{i,j} + \gamma_{0.11} * L2Mentoring_{11,j} \\ & + \gamma_{11.0} * Remuneration_{i,j} + \gamma_{0.12} * L2Remuneration_{12,j} \\ & + \gamma_{12.0} * FemEff_{i,j} * Mentoring_{i,j} \\ & + \gamma_{13.0} * ConEducation_{i,j} * SESHigh_{i,j} + U_{0,j} + r_{i,j} \end{aligned}$$

In the model above, the i^{th} motivation related to officiating of the j^{th} provinces is equal to the sum of the conditional mean ($\gamma_{0.0}$), the unique effects of female status, official levels, age, SES, administrator consideration, stress, continuing education, mentoring, remuneration, two interactions ($\gamma_{1.0} - \gamma_{13.0}$), and the residual error due to provincial membership ($U_{0.j}$), and tennis officials ($r_{i.j}$).

Effect sizes for fixed-effects coefficients were computed as approximate squared semi-partial correlation (sr^2) values for each coefficient separately by dividing the coefficient by the product of the standard error and square root of the total sample size. Model R^2 values for fixed and random effects were computed using *r2mlm* package (Rights and Sterba, 2019; Shaw et al., 2020); Model estimated with full information maximum likelihood were conducted using *lme4* and *lmerTest* packages (Bates et al., 2009; Kuznetsova et al., 2015). Data analyses were performed in R for Windows version 4.3.1 (R Core Team, 2021).

Results

Measurement validation and internal reliability

Seven latent variables were accepted as the most adequate structural representation of the 25-Item RRS-CN. Accordingly, CFAs were conducted on all latent variables, ensuring an adequate fit of the measurement model. Preliminary results from EFA and CFAs are shown in Appendix A. Given the results, the validated RRS-CN was then used in the main study for model testing.

Main study

Correlations

Means, standard deviations (*SDs*), and zero-order correlations among all variables are given in Table 2. As can be seen, high SES, white badge or higher level officials, administrator consideration, stress, continuing education, and mentoring were significantly

TABLE 2 Zero-order disaggregated correlations for variables used in analysis.

Measure	*ICC*	*M*	*(SD)*	1.		2.		3.		4.		5.		6.		7.		8.		9.		10.		11.		12.	
Outcome																											
1. Sense of community	0.03	6.46	(0.91)	–																							
2. Motivation	0.04	6.41	(0.90)	0.62	***	–																					
Predictors																											
3. Fem_Eff	0.02	0.27	0.45	−0.06		−0.05		–																			
4. L2_Fem	–	–	–	−0.02		−0.03		0.24	***	–																	
5. Off_W	0.16	0.06	0.24	−0.09	*	−0.07		−0.03		−0.08		–															
6. L2_Off_W	–	–	–	−0.11	*	−0.12	**	−0.04		−0.16	***	0.39	***	–													
7. Off_N	0.31	0.29	0.46	−0.04		−0.07		−0.09	*	−0.06		0.81	***	0.23	***	–											
8. L2_Off_N	–	–	–	−0.05		−0.04		−0.02		−0.09	*	0.47	***	0.26	***	0.56	***	–									
9. Age	0.07	0.44	0.50	−0.03		0.03		0.19	***	0.14	**	−0.49	***	−0.14	**	−0.48	***	−0.24	***	–							
10. L2_Age	–	–	–	0.06		0.07		0.10	*	0.40	***	−0.38	***	−0.38	***	−0.40	***	−0.69	***	0.36	***	–					
11. SES_H	0.06	0.15	0.36	0.00		0.02		−0.02		−0.02		0.17	***	0.08		0.14	**	0.07		−0.08		−0.05		–			
12. L2_SES_H	–	–	–	−0.11	**	−0.09	*	−0.05		−0.21	***	0.33	***	0.45	***	0.31	***	0.50	***	−0.21	***	−0.59	***	0.21	***	–	
13. SES_L	0.05	0.16	0.37	−0.02		0.02		0.04		0.07		−0.13	**	−0.04		−0.14	**	−0.09	*	0.30	***	0.18	***	0.72	***	−0.04	
14. L2_SES_L	–	–	–	0.04		0.06		0.07		0.31	***	−0.31	***	−0.35	***	−0.31	***	−0.53	***	0.30	***	0.84	***	−0.02		−0.59	***
15. Event	–	0.76	0.43	−0.06		0.01		0.01		0.06		−0.19	***	−0.17	***	−0.20	***	−0.35	***	0.10	*	0.27	***	0.03		−0.10	*
16. Admin	–	–	–	0.26	***	0.15	***	0.11	*	0.00		0.00		0.00		−0.02		0.00		−0.03		0.00		−0.05		0.00	
17. L2_Admin	0.20	4.91	1.69	0.04		−0.01		−0.02		−0.10	*	0.11	*	0.08		0.13	**	0.22	***	−0.03		−0.07		−0.03		0.01	
18. Stress	–	–	–	0.11	*	0.06		0.01		0.00		0.01		0.00		0.01		0.00		−0.14	**	0.00		−0.12	**	0.00	
19. L2_Stress	0.01	4.58	1.61	0.02		0.01		−0.04		−0.18	***	0.08		0.02		0.10	*	0.19	***	−0.05		−0.13	**	0.06		0.27	***
20. ConEducation	–	–	–	0.54	***	0.46	***	−0.06		0.00		−0.02		0.00		−0.04		0.00		−0.03		0.00		0.03		0.00	
21. L2_ConEducation	0.01	6.29	0.99	0.17	***	0.17	***	−0.05		−0.20	***	−0.15	***	−0.46	***	−0.06		−0.04		0.01		0.02		−0.03		−0.10	*
22. Mentoring	–	–	–	0.48	***	0.51	***	−0.06		0.00		−0.08		0.00		−0.09	*	0.00		0.04		0.00		−0.06		0.00	
23. L2_Mentoring	0.01	6.09	1.15	0.16	***	0.17	***	−0.05		−0.21	***	−0.22	***	−0.44	***	−0.17	***	−0.25	***	0.08		0.22	***	−0.04		−0.26	***
24. Remuneration	–	–	–	−0.03		−0.03		−0.03		0.00		−0.09	*	0.00		−0.11	*	0.00		0.24	***	0.00		−0.03		0.00	
25. L2_Remuneration	0.04	4.03	1.75	0.08		0.10	*	0.09	*	0.35	***	−0.25	***	−0.20	***	−0.28	***	−0.49	***	0.13	**	0.37	***	−0.06		−0.45	***

(Continued)

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TABLE 2 (Continued)

	13.		14.		15.		16.		17.		18.		19.		20.		21.		22.		23.		24.		25.	
Outcome																										
1. Sense of community																										
2. Motivation																										
Predictors																										
3. Fem_Eff																										
4. L2_Fem																										
5. Off_W																										
6. L2_Off_W																										
7. Off_N																										
8. L2_Off_N																										
9. Age																										
10. L2_Age																										
11. SES_H																										
12. L2_SES_H																										
13. SES_L	–																									
14. L2_SES_L	0.23	***	–																							
15. Event	0.11	*	0.38	***	–																					
16. Admin	−0.05		0.00		0.00		–																			
17. L2_Admin	−0.07		−0.21	***	−0.45	***	0.00		–																	
18. Stress	−0.16	***	0.00		0.00		0.51	***	0.00		–															
19. L2_Stress	0.00		−0.12	**	−0.28	***	0.00		0.52	***	0.00		–													
20. ConEducation	0.02		0.00		0.00		0.17	***	0.00		0.01		0.00		–											
21. L2_ConEducation	−0.02		−0.01		−0.09		0.00		0.06		0.00		0.26	***	0.00		–									
22. Mentoring	0.03		0.00		0.00		0.21	***	0.00		0.05		0.00		0.46	***	0.00		–							
23. L2_Mentoring	0.04		0.26	***	0.09	*	0.00		0.10	*	0.00		0.06		0.00		0.64	***	0.00		–					
24. Remuneration	0.06		0.00		0.00		−0.34	***	0.00		−0.40	***	0.00		0.05		0.00		0.11	*	0.00		–			
25. L2_Remuneration	0.08		0.47	***	0.24	***	0.00		−0.20	***	0.00		−0.18	***	0.00		0.11	*	0.00		0.45	***	0.00		–	

N = 523 participants within 26 provinces; Admin, administrator consideration; Stress, lack of stress; ConEducation, continuing education; Off_W, white-card or higher level officials; Off_N, national-level officials; Age, 35 years or younger (yrs); SES_H, high socioeconomic status; SES_Low, low socioeconomic status; Event, hosted one or more events annually (2019); ICCs were not reported in level 2 predictors; to note, categorical variables are dummy coded for mean and standard deviation (SD), and effect coded for Pearson's rs; level 2 predictors were grand mean centered (GMC) and standardized in z scores that mean equals to zero and SD equals to one; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

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correlated with the sense of community, but they are also correlated with each other and may not uniquely predict the sense of community of participants related to officiating. Furthermore, besides the same predictors aforementioned except for stress, level 2 remuneration was also significantly correlated with motivation.

Model results

The intercept-only model was specified to evaluate ICCs. As can be seen in Table 2, the first set of columns, the mean of the outcome variables ICCs, sense of community and motivation were 0.03 and 0.04, respectively, which were not significantly different from zero. The results indicated that 3% and 4% of variance in the sense of community and motivation scores, respectively, were explained by the provincial membership. The ICC for all the level 1 predictors ranged from 0.01 to 0.31, which was not significantly different from zero, indicating the expected correlation between any pair of random drawn predictor scores/categories within the same province is 0.01 to 0.31. Given the climate, ignoring non-zero dependencies in the outcomes and predictors by running a unlevel regression would cause biased slope standard errors and parameters, also known as blended slope problem (Raudenbush and Bryk, 2002; Snijders and Bosker, 2012). Therefore, a two-level modeling process was appropriate.

Sense of community

Next, demographic predictors were added to model 1. As shown in Table 3 (first set of columns), only the level 2 aggregate high SES (%) was significant. In the following, a group of predictors were added to model 2. As shown in Table 3 (second set of columns), officials with a white badge or higher, high or low SES, administrator consideration, mentoring, continuing education, level 2 aggregate high SES (%), and continuing education were significant. The approximate variance explained with this set of predictors was 0.44, which is 0.40 more than model 1. The likelihood ratio test (LRT) comparing model 2 to the previous, indicated a significant Chi-squared change ($\chi^2 = 286.23$, $\Delta df = 11$, $p < 0.001$), and the Bayesian information criterion (BIC) value decreased by 217.40 points, indicating that the model with the second group of predictors was improving model-data fit.

Afterward, two interaction terms were added to model 3. As shown in Table 3 (last set of columns), the approximate variance explained with this set of predictors was 0.46, which was 0.02 more than the previous model (model 2). The LRT comparing model 3 to the previous, indicated a significant chi-square change ($\chi^2 = 12.20$, $\Delta df = 2$, $p = 0.002$), and the BIC value increased by 0.40 points, overall, indicating that the model with interactions was improving model-data fit.

In examining the coefficients for this final model, we see that the intercept, officials with white badge or higher, in high or low SES, administrator consideration, mentoring, continuing education, and level 2 aggregate continuing education were significant. Results indicated that the mean level of sense of community was 6.34 points, with all else held constant. Tennis officials with white badge or higher were predicted to be 0.21 points lower than the sample average on the sense of community, all else held constant. Tennis officials in high SES were predicted to be 0.18 higher than the sample average on the sense of community, all else held constant. Furthermore, for every *SD* increase in administrator consideration within their provinces, tennis officials' sense of community was predicted to increase 0.13 points, all else held constant. For every *SD* increase in mentoring within their provinces, tennis officials' sense of community was predicted to increase 0.26 points, all else held constant. In addition, for every *SD* increase in continuing education within their provinces, tennis officials' sense of community was predicted to increase 0.35 points, all else held constant. Meanwhile, for every *SD* increase in provincial mean continuing education, tennis officials' sense of community was predicted to increase 0.20 points, all else held constant.

Finally, two significant interactions were detected, one was between level 2 aggregate administrator consideration and event hosted, and the other was between mentoring and level 2 aggregate mentoring. To understand the nature of the interaction, model-implied values were computed for two levels of each (−1 *SD* and + 1 *SD*) and (+1 = hosted event, −1 = no event). As shown in Appendix B Figure 1, the first interaction was disordinal and showed that the positive relation between provincial mean administrator consideration (of 0.04 points per *SD* decreased administrator consideration) and sense of community was predicted to increase by 0.19 points for every *SD* increase if their provinces even hosted tennis events(s) in 2019. The other interaction was ordinal and showed that the positive relation between mentoring within their province (of 0.26 points per *SD* of increased mentoring) and sense of community was predicted to decrease by 0.09 points for every *SD* increase in their provincial mean mentoring (Appendix B Figure 2).

Motivation

Demographic predictors were first added to model 1. As shown in Table 4 (first set of columns), no predictor was found significant at the 0.05 level. In the following, the group of predictors was added to model 2. As shown in Table 4 (second set of columns), high SES, continuing education, mentoring, and remuneration were significant. The approximate variance explained with this set of predictors was 0.39, which is 0.37 more than model 1. The LRT comparing model 2 to the previous model indicated a significant chi-square change ($\chi^2 = 243.26$, $\Delta df = 11$, $p < 0.001$), and the BIC value decreased by 243.30 points, indicating that the model with the second group of predictors was improving model-data fit.

Afterward, two interaction terms were added to model 3. As shown in Table 4 (last set of columns), the approximate variance explained with this set of predictors was 0.40, which is 0.01 more than the previous model. The LRT comparing model 3 to the previous model indicated a significant chi-squared change ($\chi^2 = 11.92$, $\Delta df = 4$, $p = 0.003$), and the BIC value decreased by 11.90 points, indicating that the model with interactions was improving model-data fit.

Examining the coefficients for this final model, we see that the intercept, high SES, continuing education, mentoring, and remuneration were significant. Results indicated that the mean level of motivation was 6.40 points, all else held constant. Tennis officials with high SES were predicted to be 0.17 higher than the sample average on motivation, all else held constant. Furthermore, for every *SD* increase in continuing education within their provinces, motivation of officiating was predicted to increase by 0.31 points, all else held constant. In addition, for every *SD* increase in mentoring within their provinces, motivation of officiating was predicted to increase 0.32 points, all else held constant. Furthermore, for every *SD* increase in remuneration within their provinces, motivation of officiating was predicted to decrease 0.08 points, all else held constant.

Ultimately, two significant interactions were detected, one was between female status and mentoring, and the other was between high

TABLE 3 Multilevel linear model results for sense of community.

Fixed effects	Model 1						Model 2						Model 3					
	Coeff	*SE*	*t*	*df*		*ES*	*Coeff*	*SE*	*t*	*df*		*ES*	*Coeff*	*SE*	*t*	*df*		*ES*
Intercept (Mean)	6.30	0.08	83.47	523	***	12.83	6.31	0.06	98.22	523	***	10.27	6.34	0.06	97.96	523	***	9.98
1. Fem_Eff	−0.05	0.05	−1.08	523		0.00	−0.02	0.04	−0.60	523		0.00	−0.01	0.04	−0.42	523		0.00
2. L2_Fem	−0.08	0.08	−1.03	523		0.00	−0.02	0.08	−0.30	523		0.00	−0.01	0.08	−0.17	523		0.00
3. Off_W	−0.21	0.12	−1.75	523		0.01	−0.21	0.09	−2.31	523	*	0.01	−0.21	0.09	−2.29	523	*	0.01
4. L2_Off_W	0.03	0.08	0.43	523		0.00	0.07	0.08	0.85	523		0.00	0.03	0.08	0.43	523		0.00
5. Off_N	−0.05	0.08	−0.64	523		0.00	0.12	0.06	1.89	523		0.00	0.12	0.06	1.90	523		0.00
6. L2_Off_N	0.09	0.08	1.12	523		0.00	0.04	0.07	0.56	523		0.00	0.04	0.07	0.53	523		0.00
7. Age_Eff	−0.06	0.05	−1.08	523		0.00	−0.01	0.04	−0.22	523		0.00	−0.02	0.04	−0.37	523		0.00
8. L2_Age	0.15	0.14	1.12	523		0.00	0.13	0.13	1.04	523		0.00	0.15	0.13	1.14	523		0.00
9. SES_H	0.12	0.09	1.27	523		0.00	0.18	0.07	2.46	523	*	0.01	0.18	0.07	2.51	523	*	0.01
10. L2_SES_H	−0.10	0.09	−1.06	523	*	0.01	−0.16	0.07	−2.18	523	*	0.01	−0.14	0.07	−1.90	523		0.00
11. SES_L	−0.17	0.08	−2.14	523		0.00	−0.16	0.07	−2.20	523	*	0.01	−0.16	0.07	−2.30	523	*	0.01
12. L2_SES_L	−0.10	0.11	−0.86	523		0.00	−0.08	0.11	−0.68	523		0.00	−0.10	0.11	−0.93	523		0.00
13. Event							−0.06	0.04	−1.41	523		0.00	−0.04	0.04	−0.79	523		0.00
14. Admin							0.13	0.04	3.38	523	***	0.01	0.13	0.04	3.46	523	***	0.01
15. L2_Admin							−0.03	0.09	−0.38	523		0.00	−0.04	0.09	−0.46	523		0.00
16. Stress							0.01	0.04	0.31	523		0.00	0.01	0.04	0.40	523		0.00
17. L2_Stress							0.01	0.08	0.08	523		0.00	−0.03	0.08	−0.34	523		0.00
18. ConEducation							0.35	0.03	10.30	523	***	0.11	0.35	0.03	10.54	523	***	0.12
19. L2_ConEducation							0.17	0.08	2.01	523	*	0.00	0.20	0.08	2.34	523	*	0.01
20. Mentoring							0.27	0.03	7.65	523	***	0.06	0.26	0.03	7.49	523	***	0.06
21. L2_Mentoring							0.11	0.09	1.24	523		0.00	0.09	0.09	0.97	523		0.00
22. Remuneration							−0.01	0.03	−0.26	523		0.00	0.00	0.03	−0.13	523		0.00
23. L2_Remuneration							0.02	0.05	0.43	523		0.00	0.07	0.06	1.33	523		0.00
13. Event*15													0.19	0.08	2.56	523	*	0.01
20. Mentoring*21													−0.09	0.04	−2.41	523	*	0.01
Random effects	Var						*Var*						*Var*					
Intercept (Provinces)	< 0.01						< 0.01						< 0.01					
Residual (Participants)	0.80						0.46						0.45					

(Continued)

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TABLE 3 (Continued)

Model fit																		
Fixed-effects R^2	0.04						0.44						0.46					
Random-effects R^2	< 0.01						< 0.01						< 0.01					
BIC	1463.70						1246.30						1246.70					
Deviance (−2LL)	1369.80						1083.60						1071.40					
Residual *df*	508						497						495					
LRT Chi-square test	--						286.23	***					12.20	**				

N = 523 participants within 26 provinces; Admin, administrator consideration; Stress, lack of stress; ConEducation, continuing education; Off_W, white-card or higher levels officials; Off_N, national-level officials; Age, 35 years or younger (yrs); SES_H, high socioeconomic status; SES_Low, low socioeconomic status; ordinal predictors are cluster-mean centered (CMC) and standardized in z-scores and categorical predictors are effect coded (Eff); L2 refers to level 2 predictor; level 2 predictors are in standardized mean aggregate, grand-mean centered (GMC), in SDs; ES, effect size, reported as squared semi-partial correlation (sr^2); model estimated with full information maximum likelihood using R lme4 and lmerTest packages. *p < 0.05, **p < 0.01, ***p < 0.001.

SES and continuing education. To understand the nature of the interaction, model-implied values were computed for two levels of each (+1 = female, −1 = male) and (1 = SES high, 2 = medium, 3 = low). As shown in Appendix B Figure 3, the first interaction was disordinal and showed that the positive relation between mentoring within their provinces (of 0.32 points per *SD* of increased mentoring) and motivation of officiating was predicted to decrease by 0.08 points for every *SD* increase as being female officials. In addition, the other interaction was ordinal and showed that the positive relation between continuing education within their province (of 0.31 points per *SD* of increased continuing education) and motivation of officiating was predicted to increase by 0.11 points in high SES.

Discussion

In the current study, we aimed to validate the RRS-CN measurement tool and use it to investigate the relationship between tennis officials' individual characteristics, job retention factors, and their sense of community and motivation. A total of 523 tennis officials, representing a broad and geographically diverse sample across China, fully completed the survey. Using RRS-CN, we discovered that tennis officials' sense of community and motivation are influenced by diverse individual and macro, provincial-level predictors.

A strong sense of community is an essential aspect of job satisfaction and is directly linked to retention (Warner et al., 2013; Kim et al., 2022). Chinese tennis officials, especially those in high SES, exhibited a greater sense of community within officiating. Our findings align with previous research showing that administrator fairness, transparency in game assignments, and networking contribute to officials' retention (Ridinger, 2015; Kim, 2016; Ridinger et al., 2017). Several researchers emphasized the importance of referees' feeling a sense of community to improve their engagement and psychological wellbeing (Livingston et al., 2017; Kim et al., 2022). However, high-level Chinese tennis officials reported a lower sense of community than their lower level counterparts, possibly due to social isolation and a lack of organizational understanding of mental health vulnerability. This empirical evidence provides new insights on the elite group's need for greater recognition and belonging. Future research is needed to investigate mechanisms to enhance feelings of belonging and emotional connection (e.g., increased roles within the community) and the impact of these mechanisms on a sense of community and an individual's wellbeing. Moreover, officials who were underpaid were more motivated to fulfill their duties, with remuneration negatively impacting their motivation to officiate. This could be attributed to tennis official's high and middle socioeconomic status, making them less focused on monetary rewards. The role of a tennis official serves as a symbol of their unique middle-class lifestyle (Gong, 2020).

Establishing stable mentoring relationships and offering continuous education opportunities can motivate individuals to pursue officiating positions and strengthen community bonds (Kim and Hong, 2016; Nordstrom et al., 2016; Schaeperkoetter, 2016; Ridinger et al., 2017). Sport remains a highly masculinized space where women are underrepresented in officiating and leadership positions. Toxic and male-dominated sport environments are negatively affecting female officials' wellbeing, motivation, and officiating persistence (Schaeperkoetter, 2016; Livingston et al., 2017; Webb et al., 2021; Tingle

TABLE 4 Multilevel linear model results for motivation.

Fixed effects	Model 1						Model 2						Model 3					
	Coeff	*SE*	*t*	*df*		*ES*	*Coeff*	*SE*	*t*	*df*		*ES*	*Coeff*	*SE*	*t*	*df*		*ES*
Intercept (Mean)	6.38	0.08	76.99	65	***	87.23	6.42	0.07	87.43	84	***	55.53	6.40	0.07	87.55	88	***	51.50
1. Fem_Eff	−0.06	0.05	−1.28	499		0.00	−0.02	0.04	−0.42	503		0.00	−0.02	0.04	−0.68	505		0.00
2. L2_Fem	−0.08	0.09	−0.87	36		0.02	−0.10	0.10	−1.00	44		0.01	−0.11	0.10	−1.09	47		0.02
3. Off_W	0.04	0.12	0.37	499		0.00	0.06	0.09	0.66	503		0.00	0.04	0.09	0.41	505		0.00
4. L2_Off_W	−0.16	0.09	−1.73	42		0.07	−0.07	0.09	−0.72	42		0.01	−0.03	0.09	−0.36	44		0.00
5. Off_N	−0.09	0.08	−1.17	499		0.00	−0.03	0.06	−0.45	503		0.00	−0.02	0.06	−0.36	504		0.00
6. L2_Off_N	0.11	0.09	1.14	28		0.04	0.16	0.09	1.77	34		0.06	0.16	0.09	1.80	35		0.05
7. Age_Eff	0.01	0.05	0.25	499		0.00	0.07	0.04	1.60	503		0.00	0.06	0.04	1.43	504		0.00
8. L2_Age	0.10	0.16	0.61	37		0.01	0.24	0.15	1.57	47		0.03	0.26	0.15	1.70	49		0.03
9. SES_H	0.10	0.09	1.15	499		0.00	0.18	0.07	2.45	503	*	0.01	0.17	0.07	2.38	505	*	0.01
10. L2_SES_H	−0.06	0.09	−0.67	36		0.01	−0.08	0.09	−0.92	53		0.01	−0.09	0.09	−1.01	56		0.01
11. SES_L	−0.07	0.09	−0.72	499		0.00	−0.14	0.07	−1.95	503		0.00	−0.13	0.07	−1.76	505		0.00
12. L2_SES_L	−0.07	0.13	−0.53	45		0.01	−0.18	0.13	−1.32	46		0.02	−0.18	0.13	−1.36	48		0.02
13. Event							−0.01	0.06	−0.20	19		0.00	−0.01	0.06	−0.23	20		0.00
14. Admin							−0.01	0.04	−0.33	503		0.00	−0.01	0.04	−0.33	505		0.00
15. L2_Admin							−0.11	0.11	−0.94	24		0.02	−0.09	0.11	−0.78	25		0.01
16. Stress							0.01	0.04	0.38	503		0.00	0.01	0.04	0.30	504		0.00
17. L2_Stress							0.07	0.11	0.65	31		0.01	0.04	0.11	0.40	32		0.00
18. ConEducation							0.25	0.03	7.25	503	***	0.06	0.31	0.04	7.16	516	***	0.06
19. L2_ConEducation							0.09	0.11	0.80	33		0.01	0.12	0.11	1.11	34		0.02
20. Mentoring							0.37	0.04	10.38	503	***	0.13	0.32	0.04	8.19	507	***	0.08
21. L2_Mentoring							0.11	0.12	0.91	27		0.02	0.08	0.12	0.70	29		0.01
22. Remuneration							−0.08	0.04	−2.25	503	*	0.01	−0.08	0.03	−2.28	504	*	0.01
23. L2_Remuneration							0.11	0.07	1.54	24		0.06	0.11	0.07	1.65	26		0.06
1. Fem_Eff*20													−0.08	0.04	−2.25	515	*	0.01
9. SES_H*18													0.11	0.04	2.48	523	*	0.01
Random effects	*Var*						*Var*						*Var*					
Intercept (Provinces)	0.02						0.01						0.01					
Residual (Participants)	0.77						0.48						0.47					

(Continued)

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TABLE 4 (Continued)

Model fit																		
Fixed-effects R^2	0.02						0.39						0.40					
Random-effects R^2	< 0.01						< 0.01						< 0.01					
BIC	1449.80						1275.50						1276.00					
Deviance (−2LL)	1356.00						1112.70						1100.80					
Residual *df*	508						497						493					
LRT Chi-square test	--						243.26	***					11.92	**				

N = 523 participants within 26 provinces; Admin, administrator consideration; Stress, lack of stress; ConEdeucation, continuing education; Off_W, white-card or higher levels officials; Off_N, national-level officials; Age, 35 years or younger (yrs); SES_H, high socioeconomic status; SES_Low, low socioeconomic status; ordinal predictors are cluster-mean centered (CMC) and standardized in z-scores and categorical predictors are effect coded (Eff); L2 refers to level 2 predictor; level 2 predictors are in standardized mean aggregate, grand-mean centered (GMC), in SDs; ES, effect size, reported as squared semi-partial correlation (sr^2); model estimated with full information maximum likelihood using R lme4 and lmerTest packages. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

et al., 2022). Similarly, our findings show that quality mentorship is a contributor to motivation; however, female tennis officials were found less motivated compared to their male counterparts. Tsang and Lanusi (2022) introduced a women-to-women mentorship program in helping to bring long-term support and dynamic learning for female mentees. In this way, we suggest that future research could utilize egocentric network analysis as a potential method to delve deeper into understanding the needs and expectations of female officials in mentoring relationships and programs. Such insights could significantly enhance the recruitment, retention, and training of female tennis officials, ultimately benefiting the entire officiating community.

Furthermore, the Chinese Tennis Association has organized numerous training programs and workshops in the past decade to develop tennis officials (Xinhua News Agency, 2016). This has fostered a motivated community of officials who are committed to officiating for years to come. Interestingly, stress did not significantly impact the sense of community or motivation in this study, which has been previously linked to job satisfaction and retention (Anshel et al., 2013; Warner et al., 2013). According to Haugen (2020) and Rick and Li (2023), tennis is considered a "high-end" and "elegant" sport in China, and its unique game culture differentiates it from other sports, potentially influencing officiating dynamics.

The current research does possess several limitations. First, the generalizability of study results is limited due to the survey design and sampling technique that participants represented a convenience sample from China. Furthermore, the pre-pandemic data might not accurately reflect current job satisfaction levels among tennis officials. Although the current study can serve as a pre-pandemic reference point for future research, its value may be limited. Additionally, the scale validation process is also a limitation because predictive and concurrent validities of RRS-CN were not evaluated. Finally, the two-level model employed in this study, with individual tennis officials nested at the provincial level, does not account for possible systematic missingness and partial nesting. Future research should develop a more ecologically valid model, incorporating factors such as officiating experience, city clusters, mentoring relationships, and continuing education opportunities into the analysis.

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 humans were approved by Hebei Institute of Physical Education Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LL: conceptualization, methodology, data analysis, processed the data, and wrote the manuscript. YL: data collection, manuscript review, and project administration. All authors contributed to the article and approved the submitted version.

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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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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1238153/full#supplementary-material

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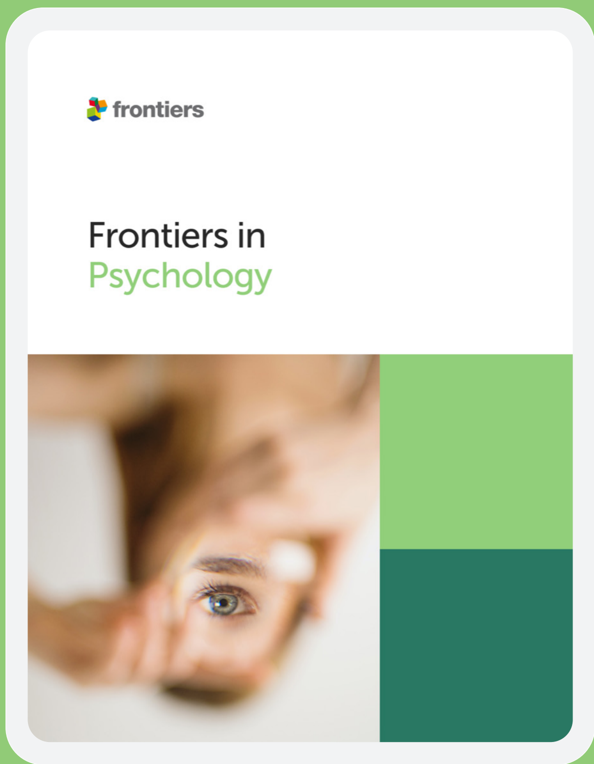

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