PSYCHOLOGICAL AND MOTOR ASSOCIATIONS IN SPORTS PERFORMANCE: A MENTAL APPROACH TO SPORTS

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PUBLISHED IN: Frontiers in Psychology and Frontiers in Sports and Active Living

frontiers Research Topics

frontiers

ISSN 1664-8714
ISBN 978-2-88966-711-6
DOI 10.3389/978-2-88966-711-6

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PSYCHOLOGICAL AND MOTOR ASSOCIATIONS IN SPORTS PERFORMANCE: A MENTAL APPROACH TO SPORTS

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Citation: Coco, M., Quartiroli, A., Di Corrado, D., eds. (2021). Psychological and Motor Associations in Sports Performance: A Mental Approach to Sports. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88966-711-6

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frontiers in Psychology

EDITORIAL
published: 08 March 2021
doi: 10.3389/fpsyg.2021.629944

Editorial: Psychological and Motor Associations in Sports Performance: A Mental Approach to Sports

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Keywords: motor, sport, well-being, performance, sport psychology

Editorial on the Research Topic

Psychological and Motor Associations in Sports Performance: A Mental Approach to Sports

INTRODUCTION

"*Mens sana in corpore sano*" is used to paraphrase the idea that physical activity in all its forms is important and essential to foster and maintain mental and psychological well-being. The mind and the body must be considered as inseparable elements that represent two distinct natures of the same experience of living, communicating with and influencing each other. While they have been traditionally explored, analyzed, and treated separately, in recent years, the mind–body unit has witnessed a growing interest in the field of psychology and neuroscience applied to sports.

In this Research Topic, we have welcomed papers evaluating different approaches to sport performance. The articles of this collection examine in detail four main themes: (i) mental training to reach peak sports performance, (ii) emotional states associated with performance, (iii) the effects of personality traits on sports performance, and (iv) cognitive and psychophysiological characteristic associated with sports performance.

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Edited and reviewed by:
Tiziano A. Agostini, University of Trieste, Italy

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *16 November 2020*
Accepted: *12 February 2021*
Published: *08 March 2021*

Citation:
Di Corrado D, Quartiroli A and Coco M (2021) Editorial: Psychological and Motor Associations in Sports Performance: A Mental Approach to Sports. Front. Psychol. 12:629944. doi: 10.3389/fpsyg.2021.629944

MENTAL TRAINING

Existing literature has widely highlighted the value of mental training in assisting participants in sports in developing and maintaining effective mental skills, which are important to reaching peak performance as well as to enjoy, and possibly succeed in, the competitive experience of sports. Six articles in this collection move from such a perspective. Mental toughness is considered a key factor of superior performance in a variety of domains including sport. Piggott et al. investigated whether skilled performance thrived across increased challenges in small-scale games in higher- and lower-skilled footballers. Mental toughness, decision-making, and motor skill execution were measured. Findings suggest higher levels of mental toughness may contribute to maintaining performance across the increased challenge of pressure within small-scale games. In a systematic review of the literature, *Neumann* explored the effects of attentional focus strategies during weightlifting tasks. The results have shown the advantages of an external attentional focus for motor skill learning. The use of music during training has been proven to have many health benefits. Patania et al. have assessed the relationship between the tempo of music and perception of effort during different metabolic demands. The results have shown that the beneficial effects of music are more visible in endurance training. Consequently, music can be an important tool to stimulate people engaging in low-intensity physical exercise. Pre-performance routines are essential skills prior to a competition for athletes. Using a qualitative research design, Yao et al. conducted in-depth interviews of 14 elite Chinese athletes in competitive diving and their coaches. The results showed that the divers' pre-performance routines encompassed four specific components. Emphasizing the key role of mental imagery, *Di Corrado et al.* have observed the cognitive abilities useful for mental imagery abilities, investigating modifications in mental imagery skills in competitive athletes and non-athletes. Competitive athletes showed higher scores on mental imagery skills than non-athletes. A final contribution is that of Zhang L. et al.. Investigating the neural efficiency hypothesis, these authors used functional magnetic resonance imaging to study the differences in brain activity between athletes imagining performing different movements. The results showed better temporal congruence between motor execution and motor imagery and vividness of motor imagery. Athletes were more effective in the representation of the motor sequences and the interoception of the motor sequences for their self-sport.

EMOTIONAL STATES AND PERFORMANCE

Emotions play a central role in sports performance. Accordingly, it is important that athletes are able to draw on a range of strategies to improve emotional control. Eight contributions focused on this area of interest. Fernández et al. compared emotional intelligence and anxiety in combat sports of lower, intermediate, and higher-level female and male athletes. Results have shown that emotional intelligence is increased in high-level female athletes, while anxiety is prevalent in low-level female athletes. An athlete's emotional state may also affect the outcome of a competition by influencing performance both during training and while competing., Damonte et al. Sors, Lourido investigated the levels of sports burnout in 85 former agonist road cyclists, depending on whether their sport abandonment was relative or definitive. The results revealed that former agonist road cyclists still involved in cycling reported that they had experienced lower levels of emotional and physical exhaustion and sport devaluation during the last year practicing this specialty, with respect to both those who started practicing a different sport and those who definitively abandoned it. Poulus et al. explored the influence of mental toughness on stress and coping in 316 electronic sports athletes. Mental toughness was associated with the selection of more problem- and emotion-focused coping strategies and less avoidance coping strategies. Schüler and Wolff explored the impact of the presence or absence of achievement incentives on participants during a bicycle ergometer task. In a within-subject experimental design, they found that the lack of achievement incentives led to the worst performance, while the presence of these incentives did not lead to the best performance in participants with a strong achievement motive. Observing 309 karate competitions, the goal of the study conducted by Frigout et al. was to determine whether it would be possible to issue coaching requirements. The authors concluded that karatekas have to make decisions, such as when taking the risk to score points and penalties. Moreover, karatekas may decide to expose or protect themselves, create situations, or simply remain realistic, and adhere to the plan. Sport is an emotional experience not only for athletes. Sors, Lourido, Parisi et al. investigated how the crowd noise influences the decisions of basketball referees when examining videos of potential fouls, taking into consideration their level of competitive anxiety of referees (low vs. high anxiety). The results indicated that the decisions of referees with high anxiety might be more easily influenced by external factors like crowd noise. In a review of the literature, Guerrera et al. provided a general overview of the possible synergism between physical activity participation and the effects of antidepressants as part of a treatment for major depressive disorder. In conclusion, in an opinion article (Calleja-Gonzalez et al.) examined how different stressors impact wellness and performance due to constant experience of traveling often required in elite professional sport. For this reason, the authors indicated some key points in order to optimize performance, reducing the effect of traveling, and sleep disturbance.

THE EFFECTS OF PERSONALITY TRAITS ON SPORTS PERFORMANCE

Personality traits refer to individuals' characteristics that are stable over time. Three articles in this collection explore the role of personality traits in sport. Zhang G. et al. illustrated the relationship between the Big Five personality traits and self-control in 210 Chinese boxers and investigated self-efficacy as a mediator between the two variables. Results showed significant differences in self-control and self-efficacy among boxers of different competitive levels. Finally, self-efficacy mediated personality traits and self-control, indicating that personality traits predict self-control not only directly but also indirectly through self-efficacy. In another cross-sectional study, Baños et al. assessed how 890 high school students evaluate the professional personality competence of physical education teachers and its relation to students' satisfaction with school and satisfaction with life itself. The results showed that students' perceived competence, predicted self-determined satisfaction, which in turn corresponds to life satisfaction. In the last study, Valenzano et al. extended the work on individual differences in the relationship between personality traits and the cortisol response by examining the interaction effects of sex and the role category of 70 Italian adolescent elite dinghy sailors. Their findings showed positive associations among cortisol levels, extraversion, and consciousness in both male and female bowmen groups.

COGNITIVE AND PSYCHO-PHYSIOLOGICAL CHARACTERISTICS

Over time, athletes show extraordinary skills in their favorite sport. While their sporting acumen may seem like a fundamentally physical attribute, it is actually supported by a range of cognitive skills spanning the sensorimotor line, from perception to action execution. Six contributions under this theme report on empirical studies. One such skill that has received considerable attention from experimental psychologists is the expert anticipatory advantage. Jalali et al. assessed the expert anticipatory advantage in 34 skilled tennis players via the approach "bubbles" (information is randomly removed from videos in each trial). Results showed that skilled tennis players could anticipate upcoming shots based on their opponent's body kinematics. Storniolo et al. have deepened the time delay between maximal sprint end and heart rate decay onset, exploring the relationship between sympathovagal balance and performance in 24 healthy adults. Results seem to confirm that a delay between sprint end and heart rate decay is a significant marker for the autonomic nervous system recovery after a sprint test. Papadopoulou et al. have observed the prevalence of relative age effect (RAE) in 72 selected and 53 non-selected youth female volleyball players. Their findings showed that RAE was not observed in the selected or non-selected players, (b) anthropometric and physiological characteristics did not differ among birth quarter groups, and (c) the relationship of anthropometric and physiological characteristics with age varied by performance group with stronger correlations observed in the non-selected than in the selected group. In a case study (28-year-old male), Dhawan demonstrated the effect of neuronal ensemble and memory formed during High-intensity aerobic training (VO2 max) and Target Heart-Rate (THR) training and the effect of reactivation of same memory on THR and performance. With this study, he showed how reactivation of previously acquired memory or using the stimulation from the neuronal ensemble of consolidated memory during a specific training event might exert similar physiological effects on exercise or the body to those that are learned during the memory acquisition phase. Focusing on cognitive features, Coco, Buscemi, Cavallari et al. determined whether aerobic exercise performed at two different intensities is able to affect executive functions in 20 healthy young male athletes. The results showed that a 30-min aerobic exercise is not associated with a worsening of executive functions as long as the blood lactate levels stay within the 4 mmol/l threshold. Finally, focusing on cognitive deficits, Coco, Buscemi, Perciavalle et al. explored whether the practice of scuba diving is capable of determining damage to the brain white matter (WM) in a dose-dependent manner and, consequently, a possible deficiency in their cognitive abilities in 54 professional scuba divers (35 men and 19 women). Their results lead to the conclusion that repeated dives, even performed in compliance with the current decompression tables, can progressively lead in the central nervous system to the formation of micro-lesions in the myelin sheet capable of altering the functioning of the neuron.

To conclude, we believe that all the studies in this Research Topic contributed to add support to the pluridimensional nature of motor and sport sciences; the findings, insights, and perspectives discussed in each paper can inspire new research and theory, opening up new horizons in this domain. We gratefully acknowledge the precious collaboration of the reviewers, editors, and staff of Frontiers.

AUTHOR CONTRIBUTIONS

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

ACKNOWLEDGMENTS

We gratefully acknowledge the precious collaboration of the reviewers, editors, and staff of Frontiers.

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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 03 July 2019
doi: 10.3389/fpsyg.2019.01552

Coach Rating Combined With Small-Sided Games Provides Further Insight Into Mental Toughness in Sport

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *28 May 2019*
Accepted: *19 June 2019*
Published: *03 July 2019*

Citation:
Piggott B, Müller S, Chivers P, Burgin M and Hoyne G (2019) Coach Rating Combined With Small-Sided Games Provides Further Insight Into Mental Toughness in Sport. Front. Psychol. 10:1552. doi: 10.3389/fpsyg.2019.01552

Literature indicates that mental toughness contributes to successful performance when faced with challenge. This study used an exemplar sport of Australian Rules football to investigate whether skilled performance thrived across increased challenge in small-sided games. Higher (n = 14) and lower (n = 17) skilled Australian footballers were recruited. First, coaches rated participants' mental toughness (MTC) using the Mental Toughness Index. Second, participants competed in small-sided games where challenge was manipulated by varying the attacker to defender ratio to create lower and higher pressure scenarios. Decision-making, motor skill execution, and a combined total were measured. MTC rating was higher for higher skilled players. Total score of higher skilled players was significantly superior to lower skilled players in higher and lower pressure scenarios (p = 0.003). A "pressure differential score," calculated to determine whether participants maintained performance across increased challenge, indicated a significant decrease in performance (total score) from lower to higher pressure scenarios for lower skilled (p = 0.011), but not for higher skilled (p = 0.060) players. Furthermore, MTC scores were predictive of high pressure scenario total scores (p = 0.011). Findings suggest higher levels of mental toughness may contribute to maintain performance across the increased challenge of pressure within small-sided games. Practitioners can subjectively rate athlete mental toughness and then structure small-sided games to objectively measure performance under pressure scenarios. This provides an interdisciplinary approach to assess and train psychomotor skill.

Keywords: mental toughness, psychomotor skill, pressure scenarios, perceptual-cognitive-motor skill, sports specific assessment

INTRODUCTION

In the Australian Football League (AFL) grand final of 2010, both St Kilda and Collingwood had scored 68 points when the siren sounded for full time; a draw. The rules of the competition stated that the final had to be replayed the following week. In the week preceding the rematch, Collingwood coach, Michael Malthouse, penned a newspaper article titled "Mental toughness will decide premiership" (Malthouse, 2010). Collingwood went on to win the grand final replay by 56 points. They were able to perform to a higher level than their opposition, despite the challenge of having already played in a grand final seven days earlier in front of 90,000 spectators, and the adversity of having fatigued and injured players. According to their coach, the success of Collingwood in the replay of 2010 grand final would suggest that mental toughness (MT) played a major role. MT is a concept that indeed warrants further investigation in sports-specific *in situ* settings.

Mental toughness has gained significant interest from the general public, practitioners, and researchers in recent years because it is considered a key factor of superior performance in a variety of domains including sport (Giles et al., 2018). Based upon scientific evidence of MT in a variety of domains such as business, military, education, and sport, the focus has been upon defining the phenomenon and formulation of a theoretical framework from which hypotheses could be tested (Gucciardi et al., 2015). Accordingly, MT has been defined as a personal capacity to produce consistently higher levels of subjective or objective performance, despite everyday challenges, stressors and significant adversities (Gucciardi et al., 2015). Research into MT has also developed and validated several introspective questionnaires in order to measure MT in several domains, and in turn, test and further refine its theoretical framework (Newland et al., 2013). Some of these questionnaires include the Mental Toughness Questionnaire-48 (MTQ48) (Clough et al., 2002), the Sport mental toughness questionnaire (SMTQ) (Sheard et al., 2009), and the Mental toughness index (MTI) (Gucciardi et al., 2015). Therefore, the vast majority of what is known about MT measurement is based upon introspective survey methodology.

Surveys can provide scientists with valuable information about psychological and emotional states of participants, but there has been a call for incorporation of other methodologies that can provide insight to the link between psychomotor skill capability and MT in athletes (Gucciardi et al., 2008, 2013; Gucciardi and Gordon, 2013; Mahoney J. et al., 2014). The broader field of sport psychology has relied predominantly on introspective surveys and interviews, often undertaken sometime after the competition event. This relies on the athlete having to reflect on their own performance, which can be quite subjective. There is scope, however, to utilize an alternative methodology to better understand the link between psychomotor skill performance and MT in sport. For example, Mahoney J. et al. (2014) recommended that a key starting point for future investigation of MT, is objective measurement of performance under manipulation of lower and higher pressure *in situ* contexts in sport. This would enable a quantitative assessment of a component prediction of MT theory through varying degrees of pressure that creates increased challenge to performance. This form of assessment places a participant in a game-like pressure context and would help coaches to identify those players who thrive or succumb to the pressure (Mahoney J. et al., 2014). Accordingly, it has been suggested that a characteristic of mentally tough athletes is for their performance to thrive (i.e., performance maintained to a greater degree) when under increased task pressure or challenge (Jones et al., 2007; Gucciardi et al., 2008).

The importance of MT to superior performance in sport is well recognized among coaches, athletes and sport scientists (Connaughton and Hanton, 2009). Several studies in sport have reported that athletes with higher self-reported scores on MT questionnaires tend to perform better in competition (Drees and Mack, 2012; Newland et al., 2013; Mahoney J.W. et al., 2014; Cowden, 2016). For example, Cowden (2016) reported that amongst professional tennis players, achievement of higher MT scores were correlated with a greater likelihood of winning a national tournament. Drees and Mack (2012) also reported that higher MT scores of high school wrestlers was positively correlated with the season winning percentage. Moreover, Mahoney J.W. et al. (2014) reported a negative relationship such that higher MT scores of adolescent cross-country runners correlated with faster race times. In collegiate basketball players, Newland et al. (2013) reported that MT score partially predicted basketball performance (measured using a metric that combined shot percentage, points, rebounds, assists, steals, turnovers and personal fouls). To our knowledge, there has been no integration of MT survey methodology with systematic manipulation of sports-specific pressure and assessment of perceptual-cognitive-motor skill to further understanding of MT.

Small-sided games (SSG) have been used with several invasion sports such as soccer, field-hockey and Australian rules football (ARF) to assess the perceptual-cognitive-motor skill of athletes (e.g., see Práxedes et al., 2018). Assessment of the correct decision, such as to pass the ball to a teammate or retain possession of the ball, provides a measure of perceptual-cognitive or decision-making skill (Starkes et al., 2004). Alternatively, assessment of the capability to successfully pass the ball to a teammate provides a measure of motor skill execution (Starkes et al., 2004). Recently, Piggott et al. (2019) designed a sports-specific ARF test based upon SSG (six attackers vs. five defenders) in order to assess the perceptual-cognitive-motor skills of Australian footballers. The authors reported that higher skilled players were significantly superior on the total score (decision-making plus execution) compared to lesser skilled Australian footballers. By manipulation of the ratio of defenders to attackers it is possible to increase or decrease pressure in SSG (see Davids et al., 2013), which can then form scenarios to investigate how athletes deal with challenge (as predicted in MT theory) that may affect performance.

This study incorporated existing MT survey methodology with an *in situ* sports-specific test. ARF was used as the exemplar sport skill to further understand the link between MT and psychomotor skill in sport. A sports-specific *in situ* test for ARF was designed based upon SSG that measured participants' decision-making and motor skill execution under higher and lower pressure scenarios. The purpose of this study was to investigate whether: (i) differences existed between higher and lower skilled ARF players during pressure scenarios of a SSG test, which provided a proxy to test a component of MT theory that performance in terms of perceptual-cognitive-motor skill would thrive (be maintained) under increased pressure, and (ii) whether MTC scores predicted performance scores in the high pressure scenario. Based upon MT theory and the above literature, it was hypothesized that: (a) higher skilled players will perform signficantly better than lower skilled players in both pressure scenarios, (b) higher skilled, rather than lesser skilled players, would better maintain performance across lower to higher pressure scenarios, and (c) MTC questionnaire scores can predicthigh pressure scores inn SSG.

MATERIALS AND METHODS

Participants

A total of 31 male participants were recruited for this study. A higher skilled group (*n* = 14) comprised of one semi-professional West Australian Football League (WAFL) club who participated in the state league. The lower skilled group (*n* = 17) was recruited from two West Australian Amateur Football League (WAAFL) clubs. For a participant to be included in the higher skilled group they had to have played a minimum of one senior WAFL game within the previous two years. The age of the WAFL group was (Mage = 23.0 years, age range: 20–29 years) and the WAAFL group was (Mage = 23.9 years, age range: 19–30 years). Based upon Piggott et al. (2019), a power analysis was conducted using $\alpha = 0.05$, power $(1-\beta) = 0.8$, effect size = 0.15, and two skill groups, which indicated that appropriately 351 trials in total were required. Ethical approval was received from the relevant university committee and participants provided written informed consent.

Materials and Procedures

Mental Toughness

All testing was completed at the end of the pre-season training period and before competition games began for the 2017 season. The first component of this study involved coach rating of each participant using the MTI, an eight item scale that when developed displayed strong factor loadings and composite reliabilities were reported to be excellent (ρ=0.86 *to* 0.89) (Gucciardi et al., 2015). Example items from the scale include *I am able to regulate my focus when performing tasks* and *I am able to execute appropriate skills or knowledge when challenged*. The MTI has been used in previous research with athletes and has been reported to correlate with competition performance (e.g., Gucciardi et al., 2015). The measuring of coach rated MT (MTC) has also been used in previous research (Bell et al., 2013; Cowden et al., 2014) and is a way of overcoming self-attribution bias that can occur when using self-report. To establish face validity for coach rated MT using the MTI, a panel of expert AFL coaches was consulted and all agreed that the questionnaire was an appropriate measure of assessment. A senior member of each of the teams' coaching staff involved in the study completed the MTC rating for each participant that they coached.

Small-Sided Games

The second component of this study involved both skill groups and relates to item 7 on the MTI: *I am able to execute appropriate skills or knowledge when challenged*. This refers in part to MT theory mentioned earlier and was deemed the easiest to manipulate in terms of pressure contexts in a sports-specific *in situ* test. For this study, the previous data set from Piggott et al.'s (2019) was built upon to include another series of SSG involving six attackers versus three defenders. The two series of SSG were termed "higher pressure" (six vs. five) and "lower pressure" (six vs. three), respectively. Both scenarios involved attackers attempting to maintain possession of the ball in a 40 m × 40 m grid using a handpass or kick, whilst defenders tried to spoil or tackle. After a 15 min warm-up, each skill group completed three sets each in attack and defense. The test was umpired by a research assistant with ARF knowledge. Each skill group completed the higher pressure scenario in one session and the lower pressure scenario in another session at least one week apart due to logistics. Each time an attacking player passed the ball by a kick or handball it was recorded as a trial. Decision-making and motor skill execution scores for each disposal (trial), as well as both combined (total score) were coded as objective performance measures. Each session was recorded using a standard 25 Hz video camera (Panasonic SDR-H250, Australia) for later coding (see Piggott et al., 2019, for details of this method).

The scoring system used in both higher and lower pressure scenarios is outlined in **Table 1**. In relation to item 7 of the MTI, we reasoned that decision-making score reflects "knowledge," the execution score reflects "skills," and "challenge" reflects the increase in defenders from three to five in the *in situ* scenarios. The reliability of scoring the scenarios was assessed by inter- and intra-rater reliability. A novice coach scored all trials by viewing the video record of the SSG. Intra-rater reliability was assessed by the same novice coach (two weeks apart) and inter-rater reliability was assessed by an expert ARF coach (Level 3) on 136 (14%) randomly selected trials, across both high and low pressure scenarios, using the video record.

Data Analysis

Statistical analysis was performed using IBM SPSS version 24 (IBM SPSS Statistics for Windows. IBM Corp., Armonk, NY, United States). Data was checked for normality using the Shapiro Wilk's test so that the appropriate statistical tests could be employed. Alpha level was set at 0.05.

TABLE 1 | Composite score for test trials.

Measure	Rating
Decision-making	0 = Incorrect decision
	2 = Next correct decision
	3 = Most correct decision
Execution	0 = Ball does not reach target player at all
	1 = Ball reaches target player but not on full
	2 = Ball reaches target player on full; however, the target player had to change direction to ensure this occurs
	3 = Ball reaches target player on full
Total	Decision Making + Execution Scores

Adapted from Piggott et al. (2019). "Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers." Journal of Sports Sciences, p. 3.

During the SSG, each time an attacking player passed the ball by a kick or handball it was recorded as a trial, with a total of 980 trials recorded; 423 in the higher pressure scenario and 557 in the lower pressure scenario. The participants' total score for the SSG was the dependent variable, which equalled the sum of the decision and execution scores for each trial with the maximum score achievable being six. Total score had previously been reported to discriminate superior performance of higher and lower skilled Australian footballers (see Piggott et al., 2019).

Inter- and intra-rater reliability of the scoring of the SSG test was assessed using a two-way mixed intra-class correlation coefficients (ICC) according to Portney and Watkins (2009). The cut-off interpretations used for the ICC values were; less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 indicative of poor, moderate, good, and excellent reliability, respectively.

Hypothesis one predicted that higher skilled players will perform significantly better than lower skilled players in both pressure scenarios. To address this hypothesis, repeated measures of trials were examined for between skill group differences for total score on the SSG test, in both higher and lower pressure scenarios, using generalised estimating equations (GEE). GEEs use the generalized linear model to estimate more efficient and unbiased regression parameters relative to ordinary least squares regression that accounts for the form of within-subject correlation of responses on dependent variables of many different distributions (Ballinger, 2004). A 2 (skill group) × 2 (pressure scenario) mixed between-within factorial GEE model was used to examine main and interaction effects. Total score was the dependent scale variable in the GEE model. For *post hoc* comparisons, a Bonferroni adjustment was applied. Cohen's *d* effect sizes were also calculated, with 0.2 considered small, 0.5 medium and 0.8 large effects (Cohen, 1998).

Hypothesis two predicted that higher skilled, rather than lesser skilled players, would better maintain performance across lower to higher pressure scenarios. To address this hypothesis, a mean of the trials' total score for each participant was calculated for each higher and lower pressure scenarios on the SSG test for both skill groups. A "pressure differential score" was then calculated by subtracting higher pressure scenario mean total score from lower pressure scenario mean total score. For example, if a participant had a lower pressure mean total score of 5.4 and higher pressure mean total score of 4.6, their pressure differential score would be; 5.4 – 4.6 = 0.8. A pressure differential score closer to zero indicated better sustained performance across lower to higher pressure scenarios; which meant participants were able to maintain perceptual-cognitive-motor skills when challenged. A one-sample *t*-test was used to compare the mean pressure differential scores to a no-performance-change score of zero for higher and lower skilled players.

Hypothesis three predicted a relationship between MTC questionnaire scores and SSG high pressure scores. To address this hypothesis, a GEE regression model was used to investigate the relationship between MTC and high pressure scenario total score.

RESULTS

Reliability of SSG Test Scoring

Inter-rater reliability for decision (r = 0.91, range = 0.88 to 0.94) and execution (r = 0.98, range = 0.98 to 0.99) indicated excellent levels of agreement. Intra-rater reliability for decision (r = 0.86, range = 0.80 to 0.90) and execution (r = 0.96, range = 0.95 to 0.97) also indicated good and excellent levels of reliability, respectively.

Skill Group Differences for SSG

The estimated marginal means derived from the GEE model are presented in **Figure 1**. The model indicated significantly superior overall performance by higher skilled players over lower skilled players (β = 0.22, SE = 0.07, p = 0.003). In addition, performance under the low pressure scenario was significantly higher than under the high pressure scenario (β = −0.47, SE = 0.15, p = 0.002). The interaction between skill level and pressure was not significant (β = 0.20, SE = 0.18, p = 0.282). However, pairwise comparisons revealed a significantly higher total score by higher skilled players (M = 5.32, SE = 0.08), over lower skilled players (M = 4.90, SE = 0.14), under the higher pressure scenario (p = 0.049, d = 0.31). Pairwise comparisons also revealed a significantly higher total score by higher skilled players (M = 5.59, SE = 0.05), over lower skilled players (M = 5.37, SE = 0.06), under the lower pressure scenario (p = 0.017, d = 0.22). When the total score of higher skilled players was compared across lower (M = 5.59, SE = 0.05) to higher (M = 5.32, SE = 0.08) pressure scenarios, a significant difference was found (p = 0.034, d = 0.12). A significant difference was also found for lower skilled players across lower (M = 5.37, SE = 0.06) to higher (M = 4.90, SE = 0.14) pressure scenarios (p = 0.014, d = 0.35).

In relation to performance across scenarios, the pressure differential score indicated that for lower skilled players there was a significant difference compared to a no-performance-change score of zero, $t(16) = -2.89$, p = 0.011. This indicates performance decrement for lower skilled players. Conversely, no significant difference was found for pressure differential score for higher skilled players, $t(13) = -2.06$, p = 0.060. This indicates maintenance of performance for highly skilled players. There was a medium effect size (d = 0.46) for the pressure differential scores between higher (M = 0.22, SD = 0.40) and lower (M = 0.48, SD = 0.68) skilled players.

MTC Scores and Relationship to SSG

The MTC scores for higher and lower skilled groups were (M = 43.71, SD = 4.41) and (M = 42.50, SD = 5.37), respectively. There was no significant difference between the two groups for MTC; $t(26)$ = 0.519; d = 0.24).

When examining the relationship between subjective and objective measures, MTC scores were able to predict high pressure scenario total scores (β = 0.04, SE = 0.01, p = 0.011).

DISCUSSION

The purpose of this study was to integrate methodologies in order to test a component of MT theory that predicts whether an athlete

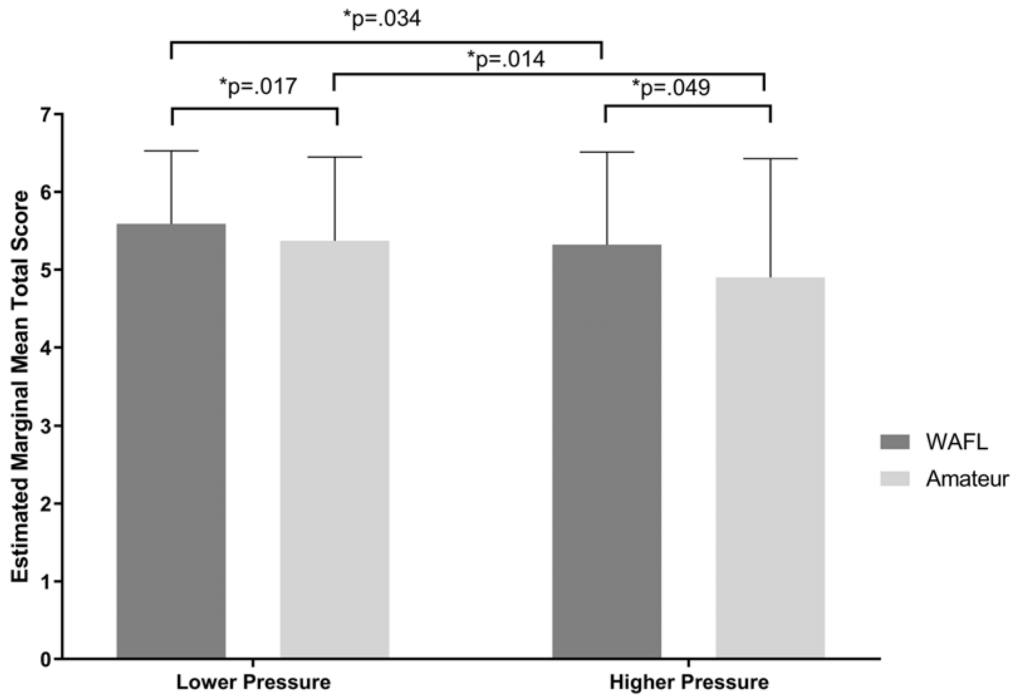

FIGURE 1 | Estimated marginal means for total score in small-sided games test based on GEE model. Pairwise comparisons are depicted $*p < 0.05$. Error bars represent standard error.

will thrive under pressure situations and maintain performance. This was done in interlinked components; first, a validated questionnaire was used for coaches MT rating of participants. Second, perceptual-cognitive-motor skill differences between higher and lower skilled ARF players were compared across two pressure conditions of a SSG test. Third, the relationships between quantitative and qualitative measures was explored. Fourth, the reliability of scoring the SSG test was checked through inter- and intra-rater reliability. Skill group differences were found in each pressure scenario, with higher skilled players better able to maintain performance across the pressure scenarios. Furthermore, MTC was predictive of performance under high pressure. Therefore, this study made initial steps to address the call for MT research methodology to be extended and incorporate experimental designs that involve systematic manipulation of pressure contexts within an *in situ* setting (Mahoney J. et al., 2014).

Both higher and lower pressure scenarios were able to discriminate skill levels, with higher skilled players performing at a superior level than lower skilled players. Previously, MT research in sport has used only survey methodology to attempt to discriminate between skill levels or categories; such as starters and non-starters in basketball (Newland et al., 2013) and team ranking in tennis (Cowden et al., 2014). This study showed that perceptual-cognitive-motor total score in the lower pressure (six vs. three) scenario was also able to discriminate between higher and lower skilled players. This builds upon Piggott et al.'s (2019) study providing further evidence of the capability of SSG's to discriminate between closely related skill levels of ARF. The design of tasks that involve differing levels of pressure that are highly representative of the competition environment and can discriminate between skill levels provides an important method to test MT theory. Therefore, supporting evidence was provided for hypothesis one.

A unique aspect of this study, was the calculation of the pressure differential score to test a component prediction of MT theory. The theory predicts that mentally tough athletes are able to thrive under pressure (Jones et al., 2007; Gucciardi et al., 2008). The pressure differential score enabled direct investigation of how participants met this challenge by quantification of the degree to which they maintained performance across increased pressure scenarios. Our study showed that higher skilled players could maintain their perceptual-cognitive-motor skill performance across increased pressure scenarios as evidenced by a lower pressure differential score. In contrast, lower skilled players were less able to maintain their perceptual-cognitive-motor skill performance across increased pressure scenarios as evidenced by an increase pressure differential score. Therefore, supporting evidence was provided for hypothesis two. This addressed the call in the literature for an objective measure of MT under manipulation of lower and higher pressure contexts (Mahoney J. et al., 2014).

The findings of this study have also furthered understanding of a subjective measure of MT and its relationship to an objective measure of perceptual-cognitive-motor skill performance. This is important because Gucciardi and Gordon (2013) stated that there was a lack of evidence supporting the link between MT and an objective measure of performance. The significant predictive relationship between coaches' MT rating of athletes and *in situ* performance in the higher pressure scenario provides support for the theory that higher levels of MT correspond with higher levels of performance. This evidence supports hypothesis three and is consistent with previous studies that have shown a relationship between self-reported MT and competition performance (Drees and Mack, 2012; Newland et al., 2013; Mahoney J.W. et al., 2014; Cowden, 2016). This indicates that either coach or self-report of MT is relevant to motor skill performance, but our study is unique as we have been able to demonstrate through manipulation of the pressure component in which the task is performed, we showed that MTC has predictive capabilities in relation to *in situ* perceptual-cognitive-motor skill.

PRACTICAL IMPLICATIONS AND LIMITATIONS

The integration of methods to test theory and evidence presented in this study provides opportunities for practical application in terms of assessment and development of athletes. Accordingly, a multi-method approach to MT could be used (Gucciardi et al., 2013). For example, an ARF coach, in consultation with a sport psychologist, could complete the MTI for an athlete as part of their development. The coach could then discuss their responses with the athlete and how they derived each score per item. On item 7 of the MTI (*I am able execute appropriate skills or knowledge when challenged*), the coach may score the athlete three out of seven and could explain that the athlete needs to improve their decision-making and/or skill execution when under pressure situations in competition. The coach would then work with a sport psychologist to design a six week training plan that develops MT. In addition, the coach assisted by a skill acquisition specialist can design a perceptual-cognitive-motor skill training program for a variety of game-specific pressure contexts. Prior to the commencement of the six week training program, the athlete would complete the SSG games test and may record a high pressure score of 4.0 and low pressure score 5.4 (pressure differential = 1.4). The athlete and the coach could set a goal for the athlete to achieve a pressure differential of <1.0 when retested at the completion of the training program.

A potential limitation of the study is that when using SSG and *in situ* methodology, the number of trials per participant can vary. However, Müller et al. (2015) argue that this variation is representative of the game situation. Previously, we have shown using SSG player involvements (trials) is comparable to player involvement (statistics) in competition (Piggott et al., 2019).

CONCLUSION AND FUTURE RESEARCH

Researchers in the domain of mental toughness have called for an extension of methodology beyond traditional surveys often used in sports psychology research. This study used an *in situ* methodology within ARF to create two scenarios; lower pressure and higher pressure SSG scenarios. These two scenarios were able to discriminate between higher and lower skilled players. Also, the pressure differential score showed that the higher skilled players, but not the lower skilled players, could sustain their performance across lower to higher pressure scenarios. This is in line with a component prediction of MT theory. MTC scores were predictive of total scores in the high pressure scenario, indicating a causal relationship between objective and subjective measures of MT. Therefore, through careful manipulation of a SSG task, a prediction of MT theory was tested, which provides support for further application of SSG in field-based sport settings.

Further research is necessary to replicate these findings with other sports, as well as further probe the causal relationship between mental toughness and perceptual-cognitive-motor skill. In relation to the first point, future research could determine the variance that mental toughness scores account for in the SSG task performance. This will help determine how much mental toughness contributes to performance in SSG. In relation to the second point, a psychological skills training program aimed at improving mental toughness could be compared to a perceptual-cognitive-motor skill training program, with their relative benefits assessed using small-sided game pressure scenarios. A psychological skill intervention has been reported to improve mental toughness and performance in cricket batting (see Bell et al., 2013), but has not specifically been compared to perceptual-cognitive-motor skill training and performance in small-sided game scenarios. Collectively, fruitful opportunities exist to further understand how mental toughness and perceptual-cognitive-motor skills contribute to performance of sports skills.

DATA AVAILABILITY

The datasets generated for this study will not be made publicly available to maintain confidentiality.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Human Research Ethics Committee University of Notre Dame Australia. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

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

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Conflict of Interest Statement: 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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 08 August 2019
doi: 10.3389/fpsyg.2019.01690

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The Relationship Between Big Five and Self-Control in Boxers: A Mediating Model

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OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *16 May 2019*
Accepted: *04 July 2019*
Published: *08 August 2019*

Citation:
Zhang G, Chen X, Xiao L, Li Y, Li B, Yan Z, Guo L and Rost DH (2019) The Relationship Between Big Five and Self-Control in Boxers: A Mediating Model. Front. Psychol. 10:1690. doi: 10.3389/fpsyg.2019.01690

Self-control seems to be the core element for achieving optimal competitive performance, and be of great importance to well-being and healthy development of humans. According to the literature, there exist some correlations between personality traits and self-control. The aim of this study was to shed some additional light on the relationship between the Big Five personality traits and self-control in boxers and investigate self-efficacy as a mediator between the two variables. Two hundred and ten boxers (age: M = 18.89, SD = 3.83; amount of boxing practice: M = 4.93 years, SD = 3.22; 76 males) of Chinese national athletes participated the study. Results showed a pronounced level of self-control. The higher the competitive level, the higher the level of self-control. There were significant correlations among the Big Five, self-control, and self-efficacy. Self-efficacy mediated the relationship between the Big Five personality traits and self-control.

Keywords: Big Five personality traits, self-efficacy, self-control, mediating effect, boxer

INTRODUCTION

Self-control refers to the phenomenon of people overcoming their natural and automatic tendencies, desires, and behaviors and resisting short-term temptations to achieve long-term goals (Baumeister et al., 2007). It is essential for the well-being and healthy development of humans. Sigmund Freud believed that self-control is a major characteristic of a civilized society (Freud, 1993), while Hare et al. suggested that "the ability to exercise self-control is the key to human success and happiness" (Hare et al., 2009). Good self-control not only prevents drug abuse, criminal offenses, and other undesirable social behaviors, but also promotes the healthy growth of individuals and the harmonious development of society (Moffitt et al., 2011; Tangney et al., 2014). Self-control seems to be the core element for achieving optimal competitive performance (Zhang, 2013; Englert, 2016). Scholars in sport psychology have called for research that "gives a voice" to marginalized groups, which would arguably include boxers (Fisher et al., 2003; Ryba and Wright, 2005; Simpson and Wrisberg, 2013). Boxers should have a pronounced self-control and self-efficacy (Lane, 2006; Yu et al., 2012). Thus, boxing is well suited for applied sport psychology interventions (Schinke, 2007); more emphasis should be put into research on the self-control and self-efficacy of boxers.

Exploring the relationships between self-control, personality traits, and self-efficacy can serve as a starting point for an in-depth study of self-control. Mao et al. (2018) found that openness, conscientiousness, extraversion, and agreeableness were all positively correlated with self-control, and neuroticism was negatively related to self-control. In addition, Vera et al. (2004) believe that self-control is affected by self-efficacy. Most of the existing research on self-control in sporting contexts focused on soccer players, divers, middle-distance runners, and college athletes of all types. There is only limited research on the psychology of boxing in China, especially on the relationship between boxers' personality traits and self-control. This study invited Chinese boxers of national athletes to take part in an examination of the relationship between their personality traits and self-control, and to look for any mediating effect of self-efficacy.

Personality Traits and Self-Control

Previous studies have well documented the relationship between the Big Five and self-control. Neuroticism has a negative correlation with self-control; agreeableness, extraversion, openness, and responsibility are positively related to self-control; self-control is a prerequisite for individuals to adapt to their social environment (Andrei et al., 2014; Coyne and Wright, 2014). In addition, researchers found differences in the relationship between extraversion, openness, and self-control; some studies found that extraversion and self-control had a significant negative correlation (Green et al., 2016), while some others found extraversion was not significantly related with self-control (de Vries and van Gelder, 2013). In the same way, researches on the relationship between openness and self-control had also produced inconsistent results (Andrei et al., 2014; Bazzy et al., 2017). Due to its consistency and stability across languages and cultures (Pilarska, 2018), the Big Five is often used to predict self-control (McCrae and Terracciano, 2005). Therefore, due to the inconsistency of the relationship between Big Five and self-control, and lack of studies among boxers, we hypothesized that 1: Neuroticism is negatively correlated with self-control, while agreeableness, conscientiousness, and extraversion are positively correlated with self-control among Chinese boxers.

Personality Traits and Self-Efficacy

Personality traits are important factors influencing the self-efficacy of individuals (Stajkovic et al., 2018). Studies have linked the Big Five traits and self-efficacy (Judge et al., 2007; Cristina et al., 2018; Coco et al., 2019), for example, neuroticism is negatively correlated with self-efficacy, and extraversion, openness, agreeableness, and responsibility positively correlated with self-efficacy (Judge et al., 2007). Some scholars found that individuals with higher scores of conscientiousness had higher self-efficacy beliefs (Brown et al., 2011). Openness shifts perceptions of demands into challenges to be tackled, broadening task engagement and self-efficacy (Sanchez-Cardona et al., 2012). Research has found that agreeableness can lead to increased self-efficacy (Caprara et al., 2010). Certain researchers have found that individual self-efficacy is positively correlated with extraversion and negatively correlated with neuroticism (Schmitt, 2007). The finding of Djigić et al. (2014) indicated that conscientiousness predicts the self-efficacy of teachers, while Marcionetti and Rossier (2016) believed that conscientiousness, neuroticism, and extraversion are significantly correlated with self-efficacy. Furthermore, Brown and Cinamon (2016) proposed that higher conscientiousness and extraversion, and lower neuroticism, help enhance self-efficacy.

In sports, Wang et al. (2009) found that neuroticism has a significant negative predictive effect on the general self-efficacy of basketball players, while extraversion and conscientiousness have significant positive predictive effects. Based on the existing literature, the current study hypothesized that neuroticism is negatively correlated with self-efficacy, while agreeableness, conscientiousness, and extraversion are positively correlated with self-efficacy in boxers.

Self-Control and Self-Efficacy

Self-efficacy may play a mediating role between personality and self-control. According to Bandura's self-efficacy and self-regulation theories, self-control is affected by self-efficacy, and there was a significant positive correlation between the two (Bandura, 1978). Research found a positive correlation between self-efficacy and self-control (Au, 2015). Graham and Bray (2015) studied self-efficacy as a psychological factor to explain how self-control is performed. Baumeister's analysis showed that self-control requires an individual's own control resources, and self-efficacy complements this resource by acting as a positive emotion (Baumeister, 2002). Yu and Yang's (2008) study concluded that there is an interaction effect between self-efficacy beliefs and self-control behavior.

A large number of researches have shown that there is a positive correlation between self-efficacy and self-control in different population groups (Huang and Yang, 2015). Jones et al. found that self-efficacy and sense of control are important indicators of an athlete's state (Jones et al., 2009). Research shows that self-efficacy had a positive effect on self-control in athletes (Yang et al., 2013). Specifically, self-efficacy mediated the relationship between other psychological traits and self-control among different groups (Wang et al., 2009; Fang et al., 2015). Therefore, the present study further explores whether self-efficacy has a positive effect on self-control in boxers, and whether self-efficacy has a mediating effect between personality traits and self-control. The current study hypothesized: the self-efficacy and the self-control of Chinese boxers are positively correlated; the self-efficacy of Chinese boxers mediates the effects of neuroticism, agreeableness, conscientiousness, and extraversion on self-control.

MATERIALS AND METHODS

Sample

The participants, acquired by cluster sampling, comprised boxers from Chinese national boxing teams as well as teams at several provinces and cities including Shenyang, Hubei, Anhui, Inner Mongolia, Chongqing, and Sichuan. All subjects gave written informed consent in accordance with the Declaration of Helsinki. Permission was obtained from the Southwest University's Human Research Ethics Committee. Prior to answering the items, participants read information about the purpose of the study, implications of participation, and data protection. The information stressed that participation was completely voluntary and anonymous. A total of $N = 230$ questionnaires were distributed, and $N = 210$ valid ones (91%) were returned. Among the participants, $n = 76$ were males (36.2%) and $n = 134$ females (63.8%). There were 79 Level-3 athletes (37.6%), 24 Level-2 athletes (11.4%), 49 Level-1 athletes (23.3%), 45 Master-Level athletes (21.4%), and 13 athletes at the International Master-Level (6.2%). Level-3 is the lowest and the International Master-Level is the highest. The average age was $M = 18.89$ years (SD = 3.83), with the average prior training period being $M = 4.93$ years (SD = 3.22). Fifty participants were under 18 years of age and permissions from their parents were obtained; written and informed consent was obtained from the parents/legal guardians of all non-adult participants. The average time for completing the survey was 20 min.

Procedure

After receiving informed consent from the management, coaches, and athletes of the national team and other sports teams, the questionnaires were distributed to teams at the provincial level or above. The instructions were explained in detail and example questions were provided to the participants, who were asked to read the questionnaire carefully and answer it. The questionnaires were distributed at Jilin Sport University, Wuhan Sport University, Anhui, Inner Mongolia, Chongqing, and Sichuan between the 11th of October and the 9th of November, 2017.

Measures

NEO Five-Factor Inventory

Personality was measured with the validated Chinese NEO-PI-R (Costam and McCrae, 1992; Chen et al., 2016). The NEO-PI-R contains 60 items and is one of the most widely used measures for the Big Five personality traits. The self-report items are rated on a 5-point Likert scale ranging from "strongly disagree (1)" to "strongly agree (5)" and reflect the five higher order domains Neuroticism, Extraversion, Openness to Experiences, Agreeableness, and Conscientiousness. There are 12 items per FFM-FFI domain. A confirmatory factor analysis confirmed the one-dimensionality of the scale (CFA): $\chi^2/df = 1.33$, RMSE = 0.04, TLI = 0.99, GFI = 0.98, CFI = 0.99. The factor loadings of the items ranged between $a = 0.50$ and $a = 0.73$. The internal consistencies of the inventory's five scales were $\alpha = 0.77$ (Neuroticism), $\alpha = 0.76$ (Agreeableness), $\alpha = 0.80$ (Conscientiousness), $\alpha = 0.72$ (Extraversion), and $\alpha = 0.57$ (Openness). The Openness scale was not used furthermore due to its unsatisfactory internal consistency and its cultural unsuitability for Chinese boxers.

Self-Control Questionnaire for Athletes

Self-control was measured by a 24-item, 5-point Likert Chinese scale questionnaire, ranging from "1 = not at all" to "5 = very much"; higher scores indicate better self-control (item example: "In order to complete the training task, I can endure extreme fatigue"). In a previous study, the scale provided a reference for athlete selection (Li and Zhang, 2011). A confirmatory factor analysis confirmed the one-dimensionality of the scale (CFA): $\chi^2/df = 1.15$, RMSEA = 0.03, TLI = 0.97, GFI = 0.92, NFI = 0.87, CFI = 0.98. The factor loadings of the items ranged from $a = 0.49$ to $a = 0.75$. The internal consistency of the questionnaire was good ($\alpha = 0.87$).

Self-Efficacy Scale for Athletes

Based on self-efficacy theory and related theories about competitive sports, Wei et al. (2008) compiled a self-efficacy scale for athletes in intensive sports. This scale consisted of 15 items, such as "I can keep my mind clear and focused during the competition." Each item was measured by a 5-point scale (1 = never been like this; 5 = always so). A higher score indicates a higher self-efficacy. The one-dimensionality of the scale was proved by a confirmatory factor analysis (CFA): $\chi^2/df = 1.07$, RMSEA = 0.02, TLI = 0.99, GFI = 0.96, NFI = 0.95, CFI = 0.99, IFI = 0.99. The factor loadings of the items ranged from $a = 0.43$ to $a = 0.75$. The internal consistency of the scale was good ($\alpha = 0.92$).

DATA ANALYSES

A two-way analysis of variance (ANOVA, LSD-*post hoc* test) was run for testing mean differences. The bias-corrected percentile bootstrap method was used to conduct regression analyses (Fang et al., 2012). To implement this method, we used the Model 4 PROCESS macro for SPSS created by Hayes (2013). Gender, age, years of training, and competitive level were controlled. The 95% confidence intervals of the mediating effects are reported. The statistical significance level was set to $\alpha = 0.05$.

RESULTS

Testing for Common Method Bias

To avoid response bias, some items in the questionnaires were expressed in reverse wording, AMOS 21.0 was used to conduct a CFA, with the common factor of all variables set to 1, and all item variables were used as explicit variables. The CFA results showed that the model fit was low, indicating no serious common method bias. ($\chi^2/df = 2.01$, RMSEA = 0.07, NFI = 0.34, CFI = 0.50, TLI = 0.49, GFI = 0.55, IFI = 0.50).

Self-Control and Self-Efficacy: Group Differences

The averaged item score of the self-control was $M = 3.68$ (SD = 0.49), indicating a relatively high level of self-control among boxers in China. This study also examined the effect of gender and competitive level differences on self-control; the results indicated no significant gender differences ($F = 1.14$,

$p = 0.28$, $d = -0.011$), but a significant main effect of competitive level ($F = 7.81$, $p < 0.01$, $\eta^2 = 0.12$). The interaction between gender and competitive level was not significant ($F = 1.82$, $p = 0.13$, $\eta^2 = 0.04$). The item-based averaged self-control scores of boxers from the five different competitive levels were significantly different. The higher the competitive level, the higher the level of self-control (International Master-Level: $M = 3.92$, SD = 0.62; Master-Level $M = 3.79$, SD = 0.48; Level-1: $M = 3.77$, SD = 0.45, Level-2: $M = 3.83$, SD = 0.49; Level-3: $M = 3.47$, SD = 0.43. The simple analysis showed that the averaged item score of self-control in International Master-Level was significantly higher than that of the Level-3, $p < 0.01$, $d = 0.98$).

The average item score of self-efficacy was $M = 3.50$ (SD = 0.64), indicating that the Chinese boxers' self-efficacy exceeds the theoretical item mean. There was no significant difference between male and female boxers ($p > 0.05$, $d = 0.24$). The mean item scores of self-efficacy among boxers from five different competitive levels differed significantly: the higher the competitive level, the higher the self-efficacy (International Master-Level: $M = 3.81$, SD = 0.76; Master-Level: $M = 3.66$, SD = 0.60; Level-1: $M = 3.53$, SD = 0.58; Level-2: $M = 3.60$, SD = 0.71; Level-3: $M = 3.30$, SD = 0.60). There was a significant difference on self-efficacy between International Master-Level and Level-3 ($p < 0.01$, $d = 0.81$).

Personality Traits, Self-Efficacy, and Self-Control: Correlations

Neuroticism was significantly and negatively correlated with self-efficacy and self-control, while extraversion, agreeableness, and conscientiousness were significantly and positively correlated with self-efficacy and self-control. Self-efficacy and self-control were positively correlated (see **Table 1**).

Testing for Mediation by Self-Efficacy on Effects of Neuroticism, Agreeableness, Extraversion, and Conscientiousness on Self-Control

This study used the Bootstrap method proposed by Fang et al. (2012) and the Model 4 PROCESS macro for SPSS created by Hayes (2013) to conduct mediating effect testing; gender, competitive level, age, and years of training were set as control variables.

Regression analysis showed that neuroticism negatively predicted self-efficacy ($\beta = -0.23$, $p < 0.01$), while self-efficacy positively predicted self-control ($\beta = 0.88$, $p < 0.001$). Neuroticism negatively predicted self-control ($\beta = -0.32$, $p < 0.001$). Extraversion was a positive predictor of self-efficacy ($\beta = 0.17$, $p < 0.001$), while self-efficacy positively predicted self-control ($\beta = 0.78$, $p < 0.001$). Extraversion and self-efficacy were positive predictors of self-control ($\beta = 0.27$, $p < 0.001$). Agreeableness positively predicted self-efficacy ($\beta = 0.26$, $p < 0.001$), and self-efficacy was a positive predictor of self-control ($\beta = 0.77$, $p < 0.001$), as was agreeableness ($\beta = 0.44$, $p < 0.001$). Conscientiousness positively predicted self-efficacy ($\beta = 0.43$, $p < 0.001$), and self-efficacy was a positive predictor of self-control ($\beta = 0.58$, $p < 0.001$), as was conscientiousness ($\beta = 0.47$, $p < 0.001$).

Figures 1–4 present the standardized effects of the paths of neuroticism, extraversion, agreeableness, and conscientiousness on self-control. The bootstrap 95% confidence interval of the indirect effect of self-efficacy did not comprise 0, indicating that

TABLE 1 | Means, standard deviations, and correlation coefficients of personality traits, self-control, and self-efficacy.

	M	SD	1	2	3	4	5	6
Neuroticism	2.94	0.53	1					
Extraversion	3.63	0.49	−0.40*	1				
Agreeableness	3.78	0.46	−0.49*	0.37*	1			
Conscientiousness	3.50	0.48	−0.52*	0.47*	0.54*	1		
Self-efficacy	3.50	0.64	−0.42*	0.48*	0.45*	0.70*	1	
Self-control	3.68	0.49	−0.57*	0.48*	0.68*	0.74*	0.70*	1

Indicates p < 0.05.

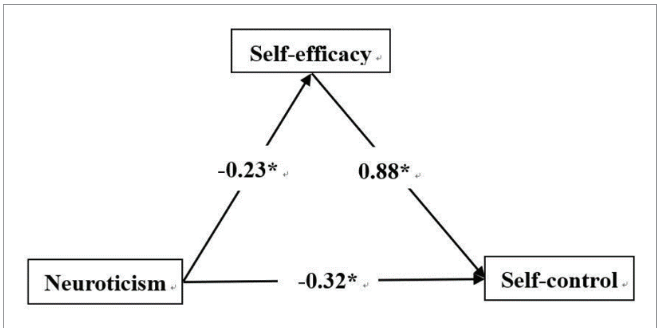

FIGURE 1 | Neuroticism → self-efficacy → self-control. *Statistically significant.

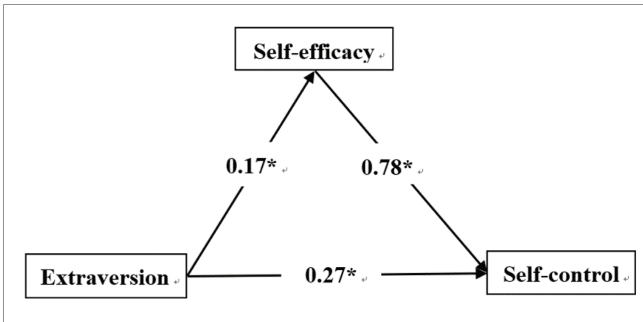

FIGURE 2 | Extraversion → self-efficacy → self-control. *Statistically significant.

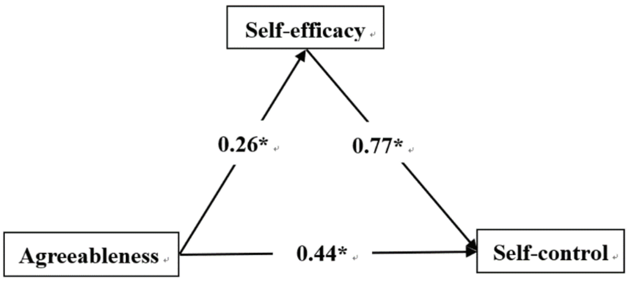

FIGURE 3 | Agreeableness → self-efficacy → self-control. *Statistically significant.

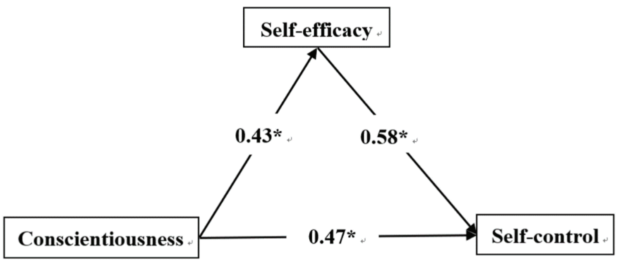

FIGURE 4 | Conscientiousness → self-efficacy → self-control. *Statistically significant.

self-efficacy had a significant mediating effect on neuroticism, extraversion, and agreeableness. Conscientiousness had a mediating effect on self-control. Taking together, neuroticism explained 22% of the change in self-efficacy, extraversion 27%, agreeableness 26%, and conscientiousness 50%. As such, H_4 was confirmed.

DISCUSSION

Direct Influence of Personality Traits on Self-Control

In the current study, there were significant positive correlations between agreeableness, conscientiousness, extraversion, and self-control, and a negative correlation between neuroticism and self-control.

Previous studies have shown that agreeableness, conscientiousness, and extraversion are positively related to self-control (Bazzy et al., 2017), while neuroticism significantly correlated with self-control (Andrei et al., 2014). Based on those studies, the current study assumed that neuroticism is negatively correlated with self-control, while agreeableness, conscientiousness, and extraversion are positively correlated with self-control. These hypotheses are supported and are consistent with the results of Deng and Gao (2015) and Pilarska (2018).

Avoiding injuries and reducing the number of fouls are very important skills for boxers. Self-control is a very important psychological characteristic that influences those skills (Yu et al., 2012). By understanding the mediating relationship between personality and self-control, boxers can not only avoid injuries but also reduce the number of fouls by improving their self-control level and their own skills and tactics (Ba and Zhu, 2008). Song et al. (2009) suggested that boxers should continuously enhance their psychological stability by focusing on the actual combat element of boxing. Therefore, the Big Five factors and the self-control could perhaps be used as psychological criteria to select boxers and the relationship between them is an important first step in order to further boxers. Longitudinal research is needed to evaluate the relevance of these predictors.

The Mediating Role of Self-Efficacy Between Personality Traits and Self-Control

Studies have shown that four of the Big Five factors have indirect predictive effects on self-control through self-efficacy. Theories of self-efficacy hold that the subjective judgment and self-feeling that individuals have about their ability to perform a certain behavior or tasks play an important role in the decision-making process before a behavior is performed (Eastin and La-Rose, 2000). In sporting contexts, scholars have found that the stronger an athletes' self-efficacy, the better their performance in sports as diverse as athletics, tennis, scuba diving, and gymnastics (Vancouver et al., 2002): when athletes perform a task for the first time, their self-efficacy affects their performance (Myers et al., 2004). Other studies have demonstrated that, even despite excellent skills and motivation to win, people with outstanding capabilities are less likely to achieve success if they have poor self-efficacy (Earley and Lituchy, 1991). The present study hypothesized that neuroticism is negatively correlated with self-control, while agreeableness, conscientiousness, and extraversion are positively correlated with self-control; and these hypotheses were supported by the results of this study and are consistent with the results of Zhang (2016) and Marcionetti and Rossier (2016). Moreover, the recent study found that self-efficacy has a significant positive predictive effect on self-control, consistent with the results of Huang and Yang (2015) and Kaida et al. (2006).

The present study also hypothesized that self-efficacy mediates the effects of neuroticism, agreeableness, conscientiousness, and extraversion on self-control. The present study observed four mediating paths, showing partial mediating effects of self-efficacy on self-control for each personality trait variable. Many other researchers have also found that self-efficacy mediates the link between personality traits and self-control, such as Fang et al. (2015) and Stajkovic et al. (2018). Therefore, cultivating and upgrading the self-efficacy of boxers should be emphasized in their training.

LIMITATIONS

Firstly, with the cross-sectional design, no causal relationship could be established. Secondly, the present study focused on the role of self-efficacy in the relationship between Big Five personality traits and self-control, but there are still many other important mediating variables which may influence self-control, such as depression, anxiety, or self-esteem and self-concept, which should also be explored in future research. Finally, the current study focused on Chinese boxers. Further research is needed to figure out whether the results of this study can be generalized to other sports or western cultures.

Despite these limitations, the present study contributes to understand the inherent relationship between big five personality and self-control as well as its possible mechanisms among Chinese boxers. The exploration of the variables can add a fruitful avenue toward the development of knowledge about the processes involved in self-control in sport.

CONCLUSIONS

First, there were significant differences in self-control and self-efficacy among boxers of different competitive levels. Second, there are significant correlations of neuroticism and agreeableness, conscientiousness, and extraversion with self-control, indicating that these four dimensions are direct statistical predictors of self-control. Self-efficacy is positively correlated with self-control. Finally, boxers' self-efficacy mediates personality traits and self-control, indicating that personality traits predict self-control not only directly but also indirectly through self-efficacy. Overall, the mediation effect models constructed in this study had some explanatory power for self-control.

DATA AVAILABILITY

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

ETHICS STATEMENT

The protocol was approved by the Southwest University's Human Research Ethics Committee. Prior to initiation of the study, all subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

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

FUNDING

This work was supported by the Sports Scientific Research Project of Chongqing in 2016 (B201622), Fundamental Research Funds for the Central Universities of China (SWU1809220) and (SWU1709116).

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Conflict of Interest Statement: 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.

frontiers in Sports and Active Living

SYSTEMATIC REVIEW
published: 09 August 2019
doi: 10.3389/fspor.2019.00007

A Systematic Review of Attentional Focus Strategies in Weightlifting

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The way an athlete focuses their attention when lifting a weight has the potential to influence strength development during training and performance outcomes during competition. The effects of attentional focus strategies during weightlifting tasks was investigated through a systematic review. Major databases (SportDISCUS, PsycINFO, Scopus) were searched using key terms relevant to attentional focus and weightlifting and reference lists of identified articles were also searched. Following screening, 16 articles were retained for analysis. The review showed that researchers have recruited experienced and novice weightlifters of both genders in their studies, although male experienced weightlifters are the most commonly studied demographic. Weightlifting tasks have varied from bench press, biceps curls, squats, and leg extensions with some studies using measures of force production against a force plate. The predominant manipulations have been between internal-associative and external-associative foci. An external attentional focus has shown to be beneficial in terms of movement economy as reflected in a variety of outcome measures. The results are interpreted within the framework provided by the Constrained Action Hypothesis and more generally the advantages of an external attentional focus for motor skill learning. An external focus of attention promotes automatic control of actions, thus preventing the motor system being constrained by conscious cognitive control. Implications for informing training programs for athletes and for advising athletes to maximize performance during competition are discussed.

Keywords: attention, weightlifting, concentration, performance, strength training, attentional focus

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Sports and Active Living

Received: *31 May 2019*
Accepted: *15 July 2019*
Published: *09 August 2019*

Citation:
Neumann DL (2019) A Systematic Review of Attentional Focus Strategies in Weightlifting. Front. Sports Act. Living 1:7. doi: 10.3389/fspor.2019.00007

INTRODUCTION

The action of lifting a weighted apparatus is ubiquitus in sport and exercise. It is used during training to develop muscle strength, muscle mass, and joint strength. It is is also a competitive sport in its own right, as reflected in its Olympic Games status and the formation of national and international governing bodies. The sport of weightlifting requires lifts of the snatch and the clean and jerk with athletes aiming to lift the heavest weight for their division during competition. Other competitive events, often referred to as powerlifting, require the deadlift, squat, and bench press. Weightlifting is also a key component of training for other sports and as part of a physical exercise program. In these situations, there are a multitude of different types of lifts according to the muscles required, equipment used, and the speed, duration, and complexity of the movements.

The physical nature of weightlifting has naturally led to research on physical factors, such as physiology, biomechanics, diet, and injury. Comparatively less work has been conducted on the psychological processes associated with weightlifting. The psychology of weightlifting has been examined from various perspectives, including self-efficacy, intention, and self-regulation behaviors (Rhodes et al., 2017), mindfulness and contemplative movement (Vernon, 2018), and instruction techniques (Milanese et al., 2017). Attentional focus is another psychological factor that has potentially important implications for learning and performance in weightlifting.

Attentional focus, in the context of sport and exercise performance, refers to the process in which the athlete allocates mental resources to cues, stimuli, or states. Attentional focus is commonly classified along one or more dimensions. Nideffer (1976) proposed two dimensions of direction (internal or external) and width (broad or narrow). Stevinson and Biddle (1998) also proposed two dimensions, although they divided attentional foci along task-relevance (association or dissociation) and direction (internal or external). Two dimensional schemes such as these will allow for a particular attentional focus to reflect a combination of the two dimensions. For instance, the task-relevance and direction scheme results in four combinations of internal association (e.g., muscle fatigue, breathing, pain), internal dissociation (e.g., daydreams, mental puzzles, recalling memories), external association (e.g, split times, distance markers, targets), and external dissociation (e.g., scenery, crowd, listening to music).

Subsequent classification schemes have extended upon the task-relevance (or association) and direction dimensions of Stevinson and Biddle (1998). Wininger and Gieske (2010), for example, divided a task-relevance internal foci into bodily sensations, task-relevant thoughts, and self-talk. Brick et al. (2014) used two internal association categories of internal sensory monitoring and active self-regulation. The external association combination has also been conceptualized in different ways, such as a focus on the movement effect (Wulf, 2013). The dimensions or specific categories in a dimension may be more relevant for some types of sports than others. For example, the scheme proposed by Brick et al. (2014) provides an excellent framework for endurance sports like running, cycling, and rowing.

Attentional focus in weightlifting has been largely investigated from the attentional focus strategies of internal association and external association (usually simply referred to as internal and external foci). This approach stems from the influential work by Wulf et al. demonstrating the performance benefits of an external attentional focus over an internal attentional focus in ski-simulator and balancing tasks (Wulf et al., 1998). The external attentional focus benefits were subsequently extended to other motor and sport-related tasks (for reviews, see Wulf, 2007, 2013; Marchant, 2011; Lohse et al., 2012; Wulf and Lewthwaite, 2016). The research has generally shown that focussing away from the body and on the intended movement effect (external focus) produces superior learning and performance outcomes than focussing toward the body (internal focus). Moreover, this effect seems to be due to a relative improvement in performance with an external focus, rather than a relative impairment of performance with an internal focus, because an external focus will typically produce better outcomes than no specific attentional focus instructions.

The benefits of an external focus of attention for motor learning and performance has been reflected in a range of tasks and outcome measures (for details see Wulf and Lewthwaite, 2016). Benefits have been observed in movement effectiveness (e.g., better balance, higher accuracy), movement efficiency (e.g., reduced muscular activity, higher peak force, greater speed, longer endurance), better movement form, and more automatic and fluid movements. The potential for an external focus of attention to enhance movement efficiency is of particular relevance for weightlifting. For example, it may allow an athlete to lift the same weight through less muscular effort. Conversely, and more importantly for competition, it may allow an athlete to lift a heavier weight than would otherwise be possible when no specific attentional focus is adopted.

The present review examined research on attentional focus strategies during weightlifting. A systematic literature review was conducted in which relevant electronic databases were searched using key terms. Search results were screened to yield a final set of articles for coding and analysis. The review aimed to answer the following questions:

1. What types of weightlifting tasks and equipment are used in research?
2. What are the characteristics of the participants who have been studied?
3. What have been the aims, methods, conditions, measures and key findings of research?
4. What theoretical framework has been used to guide the research and interpret the findings?

Following a review of these questions, it was hoped to develop some general principles from what is known about attentional focus in weightlifting. Practical applications and suggestions for research are also offered.

METHODS

The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines were followed for the literature search (Liberati et al., 2009), and the rules of inclusion and exclusion described by Meline (2006) were applied. Initially, the SPORTDiscus, PsycINFO, and Scopus databases were searched. The terms used in conducting the search included: ("focus of attention" OR "attentional focus" OR "attentional focusing") AND ("weight lifting" OR weightlifting OR "weight training" OR "strength training" OR "force production" OR "motor control") AND (internal OR external OR association OR dissociation OR associative OR dissociative). The search was not limited by date of publication and included all articles available at time of search (October, 2018). Additionally, to identify articles that may have been missed due to inconsistent use of terms (e.g., "attentional focus" vs. "focus of attention"), the reference lists of

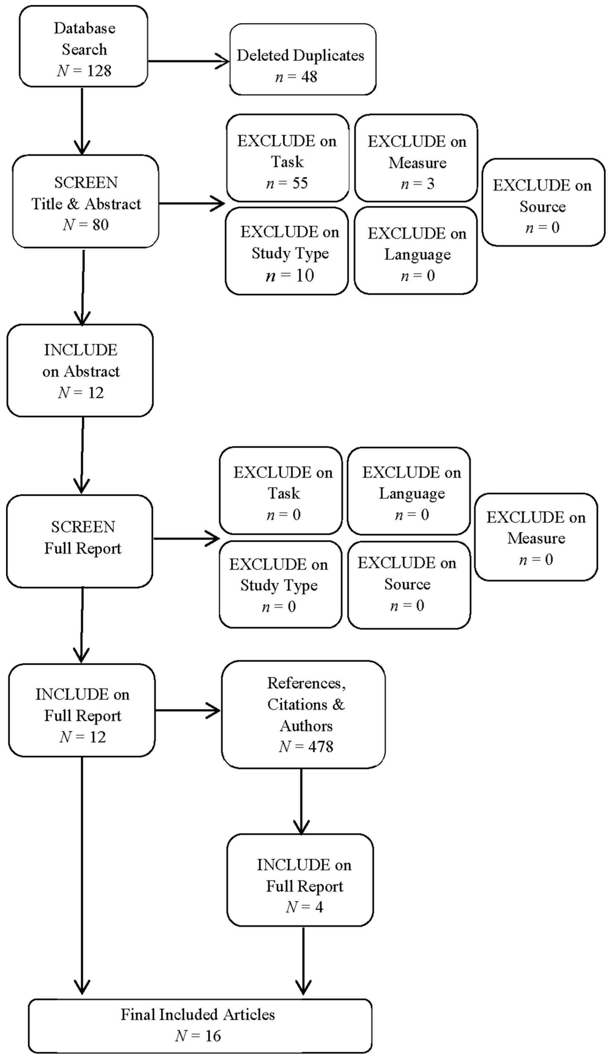

FIGURE 1 | Search results and outcomes of the screening process.

all articles initially selected for inclusion from the database search were examined.

The results from the literature search and screening are shown in **Figure 1**. The database search resulted in 27 articles from PsychINFO database, 46 articles from SPORTDiscus database, and 55 articles from Scopus database, totaling 128 articles. Following the removal of duplicates, this number was reduced to 80 unique articles. Articles were then screened for exclusion or inclusion in a two-step process: title and abstract (step 1) and the full article (step 2). Articles were excluded based on the following criteria: language (not published in English language), source (a dissertation, thesis, abstract only, magazine article, or from a non-peer reviewed source), study type (review, meta-analysis, commentary, letters, or any non-empirical article), did not measure or manipulate attentional foci, did not examine movement against a weight or force plate, or did not include a measure of physical performance or physiological activity.

Following this selection process, a total of 12 articles from the database search, with a further four articles identified following the examiniation of the selected articles reference lists were obtained. As such, a total of 16 articles were included in the systematic review. **Table 1** shows the citation metrics for the articles that were published in journals present in the Scimago Journal & Country Rank database. The mean 2-year impact factor was 1.90 (range 0.968–2.717, *SD* = 0.54), the mean journal h-index was 86.33 (range 42–117, *SD* = 22.64), and seven journals were Q1 ranked. These citation metrics suggest that the journals that published this research were of moderate to high quality. The articles were coded by study characteristics (aims, conditions/groups, outcome measures, and key findings), participant characteristics (sample size, age, gender, weight lifting experience, and location), and task characteristics (exercise/movement completed and equipment used).

RESULTS

Tasks and Equipment Used in Research

The types of weightlifting tasks and equipment used in research on attentional focus strategies are shown in **Table 2**. As can be seen, the bench press (Marchant et al., 2011; Snyder and Fry, 2012; Calatayud et al., 2018a,b; Kristiansen et al., 2018), force plate (Lohse et al., 2011; Lohse, 2012; Lohse and Sherwood, 2012) and bicep curls (Vance et al., 2004; Marchant et al., 2008, 2009; Neumann and Heng, 2011) have been the most commonly used. The bench press and bicep curls are advantageous because they involve relatively simple movements and effectively isolate key muscles. The bench press is also a powerlifting event, and so enhances the real-world relevance of outcomes for competition. The snatch was used by Schutts et al. (2017), which is the only study found in the search to have used an Olympic weightlifting event.

Lohse et al. (2011), Lohse (2012), and Lohse and Sherwood (2012) examined force production when participants pushed with their feet against a force plate. The apparatus allows for the investigation of motor planning (Lohse, 2012), as well as intermuscular coordination (e.g., co-contraction of muscles) and intramuscular coordination (e.g., motor-unit recruitment) under different types of attentional foci (Lohse et al., 2011). The use of a force plate is thus a useful complement to free weights in research. Although not included following the screening process, research has also examined attentional focus effects on muscle activity during a sit up task (Neumann and Brown, 2013), which was a task that did not involve muscular force against any apparatus. There are thus a wide variety of tasks that researchers have used to examine attentional foci at the neuromuscular level.

Participant Characteristics

The characteristics of the participants who have been studied in research are shown in **Table 3**. Most studies have used both male and female participants, with some studies restricting their sample to males only. No studies exclusively used female participants. Although sex does not typically moderate attentional focus effects (but for examples see Becker and Smith, 2013; Flôres et al., 2016; Emad et al., 2017), it is still

TABLE 1 | Publication details of the studies selected for review.

References	Journal name	2-year impact factor	Journal h-index	Quartile
Calatayud et al., 2018a	Journal of sports sciences	2.715	117	Q1
Calatayud et al., 2018b	Perceptual and motor skills	0.989	60	Q4
Greig and Marchant, 2014	Human movement science	1.956	80	Q2
Halperin et al., 2016	Journal of strength and conditioning research	2.340	108	Q1
Kristiansen et al., 2018	Journal of strength and conditioning research	2.340	108	Q1
Lohse, 2012	Human movement science	1.956	80	Q2
Lohse et al., 2011	Journal of motor behavior	1.328	63	Q3
Lohse and Sherwood, 2012	Acta psychologica	1.632	88	Q1
Marchant et al., 2008	Athletic insight	–	–	–
Marchant et al., 2009	Journal of strength and conditioning research	2.340	108	Q1
Marchant et al., 2011	Research quarterly for exercise and sport	2.01	82	Q2
Marchant and Greig, 2017	Human movement science	1.956	80	Q2
Neumann and Heng, 2011	Journal of psychophysiology	0.968	42	Q3
Schutts et al., 2017	Journal of strength and conditioning research	2.340	108	Q1
Snyder and Fry, 2012	Journal of strength and conditioning research	2.340	108	Q1
Vance et al., 2004	Journal of motor behavior	1.328	63	Q3
	Mean (SD)	1.90 (0.54)	86.33 (22.64)	

Citation metrics of 2-year impact factor, journal h-index, and quartile ranking were obtained from Scimago Journal and Country Rank database.

an important empirical question on whether sex differences exist for weightlifting. It is thus recommended that future research include both sexes in research when possible to ensure generalisability of findings and that analyses are conducted to check for sex differences.

Participants have tended to be experienced in weightlifting, although a sizeable portion of studies did not specify the participant experience level. Experienced participants are more likely to be well-practiced and to have develop automaticity in movements. Given the notion that an external focus of attention facilitates automatic motor processes (Wulf and Lewthwaite, 2016) it may be expected that experienced participants are particularly likely to benefit from an external focus of attention than an internal one. Novice participants have also shown learning and performance benefits from an external attentional focus across a range of tasks (Wulf and Lewthwaite, 2016). However, there have been exceptions (e.g., Perkins-Ceccato et al., 2003). In line with the recommendation of Greig and Marchant (2014), further research is needed that tests for differences between experienced and novice participants in attentional focus effects.

Other characteristics of the participants have shown that many studies have recruited undergraduate students or participants aged 20–25 years on average. While some studies have used older samples, these have had a mean age no older than 31 years. Future research could recruit older adult samples to ensure the generality of the findings across a wide age range. Similarly, no studies have recruited younger participants, such as adolescents and children, and it remains to be determined whether study findings can be replicated with a young age group. Most studies have been conducted in Western countries, most noteably the USA, England, and Denmark. Finally, the sample sizes used in research has been relatively small. Samples have varied from 11 to 29 participants with a mean of 17.67 participants. It is recommended that researchers recruit larger samples to ensure that there is sufficient statistical power, to minimize the reporting of spurious findings, and to ensure generality of findings. In summary, reseach has used relatively small samples with participants typically comprised of young males from Western countries who are experienced in the sport of weightlifting.

Aims, Methods, and Key Findings

A summary of the aims, methods, conditions, measures, and main findings in the experiments reported in the 16 studies reviewed is provided in **Table 4**. An external focus of attention has produced lower EMG activity (peak EMG, average EMG, or integrated EMG) than an internal focus of attention in several studies (Vance et al., 2004; Marchant et al., 2008, 2009; Lohse et al., 2011; Lohse and Sherwood, 2012; Greig and Marchant, 2014; Marchant and Greig, 2017). An external focus has also shown superior performance over an internal focus for peak torque (Greig and Marchant, 2014), force production (Marchant et al., 2009; Halperin et al.,

TABLE 2 | Characteristics of the task and equipment used.

References	Task	Equipment
Calatayud et al., 2018a	Bench press	Barbell
Calatayud et al., 2018b	Bench press	Barbell
Greig and Marchant, 2014	Bicep curl	Isokinetic dynamometer (Biodex, System 3)
Halperin et al., 2016	Isometric midthigh pull	Barbell and 9290AD quattro jump force plate
Kristiansen et al., 2018	Bench press	Barbell
Lohse, 2012	Force production—foot pressing	Force plate
Lohse et al., 2011	Force Production—Foot Pressing	Force plate
Lohse and Sherwood, 2012		
Experiment 1	Force production—foot pressing	Force plate
Experiment 2	Force production—foot pressing	Force plate
Marchant et al., 2008	Bicep curls	Isokinetic dynamometer (biodex, system 3)
Marchant et al., 2009	Bicep curls	Isokinetic dynamometer (biodex, system 3)
Marchant et al., 2011		
Exercise 1	Assisted bench press: 40 kg for men, 20 kg for women	Smith machine
Exercise 2	Bench press: 75% of 1-RM	Standard bench and barbell
Exercise 3	Back Squat in high bar position: 75% of 1-RM	Standard barbell
Marchant and Greig, 2017	Leg extension	Isokinetic dynamometer (biodex, system 3)
Neumann and Heng, 2011	Bicep curls	Dumbbell set with changeable disc weights
Schutts et al., 2017	Snatch: 80% of 1-RM	Standard barbell
Snyder and Fry, 2012	Bench press: 50 and 80% of 1-RM	Standard barbell and bench
Vance et al., 2004	Bicep curls-–50% of 1-RM	Weighted barbell

2016), reduced pre-movement time in early stages of learning an isometric force production task (Lohse, 2012), accuracy in a force production task (Lohse et al., 2011; Lohse and Sherwood, 2012), more repetitions before failure (Marchant et al., 2011), and better movement kinematics for the snatch (Schutts et al., 2017).

The conditions that may limit the effects of an internal or external focus have also been examined. Lifting at a controlled or explosive speed did not alter the size of muscle contractions as measured by EMG for an internal focus strategy (Calatayud et al., 2018a,b). Moreover, using grips of different width does not interact with the type of attentional foci (internal or external) on EMG activity. In a study on force production, an external focus of attention produced lower EMG than an internal focus at all speeds, but an interaction between focus type and speed was observed for peak torque such that the attentional focus conditions differed in torque only at slower speeds (Greig and Marchant, 2014). The latter findings suggest that lifting speed may influence attentional focus effects.

It is often reported that an external focus is superior than both an internal focus and a control (no instructions) condition and that this is evidence for a beneficial effect of an external focus rather than a relative detrimental effect of an internal focus (Wulf, 2007). Similar outcomes have been reported in weightlifting and force production tasks (Marchant et al., 2008, 2011). However, this finding has not always been found. Both an external and control condition resulted in greater force during an isometric midthigh pull than an internal condition (Halperin et al., 2016). An external focus resulted in more repetitions to failure than an internal focus, but did not differ from a control condition for an assisted bench press (Marchant et al., 2011).

Furthermore, research has not always shown performance benefits with an external focus of attention. No differences between internal and external foci have been observed for time to failure or ratings of perceived exertion for a long duration force production task (Lohse and Sherwood, 2012). In different findings, Kristiansen et al. (2018) reported that both an external and an internal attentional focus produced greater mean and peak EMG amplitude than a baseline condition during a bench press. In the baseline condition, participants performed the lift as they normally would. The authors suggested that the results may reflect that experienced weight lifters were participants and that the use of attentional instructions of any type may have interfered with their normal technique. Another explanation could be that the baseline condition was completed first and performance in the subsequent conditions suffered from fatigue effects. Yet another explanation may relate to the relative high complexity of the attentional focus instructions. For instance, the external focus instructions required participants to maintain the same tempo of the lift as done in the baseline condition

TABLE 3 | Sample size and participant characteristics.

References	N	Gender	Age in years (SD)	Experience	Location
Calatayud et al., 2018a	18	Male	M = 31 (8)	Experienced	Denmark
Calatayud et al., 2018b	18	Male	M = 31 (8)	Experienced	Denmark
Greig and Marchant, 2014	25	Both	M = 23.53 (1.76)	Inexperienced	England
Halperin et al., 2016	22	Both	M = 22.5 (3.3) Range: 17–28	Experienced	Australia
Kristiansen et al., 2018	21	Male	M = 24.5 (2.2)	Experienced	Denmark
Lohse, 2012	24	Both	Undergraduates	Unknown	United States
Lohse et al., 2011	12	Both	Undergraduates	Unknown	United States
Lohse and Sherwood, 2012					
Experiment 1	12	Both	Undergraduates	Unknown	United States
Experiment 2	12	Both	Undergraduates	Unknown	United States
Marchant et al., 2008	29	Both	M = 19.6 (1.3)	Experienced	England
Marchant et al., 2009	25	Both	M = 22.72	Inexperienced	England
Marchant et al., 2011					
Assisted bench press	23	Both	M = 30.87 (12.27)	Experienced	England
Bench press	17	Male	M = 20.82 (1.42)	Experienced	England
Back squat	17	Male	M = 20.82 (1.42)	Experienced	England
Marchant and Greig, 2017	20	Both	M = 20.2 (1.47)	Experienced	England
Neumann and Heng, 2011					
Group 1	16	Both	Male: M = 23.14 (4.28) Female: M = 29 (11.31)	Novice	Australia
Group 2	14	Both	Male: M = 24.31 (3.30) Female: 22	Experienced	Australia
Schutts et al., 2017	12	Both	M = 23.7 (2.9)	Experienced	United States
Snyder and Fry, 2012	11	Male	Undergraduates	Experienced	United States
Vance et al., 2004					
Experiment 1	11	Male	M = 26.00 (6.00)	Experienced	United States
Experiment 2	12	Both	Not provided	Experienced	United States

while also attending to the movement of the barbell and making the move as smooth as possible. The internal focus instructions also referred to moving the barbell as smooth as possible and at the same tempo as the baseline condition, as well as focusing on the pectoralis muscle contractions. These internal focus instructions included some reference to an external focus (move the barbell as smooth as possible). Wulf (2007) has suggested that the use of vague or complex attentional focus instructions may mitigate the benefits of an external focus over an internal one.

To elicit an internal attentional focus, researchers have typically used simple instructions requiring participants to attend to the feelings of the muscle or combinations of muscles primarily involved in the lift. A focus on the primary muscles involved in lifting will increase EMG activity measured from that muscle (Calatayud et al., 2018a). Moreover, a focus on secondary muscles for a lift (e.g., triceps for a bench press) will increase EMG activity of the primary muscle (i.e., pectoralis). However, it should be noted that effects of focusing on a specific muscle may vary across the weights being lifted. Attention to a specific muscle increased activity of the muscle that attention was directed toward when a lighter weight was lifted (50% of 1-RM) but not when a heavier weight was used (80% of 1-RM) for a bench press (Snyder and Fry, 2012).

Instructions used to induce an external focus of instruction have typically required participants to focus on the movements of the barbell, dumbbell, crank handle, or platform (see **Table 4**). Calatayud et al. (2018b) defined an external focus as lifting the barbell in a regular way. However, it may be argued that this instruction did not adequately require participants to focus on the movement effects of the exercise. Further research would be required to evaluate this possibility.

In the only research to examine other forms of attention focus strategies, Neumann and Heng (2011) compared an associative and dissociative focus strategy during a biceps curl task. The study was also unique in measuring heart rate in addition to muscle activity (see Neumann and Thomas, 2009, 2011 for examples of attentional focus effects on heart rate during sport tasks). The dissociative condition required participants to listen to audio of a song whereas the associative condition consisted of listening to audio of a tone that changed in nature based on the EMG amplitude recorded from the biceps muscle. A control condition using no audio and no specific focus instructions was also used. The results showed that EMG, iEMG, and heart rate were lower during the associative strategy than during the dissociative strategy and control conditions. The differences between conditions may reflect a relative benefit of an associative strategy for muscular efficiency. The benefit may reflect that the associative condition had a predominantly external focus (i.e., the effects of the movement on the external audio stimulus). However, the associative condition may have also had an internal

TABLE 4 | Characteristics of the aims, conditions, measures, and key findings.

References	Aims	Conditions	Measures	Key findings
Calatayud et al., 2018a	To investigate the effect of different attentional focus strategies on muscle activity during the bench press at explosive and controlled speeds.	Focus instruction: regular focus (lift the barbell in a regular way), focus on pectoralis (try to focus on using your chest muscles only), focus on triceps (try to focus on using your triceps muscles only) Barbell speed: controlled (2 s rate of descent 2 s ascent), explosive (as fast as possible)	Electromyography (EMG) Contraction duration (for explosive condition)	During the controlled condition, focusing on either the pectoralis or triceps resulted in increased EMG activity in the pectoralis by 6 and 4%, respectively, over using a regular focus. Additionally, in the controlled condition, activity in the triceps increased 4% when a triceps focus was used. There was no difference found in EMG activity or contraction duration between the focus conditions when lifting explosively.
Calatayud et al., 2018b	To investigate the effects of either external or internal focus strategies and varying grip widths on muscle activity during the bench press	Focus instruction: internal for pectoralis (try to focus only on using your chest muscles), internal for triceps (try to focus only on using your triceps muscles), external focus (just lift the barbell in a regular way)	EMG	Significant main effects for attentional focus and grip width for EMG activity in both the pectoralis and triceps muscles (higher during internal focus than external focus), but no significant interactions.
Greig and Marchant, 2014	To investigate the effects of internal and external focusing instructions on force production and muscle activity at varying movement speeds.	Focus instructions: internal (focus on the movement of your arm and muscles during the lift), external (focus upon the movement of the crank hand-bar during the lift). Speed: move the crank at 60°, 180°, or 300° per second.	Force production measured using peak torque Muscle activity measured using EMG	External focus associated with lower EMG in all speeds compared to internal focus. However, an external focus only produced greater torque than in an internal focus when speed was at 60° per second condition. This suggest that focusing instructions may be less effective for explosive movements.
Halperin et al., 2016	To investigate the effect of attentional focus on a force production during an isometric midthigh pull in trained athletes.	Focus instructions: control (Focus on going as hard and as fast as you possibly can), internal (Focus on contracting your leg muscles as hard and as fast as you possibly can), external (Focus on pushing the ground as hard and as fast as you possibly can)	Force measured using Newtons (N).	Both the external focus and control instructions resulted in greater force production than the internal focus instructions (9 and 5%, respectively). This suggests that adopting an internal focus while exerting maximal force hinders performance.
Kristiansen et al., 2018	To compare the effect of internal and external focus with no focus instruction on muscle activity during a 60% 3 RM bench press	Three conditions completed by all participants. Baseline included no focus instructions. External condition instructed participants to focus on the movement of the barbell and that the movement should be as smooth as possible. Internal condition required participants to focus on the contraction of the pectoralis muscle.	Electromyography (EMG)	Both internal and external focus conditions resulted in significantly greater mean and peak EMG amplitudes for 6-upper body muscles compared to baseline, despite all conditions involving the same weight and repetitions. These results suggest that both focus instructions were detrimental to performance. Results could be explained by the fact that participants were experienced lifters and introducing complicated instructions may have interfered with their natural technique.
Lohse, 2012	To investigate the effect of attentional focus on accuracy and pre-movement time during an isometric force production task	Focus instructions: External focus (Mentally focus on the push of your foot against the platform and push harder or less on the platform), Internal focus (Mentally focus on the calf and contract the muscle harder or less)	Accuracy (needed to meet maximum voluntary force [MVC] of either 25% or 50%)	External focus resulted in reduced pre-movement time in early stages of learning, and improved transfer performance (moving from 25% MVC target to 50% MVC target or vice versa) over internal focus.

(Continued)

TABLE 4 | Continued

References	Aims	Conditions	Measures	Key findings
Lohse et al., 2011	To investigate the effect of attentional focus instructions on force accuracy and muscle activity during an isometric force production task	Focus instructions: External focus (Mentally focus on the push of your foot against the platform), Internal focus (Mentally focus on pushing with the muscle of your calf)	Accuracy (target = 30% of maximal force) EMG	Greater accuracy in the external focus condition, and less muscle activity in the tibialis anterior of the calf, but no difference in activity in the soleus. These results suggest that muscles were more efficient and performed better when using an external focus than using an internal focus.
Lohse and Sherwood, 2012				
Experiment 1	To test the effects of attentional focus on accuracy and efficiency at varying levels of muscle contraction	Focus instructions: External focus (mentally focus on the push of your foot against the platform), Internal focus (mentally focus on pushing with the muscle of your calf) Target force: 30, 60, and 100 %MVC. Participants were informed how this force would translate to pounds of force. Force held for 4 second windows.	Accuracy (absolute error: average force across 3 s window with participant's target force subtracted) Cocontraction-ratio (dividing tibialis activity by soleus activity)	External focus produced more accurate force production across all force production targets. Additionally, an external focus reduced cocontraction, suggesting that the muscles performed more efficiently.
Experiment 2	To test the effects of attentional focus on muscle fatigue at varying level of muscle contraction	Focus instructions: External focus (mentally focus on the push of your foot against the platform), internal focus (mentally focus on pushing with the muscle of your calf) Target force: 30, 60, and 100 %MVC. Participants were informed how this force would translate to pounds of force. Participants were required to hold the target force for 60s for 30 and 60 %MVC or until failure for 100 %MVC.	Accuracy (absolute error: average force across 3 s window with participant's target force subtracted) Cocontraction-ratio (dividing tibialis activity by soleus activity) Time to failure (length of holding 100% MVC) Ratings of perceived exertion (for 100% MVC)	Attentional focus had no effect on time to failure, RPE, or accuracy. However, an internal focus of attention resulted in greater cocontraction in early trials, suggesting less efficient muscular coordination.
Marchant et al., 2008	To investigate the effect of attentional focusing on muscular activity during the bicep curl with controlled movement speed	Focus instructions: no instruction, internal focus (focus upon the movement of the arm during the lift), external focus (focus upon the movement of the crank handle during the lift)	Peak EMG Activity Integrated/total EMG activity over 10 repetitions	Peak muscle activity was lower when using external focus than using internal focus and no specific instructions. Total muscle activity was also lower in the external condition than internal condition. These results suggest that the use of external focus resulted in more efficient muscle control.
Marchant et al., 2009	To investigate the influence of attentional focusing instructions on force production and muscle activity during isokinetic elbow flexions.	Focus instructions: internal (focusing internally onto movement mechanics), external (focusing externally onto the outcome of the movement)	EMG Force production (torque)	An external focus of attention results in greater force production and lower EMG activity than an internal focus.
Marchant et al., 2011	To investigate the influence of attentional focusing instructions on muscular endurance in three types of exercises in experienced athletes	Focus instructions: Control (perform as many repetitions as you can before failure), internal (focus on moving and exerting force with your arms/legs), external (focus on moving and exerting force through the barbell)	Repetitions until failure	For the assisted bench press, an external focus of attention resulted in more repetitions before failure than an internal focus, but not for the control instructions. For the standard bench press and back squat, using an external focus of attention resulted in more repetitions before failure than both the internal focus and control instructions.

(Continued)

TABLE 4 | Continued

References	Aims	Conditions	Measures	Key findings
Marchant and Greig, 2017	To investigate the effect of internal focus instructions which emphasize specific muscular activity compared to external focus instructions which emphasize outcome on force and muscle activity during a knee extension task.	Focus instructions: internal focus (focus on muscular activation), external (focus onto the movement outcome)	Force (Peak torque and mean power output) Integrated EMG of vastus lateralis (VL), vastus medialis oblique (VMO), and rectus femoris Ratio of activation for VMO and VL	No difference in torque produced between the focus instructions. External focus instructions resulted in lower iEMG magnitude across muscles than internal focus. Internal focus resulted in greater EMG activity, but not in the specific VMO, suggesting that the internal focus did not result in a selective isolation. Instead, there was a spreading activation effect with elevated activity in muscles not within the focus of attention. Findings suggest that an external focus of attention results in increased muscular efficiency.
Neumann and Heng, 2011	To investigate the effects of an associative and dissociative attentional strategy on muscle activity for a biceps curl	Focus instructions: control (repeat previous lifting technique), dissociative (listen to lyrics of a song playing, and count the occurrence of a word), associative (attend to an auditory tone which varied based on EMG from biceps activity)	EMG and iEMG Heart rate Perceived exertion and exercise satisfaction Movement degrees and velocity	Adopting an associative strategy resulted in lower EMG, iEMG, and heart rate compared to dissociative and control strategies. No difference found in subjective measures of exertion or satisfaction. Movement velocity slower in associative condition than in dissociative or control condition.
Schutts et al., 2017	To investigate the effect of focus of attention on kinematic performance of the snatch	Focus instructions: internal focus (concentrate on moving your elbows high and to the side rapidly), external focus (concentrate on moving the barbell back and up rapidly)	Barbell-cervical-hip angle Vertical/Horizontal barbell velocity Peak elbow velocity	Internal focus resulted in increased elbow velocity compared to external focus. External focus increased horizontal barbell velocity compared to internal. The internal focus also resulted in the athlete squatting under the barbell too soon.
Snyder and Fry, 2012	To investigate the ability of athletes to isolate specific muscles when given internal focus instructions during the bench press	Focus instructions: non-specific instructions, internal (focus on chest muscles), internal (focus on arm muscles)	EMG	Instruction to focus on the chest muscles and triceps muscles increased muscle activity over baseline in these specific areas when bench pressing 50% of 1-RM. At 80% of 1-RM only instructions to focus on chest muscles resulted in an increase in muscle activity over baseline, while instructions regarding a focus on triceps resulted in no further activity over baseline.
Vance et al., 2004				
Experiment 1	To investigate the effect of focus of attention on movement speed and muscle activity during the biceps curl	Focus instructions: internal (concentrate on biceps muscles), external (concentrate on the curl bar)	Angular velocity, EMG and iEMG	Movement was faster and iEMG was reduced in the external focus condition compared to the internal focus condition.
Experiment 2	To investigate the effect of focus of attention on muscle activity when timing is controlled during the biceps curl	Focus instructions: internal (concentrate on biceps muscles), external (concentrate on the curl bar)	Angular velocity, EMG and iEMG	iEMG was reduced when adopting an external focus compared to an internal focus. This was true even with average range and movement time the same between focus conditions.

component due to the audio being directly linked to muscle contraction strength.

Theoretical Frameworks

The beneficial effect on performance of adopting an external focus of attention compared to an internal focus is well-established across a range of different motor tasks, including those that are sport-related (Wulf, 2013; Wulf and Lewthwaite, 2016). The same conclusion has been reached in most, but not all, of studes examining internal and external attentional foci during weightlifting tasks (see **Table 4**). In addition, it has been shown that adopting an associative strategy results in beneficial effects over a dissociative strategy for bicep curls (Neumann and Heng, 2011), which may reflect that the associative condition in the study was largely external in nature.

The benefits of an external focus over an internal focus of attention in terms of reduced muscle activity may be explained by differences in the spread of activation between the two types of foci. In a knee extension task, Marchant and Greig (2017) reported that an internal focus of attention produced higher overall EMG, and that this was not specific to the muscles isolated in the task but that it reflected a spreading activation of increased muscle activity. The authors suggested that this pattern reflects than an external focus of attention results in increased muscular efficiency. A similar interpretation has been made using the measure of integrated EMG (iEMG) (Vance et al., 2004). An external attentional focus has resulted in lower iEMG than an internal focus (Vance et al., 2004; Marchant and Greig, 2017).

Increased muscular efficiency is a key component of the constrained action hypothesis (Wulf et al., 2001), which is one framework in which prior research has been based on. The constrained action hypothesis proposed by Wulf et al. (2001) suggests that adopting an external attentional focus promotes automatic, natural movement control, whereas adopting an internal attentional focus disrupts this automaticity and constrains the neuromuscular system (Wulf, 2013). When an individual focuses on an external cue, it facilitates attention to stimuli distant from their body. This then allows automatic behavior to dominate, improving performance. In contrast, an internal cue constrains motor control, reducing performance. The constrained action hypothesis has since been supported by a number of studies in several different contexts.

Initial evidence for the constrained action hypothesis came from a dynamic balancing task using a stabilometer (Wulf et al., 2001). Participants given an internal instruction were told to focus on their feet and to keep them horizontal, while participants given an external instruction were told to focus on markers attached to the balance platform. Participants underwent 2 days of practice, with each day consisting of seven 90 s balance trials, followed by a retention test on the third day in which no focus instructions were given. Performance was measured on three measures, including reaction time to a dual-task procedure, balance performance, and frequency of adjustments. Participants given the external cue had significantly quicker reaction times, better balance performance, and higher frequency of adjustments. This suggests that those given the external cue experienced lower attentional demands, better learning of balance, and less disruption from voluntary attempts to correct posture, respectively.

McNevin et al. (2003) expanded on these findings in a similar balancing task by introducing different levels of external focus by varying the distance from the body on which participants were instructed to focus. Four groups of participants were instructed to focus on their feet (internal), markers close to the feet (near), markers in the center of the balance platform (far inside), and markers on the outside of the platform (far outside). Findings were similar to that of Wulf et al. (2001) with all three external foci groups performing better than the internal focus group. Additionally, the far inside and far outside groups showed a higher frequency of adjustments, demonstrating the use of more natural automatic motor control.

Most recently, Vidal et al. (2018) investigated the constrained action hypothesis using a standing long jump task with internal and external focus instructions. As expect, participants given an external focus of attention jumped significantly further than those given an internal focus instruction. Additionally, attention instructions affected the movement strategy used by participants, with a difference found in ankle-knee coordination. Those given an internal focus to extend their knees as rapidly as possible showed a jump that recruited primarily knee movement, with minimal hip or ankle movement. In contrast, those given an external focus of trying to jump to cones placed in the distance showed good ankle-knee coordination. These results suggest that the internal focus constrained participants to employing knee flexion, whereas an external focus allowed an automatic coordinated movement pattern between knee and ankle.

The constrained action hypothesis has provided a good explanation of findings from motor tasks as well as weightlifting tasks. Attempts have been made to integrate the hypothesis with other notions of attentional focus effects at the neuromuscular level (see Lohse, 2012; Lohse and Sherwood, 2012). For example, (Willingham, 1999) Control Based Learning Theory of motor control (COBALT) suggests that there are stages of processing that can operate through explicit or implicit modes of control when performing a motor task. Implicit modes are advantageous because they promote automatic selection of spatial targets and automatic movement sequences. An external focus of attention may thus promote implicit control of motor actions and result in better performance. The nodal-point hypothesis (Hossner and Ehrlenspiel, 2010) is another notion with similarities to the constrained action hypothesis. This hypothesis suggests that attention serves to select appropriate actions through the selection of sensory feedback and making ongoing corrections to movements in response to this feedback. This process is faciliated when attention is directed to the effects of movements rather than the movement execution itself. Further research is required to examine the links between the various theories of motor performance within a weightlifting context.

DISCUSSION

The research conducted to date has potentially important implications for training and performance of weightlifting tasks. The increased muscular efficiency and accuracy of force production with an external focus of attention over no specific focus or an internal focus suggests that athletes should adopt an external focus during competition. An external focus may result in superior performance to allow the athlete to lift a heavier weight than may otherwise be possible if attention is directed in other ways. Athletes should practice adopting an external focus when simulating competition during training so that it becomes a component of their competition lifting routine.

Conversely, if increased activation of muscles is the desired goal, there is an argument that athletes should adopt an internal focus of attention. Such benefits of an internal attentional focus would typically exist for training programs that aim to increase muscle growth or strength gains (Marchant et al., 2008). The increased activation of the muscle is likely to be observed in the muscle attended to and to spread to other muscles involved in the lift as suggested by the findings of Marchant and Greig (2017). A similar effect of increased muscle activation might also be observed if athletes adopt a dissociative attentional focus, based on the findings of Neumann and Heng (2011). Whether adopting an internal or dissociative strategy has any actual beneficial effect in training in the short or long term (e.g., increase muscle fatigue more quickly or lead to increased gains in strength) remains to be determined.

An important practical consideration is to determine exactly how the benefits of an external focus of attention for sport performance (or an internal focus on muscle activation) can be achieved in practical terms. The first step in developing effective strategies is to identify what are the key elements that athletes should direct their attention to (Marchant et al., 2008). In research conducted to date, an external focus has been effective when attention is directed to bar or weight being lifted. However, some weight training exercises does not use any apparatus (e.g., unweighted squats, sit ups). In cases when there is no specific implement or object used in a sport, Wulf (2007) suggests analogies and metaphor could be used. Neumann and Brown (2013) had participants direct their attention externally during a sit up task by asking them to focus on making smooth movements without any reference to a body part. For an internal focus of attention, the muscle (e.g., bicep, pectoralis) or the body part (foot, legs) has been commonly used in research as the focal point of attention.

The second consideration is the mechanism by which an instructor promotes an increased attentional focus. The use of instructions, as done in research to date, is the simplest approach and has shown to be effective. Coaches can work with athletes by using instructions to provide clear guidance on how to direct attention effectively. An external focus can be promoted by directing athletes to focus on visual cues like bar movement, the sound of the machine, pushing against the bar, or the end result of the lift. An internal focus can be promoted by instructions that direct athletes to focus on muscle tension, body movements, technique, and form.

Coaches should also provide feedback to athletes to reinforce their learning. Feedback might be enhanced by using additional cues to provide information. For an external focus of attention, this might involve placing markers on the bars or weights, using mirrors, making video recordings, or attaching sensors to the bar or weights to measure movement dynamics (acceleration, velocity, smoothness). For an internal focus, EMG recordings of muscles or movement sensors attached to the body can be used provide visual or auditory feedback to athletes. In addition, athletes should be aware that their own use of "psyching up" or self-talk might need to be modified to ensure that the appropriate attentional focus is used. For example, cue words like "strong" and "powerful" might inadvertently direct the athlete to focus their attention internally and should be modified accordingly during competition.

The third consideration is how to tailor the approach to the specific context. In simple lifts, like the biceps curl, attentional focus instructions are relatively simple because the movement is constrained. However, compound lifts will involve multiple muscles and limbs. In addition, multiple component lifts like the clean and jerk involve discrete movements performed in sequence. Internal focus instructions might need to be varied according to the stage of the lift. Whether external focus instructions need to be varied across the lift remains to be determined. Based on the notion that external attentional focus benefits might result from both intramuscular efficiency and intermuscular efficiency (Vance et al., 2004) the adoption of a single focus may be the most beneficial throughout. For the clean and jerk, for example, the athlete would merely focus on exerting force on the barbell at all stages of the lift. Importantly, when research has examined different types of lifts, the results suggest that the benefits of an external focus of attention may become more pronounced as the movement complexity increases (Marchant et al., 2011). Another important consideration is the amount of weight being lift. Attentional focus instructions may be less effective with higher intensity lifts (Snyder and Fry, 2012). The use of very simple instructions, or just cue words, and extensive practice at lighter weights might mitigate the negative impact of heavy weights on attentional focus effects. Indeed, Schutts et al. (2017) recommends that in general coaching cues for lifting are best if they are short, concise, and specific to the key element being trained.

Exercise psychologists and fitness trainers might also consider appropriate psychological strategies in attentional focus for recreational exercisers. For instance, an external focus of attention may benefit recreational exercisers to adhere to exercise programs. This is because an external focus could draw attention away from negative cues associated with physical exertion and toward positively reinforcing outcomes of the weightlifting exercise (e.g., completion of a rep or set). Research in our laboratory has shown that an external attentional focus has benefits to physical and psychological states during cardiovascular exercise tasks (e.g., Neumann and Piercy, 2013). Moreover, external attentional focus strategies may complement dissociative focus strategies like listening to music, in promoting exercise adherence. An external associative focus may be particularly beneficial given that dissociation can be more difficult to maintain at high levels of exercise intensity. Cognitive strategies like attentional focus may also be integrated with other approaches to promoting physical exercise, like goal setting (e.g., Salehian et al., 2011; Neumann and Honke, 2018).

The studies examined in the present review used weightlifting tasks that were typically of short duration by limiting the number of repetition and sets performed. In considering their findings of less efficient muscular coordination with an internal focus than an external focus, Lohse and Sherwood (2012) suggested that their findings could be relevant to endurance type tasks such as long distance running. It was noted that even a small difference in stride efficiency could be magnified over the course of the entire race due to the high repetitions of the movement. They noted that their internal focus condition produced a trend for shorter time to failure than the external focus condition and that this could reduce performance in endurance running. The benefits of an external attentional focus over an internal attentional focus have been demonstrated in running tasks of short duration (e.g., Schücker et al., 2009; Neumann and Piercy, 2013). However, in a time to exhaustion running task, no difference between internal and external foci was observed in performance or physiological variables (Vitali et al., 2019). Further research is thus required to examine the effects of different attentional foci at the neuromuscular level for endurance tasks and for weight lifting tasks that are performed to exhaustion.

Further research can be conducted to extend upon research regarding the potential benefits of adopting an external (or internal) attentional focus. Importantly, the studies conducted to date have typically been conducted in single-session designs. Thus, the long-term benefits of an external attentional focus remain to be determined. Similarly, transfer effects need to be established to determine whether beneficial attentional focus instructions practiced with one type of lifting exercise in the laboratory will transfer to real world training or competition or to other types of lifting exercises. In addition, it would be worthwhile to examine whether transfer occurs to similar sporting tasks. For example, some sports like shot put and discus, require a short-term maximal muscular effort. It would be informative to examine whether training in an external focus of attention transfers to these tasks (Vance et al., 2004).

The use of new technology to induce attentional foci or that provide additional contexts in which weightlifting can occur requires further investigation. Virtual reality (VR) has emerged as a technology applied to sport (for reviews see Neumann, 2016, 2019; Neumann et al., 2018) and has been most commonly applied to cardiovascular exercises (Murray et al., 2016; Neumann and Moffitt, 2018; Parton and Neumann, 2019) but has also been examined with weightlifting. Chen et al. (2015) examined weightlifting in a virtual environment and found that bicep muscle activity and ratings of perceived workload during bicep curls was higher in the VR condition than a non-VR. These findings may reflect that the VR condition increased an internal attention focus on the mechanics of the movement within the virtual environment. The substitution of a weighted apparatus that participants must move to produce an effect in a virtual environment would be one way to promote an external attentional focus (e.g., completing a deadlift could be translated into virtually lifting a heavy bar to free a trapped virtual person). Physiological measures can also be applied in sport in the form of biofeedback. The study by Neumann and Heng (2011) is an example where muscle activity was translated into an audio signal to direct attentional focus during a biceps curl. In addition, physiological measures other than EMG could be used to examine attentional focus effects on general arousal or emotional reactivity due to the relationship between central and peripheral measures with emotional states (e.g., see Neumann and Westbury, 2011).

CONCLUSIONS

Weightlifting for physical conditioning or sport depends on many physical and psychological factors. Research examining cognitive strategies has shown that performance at the neuromuscular and behavioral level are influenced by the attentional foci that an athlete adopts. To maximize muscular efficiency, an external focus of attention is more optimal than an internal focus of attention or no specific focus in most cases. The challenge remains for researchers to further explore this effect and determine under which conditions it may be magnified. This information will assist in translational research that can allow athletes to reach a higher level of performance than might otherwise be possible.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

ACKNOWLEDGMENTS

The assistance of Brett Parton in the literature search and article collation and screening is acknowledged.

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

frontiers in Psychology

ORIGINAL RESEARCH
published: 27 August 2019
doi: 10.3389/fpsyg.2019.01969

Information Accrual From the Period Preceding Racket-Ball Contact for Tennis Ground Strokes: Inferences From Stochastic Masking

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Specialty section:
This article was submitted to
Movement Science and Sport
Psychology,
a section of the journal
Frontiers in Psychology

Received: 02 July 2019
Accepted: 12 August 2019
Published: 27 August 2019

Citation:
Jalali S, Martin SE, Ghose T, Buscombe RM, Solomon JA and Yarrow K (2019) Information Accrual From the Period Preceding Racket-Ball Contact for Tennis Ground Strokes: Inferences From Stochastic Masking. Front. Psychol. 10:1969. doi: 10.3389/fpsyg.2019.01969

Previous research suggests the existence of an expert anticipatory advantage, whereby skilled sportspeople are able to predict an upcoming action by utilizing cues contained in their opponent's body kinematics. This ability is often inferred from "occlusion" experiments: information is systematically removed from first-person videos of an opponent, for example, by stopping a tennis video at the point of racket-ball contact, yet performance, such as discrimination of shot direction, remains above chance. In this study, we assessed the expert anticipatory advantage for tennis ground strokes via a modified approach, known as "bubbles," in which information is randomly removed from videos in each trial. The bubbles profile is then weighted by trial outcome (i.e., a correct vs. incorrect discrimination) and combined across trials into a classification array, revealing the potential cues informing the decision. In two experiments (both with $N = 34$ skilled tennis players) we utilized either temporal or spatial bubbles, applying them to videos running from 0.8 to 0 s before the point of racket-ball contact (cf. Jalali et al., 2018). Results from the spatial experiment were somewhat suggestive of accrual from the torso region of the body, but were not compelling. Results from the temporal experiment, on the other hand, were clear: information was accrued mainly during the period immediately prior to racket-ball contact. This result is broadly consistent with prior work using nonstochastic approaches to video manipulation, and cannot be an artifact of temporal smear from information accrued after racket-ball contact, because no such information was present.

Keywords: sports, tennis, occlusion, reverse correlation, anticipatory ability

Elite athletes demonstrate extraordinary ability in their sport of choice. While their sporting acumen may seem like a fundamentally physical attribute, it is in fact scaffolded by a range of cognitive skills that span the sensorimotor pipeline, from perception to action execution (Yarrow et al., 2009). One such skill that has received considerable attention from experimental psychologists is the expert anticipatory advantage.

The expert anticipatory advantage in sports describes a domain-specific benefit that sportspeople exhibit when predicting what is about to happen based on their opponent's current bodily kinematics (as opposed to their opponent's previous action history, which provides a separate cue for predicting current behavior; Mann et al., 2014). This advantage has been demonstrated in experiments simulating a variety of sports, most commonly via temporal and spatial occlusion methodologies (e.g., Jones and Miles, 1978; Abernethy, 1988). Hence, the advantage is widely exhibited, although the extent to which it benefits actual competitive performance remains uncertain (van Maarseveen et al., 2018).

A typical occlusion experiment runs as follows. A sporting scenario is selected, for example, a football (soccer) goalkeeper attempting to save penalties (e.g., Dicks et al., 2010; Smeeton and Williams, 2012). Videos are shot from the sportsperson's (here, the goalkeeper's) perspective, capturing various instances of two or more categories of outcome (for example, penalties struck to the left or right of the goalkeeper). In the actual experiment, participants, often varying in sports expertise (e.g., novice vs. expert goalkeepers) view these videos, attempting to discriminate which outcome will occur on each trial. Critically, the videos are manipulated to exclude some of their visual information. In temporal occlusion, the video is usually terminated early (for example, at or before ball contact), so that only particular sequences of body kinematics are available to guide the response. In spatial occlusion, particular features at constrained spatial locations (for example, the striker's hips) are also removed from the video.

The logic of these experiments is that participants will only be able to perform at above-chance levels if there is information in the video to guide their decision, with performance declining toward chance as this information is systematically removed. Certain sports, such as cricket, have been long-running favorites in the occlusion literature (e.g., Abernethy and Russell, 1984; Müller and Abernethy, 2006; Müller et al., 2006), but occlusion approaches have been applied to sports as diverse as volleyball (e.g., Loffing et al., 2015) and karate (Mori et al., 2002).

Racket sports (e.g., badminton and squash; Abernethy and Russell, 1987; Abernethy, 1990) have been particularly well studied via occlusion techniques. The focus of the current study is the sport of tennis. This sport was among the first to provide evidence of an expert anticipatory advantage, with Jones and Miles (1978) showing that experts were above chance (and better than intermediate or novice players) at guessing the landing position of a serve when the video was stopped 0.042 s before ball contact. Subsequent work has found, for example, that experts extract information from the time when the ball's toss is at its apex onward when predicting spin (Goulet et al., 1989). The temporal occlusion method has also been adjusted slightly to present one of several possible windows of visibility (0.3 s in duration) during service, with above-chance performance for experts when viewing the video for only the 0.3 s immediately before ball contact (Farrow et al., 2005). These temporal occlusion results are supplemented by spatial occlusion studies showing that, for example, experts can still discriminate the direction of tennis serves at above-chance levels following removal of body regions such as the entire lower body, but not when the ball's toss was occluded (Jackson and Mogan, 2007). Experts were also impaired (but to a lesser extent) by removal of the arm and racket.

While the tennis serve is the most straightforward scenario to investigate, ground strokes have also been probed via occlusion methods. With temporal occlusion at ball contact, experts were above chance to discriminate between left/right lobs and passing shots when shutter goggles were used to block vision *in situ* on a tennis court (Shim et al., 2005). More traditional video-based studies have shown that unlike novices, experts could already predict shot direction above chance at −0.12 s relative to ball contact, with further improvements for occlusion occurring at −0.08 and −0.04 s (Rowe et al., 2009). Spatial occlusion work suggests that the arm/racket regions are critical when predicting ground-shot direction (Shim et al., 2006).

Video-based occlusion methods are not perfect, and our knowledge about the expert anticipatory advantage has been supplemented by a variety of techniques. Such techniques include eye tracking to provide information about where sportspeople attend, and animating/manipulating the opponent (e.g., Cañal-Bruland et al., 2011; Ida et al., 2013) including via virtual reality (Vignais et al., 2015). For example, Ida et al. (2013) manipulated the arm/racket angles of computer-generated opponents to successfully influence experts' analogue estimates of the direction, speed, and spin of a tennis serve. In another study, swapping the arm/racket of stick-man representations of an opponent to that of a different shot confused experts trying to predict the direction of ground strokes (Cañal-Bruland et al., 2011). However, here we stay closer to the traditional occlusion approach, but attempt to remedy a possible weakness of the method: its dependency on experimenter decisions regarding exactly what to occlude.

To this end, we utilize a stochastic method of video occlusion borrowed from the psychophysical literature (Ahumada and Lovell, 1971), specifically a form of classification-image analysis (sometimes called reverse correlation) known as bubbles (Gosselin and Schyns, 2001). Bubbles are Gaussian-profiled windows of visibility that reveal the information from an otherwise masked (e.g., uniform gray) display. In the temporal domain, they are rather like the occlusion approach of Farrow et al. (2005), who displayed only a 0.3 s window of information from a video at a time. However, unlike in that study, which utilized a discrete set of nonoverlapping windows as separate conditions, in a bubbles experiment, several bubbles typically appear on each trial and the midpoint of each bubble is chosen at random. Furthermore, their Gaussian profiles remove transients and give the impression of the underlying display being smoothly revealed and subsequently re-masked (see **Figure 1**, for illustration). At the analysis stage, the random bubbles profiles from the different trials are binned by correctness of response and combined to produce a classification sequence. This classification can then be used to highlight the regions from which information must have been utilized to generate correct discriminations.

Although bubbles are typically applied to sparse, tightly controlled psychophysical stimuli, their applicability to a complex real-word scenario like tennis anticipation has been demonstrated

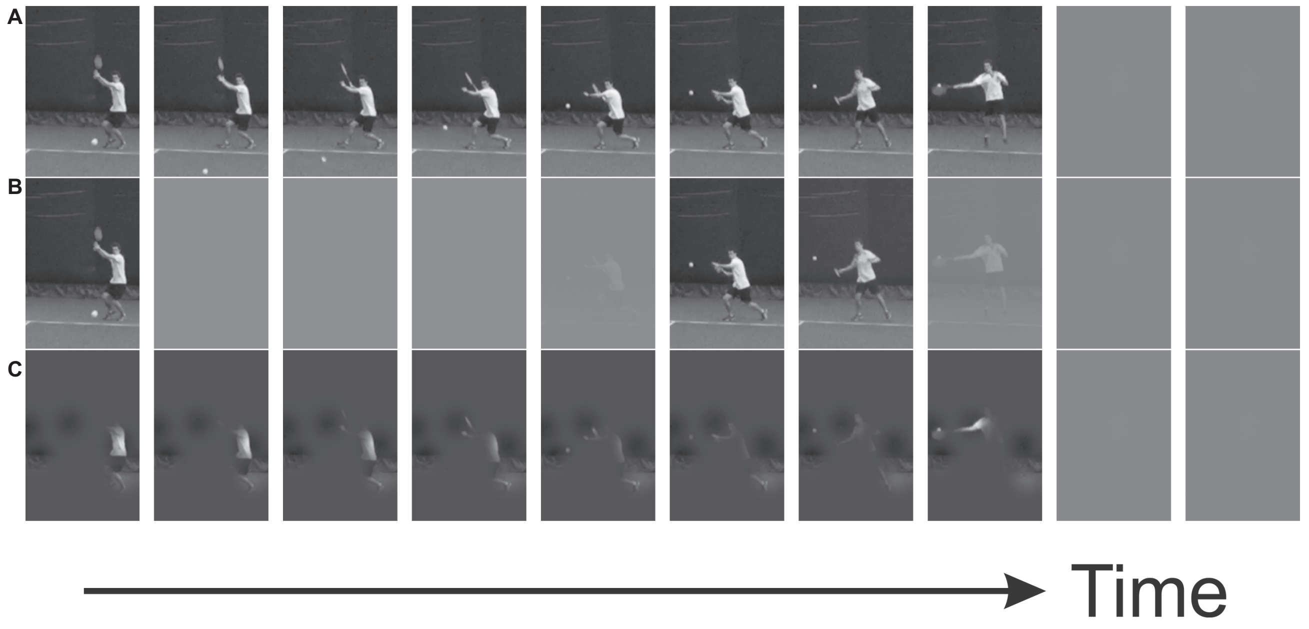

FIGURE 1 | Example stimuli, shown as snapshots from video every 100 ms. **(A)** Video occluded at point of racket-ball contact but with no bubbles manipulation (equivalent to pretest trials here). **(B)** Temporal bubbles permit viewing of entire image, but only at certain times. **(C)** Spatial bubbles permit viewing of only certain regions of the image, but across all (precontact) frames.

recently (Jalali et al., 2018). In that study, we had both novice and competent tennis players view opponents in both service and forehand-groundstroke scenarios. We did not stop the video at racket-ball contact, but the structure of the experiment encouraged participants to respond as quickly as possible while maintaining an acceptable level of accuracy. The bubbles technique proved effective in both the temporal and spatial domains, but it suggested that our participants were primarily utilizing information from the beginning of the ball's trajectory off the racket face rather than their opponent's precontact kinematics. However, the temporal classification sequence did imply possible information accrual just prior to racket-ball contact as well, but this interpretation remained speculative. The reason is that the bubbles technique yields a classification sequence in which very discrete information sources can become smeared (i.e., exaggerated in extent), such that an information source at or just after racket-ball contact might spread back to appear significant in the immediately preceding frames.

Here, we again use bubbles to attempt to find evidence of an expert anticipatory advantage in tennis. Our aim is to quantify the extent of the temporal and spatial regions, prior to ball contact, from which skilled tennis players are able to extract useful information about shot direction, but using a stochastic masking technique (i.e., bubbles). The implementation of the bubbles method does not require any intuitions about information sources, which need to be designed as separate conditions, but rather allows any region of information to emerge in a bottom-up manner. As such, we believe it provides a useful form of methodological triangulation relative to traditional occlusion approaches. However, we made an important change relative to our previous study: We stopped the video at racket-ball contact, with bubbles appearing at random up to that point but no information ever provided afterwards. This change guarantees that any information sources we identify, even if near the point of racket-ball contact, are not the result of the aforementioned temporal smear arising at the analytic stage. We also focus on ground strokes only, without considering services. To presage our results, we find unequivocal evidence for the utilization of kinematic information by competent tennis players, but only for the period immediately prior to ball contact.

MATERIALS AND METHODS

Participants

We utilized a smorgasbord[1] sampling method, attempting to recruit participants with experience playing competitive tennis by various means. Where possible, we recorded their years of experience, current competitive tennis matches per year, and International Tennis Number (ITN), which is an index of their standard of play and ranges from ITN 1 (a player with extensive professional tournament experience and who currently holds or is capable of holding an ATP/WTA ranking) to ITN 10 (a player that is just starting to play competitively). Eleven participants (8 male, 3 female, mean age 30, mean years of tennis experience 13, mean matches per year 48, mean ITN 2.8) were recruited via adverts at London tennis clubs and by word of mouth, and traveled to City, University of London to participate. All completed

[1]This is our own dubious terminology. We originally intended to recruit several separate samples and address additional questions, but recruitment proved more challenging than expected, leading us to form a composite sample.

both temporal and spatial bubbles sessions (see design, below)[2]. We also took the opportunistic step of developing a portable setup and taking it to the National UK University championships, where we recruited participants in their down time between matches (or after they had been eliminated). We tested 22 such participants in total, with 13 completing a spatial bubbles session (8 male, 5 female, mean age 22, mean years' experience 11, mean matches per year 37, mean ITN 2.1) and 13 completing a temporal bubbles session (8 male, 5 female, mean age 22, mean years' experience 10, mean matches per year 44, mean ITN 2.1)[3]. We subsequently took our portable setup to a second lab (at Technische Universität Kaiserslautern) in order to exploit its proximity to an elite school for sport (Heinrich Heine Gymnasium) attended by promising young tennis players and their coaches. We tested 10 such participants (8 male, 2 female, median age 16) who completed both spatial and temporal bubbles sessions[4]. For the German participants, we recorded their "Leistungsklassen" or performance class abbreviated as LK. According to the German Tennis Federation (DTB), the lowest class is LK23 and the highest LK1 consisting of top ranked players in Germany. The German pool had three LK1 players, one LK23 and average of LK 10 (std 8.5). They averaged 7.7 years of experience and 26 competitive matches per year. Finally, from the resulting complete samples of 34 (temporal bubbles)/34 (spatial bubbles) participants, we rejected participants, who were unable to perform the task significantly above chance during bubbles blocks (<55%, yielding binomial $p > 0.05$ that they were simply guessing), but only for our mean classification-array analysis (one of several analyses we ran; see below). We did this because an inability to perform the task makes it impossible for the bubbles technique to retrieve meaningful sources of information. This left final samples of 24 (spatial) and 27 (temporal) participants for mean classification-array analysis. Informed consent was obtained from all participants, who were paid £10 per h (London) and €10 per h (Germany) for their time. Ethical approval was granted by the relevant local Ethics Committees at City, University of London, and Technische Universität Kaiserslautern.

Apparatus and Stimuli

We used the ground-stroke subset of video stimuli from those previously described by Jalali et al. (2018). They were recorded at a tennis club using a tripod-mounted camera (frame rate 120 Hz, frame size 1280 × 720 pixels). Four club coaches/hitters of a good but not elite standard acted as models and were instructed to "hit winners" without attempting explicit deception. They were situated near the baseline and recorded against a largely uniform blue backdrop. They were recorded playing forehand ground strokes (running rightward from a central position to return near the singles side line), directing their shots toward an imaginary receiver's forehand or backhand. To increase image resolution, the camera was positioned at the net, on a line projecting from the filmed player to the imaginary receiver at the opposite baseline (height = 1.6 m, left of center line by 1.25 m).

Videos were first transformed to eight-bit grayscale. Two authors picked a subset of videos that were unambiguous (regarding the direction of the shot – line/cross), relatively homogeneous in terms of the position of the players at the time of ball contact, and lacking in artifactual cues that might allow the videos to be easily remembered for future classification (e.g., an unusual delivery trajectory). In each video, the frame corresponding to ball contact and the position at which the ball struck the racket head on this frame were manually identified for use in the subsequent presentation and analysis (see below).

The experiment was controlled by computers running scripts written in Matlab® (The Mathworks, Natick, U.S.A.) using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). Video stimuli were presented via either a cathode-ray tube monitor (for sessions at City, University of London), a short-throw gaming projector (Optoma® GT760; for sessions at Kaiserslautern and temporal sessions at UK university championships), or a MacBook® Pro (spatial sessions at UK university championships). The former two displays had a vertical refresh rate of 120 Hz, while the latter refreshed at 60 Hz, playing a down-sampled video. Only a central 600 × 400 pixel region of each video that excluded irrelevant peripheral information was presented. Displays were presented at around eye level and viewed at an appropriate distance in order to present the opposing tennis player with a height subtending ~4° visual angle (approximating their size as seen from the baseline during actual play). Participants responded by either stepping rightward or leftward, thus lifting the corresponding foot from one of two digital pedals, monitored at 100,000 Hz via a 16 bit A/D card (National Instruments X-series PCIe-6,323; for sessions at City) or by pressing an appropriate arrow key on a computer keyboard (all other sessions).

Design and Procedure

There were two types of session incorporating either temporal or spatial bubbles blocks with participants completing one or both of these sessions, and in some cases up to two additional sessions not reported here (see footnotes 2–4). Each session took around an hour, and consisted of three blocks: One practice, one pretest, and one bubbles block (in that order). During practice, participants viewed small number of videos (between 10 and 24 depending on the experimental location; 50% to forehand, 50% to backhand) containing any of four players (8 possible videos per player) but with a preponderance of videos (70%) from one player and fewer videos (10% each) from the remaining three players, who were saved mainly for the experimental trials (see below). Videos were randomized with replacement.

[2]Most of these participants also completed sessions in which they attempted to guess the direction of serves, but our service stimuli proved extremely difficult to discriminate, thus yielding no conclusive results, and are omitted from our report for concision.

[3]Nine from each group completed just a single block, and four competed both. Some participants failed to report some measures of experience, particularly ITN, so the means are based only on those who responded. Three participants from this group also completed a block using service stimuli, not reported here (see footnote 2).

[4]These participants completed two further blocks with a modified presentation sequence (a fixed rather than random ordering of opponents, to see if experiencing the same opponent repeatedly made them easier to predict) but this change did not generate any clear trend, and these blocks are not analyzed here.

Videos presentations began at −0.8 s relative to racket-ball contact. The practice block constituted a warm-up in which trials terminated at +0.2 s relative to racket-ball contact to provide clear information about the trajectory of the ball off the racket head. By contrast, in pretest and bubbles blocks, videos terminated at racket-ball contact (replaced with a uniform gray screen) or at the time of response if earlier than this.

For these pretest and bubbles blocks, 24 new videos (8 per player, 50% to forehand and 50% to backhand) were selected from the three players seen less often during practice. For the pretest, the videos were presented between one and four times each in a random order, yielding a block of either 24 trials (City and Kaiserslautern) or 96 trials (UK university championships). These differences reflected the fact that City and Kaiserslautern participants typically performed multiple sessions, hence, could have their pretest data combined across them. For the critical bubbles block, these videos were presented further 16 times each in a random order, yielding a block of 384 trials. Participants responded without any deadline. Trials with presentation glitches, that is, where one or more frames were dropped after the −0.2 s time point, were re-randomized and repeated at the end of the block. Feedback about correctness was provided after every trial.

Importantly, during bubbles trials only, the videos were subjected to random masking via the application of bubbles [see **Figure 1**; for videos showing examples of temporal and spatial bubbles, see videos 1 and 2, respectively from Jalali et al. (2018), available at https://www.frontiersin.org/articles/10.3389/fpsyg.2018.02229/full#supplementary-material]. Individual bubbles were combined to generate bubbles profiles in one (temporal) or two (spatial) dimensions. The number of bubbles presented began at 8 or 20 for temporal and spatial sessions, respectively. In principle, this (maximum) number could then be adjusted downward via a Quest staircase (Watson and Pelli, 1983), varying the number of bubbles in order to try and maintain participants' performance at around 75% correct (i.e., lowering the number of bubbles if the task was too easy). However, as discussed further below, this was never required as the task was very hard even in the absence of any masking. The profile of each individual bubble was that of a 1 or 2-dimensional Gaussian density function, scaled to have unit height. In the temporal sessions, its width (σ) was 3 frames; in the spatial sessions, its width was 12 pixels (vertically and horizontally)[5].

Bubble mean positions were selected at random within a domain extending throughout the relevant space of the video. Bubbles profiles were determined by combining the individual bubbles together. This was achieved by first reflecting bubble magnitudes around 0.5, then multiplying them together, and finally re-reflecting:

$$\text{Bubbles} = 1 - \prod\nolimits_{b=1}^{B} \left(1 - \text{bubble}_b\right) \quad (1)$$

Pixel intensities were then calculated for display as the mean pixel intensity plus the difference between original and mean intensities multiplied by the Bubbles profile at each point. Expressed in terms of Weber contrasts, pixels were displayed at their original Weber contrasts multiplied by the Bubbles profile.

Data Analysis

The saved Bubbles profiles from each trial formed the starting point in generating classification sequences (temporal conditions) or images (spatial conditions), which reveal the regions from which information supporting a correct response has been extracted. We calculated these classification arrays as per our previous report (Jalali et al., 2018). First, for the spatial condition only, Bubbles were re-centered so that the profile (saved in video coordinates) was translated to a new coordinate frame, centered on the ball at the time of racket-ball contact. Next, for each participant, a weighted sum of (re-centered) bubbles profiles yielded the raw classification array. The sum weights profiles from correct trials positively and profiles from incorrect trials negatively:

$$\text{RCA} = \sum\nolimits_{c=1}^{C} \text{Bubbles}_c - \sum\nolimits_{i=1}^{I} \text{Bubbles}_i \quad (2)$$

However, in order to provide more intuitive values for visualizing and combining data across participants, raw classification arrays were normalized to a z-like format. This was achieved via a permutation approach. For each of 2,000 iterations, correct/incorrect labels were randomly re-assigned (without replacement) to individual trials. The means and standard deviations at each point (i.e., each frame and/or pixel) calculated over these 2,000 permutations were used to z-score the classification array. This yielded an array varying around zero with positive values indicating regions of possible information accrual.

In order to draw statistical inferences across large arrays while controlling familywise type 1 error appropriately, data from all participants who were able to perform the task at significantly above-chance levels during bubbles blocks were combined and assessed via both cluster and $t_{\max}$ (also known as pixel or single-threshold) corrected permutation tests. These methods, derived from the neuroimaging literature (Blair and Karniski, 1993; Nichols and Holmes, 2002) are standard approaches for solving the multiple comparison problems with large sets of potentially correlated and non-normal data. Our particular implementation is more fully described in Jalali et al. (2018).

We also addressed a prediction particular to the data collected in these experiments, which, unlike typical bubbles experiments, were derived from participants, who rarely achieved 75% correct in a two-choice discrimination. We reasoned that the variability in performance across participants might be utilized in statistical inference. Bubbles are most efficient with 75% correct performance (Gosselin and Schyns, 2001) and would be expected to become less efficient, and thus produce classification arrays more dominated by random noise, with lower levels of discrimination performance. We would therefore expect that for an information-carrying region, there should be a positive correlation across participants between the magnitude of the classification array at that point and discrimination performance. We tested this prediction in a manner exactly analogous to the cluster/$t_{\max}$ approach, but using Pearson's r-statistic in place of Student's t-statistic in order to

[5]To speed calculations, each bubble was rounded to zero beyond 4 (temporal) or 3 (spatial) σ from its centre.

formulate cluster and r_{max} corrected permutation correlations. Where t-based tests reveal significant regions of information, r-based tests reveal regions more successfully exploited by better participants. All reported p are two-tailed, unless otherwise noted.

RESULTS

Pretests

In pretest trials, participants saw the videos without degradation, but terminating at the point of racket-ball contact. Pretests were identical in spatial and temporal sessions, and our samples were not fully overlapping between these experiments, so data were collated across all 43 unique participants. Participants showed some ability to discriminate the direction of tennis ground strokes in the absence of information about the ball's trajectory off the racket head (mean proportion correct = 0.632, SD = 0.093) and they did so on average at a level significantly above chance: Modeling these binomial data in the most appropriate way [i.e., with a general linear mixed model (GLMM) with logistic link function, incorporating a random term for the intercept] revealed a fixed intercept term of 0.55, which differed significantly from zero, that is, the null hypothesis of scoring 50% correct ($t_{[42]}$ = 9.25, $p < 10^{-10}$). For the subsets of U.K. participants reporting ITNs (N = 18), years of playing experience (N = 31), or matches per year (N = 27), these variables each were entered as lone predictors in separate GLMMs but failed to significantly correlate with discrimination performance (all $p > 0.29$). However, matches per year did become a significant positive predictor of performance (odds ratio = 1.011, 95% CI 1.004–1.18, $t_{[24]}$ = 3.28, p = 0.003) when an outlying participant (claiming 150 competitive matches per year) was excluded.

Temporal Bubbles

In temporal bubbles trials, videos ran to the point of racket-ball contact, but only those periods revealed by randomly placed temporal bubbles were visible (**Figure 1B**). The Bubbles profiles from each trial were combined with accuracy data to create classification sequences for each participant. The mean z-scored classification sequence across participants is shown in **Figure 2A**, with positive values denoting regions from which information may have been extracted. No frames were significant after t_{max} correction, but a subset of frames (from 86 onwards, that is, from around 0.083 s before racket-ball contact) contribute to a significant cluster (p = 0.013). Cluster-based testing corrects for familywise error on the overall inference that the classification

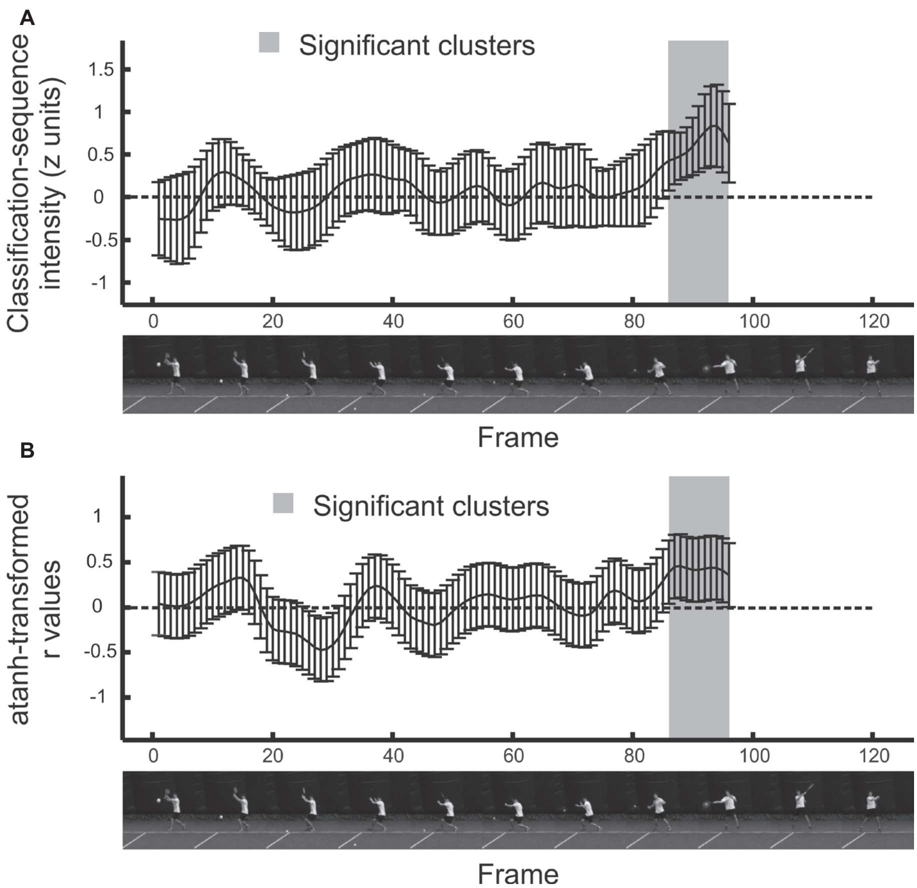

FIGURE 2 | Results from temporal bubbles experiment. Error bars denote 95% confidence intervals. Shaded regions denote significant clusters. **(A)** Mean z-scored classification sequence. **(B)** Correlations between classification sequences and classification performance across participants.

image differs reliably from zero, but does not imply that every point within the cluster is significant (Groppe et al., 2011), particularly in combination with the smoothing effects of bubbles (see Jalali et al., 2018, for further discussion). However, it is clear that some information was successfully extracted from the moment just before racket-ball contact.

Figure 2B shows additional results from a second statistical analysis. Here, instead of assessing the mean classification sequence for just those participants who were still able to perform above chance even during bubbles blocks, we assessed the correlation (for the entire sample of participants) between individual classification sequences and discrimination success. The raw values of r have been transformed to permit the creation of a constant confidence interval, which clarifies where possible clusters emerge. This happens wherever the confidence interval does not include zero, that is, for r values that are significant without any familywise correction. However, these transformed r values retain their basic meaning, in the sense that positive values represent frames where more successful participants (in terms of their ability to do the task) showed more positive classification sequence magnitudes. Our participants varied considerably in their ability to perform the task (between 50 and 75% correct). Because bubbles should be most effective (revealing pronounced peaks at points where useful information is extracted) for participants who approach 75% performance, and much less effective (reflecting mainly noise) for participants who are just guessing, these correlations are informative. Interestingly, the correlation analysis reveals a cluster with the exact same temporal extent as that found in the mean classification image ($p = 0.029$). Of course, these two analyses cannot be considered as independent tests. However, we believe they can sometimes be complementary to one another, as will become clearer in our spatial results.

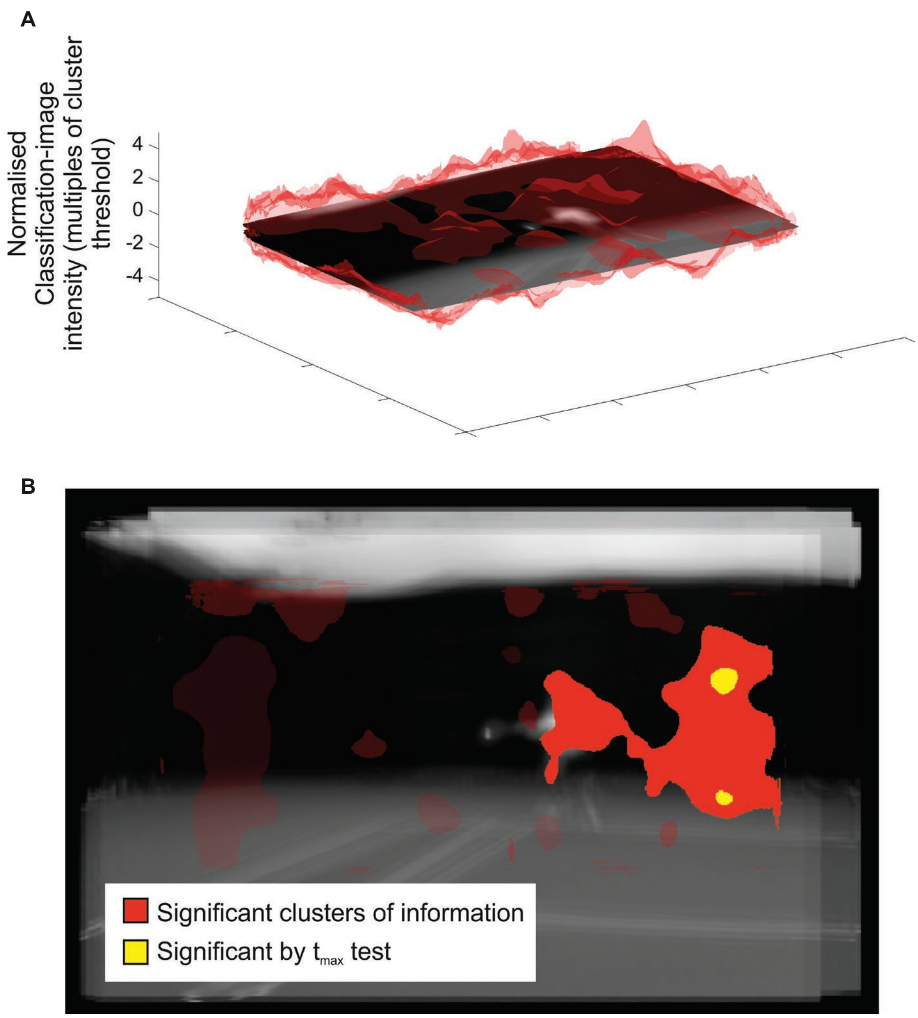

FIGURE 3 | Classification image results from the spatial bubbles experiment. Results are overlaid on an image of the mean of all presented videos for the frames capturing racket-ball contact, centered on the point of racket-ball contact (hence constituent images do not perfectly align). However, the results of the spatial analysis are not specific to any one time point. **(A)** Transparent red peaks denote mean classification-image intensity normalized to the cluster threshold value used in permutation testing (i.e., values more extreme than ±1 formed potential clusters). **(B)** Solid colored regions were significant in cluster/t_{max} permutation testing, suggesting information might have been extracted from this part of the video. Transparent red regions denote nonsignificant clusters.

Spatial Bubbles

In the spatial bubbles task, only particular areas of the video image were visible at random on each trial (**Figure 1B**). Data from our spatial bubbles experiment are shown in **Figures 3, 4**. **Figure 3** shows the mean classification image, along with associated statistical inferences, for participants able to perform the bubbles task above chance. The top part of figure shows the classification image itself, while in the bottom part of the figure statistical thresholding has been applied to reveal a single large significant cluster ($p = 0.0005$). This cluster also incorporates two smaller regions that additionally survive t_{max} correction. This contrast *should* illustrate spatial areas from which visual information was accrued. However, the result is unconvincing. Although the cluster does include a region over the position of the opposing player's body at the time of ball contact, this region only appears within the cluster by virtue of a slim connection to a larger and more pronounced region. The larger region might, at best, be considered to have overlaid parts of the opponent's body at the beginning of the video, when they started their run to intercept the ball. However, this larger region would be inconsistent with the results of the temporal experiment, which suggested that useful information guiding the decision was not extracted until near the time of racket-ball contact.

Our complementary correlation-based analysis is shown in **Figure 4**, which in this case appears somewhat instructive. The format is the same as for the mean classification image shown in **Figure 3** with the raw correlations shown at the top, and statistical thresholding applied at the bottom. However, in this case it is normalized correlation (r) values that are being illustrated and assessed for cluster or r_{max} based significance. No significant clusters were observed, but there is one nonsignificant cluster worthy of mention (one-tailed $p = 0.096$; all other clusters one-tailed $p > 0.36$) which sits over the position of the opponent's body at the time of ball contact. This suggests a trend for those participants better able to discriminate shot duration during spatial bubbles sessions to have classification

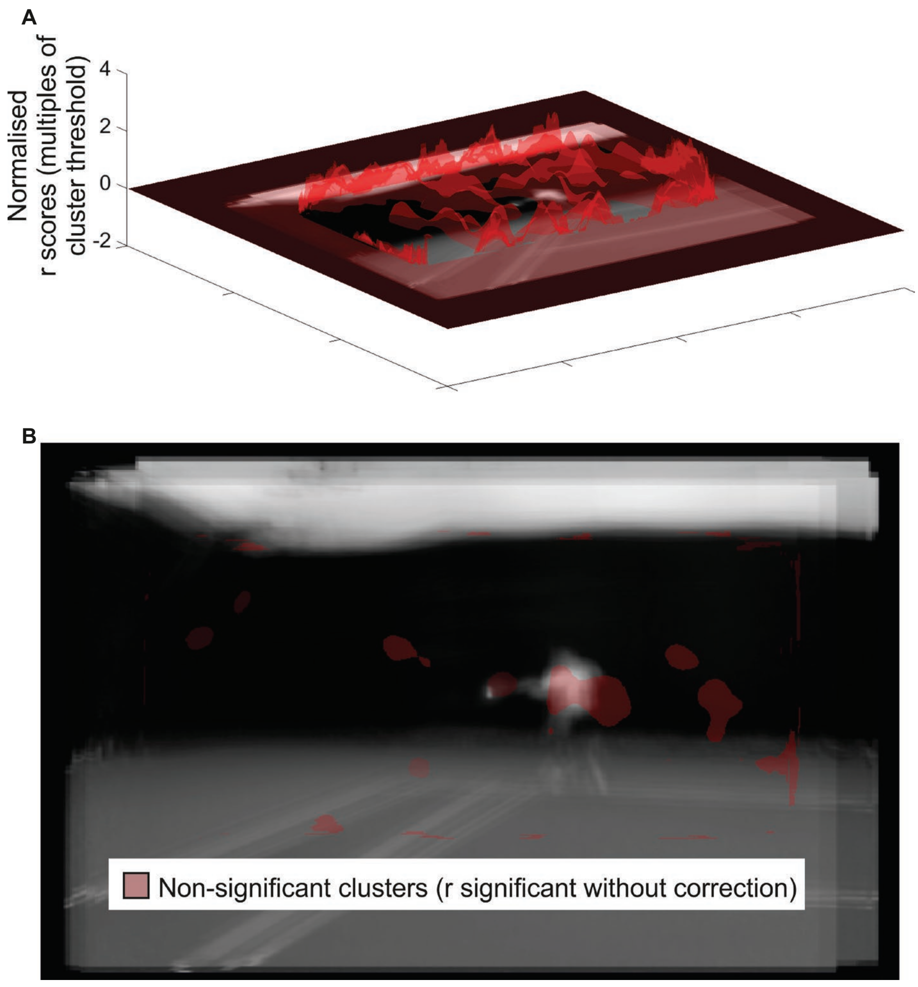

FIGURE 4 | Correlation results from the spatial bubbles experiment. Results are overlaid on an image of the mean of all presented videos for the frames capturing racket-ball contact, centered on the point of racket-ball contact (hence constituent images do not perfectly align). However, the results of the spatial analysis are not specific to any one time point. **(A)** Transparent red peaks denote correlations between classification-image intensities and discrimination performance, normalized to the cluster threshold value used in permutation testing (i.e., values more extreme than ±1 formed potential clusters). **(B)** Transparent red regions denote points where the cluster threshold (representing a significant correlation in the absence of familywise correction) was exceeded, but resulted in only nonsignificant clusters.

images that show stronger peaks in this region. In combination with the data from our analysis of the mean classification image (**Figure 3**), this result suggests that much (or all) of the cluster revealed there may represent a false positive, as it was no more likely to emerge in participants for whom bubbles had a good chance of actually working than it was for participants for whom bubbles could reveal only noise.

DISCUSSION

In our experiments, competent but nonelite tennis players first attempted to discriminate the direction of upcoming forehand ground strokes from videos of a tennis opponent, based only on information available prior to the point of racket-ball contact. On average, they were able to do so, in line with previous reports (Shim et al., 2006; Rowe et al., 2009). Unlike previous reports, we went on to remove additional information using a stochastic approach to video manipulation, by introducing bubbles rather than by applying systematic masking or image manipulation in a particular set of planned conditions. Our main finding was that participants used information from the period immediately before racket-ball contact, specifically within a window reaching back approximately 0.083 s, to perform the direction-discrimination task. Because this information source precedes racket-ball contact, it cannot include the trajectory of the ball off the racket head.

Our temporal results seem fairly consistent with previous reports. For example, Rowe et al. (2009) had tennis experts (broadly comparable to ours in competence, with ITNs of 2–4) judge forehand and backhand ground strokes (going to either the right or left) from videos which could be occluded at between −0.12 and +0.04 s relative to racket-ball contact. They found that experts could predict undisguised shot direction at approaching 75% correct when the video stopped at racket-ball contact, falling to around 60% when models were attempting disguise (c.f. 63% mean performance during pretest here; note that our models were instructed only to "hit winners," but were presented to participants with smaller spatial extents than those of Rowe et al., to be more consistent with typical match viewing). Rowe et al. (2009) also found that experts could still discriminate the direction of ground strokes significantly above chance when the video stopped at either 0.12 or 0.08 s before racket-ball contact, but performed better with occlusion at 0 s. These results imply some accrual from roughly the temporal window we obtained here (in order to show improvement) but also some additional accrual from earlier frames (in order to still be performing above chance). Indeed, a similar study utilizing stick-man graphics in place of videos even found above chance performance with occlusion at −0.24 s, although performance actually then trended worse with occlusion at −0.16, −0.08, or 0 ms (Cañal-Bruland et al., 2011).

Our method was, in principal, well-suited to find the locus of any such early periods of information accrual, because bubbles could appear at any point back to 0.8 s before ball contact. Several possibilities should be considered regarding why we failed to find any such loci, reflecting the various limitations of our approach. The first relates to statistical power. Bubbles are a trial-hungry technique, with typical psychophysical applications using fairly simple stimuli and also very large numbers of trials (Gosselin and Schyns, 2001). This limitation is exacerbated when performance is only a little above chance even in the absence of any bubbles, as was the case here. Indeed, pretest performance suggests that our stimuli were very challenging to discriminate for most participants, so perhaps our stimuli simply did not contain usable information as early as the videos used in other studies, or perhaps it was sufficiently subtle that bubbles could not reveal it.

A second possibility is that information must be integrated over a protracted period, or combined from both of two temporally distinct epochs during early shot preparation, in order to be usable. Such temporally complex cues would still be present in standard temporal occlusion approaches where videos run continuously until a single occlusion point. However, while classification arrays can in principle reveal these kinds of features with enough trials, the bubbles approach is most efficient when the temporal extent of a cue is approximately matched to the temporal extent of an individual bubble (see for example, the simulations presented by Jalali et al., 2018). Note that various suggestions have been made within the bubbles literature to address this issue (Chauvin et al., 2005; Blais et al., 2012) and might be considered in future research on sports.

Regardless of whether there were any earlier information sources that went undetected in our experiment, we can at least assert with confidence that useful information was extracted from our videos immediately prior to racket-ball contact (although, as noted in the methods, we cannot assert that every individual frame highlighted by our cluster test was important). This ability may be learnt through regular match play, generalizing immediately to the particular opponents encountered here. It is also possible that the ability to anticipate was actually learnt entirely during the experiment, given that each stimulus was encountered multiple times. The correlation between pretest performance and matches per year suggests that more regular players are at least quicker to learn their new opponent's kinematic "gives" (or perhaps they are quicker to learn other spurious cues in our videos, although we took steps to minimize these). However, this result must be considered tentative, as it was both exploratory, and relied on the exclusion of an outlying participant.

Our results from spatial bubbles sessions were not compelling and can at best be considered suggestive that our participants may have extracted some information from the torso region of their opponents. This would presumably be during the temporal window revealed by the temporal bubbles sessions, but the experiments are independent so this need not necessarily be the case. The need to apply statistical control across a much larger 2D space, relative to our temporal experiments, may have left our spatial experiment underpowered. We have previously shown that spatial bubbles can be effective with a setup and sample size similar to this one (Jalali et al., 2018), but in that case performance was nearer to 75% correct for all participants. Previous spatial occlusion work with video stimuli has been more conclusive. Shim et al. (2006) used a four-choice task (ground strokes or lobs to forehand or backhand), and found that removing the racket/arm impaired discrimination of videos when viewing was stopped at racket-ball contact. This suggests that these distal regions, which did not emerge in our analysis despite the fact that we centered our co-ordinate frame (and thus maximized power) at the racket head, are in fact important. However, they also observed performance which was still well above chance after these regions had been occluded. Therefore, participants must also have extracted information from other parts of the video, presumably proximal body segments, although the pattern of data was inconclusive in this regard. Indeed, some results from more recent studies using computer graphics in place of real videos suggest primacy for the proximal body: Fukuhara et al. (2017) found that an opponent rendered with a realistic body (but only point-light information for their arm and racket) was better predicted than one with a realistic arm and racket but only a point-light body.

In conclusion, we have replicated classic research showing that skilled tennis players can anticipate upcoming shots based on their opponent's body kinematics. We also used a novel stochastic masking approach in order to highlight the role of the period immediately preceding racket-ball contact in supporting this ability. Although our bubbles approach could in principal have revealed a wider range of information sources relative to traditional occlusion studies (where a limited set of masking conditions must be selected in advance) in practice we have revealed, if anything, fewer such loci. The approach may still have merit, but primarily as a means of methodological triangulation, making an inference based on multiple complementary approaches, such as the temporal result observed here, more secure.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

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

AUTHOR CONTRIBUTIONS

KY and JS conceived the experiments. SJ coded the experiments and analyses. SM, SJ, TG, and RB ran the experiments. KY drafted the manuscript. All authors contributed to the research design and critically revised the manuscript.

FUNDING

SJ and SM were funded by BBSRC grant BB/K01479X/1 awarded to KY and JS.

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Conflict of Interest Statement: 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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 21 October 2019
doi: 10.3389/fpsyg.2019.02380

Pressing Crowd Noise Impairs the Ability of Anxious Basketball Referees to Discriminate Fouls

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The decision-making processes of referees in sports are affected by many factors, including the pressure of spectators. While the home/visitor bias has been previously investigated, the role of crowd noise has been less studied. In the present study, we investigated how the crowd noise (calm vs. pressing) influence the decisions of basketball referees, when examining videos of potential fouls. In doing so, we also considered the level of competitive anxiety of referees (low vs. high anxiety), as factor potentially interacting with the pressure exerted by the spectators. A 2 × 2 ANOVA (Crowd noise x Anxiety) revealed a significant interaction [$F_{(1,28)} = 7.33$; $p < 0.05$; $\eta^2_p = 0.21$; power $= 0.74$], with the highly anxious referees showing poorer performances in the pressing crowd condition [$t_{(14)} = 2.24$; $p < 0.05$; $d = 0.64$]. The results indicate that the crowd noise does not seem to affect the referees' decisions, unless we consider the anxiety. The present findings suggest that the decisions of referees with high anxiety might be more easily influenced by external factors like crowd noise. Based on these results, referees' federations should consider the possibility to develop training protocols dedicated to highly anxious referees, to avoid their decisions from being biased by spectators' pressure.

Keywords: referees, basketball, crowd noise, anxiety, fouls, sport, sound

OPEN ACCESS

Edited by:
Donatella Di Corrado, Kore University of Enna, Italy

Reviewed by:
Selenia Di Fronso, Università degli Studi G. d'Annunzio Chieti e Pescara, Italy
Matej Tusak, University of Ljubljana, Slovenia

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *17 September 2019*
Accepted: *07 October 2019*
Published: *21 October 2019*

Citation:
Sors F, Tomé Lourido D, Parisi V, Santoro I, Galmonte A, Agostini T and Murgia M (2019) Pressing Crowd Noise Impairs the Ability of Anxious Basketball Referees to Discriminate Fouls. Front. Psychol. 10:2380. doi: 10.3389/fpsyg.2019.02380

INTRODUCTION

Within the context of sport psychology research, the different elements that can influence the decisions of a judge or referee have been widely investigated (for a recent review, see Aragao-Pina et al., 2018). In fact, most of the studies that evaluate judgments or identification tasks in sports are related to decisions made by the referees (Plessner and Haar, 2006).

The process of decision-making in referees can be considered as a sequence of social information processing, since the referee is in constant interaction with the athletes and the coaches, and s/he can also be influenced by the people attending the competition, that is, the supporters. The effects of various individual and social phenomena on referees' performance have been studied, namely: the anxiety they experience when performing in competitions (Johansen and Haugen, 2013); their sports and academic training (MacMahon et al., 2007); the coping of stressful situations (Wolfson and Neave, 2007; Page and Page, 2010); the verbalizations of the athletes (Lex et al., 2015) and of the coaches (Souchon et al., 2013); the nationality of the athletes (Dawson and Dobson, 2010; Pope and Pope, 2015); the attentional biases (Pazzona et al., 2018);

the order of events that take place during the competition (Plessner and Betsch, 2001; Unkelbach and Memmert, 2008; Buraimo et al., 2010); the result during matches (Lago-Peñas and Gómez-López, 2016); the condition of playing at home (Pollard, 1986; Boyko et al., 2007; Dawson et al., 2007); the importance of the supporters (Garicano et al., 2005). Altogether, the results of these studies indicate that the task of referees is quite complex and can be affected by various phenomena; among the factors constituting the complexity of refereeing, the psychological factors play an important role and can affect referee's performances to a significant extent.

Regarding the supporters, most studies have focused on the influence that various factors exert on arbitration decisions, such as the number of spectators (Downward and Jones, 2007; Pettersson-Lidbom and Priks, 2010; Picazo-Tadeo et al., 2016), the composition of the crowd, depending on whether they are local or visitors (Dohmen, 2008; Ponzo and Scoppa, 2014), the distance between the field and the stand (Scoppa, 2008; Buraimo et al., 2012), and the noise produced by the spectators (Unkelbach and Memmert, 2010). Although the relevant effect of noise on arbitration decisions was already highlighted by Greer (1983), few studies have evaluated this phenomenon experimentally (Nevill et al., 2002, 2017; Balmer et al., 2007; Unkelbach and Memmert, 2010; Myers et al., 2012).

Balmer et al. (2007) investigated the association between the bias of favoring local football teams by referees with an increase in anxiety and activation in the presence (vs. absence) of crowd noise. The results of the research indicated that, when the crowd noise was present, a bias in favor of the local teams emerged, as well as significant relationships between this bias and the increase of cognitive anxiety and perception of mental effort. The authors suggested that crowd noise is associated with an increase of anxiety and a perception of mental effort, which leads the referees facing this anxiety to take more popular decisions in favor of the local team. Thus, it seems that the referees face a double commitment: on the one hand, to be impartial due to their institutional position; on the other hand, to please the crowd (Sutter and Kocher, 2004). According to Balmer et al. (2007), as the crowd has a more immediate influence, there is a bias in favor of the team playing at home. Sometimes, arbitral inconsistencies can be explained by an avoidance coping strategy. Specifically, when facing difficult situations, referees simply avoid making unpopular decisions by ordering players to continue playing (Nevill et al., 2017).

The explanations related to favoring one team or another are marked by a strong motivational character, which would also allow the opposite outcome. Indeed, referees could show reactance to local supporters because they feel harassed (Unkelbach and Memmert, 2010). For this reason, other types of explanatory theories of the crowd noise influence on arbitration decisions have also been proposed, ranging from Bayesian decision-making models that consider some of the previously mentioned indicators (e.g., playing at home, composition and size of the crowd, number of penalties assigned; Constantinou et al., 2014), to the theory of social influence (Di Corrado et al., 2011). According to the latter theory, referees are governed by the traditional models of conformity with the majority and obedience proposed by Asch (1951) and Milgram (1963). However, this interpretation is not sufficient, according to explanations based on cognitive social theory (Plessner and Haar, 2006; Plessner et al., 2009). Considering the cognitive social theory, social knowledge and the cognitive processing of information are involved when individuals construct their subjective reality (Di Corrado et al., 2011), which in the case of the present study corresponds to the refereeing decisions. These decisions would be similar to those made in a categorization task, where the existence or not of an infraction must be determined.

Within the framework of cognitive research with sports referees, cue learning emerges (Plessner et al., 2009; Unkelbach and Memmert, 2010). This learning is due to the nature of the game in sports such as basketball or soccer, where it is continuous and dynamic, so referees often need to make quick decisions with limited information (Morris and Lewis, 2010). The latter authors point out that referees use temporary contiguity cues as additional sources of information, which are used for the decision-making process. When judging actions such as fouls, not all information is accessible at the same time (for example, limited visual information due to perspective), so concurrent cues such as noise from the crowd can be used (Plessner et al., 2009). Referees can exploit that cue because they learn the correlation between crowd noise and specific criteria in a given situation (Unkelbach and Memmert, 2010). Therefore, the prior experience of the referees with the environmental pressure will influence the signaling or not of an infraction, allowing them to improve the decision making through specific training (Webb et al., 2018). In addition, the signaling or not of an infraction may be conditioned by the anxiety levels of the referees (Balmer et al., 2007).

In the present study, rather than analyzing the effect of the home crowd or the compliance with an arbitration decision based on crowd noise, the aim was to investigate the influence of a calm vs. pressing crowd noise on the ability of basketball referees to discriminate contact situations as regular or not; in particular, in doing so the competitive anxiety characterizing the referees themselves was also considered. On the basis of the aforementioned studies, and considering that participants were not informed about the condition of "local" and "visiting" teams, the research hypotheses were the following: (1) independently from anxiety levels, the ability to correctly discriminate between fouls and non-fouls would be lower in the pressing crowd condition than in the calm crowd condition; (2) considering anxiety levels, the discrimination ability of referees with high anxiety would be more impaired than that of referees with low anxiety in the pressing crowd condition, while no differences would emerge in the calm crowd condition.

MATERIALS AND METHODS

Participants

Thirty male basketball referees voluntarily participated in the experiment. Their age ranged between 18 and 60 years (M = 27.8; SD = 11.8). They were all active at the time of experimentation, serving as referees from youth leagues to the Italian national second division; their experience ranged between 3 and 35 years

(M = 10.3; SD = 9). Participants were divided in two equally numerous groups—low vs. high anxiety (N = 15 each)—on the basis of the sample's anxiety median score; the two resulting groups were comparable in terms of age (low anxiety: M = 29.3 years; SD = 12.3; high anxiety: M = 26.3 years; SD = 11.1) and experience (low anxiety: M = 11 years; SD = 9.3; high anxiety: M = 9.7 years; SD = 8.9).

All participants had normal or corrected-to-normal vision, and reported no hearing disturbances. Written informed consent was obtained from each participant prior to the beginning of the experiment, in accordance with the Declaration of Helsinki. The experimental protocol was approved by the Ethics Committee of the University of Trieste, and the experiment was carried out in accordance with its recommendations.

Materials

Instruments

The software iMovie and Adobe Audition 3.0 were used to edit video and audio materials, respectively. A laptop computer Dell Inspiron 5559 with a 15.6" LED display was used to test participants. Sennheiser HD 205 II circumaural headphones were used to convey the auditory stimuli. The experiment was programmed with the software E-prime Professional 2.0. The statistical software SPSS 25.0 for Windows was used for data analysis.

Stimuli

The stimuli used for the present experiment were videos of basketball actions containing contact situations; the original audio was removed and replaced with that of a calm crowd and that of a pressing crowd.

The videos suitable for the experiment were selected from an archive of videos used by referee instructors during technical meetings. In particular, three instructors were requested to independently view about 80 of such videos, and to judge whether the specific contact situations were to be considered as fouls or non-fouls; this independent evaluation yielded 17 unanimous fouls and 15 unanimous non-fouls. Out of these, the three instructors were requested to collectively select 10 fouls and 10 non-fouls, by discarding the most evident cases for each category, to avoid the experimental task from being too easy. Then, these 20 videos were edited so that all of them lasted 5 s, being temporally occluded immediately after the contact to be judged.

As concerns the audio, the same three instructors as above were asked to evaluate some tracks extrapolated from videos of basketball matches found online. In **Figure 1** there are the waveforms of the two selected tracks. Beyond the quantitative differences that can be seen in the figure, the two tracks were also qualitatively different. Indeed, the calm crowd track consisted of a continuous background noise of some voices, above which the ball bounces and the players' footsteps were clearly audible. Instead, the pressing crowd track started with a drum noise lasting about 3 s, and then, after few audible footsteps, the crowd started to scream (right after the contacts to be judged by participants). These two tracks were used to replace the original audio of each of the 20 selected videos; as a consequence, the final set of stimuli consisted of 40 videos: 10 fouls with the calm crowd; 10 fouls with the pressing crowd; 10 non-fouls with the calm crowd; 10 non-fouls with the pressing crowd. An example of each can be found in the **Supplementary Material**.

Questionnaire

To measure participants' competitive anxiety, the Sport Anxiety Scale (SAS; Smith et al., 1990) was used. This questionnaire consists of 21 items in the form of statements describing thoughts and feelings that can be commonly experienced before and during sport competitions. With respect to the original version, in the instructions the three occurrences of the term "athletes" were replaced with the term "referees." The answer to each item is to be given on a four-point Likert scale, ranging from "not at all" (1) to "very much so" (4).

The items compose two subscales, i.e., somatic anxiety and cognitive anxiety; the latter can be further divided in two sub-subscales, i.e., worry and concentration disruption. A total competitive anxiety score can also be calculated by adding all the items together. In the present study, we used this total competitive anxiety score, in order to create two groups of participants (low vs. high anxiety).

Procedure and Task

Participants were tested individually in a quiet room. Upon their arrival, they were asked to seat in front of a laptop computer and to wear the headphones; then, the experimenter launched the experimental session. Participants were instructed that their task was to judge whether each contact was a foul or a non-foul, by pressing one of two keys on the laptop keyboard, namely "A" or "L"[1]; in the instructions, no reference was made to the crowd noise.

The experimental session consisted of two blocks, each composed of 20 trials, for a total of 40 trials (corresponding to the 40 stimuli). In each block there were five fouls with the calm crowd, five fouls with the pressing crowd, five non-fouls with the calm crowd, and five non-fouls with the pressing crowd. The stimuli were presented in a randomized order within each block; moreover, within each block the same action was never presented twice (e.g., foul "A" with the calm crowd was presented in the first block, while the same foul "A" but with the pressing crowd was presented in the second block). After each response, there was an interval of 1 s before the beginning of the subsequent stimulus; instead, the interval between the two blocks was of 5 min, to provide participants with an appropriate rest.

Once the experimental session was completed, participants were administered the SAS. The choice to administer it at the end of the protocol rather than at its beginning was made to avoid a possible "triggering" of anxiety-related thoughts/feelings before performing the task, which could have led (some) participants to explicitly focus on the crowd noise as a potential anxiogenic stimulus.

[1]The correspondence between the keys and the answer associated to them was inverted between the two blocks, in order to keep under control any potential effect of the dominant hand.

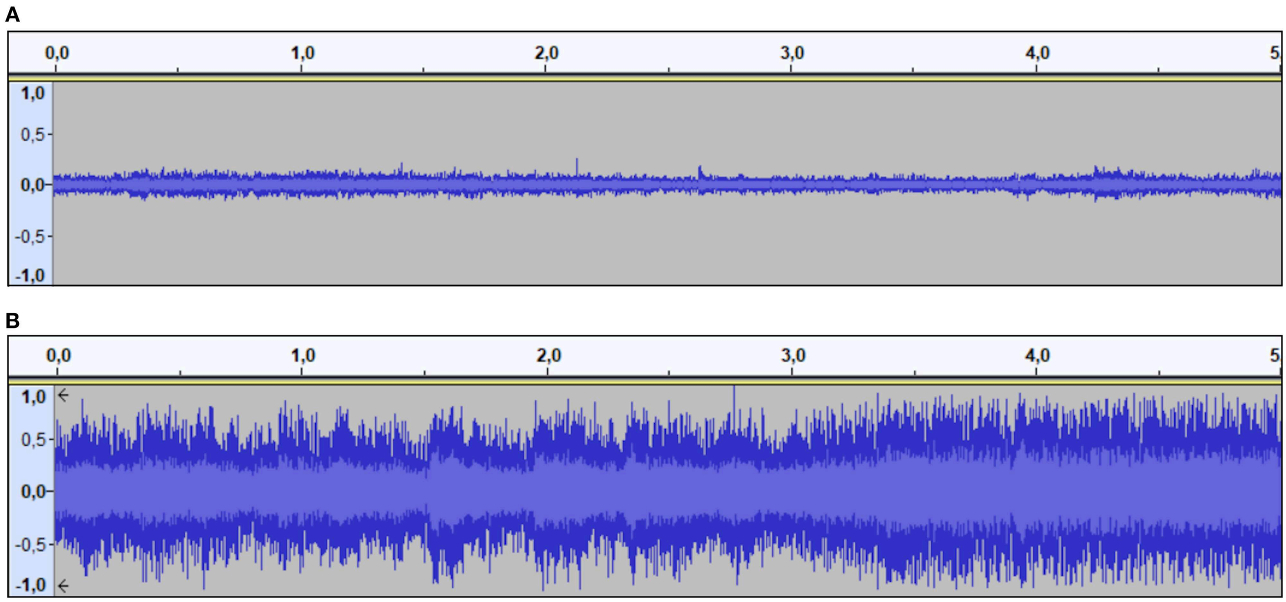

FIGURE 1 | The waveforms of the audio tracks characterizing the calm crowd condition **(A)** and the pressing crowd condition **(B)**.

Statistical Analyses

First of all, the *d*' scores for each participant in each condition—calm crowd and pressing crowd—were calculated, as measures of response accuracy. Subsequently, the competitive anxiety score for each participant was calculated. Then, participants were divided in two equally numerous groups—low vs. high anxiety (N = 15 each)—on the basis of the sample's median score. To test the research hypotheses, a 2 × 2 mixed ANOVA was conducted, with crowd noise (calm vs. pressing) as within-subjects variable, and anxiety (low vs. high) as between-subjects variable. Moreover, we conducted planned comparisons between the two groups, in each of the two crowd noise conditions, as well as within each group in the two crowd noise conditions, by means of a set of independent samples *t*-tests, and paired samples *t*-tests, respectively. For the ANOVA, the sphericity assumption was evaluated using the Mauchly test; Greenhouse-Geisser correction for degrees of freedom was applied in case of non-sphericity. The effect sizes were calculated using the partial eta square (η_p^2) (Lakens, 2013), with 0.01, 0.06, and 0.14 considered small, medium, and large effects, respectively. In the case of *t*-tests, effect sizes were calculated using the Cohen's d (Cohen, 1988), for which 0.20, 0.50, and 0.80 are considered small, medium, and large effects, respectively.

RESULTS

The mixed ANOVA did not reveal a significant main effect either for crowd noise [$F(1, 28) = 0.01$; $p = 0.97$] or for anxiety [$F(1, 28) = 0.16$; $p = 0.69$]; however, a significant interaction emerged [$F(1, 28) = 7.33$; $p < 0.05$; $\eta_p^2 = 0.21$; power = 0.74] (**Figure 2**). The set of independent samples *t*-tests revealed no difference between the two groups in the calm crowd condition [$t(28) = 0.81$; $p = 0.43$; low anxiety: M = 0.83, SD = 0.93; high anxiety: M = 1.04, SD = 0.49]; instead, in the pressing crowd condition a marginally significant difference between the two groups emerged [$t(28) = 1.59$; $p = 0.063$; $d = 0.58$; low anxiety: M = 1.14, SD = 0.86; high anxiety: M = 0.73, SD = 0.51]. The set of paired samples *t*-tests highlighted a significant difference in the two conditions for referees with high anxiety, showing lower discrimination ability in the pressing crowd condition [$t(14) = 2.24$; $p < 0.05$; $d = 0.64$]; instead, no difference emerged for referees with low anxiety between the calm and pressing crowd conditions [$t(14) = 1.69$; $p = 0.11$].

DISCUSSION

The aim of the present study was to investigate the influence of crowd noise on the ability of basketball referees to discriminate contact situations as regular or not, also on the basis of their competitive anxiety. Unlike previous studies on similar issues, here the manipulation did not simply consist in the presence vs. absence of crowd noise (e.g., Balmer et al., 2007) or in the variation of its volume (e.g., Unkelbach and Memmert, 2010); instead, to be more realistic, two different tracks were used—one of a calm crowd and one of a pressing crowd—with both quantitative and, most importantly, qualitative differences between them. Moreover, the condition of "local" and "visiting" teams was intentionally not specified to participants, as the phenomenon under investigation was different—more general—than the *home bias* itself. With these premises, and on the basis of previous research mentioned in the introduction, two hypotheses were tested: (1) independently from anxiety levels, the ability to correctly discriminate between fouls and non-fouls would be lower in the pressing crowd condition than in the calm crowd condition; (2) considering anxiety levels, the discrimination ability of referees with high anxiety would be more impaired than

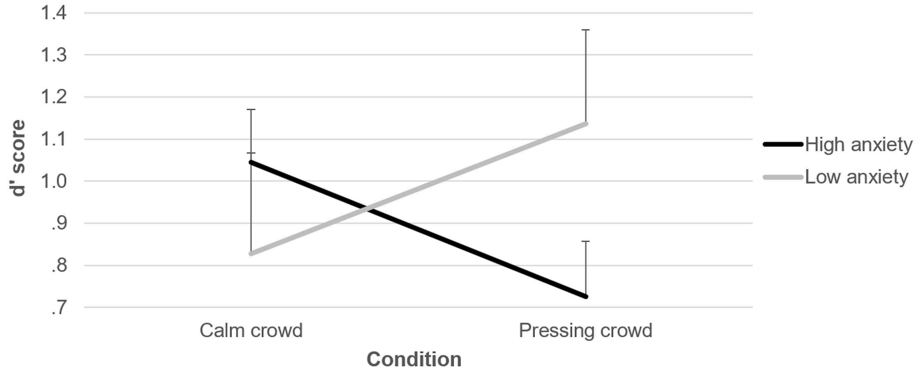

FIGURE 2 | The *d'* scores of referees with low and high anxiety in the calm and pressing crowd conditions. Error bars show the standard error of the mean.

that of referees with low anxiety in the pressing crowd condition, while no differences would emerge in the calm crowd condition.

The results of the experiment seem not to support the first hypothesis, as no difference in fouls discrimination ability emerged between the calm and pressing conditions. The explanation of this outcome can be easily found in the significant interaction between crowd noise and anxiety levels; thus, the overall apparent null effect of crowd noise was actually due to its different impact on participants on the basis of their competitive anxiety. Such an interaction, together with the decreased discrimination ability of referees with high anxiety in the pressing crowd condition, as well as the absence of difference between the two groups in the calm crowd condition, seems to support the second hypothesis. A reasonable explanation of this outcome refers to cue learning, with highly anxious referees being more prone than lowly anxious ones to rely on a salient concurrent cue (like pressing crowd noise), when judging contact situations. However, such a cue can often be misleading or at least ambiguous, thus leading to a poorer performance. Another possible explanation refers to the phenomenon of *choking under pressure*, with more anxious people/athletes being more prone to experience performance decrements in pressing situations (e.g., Otten, 2009). It is also possible to hypothesize a combination of these two explanations: an anxious referee could be performing poorly during a pressing competition, and becoming aware of this s/he could try to improve her/his performance by basing her/his decisions also on crowd reactions, which in most cases would further negatively affect the performance itself. Further studies are needed to deepen the understanding of the mechanisms underpinning the processes that led to the outcomes observed in the present experiment.

An interesting result of the present experiment is the marginally significant difference between referees with high and low anxiety in the pressing crowd condition. Looking at **Figure 2**, it appears quite evident that the trend of referees with low anxiety is opposite to that of referees with high anxiety (as confirmed by the significant interaction). However, for the low anxiety group the comparison between the two crowd noise conditions revealed no significant difference; this is reasonably due to the higher variability with respect to the high anxiety group. Anyway, it appears that the discrimination ability of at least some referees with low anxiety was higher in the pressing crowd condition than in the calm crowd condition; this observation is in line with the phenomenon of *clutch* performances, that is, a performance increase in pressing situations (Otten, 2009), and deserves further investigation to be clarified.

In the present experiment, participants were divided in two groups—referees with low and high anxiety—on the basis of the sample's median score. In future studies investigating similar issues, it would be interesting to use questionnaires/scales with cut-off values, so that participants can be divided in two (or more) groups on more grounded bases. However, existing questionnaires with these characteristics might not suit a specific population like referees, so an alternative solution to make the results more generalizable can be that of expanding the sample size. Another aspect to consider in order to foster the generalizability of the results of future studies is the use of the latest advances in technology, such as virtual reality and/or 3D displays (also for auditory stimuli), as they allow for more ecological experimental settings (Craig, 2013).

Interestingly, the present study significantly adds not only to the literature concerning referees' decision making, but also to the line of research that in recent years is revealing the relevant role of ecological sounds in sports (for a recent review, see Schaffert et al., 2019). Indeed, previous studies highlighted that ecological auditory information can be used by athletes to perceive different features of sport gestures (Murgia et al., 2012; Kennel et al., 2014; Sors et al., 2017), to predict the outcome of opponents' actions (Allerdissen et al., 2017; Camponogara et al., 2017; Cañal-Bruland et al., 2018; Sors et al., 2018), and to improve performances (Agostini et al., 2004; Sors et al., 2015; Pizzera et al., 2017). The present study indicates that the ecological auditory information is somehow important not only for athletes, but also for referees, as it provides them with an additional source of information. Independently from the fact that this information can be useful or misleading, our findings indicate that crowd noise can affect the referees' decisional processes and, consequently, their behavior.

From an applied perspective, the results of the present experiment highlight the importance of referees' competitive anxiety levels in relation with crowd noise. Indeed, while the ability of referees with low anxiety to discriminate fouls does not significantly change with a calm crowd or a pressing one, for referees with high anxiety such ability significantly decreases with a pressing crowd noise, thus determining poorer refereeing performances. Referees' federations should be aware of this phenomenon, as it may influence competitions' results to a significant extent. This does not mean that highly anxious referees should be relegated only to less important matches (where smaller/calmer crowds are expected); rather, federations should consider the possibility to develop dedicated training protocols and/or to include in their staff the figure of the sport psychologist, who could provide specific interventions.

To sum up, the present study highlighted that pressing crowd noise impairs the ability of basketball referees with high anxiety to discriminate fouls. Further research is needed to better understand why this is the case (e.g., which factors cause this bias), as well as whether it replicates also in other sports. Findings should raise the awareness of referees' federations on this and related phenomena, in order to adopt appropriate intervention strategies to avoid competitions' results from being biased by them.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

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

AUTHOR CONTRIBUTIONS

FS, IS, and MM conceived the idea. FS, DT, VP, IS, AG, TA, and MM designed the study. FS and VP prepared the stimuli. FS, IS, and AG programmed the experiment. FS, DT, and VP collected the data. FS, MM, and TA analyzed the data. FS, DT and MM wrote the first draft of the manuscript. VP, IS, AG, and TA revised the manuscript.

ACKNOWLEDGMENTS

We would like to thank the referees who took part in our experiment for their availability and their suggestions.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02380/full#supplementary-material

Video S1 | Example of foul with calm crowd noise.

Video S2 | Example of foul with pressing crowd noise.

Video S3 | Example of non-foul with calm crowd noise.

Video S4 | Example of non-foul with pressing crowd noise.

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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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 22 October 2019
doi: 10.3389/fpsyg.2019.02376

Cognitive Deficits and White Matter Alterations in Highly Trained Scuba Divers

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OPEN ACCESS

Edited by:
Mauro Murgia, University of Trieste, Italy

Reviewed by:
Maurizio Bertollo, Università degli Studi G. d'Annunzio Chieti e Pescara, Italy
Valter Prpic, De Montfort University, United Kingdom

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *26 July 2019*
Accepted: *07 October 2019*
Published: *22 October 2019*

Citation:
Coco M, Buscemi A, Perciavalle V, Maci T, Galvano G, Scavone AMF, Perciavalle V and Di Corrado D (2019) Cognitive Deficits and White Matter Alterations in Highly Trained Scuba Divers. Front. Psychol. 10:2376. doi: 10.3389/fpsyg.2019.02376

Nitrogen gas (N2), present in the normal atmospheric air, is a potential source of risk for scuba divers. It seems probable that myelin can represent, in hyperbaric conditions, a preferential site for the accumulation of N2 in central nervous system (CNS). The purpose of this study is to verify whether the practice of the scuba diving is capable to determine a damage of the brain white matter (WM) in a dose dependent manner and, consequently, possible deficiency of their cognitive abilities. For this purpose, 54 professional scuba divers (35 men and 19 women), with at least 2,000 dives in their careers, were studied. Possible alterations of brain WM were evaluated in terms of Fractional anisotropy (FA) by using Diffusion Tensor Imaging, whereas possible cognitive impairments were verified by means of neuropsychological testing, by studying: (1) General mental capability (2) Executive functioning; (3) Visuospatial construction such as Rey Complex Figure; (4) Attention and orientation: (5) Selective attention capacity and processing speed ability; (6) Memory. The results showed alteration of the WM in terms of changes in FA; these alterations, statistically significant but quantitatively quite modest, were mainly observed in the WM of the anterior part of the brain, whereas no differences were observed between left and right hemisphere. The alterations of the WM were associated with changes, also in this case statistically significant but quantitatively quite modest, of the cognitive functions, in particular of those dependent on the prefrontal cortex, such as attention and memory function. The present study leads to the conclusion that repeated dives, even performed in compliance with the current decompression tables, can progressively lead in the CNS to the formation of micro-lesions in the myelin sheet capable of altering the functioning of the neuron.

Keywords: scuba diving, white matter, Fractional anisotropy, neuropsychological testing, sport

INTRODUCTION

Nitrogen gas (N2), present in the normal atmospheric air, is a potential source of risk for scuba divers for two different reasons: during the descent may induce nitrogen narcosis and during the ascent may cause decompression sickness (DCS).

Individuals exposed to increasing N2 pressures exhibit, already at 0.3 MPa, spatial disorientation, altered judgment and impaired neuromuscular coordination (Bennett, 1993), up to the loss of consciousness when the pressure of N2 reaches 1 MPa, a condition related to nitrogen narcosis (Edmonds et al., 1981). The narcotic effect is dependent on to the increase in the partial pressure of N2; the gas in fact, with the increase in pressure, would dissolve in the cell membrane of the neuron (Behnke et al., 1935). In this way, the increased presence of N2 in the cell membrane on the one hand would modify its biophysical characteristics and, on the other hand, the binding of N2 to membrane proteins, would vary their activity (Franks and Lieb, 1994).

It is known that DCS occurs when N2 dissolved in the tissues is released too quickly during decompression, leading to the formation of bubbles that can cause damage to various organs (see Doolette and Mitchell, 2001). The relationship between N2 and adipose tissue is of particular attention in hyperbaric conditions as N2 is five times more soluble in lipids than in water (Weathersby and Homer, 1980; Langø et al., 1996). According to this point of view, the adipose tissue would act as a reservoir for N2, able to accumulate it during the compression phase and then quickly release it during decompression; in fact, it has been shown that the risk of DCS is greater in obese subjects (Carturan et al., 2002).

In the human body lipids are involved in two essential functions: in the form of triglycerides, they are an excellent substrate to be oxidized for producing energy and they are an essential component in the structure of cell membranes. Since the central nervous system (CNS) does not contain triglycerides, brain lipids have been studied to identify roles different from that of energy substrate. Actually, in addition to structural tasks in cell membranes, as myelin, they act as bioMessengers and intervene in cellular signal transduction processes (see Agranoff et al., 1999).

Myelin is a lipid-rich substance that is produced by specialized glial cells, that in the CNS are the oligodendrocytes and in the peripheral nervous system the Schwann cells (see Nave and Werner, 2014). At the level of the axons, the myelin acts as an electrical insulator, favoring the propagation of the nerve impulse at high speed from one node of Ranvier to the other (Waxman, 1980). Lipids represent about 70% of the dry weight of myelin (Norton and Poduslo, 1973), a value that is about twice that measured in the other cell membranes (Chrast et al., 2011).

From a logical point of view, it seems probable that myelin can represent, in hyperbaric conditions, a preferential site for the accumulation of N2 in CNS. However, there are no studies about the possible alterations of myelin in scuba divers, in particular in those that, for professional reasons, perform thousands of dives. It is conceivable, in fact, that a continuous exposure to conditions of high partial pressures of N2 could lead, during the decompression phase, to the formation within the myelin of microbubbles which could compromise the functioning of white matter (WM) in the CNS.

The aim of this study was to verify whether the practice of the scuba diving is capable to determine a damage of the brain WM in a dose dependent manner and, consequently, possible deficiency of their cognitive abilities. Recent literature has documented effects of diving on cognitive functions (Kowalski et al., 2011; Ergen et al., 2017; Howle et al., 2017; Bosco et al., 2018; Verratti et al., 2019). Some of these studies have reported decreased mental flexibility (Cordes et al., 2000), as well as lower verbal memory and intelligence (Hemelryck et al., 2014), sustained attention in divers reporting memory and concentration loss (Taylor et al., 2006), and decrease average response speed (Pourhashemi et al., 2016). Further, we expected that a high number of dives (at least 2,000) with compressed air is able to alter the quality of brain WM, evaluated by using diffusion tensor imaging (DTI), determining cognitive impairments.

MATERIALS AND METHODS

Participants and Procedure

Fifty-four professional scuba divers (35 men and 19 women) in the age range from 28 to 58 years (M_{age} = 40.1 years, SD = 6.08) were recruited for the study. For scuba divers, inclusion criteria were to have performed at least 2,000 scuba dives, with an average of at least 100 dives a year, proven by their personal dive log. Controls were represented by 54 individuals (35 men and 19 women) having the same mean age of divers (mean value 39.7 years ± 7.22 SD). **Table 1** summarizes the main characteristics of both groups. For both divers and controls exclusion criteria were (a) presence of neurological, pulmonary, cardiovascular, or metabolic disease, (b) positive test for thrombophilia, and (c) evidence for patent foramen oval. Prior to the beginning of the study, ethical approval was granted From the first author's university ethics committee. The study obtained ethical permission from the Internal Ethic Review Board – IERB, Department of Education Sciences, Psychology Section, University of Catania (29/11/2018). All participants were informed about the trials of the study and the anonymity of their answers before providing their written consent to participate, in accordance with the Declaration of Helsinki.

TABLE 1 | Characteristics of study participants.

	Male divers (*N* = 35)	Female divers (*N* = 17)	Male controls (*N* = 35)	Female controls (*N* = 17)
Age, years	41.0 ± 6.75	40.9 ± 4.77	38.7 ± 7.51	39.6 ± 6.56
BMI, kg/m^2	25.7 ± 3.18	25.8 ± 3.11	25.4 ± 2.21	25.6 ± 2.85
Immersions	4881.8 ± 2168.13	3841.5 ± 1060.32		

Measures

Neurological and Neuropsychological Assessment

All participants were tested by the same neuropsychologist (T.M.) using a neuropsychological test battery grouped according to major functional category.

General mental capability - Wechsler Adult Intelligence Scale– Revised (WAIS–R; Wechsler, 1981): WAIS–R Full-scale IQ (FSIQ); WAIS–R Verbal IQ (VIQ); WAIS–R Performance IQ (PIQ).

Executive functioning: Trail Making Test (Tombaugh, 2004), Trail A and Trail B; Wisconsin Card Sorting Test, WCST (Berg, 1948).

Reasoning and abstraction- WAIS-R: Similarities (Sims), Comprehension (Compr). Arithmetic (Arith).

Visuospatial construction: Rey Complex Figure (Rey, 1941) scored according to the traditional guidelines developed by Taylor (Spreen and Strauss, 1998): Copy; WAIS-R Block Design, WAIS-R Object Assembly.

Language: WAIS-R Vocabulary (Vocab).

Attention and orientation: Digit Span-forward and backward (Soylu, 2010), Corsi block-tapping test (Kessels et al., 2000) forward and backward.

Selective attention capacity and processing speed ability: Stroop Color and Word Test (Stroop, 1935), score by using the formula originally proposed by Callaway (1959), i.e., time taken to complete the color-word card minus time spent to complete the color card.

Memory: Wechsler Memory Scale–Revised (WMS-R; Wechsler, 1987): Immediate Memory (Logical Memory), Delayed Memory (verbal Paired Association) and Working Memory (Letter - Number Sequencing) were evaluated (Axelrod, 2001). Rey Complex Figure: recall.

Brain Imaging

Scans were performed with conventional techniques and DTI. Along the anterior/posterior commissure line, conventional axial T1-weighted, T2-weighted, fluid-attenuated inversion recovery (FLAIR), and DTI sequences were acquired with a 1.5T imaging system. Acquisition of DTI images were carried out with a single-shot pulsed-gradient, echo-planar imaging protocol (TR8000 ms, TE109 ms, FOV240 mm, matrix128 × 128, section thickness 3 mm). Diffusion gradients were evaluated in 25 non-collinear directions by using 2 b values (0 and 1500 s/mm^2). Duration for DTI acquisition was 8 min and 6 s.

Oval Regions of Interest (ROIs) were positioned bilaterally on images acquired without diffusion gradients (b 0 s/mm^2). Small ROIs of 9–16 pixels (31.64–56.25 mm^2) were located in correspondence of frontal lobe (FL), temporal lobe (TL), parietal lobe (PL), occipital lobe (OL), splenium of corpus callosum (SCC), genu of corpus callosum (GCC), corona radiata (CR), and corticospinal tract (CT) white matter (**Figure 1**).

For each subject, the measures of FA were separately carried out for each side of every white matter region and then averaged across all the sections bilaterally. FA was calculated using the method proposed by Basser and Pierpaoli (1996) on a pixel-by-pixel basis. The scale of FA ranges from 0 (perfect isotropy) to 1 (perfect anisotropy).

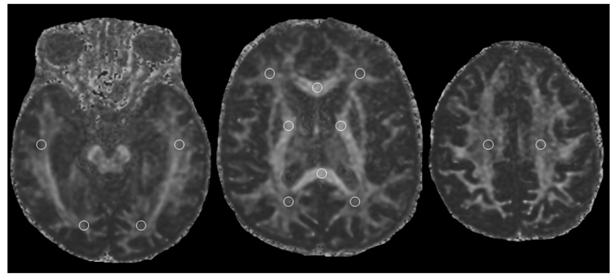

FIGURE 1 | Fractional anisotropy map showing locations white matter Regions of Interest (ROIs).

Statistical Analyses

Differences between the two groups of participants were assessed by one-way analyses of variance (ANOVA) with the nonparametric Kruskal-Wallis test. Voxel-wise group differences in FA were assessed using the ANOVA module in SPM99 followed by group-wise t-test comparisons. For these comparisons, significance was determined with a p-value of <0.05 (corrected for multiple comparisons at the cluster level) with a seven-voxel extent threshold. Statistical analyses were performed using SPSS v. 23 Statistical Software Package for windows (SPSS Inc., Chicago, IL, United States).

RESULTS

Fractional Anisotropy

The MRI of the brains of scuba divers and controls has highlighted the absence of gross lesions. However, as can be seen in **Figure 2**, if we compared the mean value of FA measured in the 8 ROIs it can be seen that the values measured in correspondence of FL, TL, GCC, CR, and CT were significantly lower in the divers compared to controls. The *post hoc* Dunn's Multiple Comparison Test has been performed (see **Supplementary Table S1**). No difference, however, was detected in correspondence of PL, OL, and SCC. The same figure allows detecting how the same pattern found on the entire sample was observed, without statistically significant differences, both in women and in men. Moreover, the figure shows that it was not possible to highlight statistically significant differences, for the different ROIs, between right and left side.

However, when in scuba divers the mean value of the FA, measured in the different ROIs, is correlated with the number of dives carried out by each of them, a strong negative correlation emerges, as can be seen in **Figure 3**, with the exclusion of SCC as well as of left and right PL and OL. Nor were any gender-dependent differences found.

However, the number of dives obviously increases with increasing age (**Figure 4**) so it is possible that the observed WM anomalies could depend on age and not on the number of dives. To evaluate this possibility, we connected the values of FA with the age of both scuba divers as well

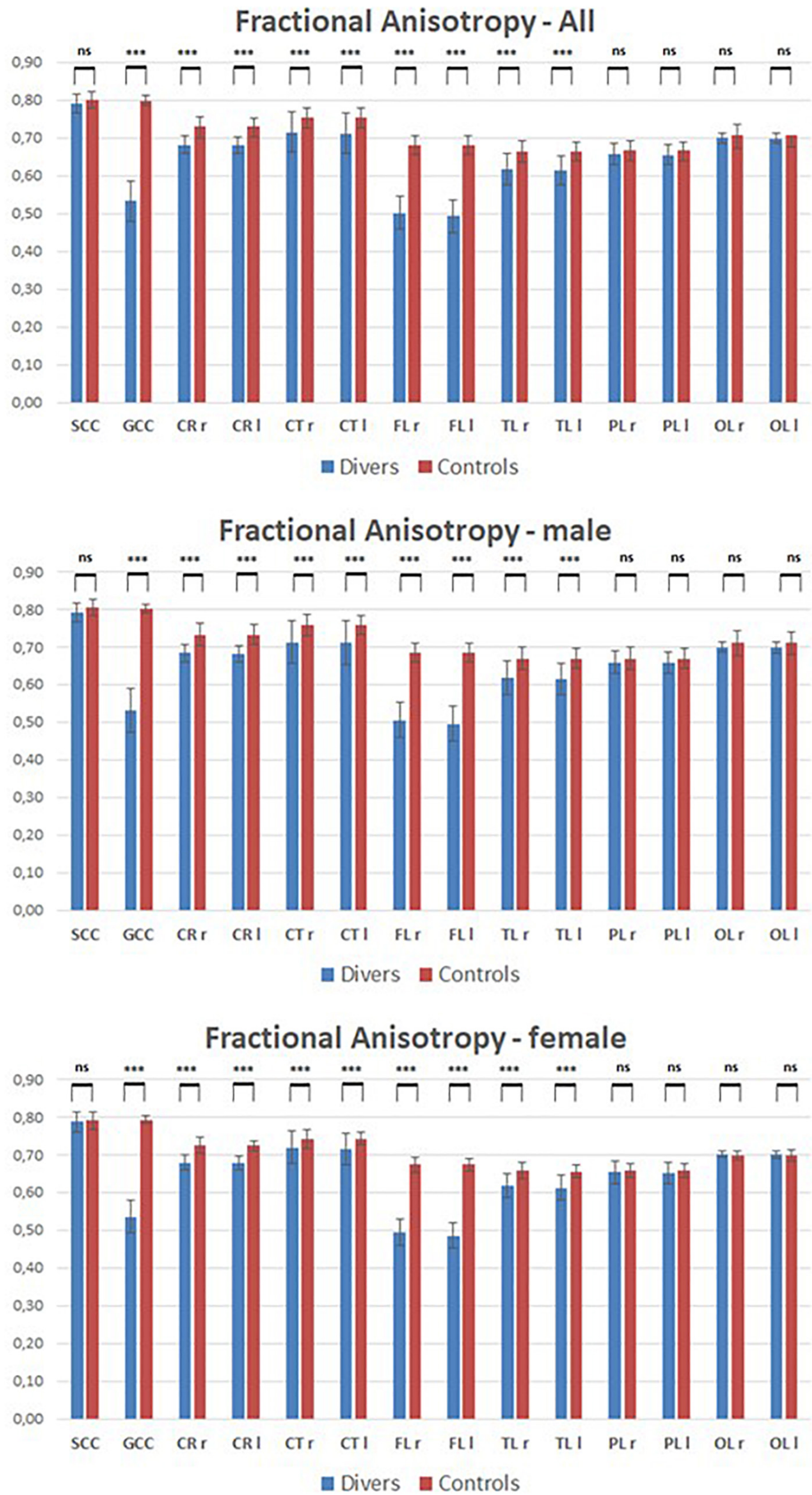

FIGURE 2 | Mean values of Fractional anisotropy measured in scuba divers and controls in correspondence of the 8 ROIs. CR, corona radiata; CT, corticospinal tract; FL, frontal lobe; GCC, genu of corpus callosum; l, left; ns, not significant; OL, occipital lobe; PL, parietal lobe; r, right; SCC, splenium of corpus callosum; TL, temporal lobe. ***$p < 0.001$.

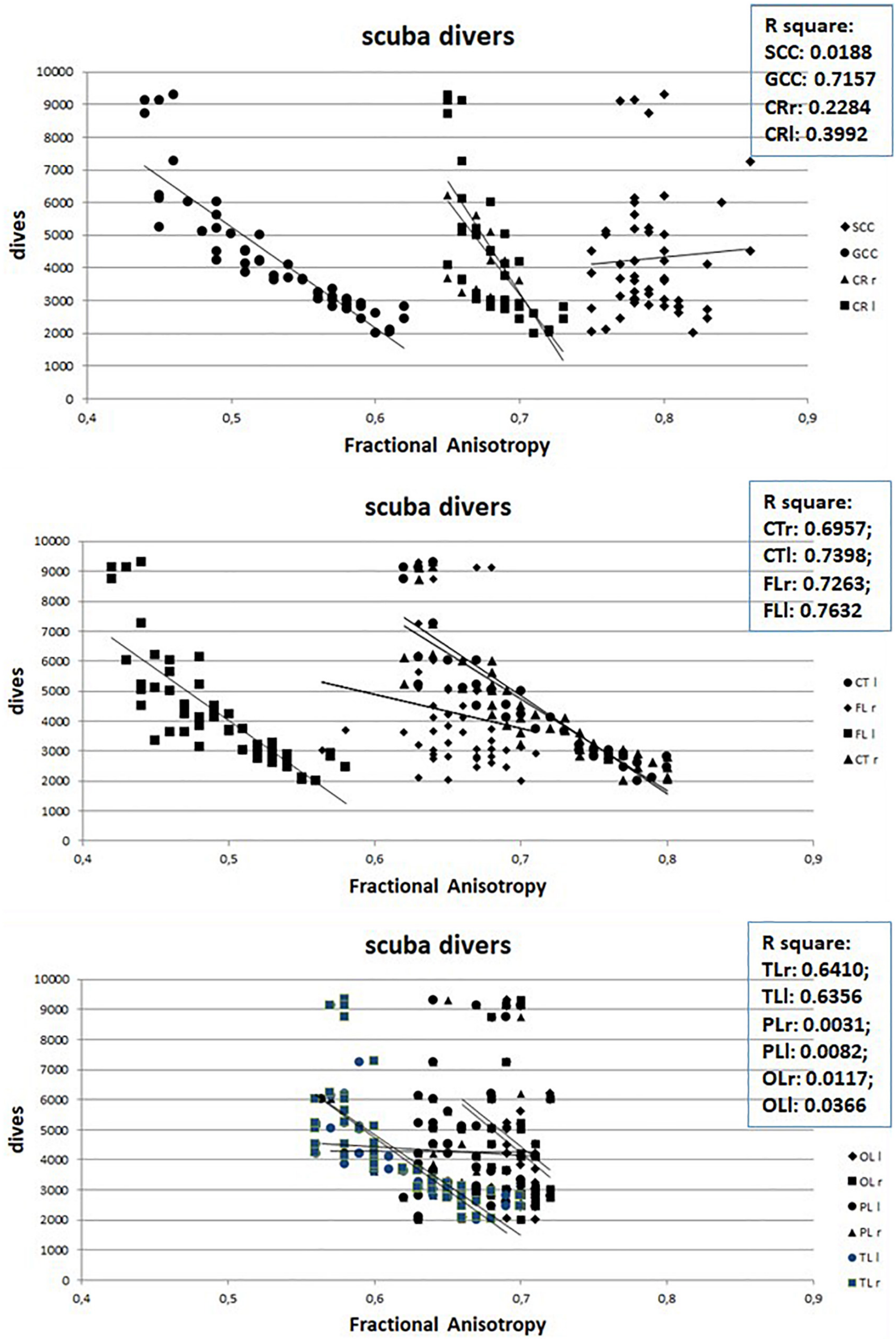

FIGURE 3 | Relation between Fractional Anisotropy and number of dives of divers. Abbreviations as in **Figure 2**.

as healthy controls. However, as can be seen in **Figure 5** where data relating to the left FL are shown, while in scuba divers the values of FA were significantly related with age, the healthy controls did not exhibit any statistically significant correlation. Statistically significant relations were also obtained by relating with age of divers FA values of right FL, GCC, as well as CT and TL of both sides; no relationship between age and FA was detected in controls. Therefore, it is possible to conclude that the changes of FA observed in scuba divers are related to the number of dives and not to age.

Neuropsychological Testing

Data from neuropsychological testing reveal small but significant impaired performances that increases with the number of dives. In **Figure 6** the results obtained for the Ray Complex Figure (top row), for the Corsi tapping test (middle row) and for the Digit Span (bottom row) are reported. The left column shows the relationships between the results obtained in the test and the dives numbers, the center column shows the relationships between the results obtained in the test and the age of the divers, while the right column shows the relationships between the results obtained in the test and the age of the controls.

It is possible to detect that, while in scuba divers there is a significant negative relation between the test's results and both the number of dives and the age, no relation has been highlighted between the test's results and age in the controls. Also in this case, no gender differences were detected (data not shown).

Figure 7 shows the R square values obtained from the correlations, both in scuba divers and controls, between the age of the subjects and the scores obtained in the different neuropsychological tests administered.

As can be seen, in all scuba divers the scores of all the different neuropsychological tests showed correlations with the age of the subjects with R square values that were less than 0.3 only for FSIQ, Trail Making Test Trail A and Trail Making Test Trail B. In the controls, however, there is no correlation between scores in neuropsychological tests and the age of the subjects, with values of R square always below 0.1. Nor were any gender-dependent differences found.

DISCUSSION

In recent years a number of studies have highlighted the presence of mild but significant cognitive deficits in scuba divers that have performed a high number of dives (Kowalski et al., 2011; Hemelryck et al., 2014; Ergen et al., 2017; Howle et al., 2017; Bosco et al., 2018; Verratti et al., 2019).

The present study aimed to assess whether underwater diving and compressed air work is capable to induce, in a dose-dependent manner, alterations of the cerebral WM and, consequently, to produce alterations of cognitive functions.

The results showed alterations of the WM both in terms of changes in FA; these variations, statistically significant but quantitatively quite modest, were mainly observed in the WM of the anterior part of the brain; no differences were observed between left and right hemisphere and between women and men.

The alterations of WM were positively related to the number of dives and the age of the divers. In controls, on the other hand, no correlation was found between the FA values of the WM and the age of the participants. This led to the conclusion that the changes of FA are more likely a result of the number of dives and are not due to the possibility that more experienced divers are too likely to be older. The absence of changes in the WM of controls is likely to be dependent on the relatively young age of the subjects (mean value 39.7 years ±7.22 SD), none of which reached 55 years (Chen et al., 2019).

In divers, the alterations of the WM were associated with changes, also in this case statistically significant but quantitatively quite modest, of the cognitive functions, in particular of those dependent on the prefrontal cortex (Coco et al., 2009; Ergen et al., 2017). The results of the present study are in agreement with cognitive deficits previously described in professional scuba divers. In particular, in this research cognitive deficits were found mainly, but not exclusively, in the domain of frontal functions. Kowalski et al. (2011) found delays in reaction time in 25 very experienced divers, compared to 23 non-divers. The findings showed that a lasting cerebral damage possibly develops only after a long diving career consisting of numerous decompressions, and repetitive dives. In addition, their results of the controls suggest that age had no direct influence on reaction times. Investigating long-term effects of diving on cognitive function in 44 experienced scuba divers, Hemelryck et al. (2014) found a worse performance in short-term memory, compared to controls.

The present study leads to the conclusion that repeated dives, even performed in compliance with the current decompression tables, could progressively induce the formation of microbubbles in the myelin, with the result of micro lesions in the axonal sheet capable of altering the functioning of the neuron. Several mathematical models to predict the probability of bubble formation for a given dive profile were proposed; the algorithms constructed on these models are the basis of decompression tables (Parker et al., 1992). Modern dive computers can evaluate in real-time the decompression status and report it to the diver (Lang and Hamilton, 1989). The present results suggest that these mathematical models are able to calculate the formation of bubbles in a short-medium temporal dimension, as in the case of divers who in their life do some hundreds of dives. However, evidently these models cannot predict the slow formation of microbubbles over thousands of dives. In conclusion, this study has shown that in individuals who have made at least two thousand scuba diving with compressed air can be seen modification of the cerebral WM in a dose-dependent manner. These alterations were particularly evident in the FL and in the GCC, without differences of side or gender. It has also been possible to detect that these structural modifications were associated with small but significant cognitive alterations that mainly concerned the executive functions, without gender differences.

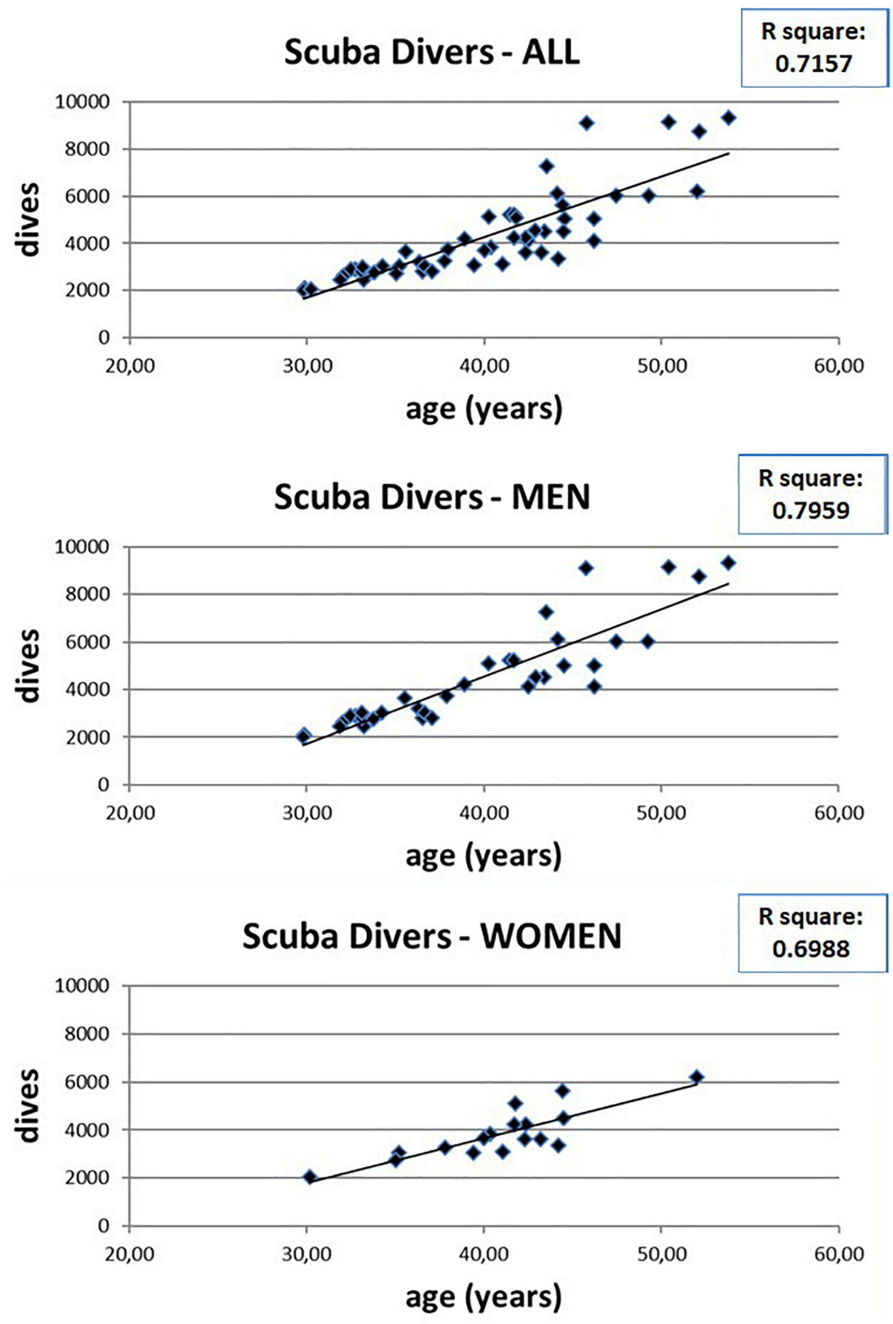

FIGURE 4 | Relation between age and number of dives in scuba divers, as well as in men and women separately.

Despite the gender differences in diver performance still being debated, Brebeck et al. (2017) demonstrated that female divers performed better than male divers on the memory tests, and Pauls et al. (2013) found highest gender differences in non-visuospatial abilities with an advantage for women.

In conclusion, it can be determined that after the diving cognitive response amount is low and it's better that divers instantly refrain from doing something with elevated attention after diving.

Of course, this study has certain limitations. For one, a weakness could be represented by the heterogeneous distribution over the years of their dives. However, these factors will make the achievement of statistically significant differences less likely. Given this heterogeneity, great care was taken to ensure randomization to the control group and experimental groups. Furthermore, in light of the sparse data on female divers, our findings suggest that gender differences in diver performance may merit further investigation.

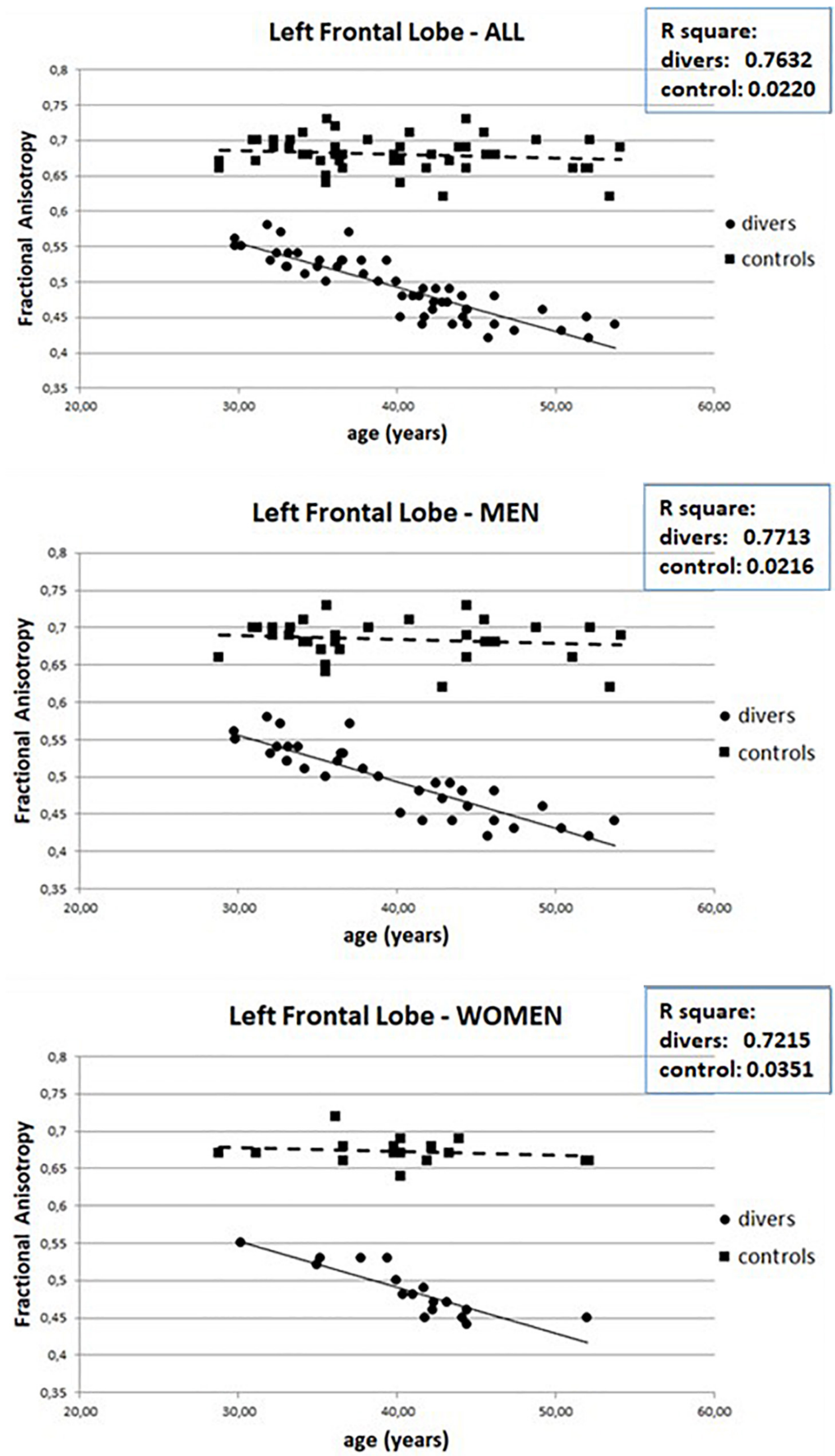

FIGURE 5 | Relation between Fractional Anisotropy and age in scuba divers and controls in left FL.

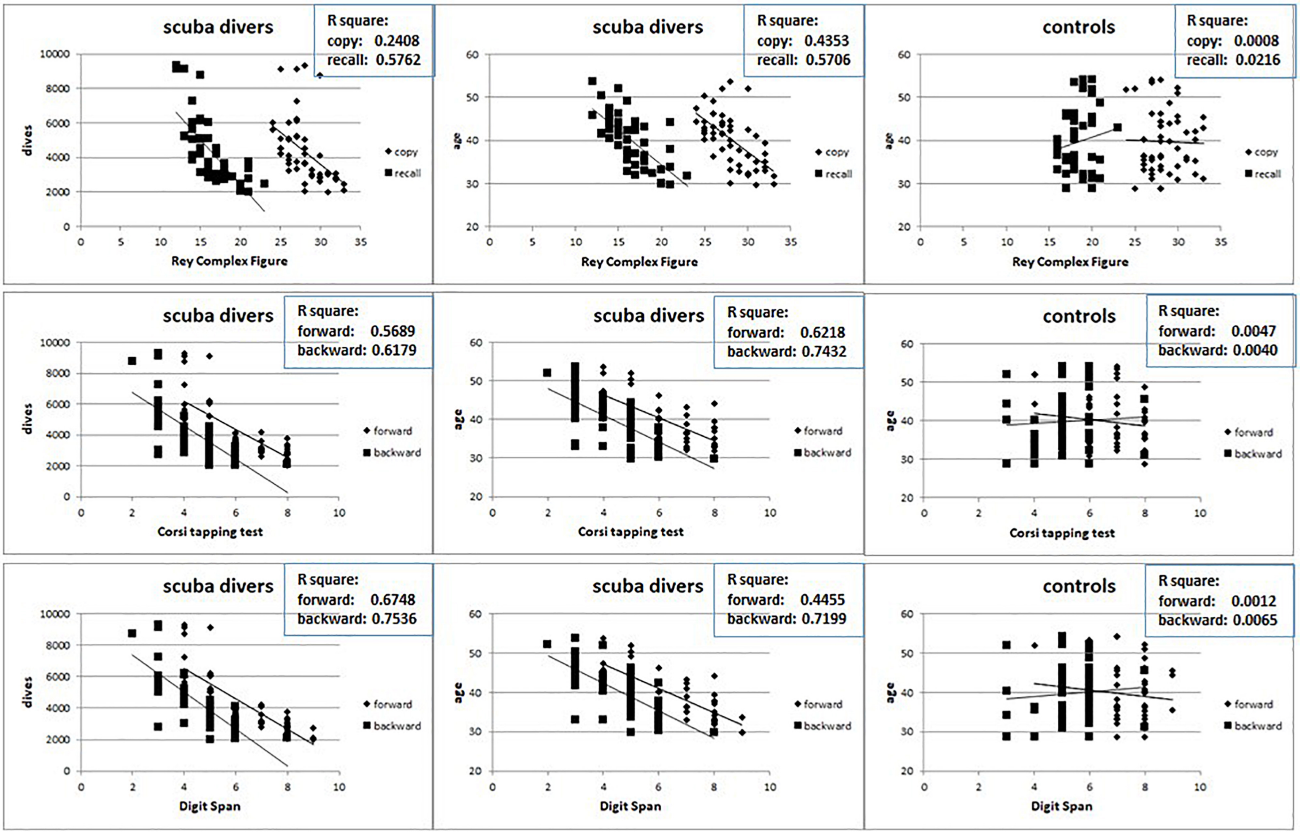

FIGURE 6 | Relation between the results at Ray Complex Figure **(top row)**, Corsi tapping test **(middle row)** and Digit Span **(bottom row)** and the number of dives and age in divers **(left and central columns)** and age in controls **(right columns)**.

FIGURE 7 | Values of *R* square measured for relations between the results at all neuropsychological tests and the age in divers (blue) and controls (red) in the whole sample (all), as well as in men and women separately.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Ethical Committees of our Institutions with written informed consent from all subjects. All subjects gave written informed consent in accordance with the 1964 Declaration of Helsinki. The protocol obtained ethical permission from the Internal Ethic Review Board – IERB, Department of Education Sciences, Psychology Section, University of Catania (29/11/2018).

AUTHOR CONTRIBUTIONS

MC, ViP, AB, and VaP contributed to the conception and design of the study. TM was responsible for neuropsychological testing whereas GG and AS performed the Fractional anisotropy evaluation. MC, AB, DD, and ViP were responsible for data collection and statistical analysis. MC, AB, and ViP was responsible for drafting and finalization of the manuscript. All authors contributed to the manuscript revision and approved the submitted version of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02376/full#supplementary-material

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

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ORIGINAL RESEARCH
published: 21 November 2019
doi: 10.3389/fpsyg.2019.02506

Prediction of the Satisfaction With the Student Life, Based on Teaching Competence and Satisfaction With the School

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The aim of this article was to assess how students evaluate the professional personality competence of physical education teachers in high school and its relation to student satisfaction and student satisfaction with life itself. In line with these aims, this study was completed as a cross-sectional study, which was carried out in a group of 890 physical education students. Of the study group, 50.3% were female and 49.7% were male. The average age was 15.49 years for females (SD 1.79) and 15.00 years for males (SD 2.00). We used a questionnaire featuring the *Physical Education Teacher Competence*, *Intrinsic Satisfaction Classroom Scale*, and *Satisfaction with Life Scale*. The results are presented as descriptive statistics, correlations, and a structural equation modeling analysis showing students' perceived competence, predicted self-determined satisfaction, which in turn corresponds to life satisfaction.

Keywords: teacher competences, classroom satisfaction, life satisfaction, student, physical education

OPEN ACCESS

Edited by:
Donatella Di Corrado, Kore University of Enna, Italy

Reviewed by:
Francesca Vitali, University of Verona, Italy
Valentina Perciavalle, University of Catania, Italy

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *04 September 2019*
Accepted: *23 October 2019*
Published: *21 November 2019*

Citation:
Baños R, Baena-Extremera A and Ortiz-Camacho M (2019) Prediction of the Satisfaction With the Student Life, Based on Teaching Competence and Satisfaction With the School. Front. Psychol. 10:2506. doi: 10.3389/fpsyg.2019.02506

INTRODUCTION

In recent years, diverse research has highlighted the importance of studying the life satisfaction of students, for the academic and personal repercussions that these carry (Méndez-Giménez et al., 2017; Salvador-Ferrer, 2017). For that, several authors (Diener, 1984; Diener and Emmons, 1985; Argyle, 1987) have used the theory of subjective well-being to study the satisfaction of people, identifying two dimensions namely: cognitive and affective dimensions. With this theory, subjective well-being can be understood as a theoretical construct that contemplates the combination of the cognitive process (judgments of satisfaction and dissatisfaction) and two affective processes (positive affect and negative affect) (Diener and Emmons, 1985). On one side, the affective dimension can be identified with emotions and affections, such as worry or boredom among others. On the contrary, the cognitive dimension is related to evaluative judgments of life satisfaction and its specific areas (Diener and Emmons, 1985). In line with this, Campbell et al. (1976) related the cognitive and affective dimensions of the theoretical construct, with life satisfaction and happiness, respectively. A decade later, Diener et al. (2003) synthesized that subjective well-being can be identified with components of life satisfaction, with satisfaction in specific areas of life and with the affect thereof (positive and negative).

On the other side, existing literature shows that school is an important factor determining happiness in teenagers, since they invest most part of their life in the academic environment (Roeser and Eccles, 2000). The relationship between life satisfaction and the diverse variables of school and educations, such as academic commitment (Lewis et al., 2011), perceived academic competence (Suldo and Huebner, 2006), auto efficiency (Maddux, 2002), disruptive behavior (Suldo and Huebner, 2004), and the academic performance (Gilman and Huebner, 2006; Vecchio et al., 2007), have been extensively researched, finding contradictory results regarding this variable.

It has been proven that the satisfaction/dissatisfaction with physical education (PE) predicts a positive or negative satisfaction with school (Baena-Extremera and Granero-Gallegos, 2015) and that music students obtain higher values of life satisfaction than those who study mathematics, geography, or language (Gültekin and Aricioğlu, 2016). This therefore opens up a new field of study, due to the existence of a relationship between satisfaction on several subjects, with the academic environment and even academic performance (Baños et al., 2019).

To understand this relationship, understanding the motivational theories is fundamental. Among these theories is the self-determination theory (Deci and Ryan, 1985), along with the variables that underline it. For example, Granero-Gallegos et al. (2012) found that students with high levels of satisfaction/or those that view PE as a fun subject were highly intrinsically motivated individuals, who valued the effort and work required in PE, with the objective to improve and to give more value to the subject. In line with this, Baños et al. (2017) show that when a student experiences a class situation where fun and/or boredom is promoted, it has a direct influence on the student's performance and can have successful results on their learning process or on the contrary lead to the abandonment of the education system. In this paper, the important role of the professor can be appreciated, as the work design can be a key element in the abandonment or the academic commitment of students (Catano and Harvey, 2011). With this in mind, the influence of the teacher is hugely relevant, as the teacher can have a direct influence on school satisfaction (Baena-Extremera and Granero-Gallegos, 2015) as well as the life satisfaction of a student.

In relation to this, the quality of a students' educational experience is greatly influenced by the teacher's experience inside the classroom (Hill et al., 2003; Yair, 2008; Baena-Extermera et al., 2013) and their teaching skills. However, it is well known that teaching is multidimensional as well as complex (Wang et al., 2011), where teachers face and respond to a series of factors that could affect the students and the teaching-learning process, for example, the characteristics of the course, classroom management, and the teacher-student interaction (Young and Shaw, 1999; Khine, 2005). Therefore, to improve teacher competence, a series of basic competencies should be broken down, with specific and observable aspects for teachers, that help improve the learning process in the classroom (Denyer et al., 2007) and influences related to aspects of motivation and learning. The efficiency of such competences could vary according to each student's personality, some requiring a smart teacher, others a perfectionist, or a careful, encouraging, and loving teacher, but above all, a teacher who has the ability to amuse, enthuse, be affective, open, and caring (Moreno, 2009). Competencies like the knowledge a teacher possesses on the subject, the clarity of their presentation, and how they interact with students as well as creativity are positively related to the satisfaction and motivation of students (Sang et al., 2013). Thus, the way in which a teacher plans and organizes PE classes, adapting to the needs of their students, may influence student satisfaction at school (Baena-Extremera and Granero-Gallegos, 2015).

Considering all the above, the importance of this research lies in studying the influence of a PE teacher's competencies has on student satisfaction. Thus, the hypothesis of this study is that a competent teacher will help students achieve school satisfaction in PE and, at the same time, promote life satisfaction. Considering this hypothesis, the aim of this study is to analyze how a PE teacher's competencies can predict school satisfaction and, in turn, the life satisfaction of secondary school students.

METHODS

Participants

The selection of the sample was of a non-probabilistic type and according to the case on which the students could be accessed. A total of 890 high school (HS) and bachelor (BACH) PE students (442 males = 49.7%, age range = 15.00, DT = 2.00; and 448 females = 50.3%, age range = 15.00; DT = 2.00), belonging to five public and private schools in the Region of Murcia and the Region of Alicante (Spain). In total, 152 students belonged to 1° grade HS (17.1%), 160 (18.0%) of 2° grade HS, 182 (20.4%) of 3° grade HS, 186 (20.9%) of 4° HS, 101 (11.3%) of 1° grade BACH and last, 109 (12.2%) of 2° grade BACH.

Instruments

The following instruments were used to carry out this investigation.

Physical Education Teacher Competence

A validated Spanish version of the *Evaluation of Teaching Competencies Scale* by Catano and Harvey (2011) was used and adapted to PE by Baena-Extremera et al. (2015). The instrument presents eight items that measure the student's perception of the teacher's effectiveness. The students were asked to indicate the degree of agreement with the items, and the responses were collected using a scale of polyatomic items ranging from low (1-2), medium (3-4-5), and high (6-7). The eight constructs that this instrument evaluates are communication, conscience of work, creativity, feedback, individual consideration of the student, professionalism, problem resolution, and social conscience.

Satisfaction With the School

The questionnaire of intrinsic satisfaction was employed and translated to Spanish and validated by Castillo et al. (2001)

from the *Intrinsic Satisfaction Classroom Scale*, by Nicholls et al. (1985), Nicholls (1989), and Duda and Nicholls (1992). This instrument presents eight items that measure the scale of satisfaction with school, with two subscales that measure satisfaction/fun (five items) and boredom with school (three items). The scale was used for the phrase "Tell us your degree of disagreement or agreement in relation with the next affirmations, in reference of all of your school subjects." Responses were collected through a scale of polyatomic items ranging between 1 (totally disagree) and 5 (totally agree).

Satisfaction With Life

The questionnaire used was translated to Spanish and validated by Cabañero et al. (2004) of Diener et al. (1985) and is composed of five items that measure only one factor. This instrument uses a five-point polyatomic scale of items, ranging from (1) totally disagree to (5) totally agree.

Procedure

The design of this work is non-experimental, sectional, descriptive, and predictive. For the development of this study, written informed consent was obtained from the educational centers, teachers, and parents/tutors, and the intention and objectives of the study was provided.

After obtaining the relevant permissions, data were collected. The participants were informed of the study's purpose, the voluntary nature of their participation, and the confidential treatment of their answers. They were told that there were no right or wrong answers and were asked for their utmost sincerity.

The questionnaires were completed in a classroom in about 25–30 min with the same researcher always present and who could be consulted regarding any doubts during the process, respecting the declaration of Helsinki (Helsinki Declaration World Medical Association, 2013).

Data Analysis

An analysis of normality in multiple variants was conducted.

For this, a *normality test based on relative multivariant kurtosis* (RMK) of the PRELIS of the LISREL 9.90 program was conducted. Given the normality, a *Confirmatory Factor Analysis* (CFA) to study the adaptation of such instruments to the samples used in this study was conducted. Multiple reliability and validity indexes were calculated, such as Cronbach's alpha, the compose reliability, and *average variability extracted* (AVE) for each instrument. A correlation analysis between the instruments used was carried out afterwards, as well as diverse models of structural equations, to answer the objective of this study. The calculations were carried out with the statistical package SPSS v.11 and LISREL 8.80.

RESULTS

Analysis of Data Normality

In **Table 1**, we can observe the normality data of the measuring instruments, where finally, the data prove abnormal behavior.

TABLE 1 | Values of the multivariate normality test.

	Multivariant normalized Kurtosis	Mardia-based-Kappa	Higher limit	Lower limit
ECTS	51.2439	0.488	1.027	0.973
SWS	6.5740	0.147	1.034	0.966
SWL	14.788	0.237	1.045	0.955

ECTS, Evaluation of Teaching Competencies Scale; SWS, satisfaction with school; SWL, satisfaction with life.

The values of RMK for the Evaluation of Teaching Competencies Scale ranged from 1.488 and from 1.123 to 1.237 for the satisfaction with school and life satisfaction, respectively.

Confirmatory Factor Analysis

First, the CFA of each instrument to determine the validity and reliability of the sample used in this study was conducted. The results (**Table 2**) were acceptable within the limits established in x^2/gl (Bentler, 1989; Tabachnick and Fidell, 2007), in GFI (Hooper et al., 2008), CFI, IFI, NFI, NNFI (Hu and Bentler, 1995), and RMSEA (Cole and Maxwell, 2003; Chen et al., 2008).

Reliability and Validity Analysis

As some dimensions of the instruments are composed by only a few items, the Cronbach's alpha represents some limitations according to Ventura-León and Caycho-Rodríguez (2017). For this reason and due to the recommendation of Domínguez-Lara and Merino-Soto (2015), the reliability was calculated by the ω of McDonald. Unlike the alpha Cronbach coefficient, it considers the factorial load, which makes the calculus more stable and reflects the true level of reliability without relying on the number of items in the dimension (see Ventura-León and Caycho-Rodríguez, 2017). Values of internal consistency (ω) are acceptable between 0.70 and 0.90 (Campo-Arias and Oviedo, 2008), although Katz (2006) can accept values from >0.65.

In **Table 3**, an analysis of each model is presented: the Cronbach's alpha values, compound reliability, AVE, the average and typical deviation of Evaluation of Teaching Competencies Scale, satisfaction with school, boredom with school, and life satisfaction. As can be observed, all the indexes of reliability, AVE, and all α, which are above the acceptable values according to Dunn et al. (2014) and Hair et al. (2009), emphasize that the compound reliability is considerably more appropriate than the Cronbach's alpha in ordinal scale types because they do not depend on the number of attributes associated with each concept (Vandenbosch, 1996), as the values are more acceptable for each factor.

Correlation Analysis

In **Table 4**, we can see how teacher competence maintains a positive and significant correlation with satisfaction with life (0.119^{**}) and satisfaction with school (0.093^{**}) but remains negative with the ABU. The satisfaction with school presents a negative and significant correlation with the opposite factor

TABLE 2 | Adjustment fit indices of each model.

	x^2	gl	x^2/gl	*p*	GFI	CFI	IFI	NFI	NNFI	RMSEA
ECTS	60.45	27		0.000	0.99	0.98	0.98	0.96	0.97	0.03
SWS	78.78	19	4.14	0.000	0.99	0.94	0.94	0.92	0.91	0.068
SWL	18.42	5		0.002	0.99	0.99	0.99	0.98	0.98	0.05

x^2, Chi-square; gl, degrees of freedom; p, significance; GFI, goodness-of-fit index; CFI, comparative fit index; IFI, adjustment index; NFI, normalized adjustment index; NNFI, non-normative adjustment index; RMSEA, root-mean squared approximation; ECTS, Evaluation of Teaching Competencies Scale; SWS, satisfaction with school; SWL, satisfaction with life.

TABLE 3 | Scale reliability and convergent validity.

	M	SD	Composite reliability	AVE	*α*	*ω*
ECTS	5.49	0.96	0.90	0.50	0.85	0.86
SWS	3.16	0.95	0.83	0.50	0.76	0.80
BWS	2.98	0.85	0.75	0.50	0.69	0.71
SWL	3.54	0.87	0.87	0.57	0.83	0.81

M, mean; SD, standard deviation; AVE, average variance extracted; α, Crombach's alpha; ω, McDonald's omega; ECTS, Evaluation of Teaching Competencies Scale; SWS, satisfaction with school; SWL, satisfaction with life.

TABLE 4 | Correlation analysis between the variables.

	1	2	3	4
1. ECTS	—	0.093**	−0.023	0.119**
2. SATD		—	−0.546**	0.272**
3. ABUE			—	−0.201**
4. SATV				—

*ECTS, Evaluation of Teaching Competencies Scale; SWS, satisfaction with school; SWL, satisfaction with life. *p < 0.05; **p < 0.01.*

on its scale (−0.546**) and positive with satisfaction with life (0.272**). The boredom with school finally correlates negative and significantly with satisfaction with life (−0.201**).

Prediction of Satisfaction With Student Life

In accordance with the objective of this study, different models have been hypothesized to test which would adjust better according to the recommendation of Markland (2007). According to the correlations, the model that better predicted the satisfaction with the student life was approved. The structural regression models were evaluated through the combination of the adjustment indexes previously explained, with their values being x^2/gl = 4.32, GFI = 0.96, CFI = 0.92, IFI = 0.92, NFI = 0.95, NNFI = 0.96, and RMSEA = 0.06. These values adjust perfectly to the acceptable parameters (Bentler, 1989; Tabachnick and Fidell, 2007; Hooper et al., 2008, among others). According with the **Figure 1**, we can observe gamma, beta, lambda-x, lambda-y, and theta delta and theta épsilon values (**Figure 1**). In it, we can appreciate how the Evaluation of Teaching Competencies Scale positively predicts the impact of the satisfaction with school (γ = 0.94), being negative for boredom with school (γ = −0.79), satisfaction with school, predicts at the same time the satisfaction with life in a positive way (β = 0.50), being the prediction of boredom with school (β = 0.05). Finally, the estimated parameters were considered significant when the value associated with value t is greater than 1.96 (p < 0.05) and all items showed individual reliability values of (λ) > 0.05.

DISCUSSION

The objective of this study was to analyze how a PE teacher's competencies can predict the satisfaction with school, and how these, at the same time, predict the life satisfaction of HS and BACH students. The importance of this research lies in the influence that a PE teacher can generate on the subjective wellbeing of adolescents, not only in the academic field but also in other areas of life. In addition, adolescence is a stage of life that carries profound changes, in which friend and family influences are transformed and where decision-making has a greater impact on adult life (Maršanić et al., 2014). Failing school and even the increasing suicide rate at this stage of life are fundamental aspects of this study, similar to those already mentioned (Kosik et al., 2017).

We emphasize that the three scales, the Evaluation of Teaching Competencies Scale, satisfaction with school and satisfaction with life, obtained viable and reliable results.

The obtained results in this study demonstrate positive and significant correlations between teacher competencies with satisfaction with school and satisfaction with life and had no correlation with boredom with school, although it did find signs of a limited negative relation. These results showed that a PE teacher who is a good communicator, with work and social conscience, a creative and problem resolution capacity, who provides feedback, who has good individual consideration with a student, and who in conclusion is professional, can affect satisfaction not only through fun and how satisfied they are with school but also can also have repercussions in their satisfaction with life. Similar results were found by Kuzmanovic et al. (2013) who showed that students were satisfied when the teacher was available to solve problems, showing consideration, and providing feedback. So, a good teacher is distinguished by his/her students, as a good stimulator, innovator, enthusiastic, with a good sense of humor, and who is self-reflective, and supportive of diversity (Johnstone, 2005; Khine, 2005; Yair, 2008; Delaney et al., 2009).

Satisfaction with school is significantly positively correlated to satisfaction with life; however, it is significantly negatively correlated to boredom with school, and this, at the same time, is significantly negatively correlated with satisfaction with life. Although it has been proven that teenagers who are perceived as happier, learn faster, behave better, and show greater

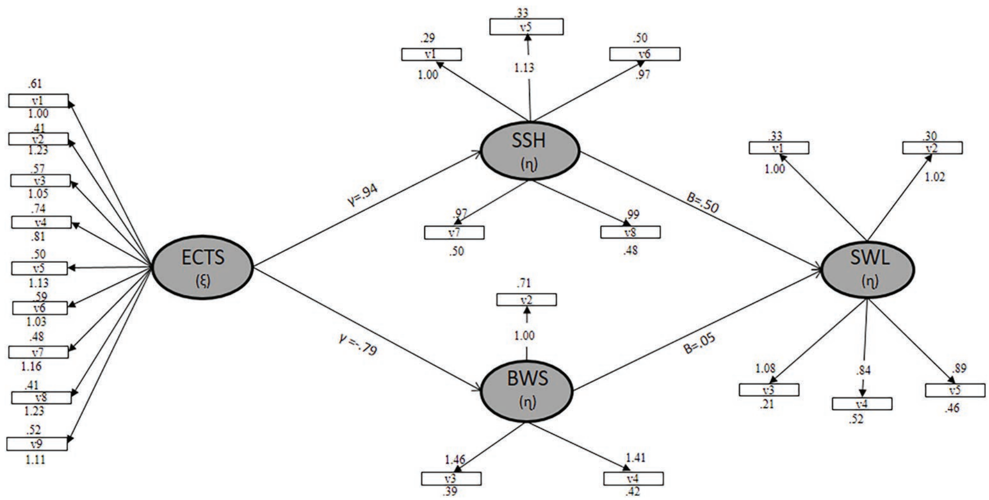

FIGURE 1 | Exogenous variable ECTS (ξ), Evaluation of Teaching Competencies Scale; endogenous bariable SSH (η), dimension of satisfaction with school; endogenous variable BWS (η), dimension boredom with school; endogenous variable SWL (η), satisfaction with life; γ, gamma values; β, beta values.

commitment and academic performance (Noddings, 2003; Ben-Arieh, 2008; Castro, 2011; Baena-Extremera and Granero-Gallegos, 2013; Lyons and Huebner, 2016), the school plays an important role in their subjective well-being, due to the time they spend on academics; therefore, if they find it monotonous and boring, their happiness could be diminished. This input was reflected in the results obtained in this present study, where a student who is unsatisfied at school is related to low levels of satisfaction with life. In line with this, Lyons and Huebner, 2016 found similar results, since students who became bored at school showed less school commitment and more dissatisfaction with their life. Considering this, the correct planning of classroom sessions to avoid monotonous and boring classes is of utmost importance and can increase the levels of satisfaction with life (Quinn and Duckworth, 2007).

In the results of the predictive model, it could be observed how the PE teaching competencies positively predicted the satisfaction with school, and in turn, the satisfaction with life, obtaining similar results to the studies realized by Baena-Extremera et al. (2015). This helped to understand the weight that a PE teacher has on the educative system and on the life of the students, where the difference of being a competent teacher or not, could directly influence the satisfaction or boredom of a student and therefore indirectly influence life satisfaction (Baños et al., 2017). It is also known that the excellence and quality of the institution, as well as the professionalism of the teacher, with traits such as fairness and impartiality, predicts the satisfaction of the student in the classroom and the satisfaction with the teaching quality (Elliot and Shin, 2002) emphasizing the need for good teaching, the setting of clear goals, suitable evaluation methods depending the level of the students, planning of appropriate workload, and having ideal general competencies for teaching (Ginns et al., 2007). However, if teachers do not produce the sufficient impact on their students (Cameron and Lovett, 2015) and the student's perception of the incompetencies of their PE teacher predicts boredom with school, they will not find the prediction of satisfaction with life. These results are important, as an unsatisfied student increases the possibility of failing school or even abandoning school (Elmore and Huebner, 2010) and increases the probability of suicide in teenagers (Singer et al., 2018). For this reason, it is important to have good teaching practices, emphasizing the influence that a PE teacher can have on their students if they are well prepared, avoiding monotonous classes, with organized planning, where the educator gives autonomy to the students and where sessions approach the students' interests (Delaney et al., 2009; Calderón et al., 2013; Lee et al., 2015; Lebrero et al., 2019). By doing this, motivation for PE classes will likely improve (Baena-Extremera et al., 2013), affecting the school and faculty (Aubert et al., 2014), improving the results on the PISA report, alarming on the Spanish education system (Casquero and Navarro, 2010).

Finally, the advances presented in this study with relation to previous research can be summarized. A PE teacher can positively predict the life satisfaction of students through the subject they teach and can especially influences stages where they experience big personal changes, morphological and psychological. Therefore, the original contribution of this study is the impact a PE teacher has not only with regard to the physical activity in a teenager's spare time (Wallhead and Buckworth, 2004; Baena-Extermera et al., 2016) but also on the satisfaction with school and life satisfaction life.

Limitations and Strengths

Future research should consider using different levels and ages and should even consider analyzing these variables in other subjects. Another limitation of this study is its design; a future possibility is to carry out a quasi-experiment, considering the school organization. Nevertheless, the strength of this study is the large number of participants used and the originality of the investigation as very few studies on this topic are present in the current literature.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

RB and AB-E conceived the hypothesis of this study and analyzed the data. RB, AB-E, and MO-C participated in data collection and wrote the paper with the most significant input from AB-E. All authors contributed to data interpretation of statistical analysis and read and approved the final 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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 03 December 2019
doi: 10.3389/fpsyg.2019.02737

Relative Age Effect on Youth Female Volleyball Players: A Pilot Study on Its Prevalence and Relationship With Anthropometric and Physiological Characteristics

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OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Movement Science and Sport Psychology,
a section of the journal Frontiers in Psychology

Received: 17 October 2019
Accepted: 19 November 2019
Published: 03 December 2019

Citation:
Papadopoulou SD, Papadopoulou SK, Rosemann T, Knechtle B and Nikolaidis PT (2019) Relative Age Effect on Youth Female Volleyball Players: A Pilot Study on Its Prevalence and Relationship With Anthropometric and Physiological Characteristics.
Front. Psychol. 10:2737.
doi: 10.3389/fpsyg.2019.02737

The relative age effect (RAE) on human performance has been well studied in many sports, especially in soccer; however, little information has been available about the prevalence of RAE in volleyball, and its role on anthropometric and physiological characteristics. The aim of the present study was to examine (a) the prevalence of RAE in selected (i.e., to be considered for the national team) and non-selected youth female volleyball players, and (b) the relationship of birth quarter (BQ) with anthropometric and physiological characteristics. Selected (n = 72, age 13.3 ± 0.7 years, weight 62.0 ± 7.2 kg, height 1.72 ± 0.06 m) and non-selected female volleyball players (n = 53, age 13.9 ± 1.1 years, weight 56.4 ± 7.3 kg, height 1.66 ± 0.06 m) performed a series of anthropometric and physiological tests. Twenty-six selected participants were born in the first quarter of the year, 19 in the second, 14 in the third, and 13 in the forth. The corresponding frequency by BQ in non-selected participants was 12, 12, 17, and 12. No association was observed between the number of participants and their frequency by BQ neither in the selected (χ^2 = 2.79, p = 0.425) nor in the non-selected group (χ^2 = 0.64, p = 0.886). Anthropometric and physiological characteristics did not vary by BQ ($p > 0.05$). The absence of RAE in female volleyball players and the similarities of anthropometric and physiological characteristics among BQ might be due to technical-tactical character of this sport. These findings would be of great practical value for coaches and fitness trainers working with young volleyball players.

Keywords: birth quarter, body composition, human performance, jumping ability, isometric muscle strength

INTRODUCTION

The relative age effect (RAE) on human performance – i.e., the larger prevalence of athletes born in the first months (e.g., first quarter) of the year ("early born") compared to their counterparts born in the last months (e.g., last quarter) of the year ("late born") – has attracted an increased scientific interest during the last three decades considering its relevance for sport performance

(Barnsley et al., 1992) and other domains of human performance (Alsaker and Olweus, 1993). This phenomenon indicated a potential advantage of "early born" compared to "late born" athletes (Duarte et al., 2019). So far, most of the research of RAE in sports has been conducted in soccer (Peña-González et al., 2018; Schroepf and Lames, 2018; Yagüe et al., 2018) and focused on the prevalence of RAE analyzing the distribution of births among months of year. On the other hand, less information exists in female volleyball (Okazaki et al., 2011), which has been one of the most popular team sports in women worldwide (Deaner et al., 2012), and – to the best of our knowledge – no study has ever examined the relationship of RAE with anthropometric and physiological characteristics in this sport.

The findings of existing literature on RAE in volleyball have been controversial so far. An absence of RAE has been observed in Dutch volleyball (Van Rossum, 2006), elite Brazilian adult female volleyball players (Parma and Penna, 2018) and Israeli Division 1 (Lidor et al., 2014). On the other hand, RAE has been shown in the top Japanese volleyball league (Nakata and Sakamoto, 2012), elite Brazilian youth female volleyball players (Okazaki et al., 2011) and female United Kingdom school-children 11–18 years volleyball players (Reed et al., 2017). With an exception, where an over-representation of the last quarters of the year for the whole population in recreational volleyball players was found (Larouche et al., 2010), RAE indicated a higher prevalence of "early born" volleyball players especially in the younger age groups suggesting that RAE was attenuating with age in volleyball. This observation was in agreement with findings in soccer, where RAE was less remarkable in the older soccer players compared to their younger counterparts (Brustio et al., 2018).

Considering the above-mentioned literature on volleyball with some studies observing RAE (Okazaki et al., 2011; Nakata and Sakamoto, 2012; Reed et al., 2017) and others not (Van Rossum, 2006; Lidor et al., 2014; Parma and Penna, 2018), it was suggested that further research on the prevalence of RAE in this sport was needed. Such information would be of great practical interest for volleyball practitioners and policy makers, since an observation of disproportionally high number of "early born" volleyball players would indicate a bias against their "late born" counterparts increasing the risk of drop-outs. This topic was particularly important in adolescence, which was a crucial period for the adherence in sports (Soares et al., 2019). Furthermore, it would be of great practical importance to examine the relationship of RAE with anthropometric and physiological characteristics related to performance in female volleyball players. It has been shown that female volleyball players of high performance level were taller, jumped higher and had larger handgrip muscle strength than their counterparts of lower performance level (Nikolaidis et al., 2015). Also, more successful female volleyball players were taller, lighter and scored higher in standing broad jump and medicine ball throw than their less successful counterparts (Milić et al., 2017). Thus, it would be interesting to examine whether "early born" volleyball players would exhibit superior anthropometric and physiological characteristics compared to "late born." Maturation has been considered previously as a confounding factor of RAE (Peña-González et al., 2018), since early maturers exhibited superior performance than late maturers (Cripps et al., 2016). Therefore, the aim of the present study was to examine (a) the prevalence of RAE in selected and non-selected female volleyball players, and (b) the relationship of RAE with anthropometric and physiological characteristics. Based on relevant research in soccer (Buchheit et al., 2014; De Oliveira Matta et al., 2015), it was hypothesized that RAE would be observed in volleyball players, "early born" would have superior anthropometric and physiological characteristics than "late born" volleyball players, and RAE would have larger magnitude in selected than non-selected volleyball players. For the purpose of this study, "selected" referred to volleyball players who were selected by national team coaches to be considered for the national team of their age group.

MATERIALS AND METHODS

A cross-sectional study design was used in the present research. Birth quarter (BQ), i.e., the quarter of birth, was defined as the independent variable, whereas anthropometric and physiological characteristics were designated as dependent variables. Selected (n = 72, age 13.3 ± 0.7 years, weight 62.0 ± 7.2 kg, height 1.72 ± 0.06 m) and non-selected female volleyball players (n = 53, age 13.9 ± 1.1 years, weight 56.4 ± 7.3 kg, height 1.66 ± 0.06 m) participated in the present study. Selected volleyball players competed in volleyball clubs in Athens. Non-selected volleyball players were members of two youth academies of competitive volleyball clubs from Athens (Greece). All procedures were in accordance with the Declaration of Helsinki as revised in 2008 and approved by the local Institutional Review Board. Participants' parents or guardians provided informed consent prior to exercise testing session. All participants played volleyball at least three years before the study, had three to four training sessions and one official match weekly.

The testing session was carried out during competitive period in indoor volleyball court. It lasted 90 min, and included a supervised warm-up (10 min submaximal running and 5 min stretching exercises) and the following tests in the specific order: weight, height, skinfolds' thickness, sit-and-reach test (SAR), Abalakov jump (AJ), four tests of isometric muscle strength (right and left handgrip, lifting with extended and flexed knees) and 20 m endurance shuttle run test (SRT). Two trials were performed for SAR, AJ, and right and left handgrip test, and the best score was recorded for each of these tests. 1 min break was provided between trials and 5 min break among tests. Although this physical fitness test battery was not sport-specific, e.g., it did not include tests corresponding to movements usually performed in volleyball, the selected tests have been used widely due to their ability to discriminate volleyball players by performance level and playing position (Nikolaidis et al., 2015; Sattler et al., 2015; Brazo-Sayavera et al., 2017; Milić et al., 2017; Paz et al., 2017).

An electronic scale (HD-351 Tanita, Arlington Heights, IL, United States) and a stadiometer (SECA, Leicester, United Kingdom) were used to measure weight and height, respectively. Body mass index (BMI) was calculated using the formula "weight (kg)/height (m)^2." Body fat percentage (BF%) was predicted using the sum of ten skinfolds' thickness (cheek, wattle, chest I, triceps, subscapular, abdominal, chest II, suprailiac, thigh, and calf; skinfold caliper Harpenden, West Sussex, United Kingdom) (Parizkova, 1978). The difference from the age at peak height velocity (Δaphv) was evaluated only in the selected group – because sitting height was measured only in this group – and was used as a measure of maturation (Mirwald et al., 2002). A parameter that was evaluated only in the selected Opto-jump system (Microgate Engineering, Bolzano, Italy) was used to measure AJ, i.e., jumping ability of single vertical jump with countermovement and arm-swing (Bosco et al., 1983). Flexibility was tested by SAR on a box providing 15 cm advantage, i.e., the participant got a 15 cm score when reaching the toes of her feet (Adam et al., 1988). Aerobic capacity was assessed by SRT, a widely used graded exercise test (Adam et al., 1988). Isometric muscle strength was evaluated as the sum of four measures (right and left handgrip test, lifting with extended and flexed knees tests; use of digital handgrip and back-and-leg digital dynamometer; Takei, Tokyo, Japan) and expressed either in absolute (kg) or relative (kg/kg of body weight) values (Heyward and Gibson, 2014).

All variables were expressed using mean and standard deviations. Statistical analyses were carried out on IBM SPSS v.20.0 (SPSS, Chicago, IL, United States) and GraphPad Prism v. 7.0 (GraphPad Software, San Diego, CA, United States). A t test examined differences in all measures between the selected and non-selected group. A chi-square test (χ^2) examined the association of the number of participants by BQ with expected values. Differences in – adjusted for age – anthropometric and physiological characteristics among BQ groups were examined by one-way multivariate analysis of covariance (MANCOVA). In the case of the selected group, the differences were adjusted for both age and Δaphv. The magnitude of the differences was tested by partial eta square, evaluated as small ($0.010 < \eta_p^2 \leq 0.059$), medium ($0.059 < \eta_p^2 \leq 0.138$), and large ($\eta_p^2 > 0.138$) (Cohen, 1988). The relationship among variables was examined by Pearson's product moment correlation coefficient (r), whose magnitude was interpreted as trivial ($r < 0.10$), small ($0.10 \leq r < 0.30$), moderate ($0.30 \leq r < 0.50$), large ($0.50 \leq r < 0.70$), very large ($0.70 \leq r < 0.90$), nearly perfect ($r \geq 0.90$), and perfect ($r = 1.00$) (Batterham and Hopkins, 2006). Significance was set at alpha = 0.05.

TABLE 1 | Descriptive statistics (mean ± standard deviation) of anthropometric and physiological characteristics of participants.

Variable	Non-selected (n = 53)	Selected (n = 72)
Age (years)	13.9 ± 1.1	13.3 ± 0.7***
Anthropometric characteristics		
Weight (kg)	56.4 ± 7.3	62.0 ± 7.2***
Height (m)	1.66 ± 0.06	1.72 ± 0.06***
BMI (kg/m^{-2})	20.4 ± 2.2	21.1 ± 2.2
BF (%)	21.2 ± 4.1	21.2 ± 4.5
Physiological characteristics		
AJ (cm)	29.2 ± 4.9	30.8 ± 5.0
SAR (cm)	25.7 ± 7.2	24.7 ± 7.4
SRT (min:s)	5 : 22 ± 1 : 24	5 : 00 ± 1 : 17
Isometric muscle strength		
Right HG (kg)	27.2 ± 5.0	29.8 ± 4.5**
Left (kg)	26.2 ± 4.1	29.5 ± 4.3***
Lifting with extended knees (kg)	68.5 ± 12.9	77.1 ± 14.6**
Lifting with flexed knees (kg)	83.7 ± 21.6	90.4 ± 19.0
Isometric strength (kg)	205.6 ± 40.0	227.1 ± 36.6**
Isometric strength (kg/kg of body weight)	3.63 ± 0.43	3.70 ± 0.64

*BMI = body mass index; BF = body fat percentage; SAR = sit-and-reach test; SRT = 20 m shuttle run test; HG = handgrip muscle strength; ***p < 0.001, **p < 0.01.*

RESULTS

The descriptive characteristics of participants are presented in **Table 1**. Twenty-six selected participants were born in the first quarter of the year, 19 in the second, 14 in the third, and 13 in the forth. The corresponding numbers in non-selected participants were 12, 12, 17, and 12. No association was observed between the number of participants and their frequency by BQ neither in the selected (χ^2 = 2.79, p = 0.425) nor in the non-selected group (χ^2 = 0.64, p = 0.886). In the non-selected group, there was no statistically significant difference among BQ groups on the combined dependent variables after controlling for age in the non-selected group [$F_{(36,\ 104)}$ = 1.198, p = 0.239, Wilks' Λ = 0.359, η_p^2 = 0.239]. In the selected group, no statistically significant difference among BQ groups on the combined dependent variables after controlling for age and Δaphv [$F_{(36,\ 157)}$ = 0.881, p = 0.663, Wilks' Λ = 0.581, η_p^2 = 0.165] (**Figures 1–3**). The relationship of anthropometric and physiological characteristics with age in the non-selected group was shown in **Figures 4–6**.

The relationship of anthropometric and physiological characteristics with age and Δaphv in the selected group can be seen in **Table 2**. Age did not correlate with of the other measures. Δaphv correlated very largely with height, moderately with weight, and with small magnitude with left handgrip muscle strength.

DISCUSSION

The main findings of the present study were that, (a) RAE was not observed in selected and non-selected female volleyball players, (b) anthropometric and physiological characteristics did not differ among BQ groups, and (c) the relationship of anthropometric and physiological characteristics with age varied by performance group with stronger correlations observed in the non-selected than in the selected group.

The absence of RAE in the examined sample of female young volleyball players was in agreement with previous studies in volleyball that did not show any difference on the frequency of BQ groups (Van Rossum, 2006; Lidor et al., 2014; Parma and Penna, 2018). An explanation of the absence of RAE in our sample might be that volleyball has been considered a team sport that did not require exceptional demands in physiological

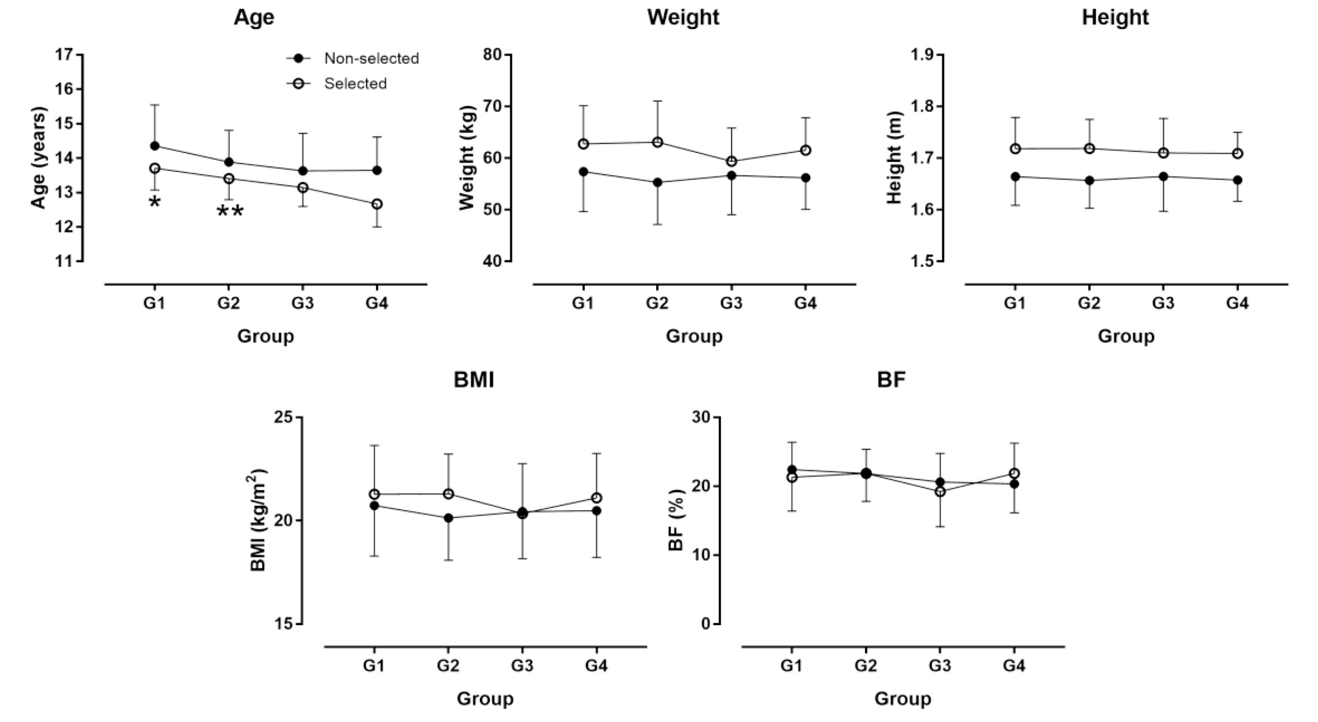

FIGURE 1 | Age and anthropometric characteristics by birth quarter. G1 = born in January, February, and March; G2 = born in April, May, and June; G3 = born in July, August, and September; G4 = born in October, November, and December; BMI = body mass index; BF = body fat percentage. *G1 older than G3 and G4, **G2 older than G4 in selected participants at $p < 0.05$.

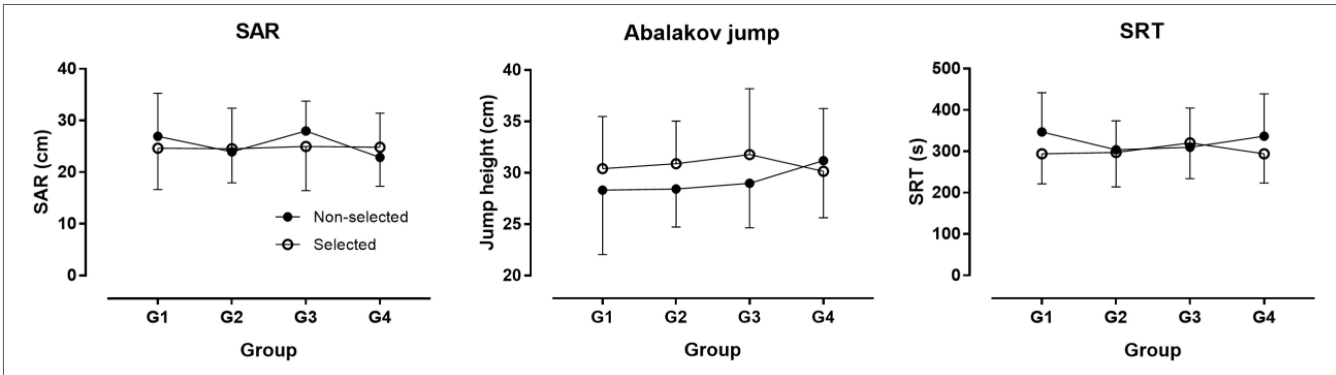

FIGURE 2 | Jumping, flexibility, and aerobic capacity by birth quarter. G1 = born in January, February, and March; G2 = born in April, May, and June; G3 = born in July, August, and September; G4 = born in October, November, and December; SAR = sit-and-reach test; SRT = 20 m endurance shuttle run test. Error bars represent standard deviations.

characteristics (Lidor and Ziv, 2010a) and was characterized by large variability in these characteristics (Nikolaidis et al., 2012). However, it was acknowledged that other studies conducted on this sport (Okazaki et al., 2011; Nakata and Sakamoto, 2012; Reed et al., 2017) observed RAE highlighting the overall conflicting findings in research on volleyball and addressing the need of further research on this topic. Based on the findings of the present study, it might be assumed that sport and human performances without high demands in physiological characteristics – e.g., aerobic capacity, muscle strength and speed – would attenuate the occurrence of RAE.

The absence of RAE in the present study was in disagreement with the existed literature on team sports with high demands in physiological characteristics. For instance, most studies (Korgaokar et al., 2018; Peña-González et al., 2018; Rađa et al., 2018; Schroepf and Lames, 2018; Yagüe et al., 2018; Marques et al., 2019) in soccer have observed an occurrence of RAE, where most soccer players were born in the first quarter or half of the year. Moreover, it has been shown that the number of soccer players born in January would be twice the number of those born in December in the top five European leagues (Rađa et al., 2018). An occurrence of RAE would have implications

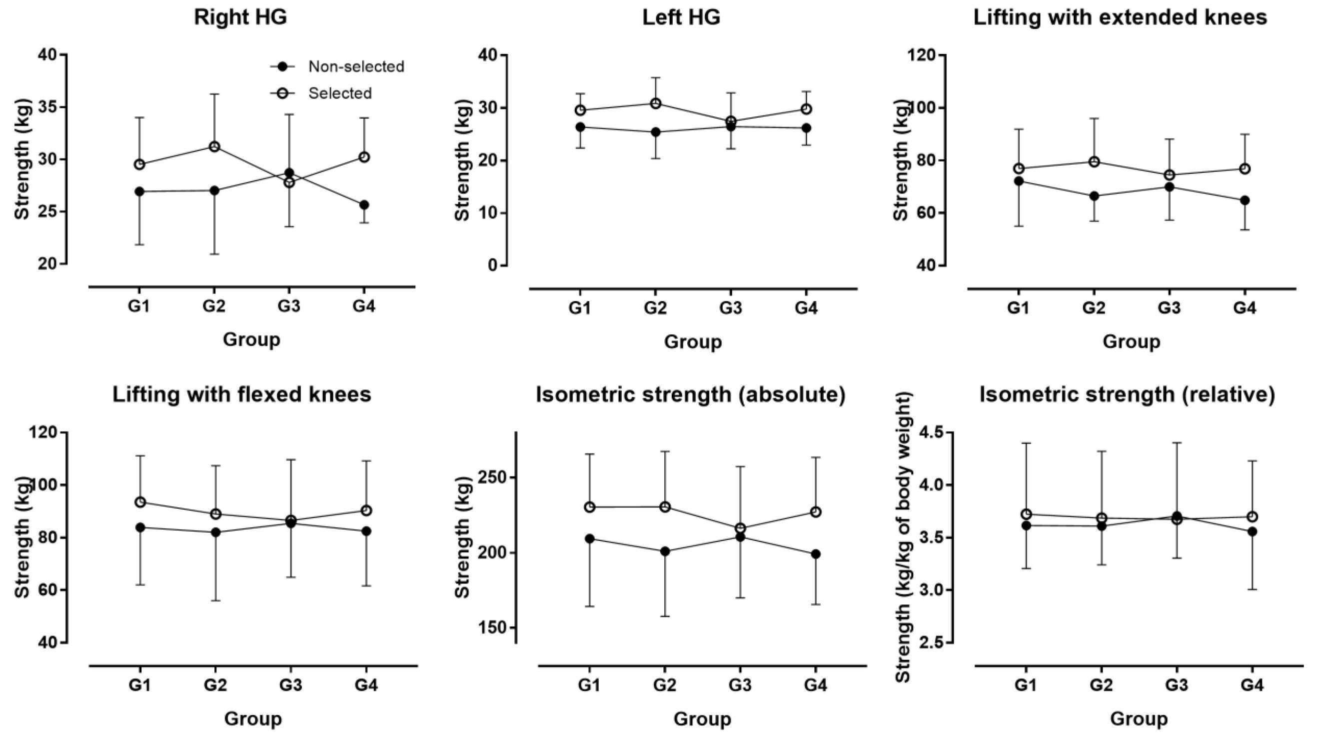

FIGURE 3 | Isometric muscle strength by birth quarter. G1 = born in January, February, and March; G2 = born in April, May, and June; G3 = born in July, August, and September; G4 = born in October, November, and December; "Isometric strength" refers to the sum of the four measures (right and left handgrip strength, lifting with extended and flexed knees. Error bars represent standard deviations.

for talent identification and soccer players' selection and would require action to balance the chances of success for players born in the end of a year (Yagüe et al., 2018). On the contrary, such a bias in talent identification and players' selection should not be a concern in volleyball.

The similar anthropometric and physiological characteristics among BQ were in agreement with the absence of RAE in the present study. This relationship has been examined previously in soccer, where some studies supported an association between BQ and these characteristics, i.e., "early born" showed superior characteristics than "late born" (Pedretti and Seabra, 2015; Altimari et al., 2018), whereas other studies did not observe differences (De Oliveira Matta et al., 2015; Junior et al., 2015; Lovell et al., 2015; Skorski et al., 2016; Peña-González et al., 2018). An explanation of the similar anthropometric and physiological characteristics among BQ might be the role of maturation as a covariate (Lovell et al., 2015; Peña-González et al., 2018).

With regards to the role of chronological age, the findings in the non-selected group showed that weight, height and isometric muscle strength increased with age, whereas BMI, BF and the other physiological characteristics did not. On the contrary, no relationship was observed between age and these characteristics in the selected group. Considering the adolescence as a period with large changes in the characteristics of volleyball players (Lidor and Ziv, 2010b), the variation in the abovementioned relationship by performance level might be partially attributed to the smaller age range of the selected compared to the non-selected group indicating that the former group was more homogeneous than the latter one. In addition, the variation of this relationship when Δaphv – measure of maturation – was considered instead of chronological age, confirmed the important role of maturation during volleyball players' selection (Melchiorri et al., 2017; Nunes et al., 2019), since height (a major determinant of success in volleyball) correlated very largely with Δaphv.

A limitation of the present study was that it was conducted in young volleyball players and it would be needed caution to generalize the findings in adult volleyball players, as it has been observed in other team sports (e.g., soccer) that the prevalence of RAE might vary by age group (Lovell et al., 2015; Korgaokar et al., 2018). Moreover, the administered fitness batter included tests corresponding to important parameters for volleyball performance (e.g., height and jump ability) (Nikolaidis et al., 2015; Milić et al., 2017); however, future studies should include sport-specific tests to mimic volleyball movements. In addition, it was acknowledged that the adopted methodological approach to evaluate maturation based on a combination of anthropometric characteristics and chronological age (Mirwald et al., 2002) provided only a proxy measure. Although this approach has been used widely in research on maturation and team sports performance (Pion et al., 2015; Rubajczyk et al., 2017; Lovell et al., 2019; Rommers et al., 2019), it would be recommended that future studies use laboratory methods (e.g., Tanner scale, hand-wrist skeleton), too. On the other hand, strength of the study was its novelty as it was the first one to examine

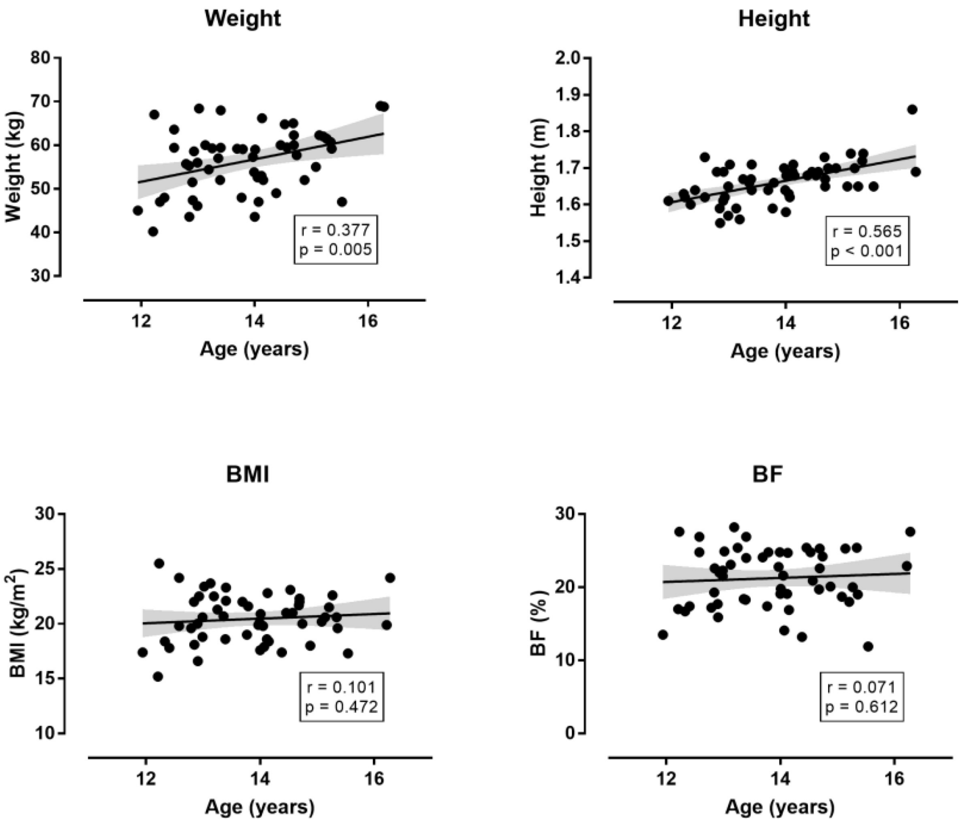

FIGURE 4 | Relationship of anthropometric characteristics with age in the non-selected group (*n* = 53). BMI = body mass index; BF = body fat percentage. The shadow line represents 95% confidence intervals.

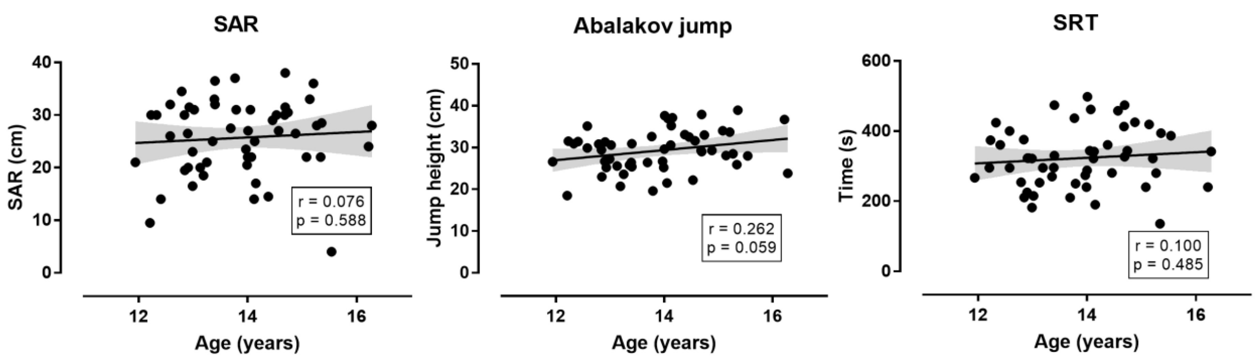

FIGURE 5 | Relationship of jumping, flexibility and aerobic capacity with age in the non-selected group (*n* = 53). SBJ = standing broad jump; SAR = sit-and-reach test; SRT = 20 m endurance shuttle run test. The shadow line represents 95% confidence intervals.

differences in anthropometric and physiological characteristics among BQ of volleyball players. These findings would be of both practical and theoretical importance for practitioners and scientists, respectively. From a practical perspective, it would be suggested that RAE should not be a concern of volleyball coaches and fitness trainers, in contrast with soccer where practitioners should manage the selection bias of their athletes due to the prevalence of RAE. Nonetheless, coaches and fitness trainers should monitor BQ of their volleyball players, especially in the context of players' selection; in case they observed RAE, they should act (e.g., setting individualized fitness goals) to prevent drop-out of potential talents. From a theoretical point of view, the absence of RAE observed in the young volleyball players under examination might imply that human performance not relying on high levels of physical abilities would not be influenced by BQ at young age. Moreover, scientists interested in this topic should examine further the prevalence of RAE and its role on anthropometric and physiological characteristics

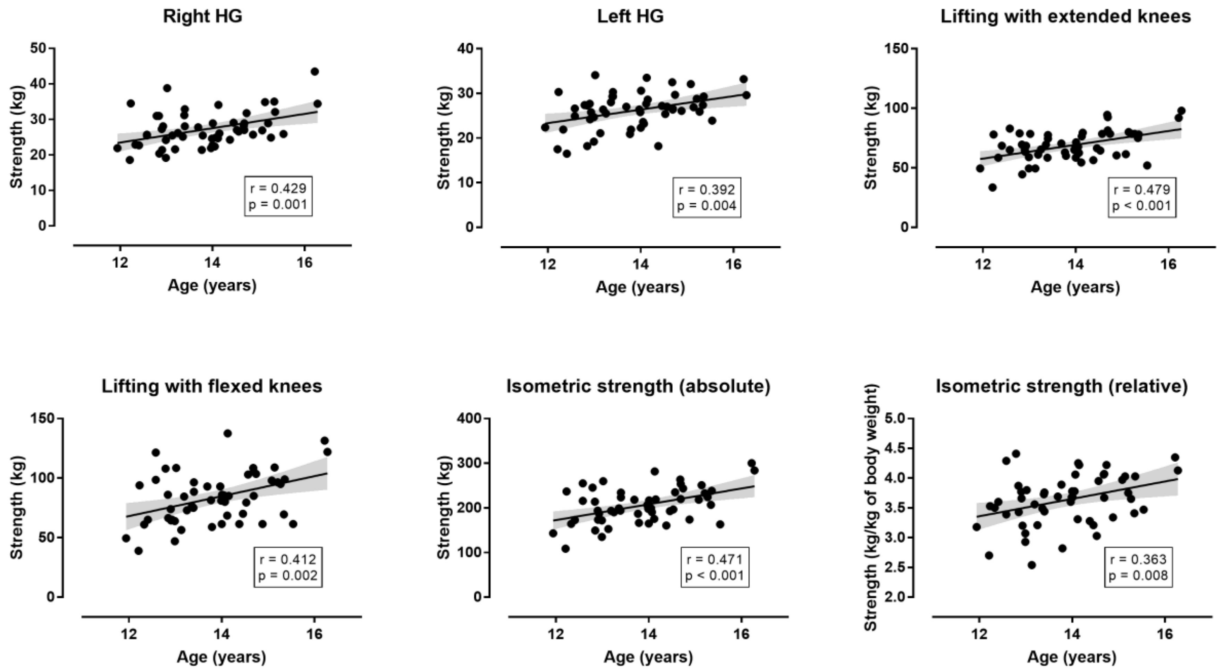

FIGURE 6 | Relationship of isometric muscle strength with age in the non-selected group (n = 53). "Isometric strength" refers to the sum of the four measures (right and left handgrip strength, lifting with extended and flexed knees. The shadow line represents 95% confidence intervals.

especially in sports with more technical than physical demands. With regards to the role of performance level, recently it was observed in soccer that RAE was more prevalent in elite than in non-elite academies (Bezuglov et al., 2019). Thus, future studies should be conducted on the variation of RAE by performance level in volleyball using large sample size to verify this trend.

TABLE 2 | The relationship (Pearson correlation coefficient r) of anthropometric and physiological characteristics with age and difference from the age at peak height velocity in the selected group (n = 72).

Variable	Age	Δaphv
Anthropometric characteristics		
Weight	0.05	0.44***
Height	0.21	0.72***
BMI	−0.08	0.02
BF	−0.13	0.05
Physiological characteristics		
AJ	0.22	−0.02
SAR	0.03	−0.14
SRT	−0.06	−0.09
Isometric muscle strength		
Right HG	0.16	0.21
Left HG	0.11	0.24*
Lifting with extended knees	0.07	0.15
Lifting with flexed knees	0.10	0.17
Absolute isometric strength	0.12	0.21
Relative isometric strength	0.09	−0.10

*BMI = body mass index, BF = body fat percentage, AJ = Abalakov jump, SAR = sit-and-reach test, SRT = 20 m shuttle run test, HG = handgrip muscle strength, Δaphv = difference from the age at peak height velocity. *$p < 0.05$, ***$p < 0.001$.*

CONCLUSION

The absence of RAE in female volleyball players and the similarities of anthropometric and physiological characteristics among BQ might be due to technical-tactical character of this sport. These findings would be of great practical value for coaches and fitness trainers working with young volleyball players.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board, Exercise Physiology Laboratory, Nikaia, Greece. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SDP and PN: conceptualization, formal analysis, data curation, and visualization. SDP, SKP, and PN: methodology, validation, investigation, and resources. PN: software. SDP, SKP, TR, BK, and PN: writing – original draft preparation and writing – review and editing. SDP, BK, and PN: supervision and project administration.

ACKNOWLEDGMENTS

The voluntarily participation of all athletes in the present study is gratefully acknowledged.

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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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 06 December 2019
doi: 10.3389/fpsyg.2019.02752

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Neural Efficiency and Acquired Motor Skills: An fMRI Study of Expert Athletes

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The neural efficiency hypothesis was investigated. Functional magnetic resonance imaging was used to study the differences in brain activity between athletes imagining performing different movements: basketball athletes imagined throwing and volleyball athletes imagined serving. These comparisons of brain activity among athletes imagining movements from their self-sport (e.g., a basketball throw in basketball athletes) versus movements from other sport (e.g., a volleyball serve in basketball athletes) revealed the neural energy consumption each task costs. The results showed better temporal congruence between motor execution and motor imagery and vividness of motor imagery, but lower levels of activation in the left putamen, inferior parietal lobule, supplementary motor area, postcentral gyrus, and the right insula when both groups of athletes imagined movements from their self-sport compared with when they imagined movements from the other-sport. Athletes were more effective in the representation of the motor sequences and the interoception of the motor sequences for their self-sport. The findings of present study suggest that elite athletes achieved superior behavioral performance with minimal neural energy consumption, thus confirming the neural efficiency hypotheses.

Keywords: neural efficiency, motor imagery, motor representation, motor repertoire, task-specific

OPEN ACCESS

Edited by:
Donatella Di Corrado,
Kore University of Enna, Italy

Reviewed by:
Nobuaki Mizuguchi,
National Center for Geriatrics and Gerontology (NCGG), Japan
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *20 August 2019*
Accepted: *22 November 2019*
Published: *06 December 2019*

Citation:
Zhang L, Qiu F, Zhu H, Xiang M and Zhou L (2019) Neural Efficiency and Acquired Motor Skills: An fMRI Study of Expert Athletes. Front. Psychol. 10:2752. doi: 10.3389/fpsyg.2019.02752

INTRODUCTION

The difference in physiological characteristics between athletes and nonathletes is an important research field in sports science. Based on the research findings, sport industry can not only understand the physiological mechanisms of high-level athlete, but also improve athlete training and competitive performance. Neural efficiency refers to patterns of more spatially localized or less intense brain activity concomitant with equal or superior performance (Neubauer and Fink, 2009).

Compared to nonexperts, experts routinely exhibit neural efficiency when performing within their domain of expertise (Babiloni et al., 2010; Nakata et al., 2010). However, existing findings are highly variegated and are often inconsistent. Some studies showed that athletes showed increased brain activation when performing motor tasks. For example, badminton athletes showed stronger activation in mirror neuron system than novices during anticipation with videos of shuttle landing (Wright et al., 2011). Basketball athletes showed higher activity in inferior parietal lobule and inferior frontal gyrus than novices in an action anticipation task with basketball free throw (Wu et al., 2013). Expert athletes had greater neural activation than novices in somatosensory and motor planning regions when passively listening to familiar sports sounds (Woods et al., 2014). However, other studies reported that the mind of expert athletes were focused or decreased activation compared with nonexperts. For example, during mental rehearsal of archery, the premotor and supplementary motor areas, and the inferior frontal region, basal ganglia and cerebellum were active in nonarchers, whereas elite archers showed activation primarily in the supplementary motor areas (Chang et al., 2011). This focused and efficient organization of task-related neural networks was also observed in golfers during pre-shot routine (Milton et al., 2007). In another study, table tennis athletes showed less neural activation in task-related brain regions during a go/no-go visual-spatial task (Guo et al., 2017). Athletes also showed less neural activation in prefrontal cortex and insula during affective challenges than controls (Costanzo et al., 2016). These discrepancies may be related to the between-group paradigm (experts vs. novices), which entangles individual differences with neural dynamics. Thus, the use of self-reference could be a better way to probe neural efficiency.

Mentally rehearsing movements has become an important technique in sport and exercise psychology. It can be done from a first- or third-person perspective (Ruby and Decety, 2001). The first-person perspective is reported to be more embodied in the way that it involves kinesthetic representation and evokes motor simulations of one's own body and mainly recruited the left hemisphere (Lorey et al., 2009). In this context, motor imagery is defined as a mental process involving rehearsal or simulation of a given action from a first-person perspective without overt movements (Jeannerod, 1994; Decety and Jeannerod, 1995; Hanakawa et al., 2003). Motor imagery and motor execution have been suggested to be functionally equivalent. At the behavioral level, evidence from mental chronometry suggested that it requires a similar time to imagine a movement or execute it, i.e., so-called temporal equivalence (Decety, 1996; Guillot and Collet, 2005). At the neural level, motor imagery and motor execution involve partially overlapping neural substrates (Grezes and Decety, 2001; Jeannerod, 2001; Grèzes et al., 2003). Specifically, these neural substrates are the supplementary motor area, the premotor cortex, and, in a growing number of studies, the primary motor cortex, the inferior parietal lobule, the basal ganglia, and the cerebellum (Lorey et al., 2009). Besides, complex movements such as ball games are not doable in the confined scanner. Here, the present study was intended to probe the neural efficiency hypothesis using motor imagery as an alternative to motor execution to examine functional differences in the brain activity associated with different tasks.

The anatomical substrate for motor imagery is largely mediated by the parietal-premotor cortical circuit including the inferior parietal lobule, the supplementary motor area, and the postcentral gyrus (Zhang et al., 2018). The parietal-premotor cortical circuit serves its function by building an integrated presentation of actions, objects acted on, and locations toward which actions are directed (Gallese, 2005). In particular, the inferior parietal lobule is a site at which internal models and body representations form (Macuga and Frey, 2011). The supplementary motor cortex has been reported to be involved in motor planning (Hayes et al., 2012; Marchand et al., 2013), while the postcentral gyrus is involved in somatic perceptual processes (Vidoni et al., 2010; Yamashiro et al., 2013; Arce-McShane et al., 2014). Thus, different patterns of functional activation may occur in the parietal-premotor circuit among individuals with different expertise levels while imagining the same movements.

Here, the present study was designed to resolve conflicting findings over neural consumption in sport expert domain by extending previous work in two critical respects. First, motor imagery task of expertise skills was used as test task. Since motor imagery is regarded as largely equivalent in neural level to motor execution, the neural differences found through motor imagery task is likely to reflect the true neural processes of given motor expertises. Second, self-reference and cross validation was used to test the behavioral and the neural differences. To do this, a factorial fMRI design was constructed in which basketball and volleyball athletes imagined throwing a basketball or serving a volleyball. The factorial design enabled self-reference within the group to exclude possible nuisance variables related to individual differences and cross validation between the groups to confirm the effect. These two movements were chose as experimental tasks based on two considerations. On the one hand, many components are kinematically comparable between these two movements. On the other hand, the integration of kinematical components into goal-directed action differs between them. Thus, while both groups of participants performed the same tasks, they had only professionally practiced the movements from their self-sport domain. Therefore, attenuated cortical activity (particularly in the parietal-premotor cortical circuit) along with superior behavioral performance observed while imagining movements from the self-sport compared to those observed while imagining movements from the other-sport would perfectly test the neural efficiency hypotheses.

MATERIALS AND METHODS

Participants

Twenty-four expert basketball athletes (19.2 ± 1.4 years old, age range, 18–21 years old) and 24 expert volleyball athletes (18.9 ± 1.5 years old, age range, 17–22 years old) were studied. All participants were right-handed males (Oldfield, 1971) recruited from the basketball and volleyball teams in Shanghai University of Sport. Basketball athletes had trained 10.7 ± 1.7 h per week for 10.8 ± 1.9 years (range: 8–14 years). Volleyball athletes had trained 9.8 ± 1.3 h per week for 8.5 ± 1.1 years (range: 7–11 years). A typical training week includes 5 days of training (Tuesday to Friday and Sunday) and 2 days of rest (Monday and Saturday). The 5 days of training is made up of 3 days of professional skill training on the court (2:45–5:00) and 2 days of indoor strength training (2:45–5:00). Compared with basketball athletes, volleyball athletes trained for similar intensity as indexed by training hours [$T(46) = 1.95$, $p = 0.06$], but they started their career later as indexed by training years [$T(46) = 5.01$, $p < 0.001$]. Both groups consisted of national first- or second-level athletes who were qualified for provincial or national level competitions. The experimental procedure was approved by the local ethics committee (No. 2018126). All participants provided written informed consent prior to the experiment.

Motor Imagery

To assess participants' general motor imagery ability, the ease of forming visual and kinesthetic images of four basic gross movements (a knee lift, jump, arm movement, and waist bend) was measured with a Chinese translation of Movement Imagery Questionnaire-revised (MIQ-R, Hall and Martin, 1997). Participants rated their ease of imaging on a 7-point Likert-type scale ranging from 1 (very hard to see/feel) to 7 (very easy to see/feel). After the items for each subscale are averaged, a cutoff score of 5 (fairly easy) was used to ensure a participant was eligible for the following motor imagery task.

Field training was applied to all eligible participants on the same day before the experiment to acquaint them with the motor tasks used in the present study, especially the motor task from the other-sport. Basketball throwing and volleyball serving were used as motor imagery tasks. Participants were instructed to use motor imagery from a first-person perspective. For basketball throwing, the participants were instructed to imagine throwing the ball toward the basket after dribbling it three times. To avoid possible fatigue or adaptation effect from a single location, five different locations each were specified for the two tasks. For basketball throwing, the five locations were the central location (the traditional point for free throws) and the other four lateral locations (bilateral to the central location) (**Figure 1A**). All five locations were the same distance from the basket. For the volleyball serve, the participants were instructed to strike the ball, causing it to cross the net after dribbling the ball three times. Similar to the procedure used for basketball throws, we specified five locations on the court as serve locations (**Figure 1B**). All five locations were the same distance from the net. The participants were instructed to perform the motor imagery task while holding the balls

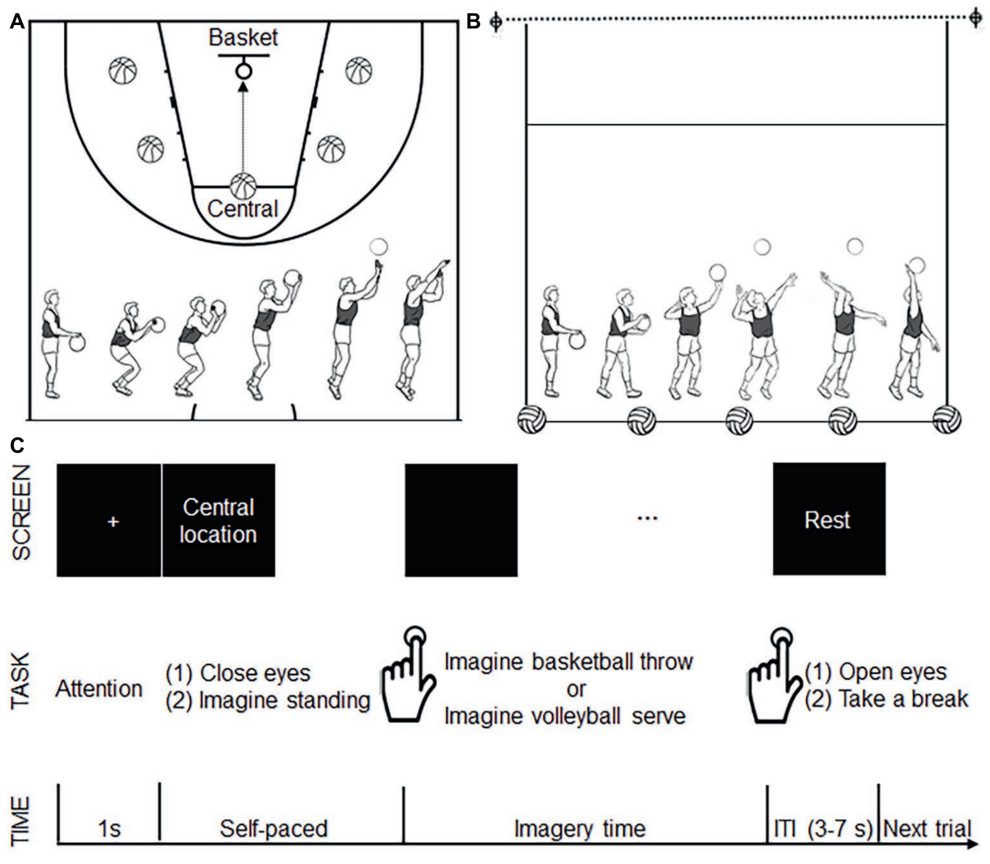

FIGURE 1 | Experimental design. **(A)** The five locations (shown as a basketball) for basketball throws. All five locations were the same distance from the basket (as shown with a circle). The bottom panel shows the decomposed movements required for a basketball throw. **(B)** The five locations (shown as a volleyball) for volleyball serves. All five locations were the same distance from the net (as shown with a dotted line). The bottom panel shows the decomposed movements required for the volleyball serve. **(C)** Time course of the motor imagery trials. During each trial, after seeing a 1-s fixation cross, the participants saw a location instruction. After finishing reading the location instruction, the participants closed their eyes and imagined standing on the specified location. The participants pressed a button to signal that they had started imagining a basketball throw or volleyball serve. The participants pressed the button again when they imagined the ball had left their hand. Following the second button press, a "rest" instruction was presented on the screen, and the participants opened their eyes and took a break. This rest period served as a variable intertrial interval (ITI 3–7 s). Another fixation cross announced the start of the next trial.

as a previous study revealed the importance of implementing task-related motor imagery (Wang et al., 2014).

Behavioral and fMRI measures were performed after field training on two separate days at least 2 weeks apart in a random order. The participants physically performed basketball throws or volleyball serves on the court from each of the five locations. Evidence from existing behavioral studies shows that imagined movements retain the same temporal characteristics as the corresponding executed movements (Sirigu et al., 1995). The execution process of each participant was recorded (Sony PXW-F37, 50 fps) and the durations of motor execution were obtained offline by reading the frame timer of the camcorder. The duration of motor execution was defined as the time between the onset of the first dribble and the offset when the ball left the hand. Three trials were repeated at each of the five locations (for a total of 15 trials) for both tasks. The duration of motor execution required for the total 15 trials was averaged, and the mean value was defined as the execution times for basketball throws and volleyball serves.

The motor imagery time was measured for both groups. Participants performed two runs of motor imagery, including one for basketball throws and the other for volleyball serves. The participants were instructed to mentally rehearse the motor imagery tasks from a first-person perspective with their eyes closed. The motor imagery task was self-paced. Participants pressed a button (E-prime 2.0, Psychology Software Tools Inc., Pittsburgh, PA) with the left index finger to label the beginning and end of their motor imagery task (duration of motor imagery). The instructions resulted in each of the five locations for motor imagery being presented to the participants in random order. Three trials were repeated at each of the five locations (for a total of 15 trials) for both tasks. The 15 trials for both tasks were averaged separately, and the mean values were defined as the imagery time for basketball throws and volleyball serves.

Because both motor imagery and execution are likely to be constrained by the same physical laws (Decety and Jeannerod, 1995; Decety, 1996), a difference in the time required for motor imagery and motor execution tasks may indicate the effects of other physiological factors on the measurement (Sirigu et al., 1995, 1996). Temporal congruence was used as a valid mental chronometry index to evaluate functional equivalence between motor imagery and motor execution (Guillot and Collet, 2005). In the present study, variances in motor time (for both execution and imagery) between the two participant groups were dependent on differences in expertise levels in the self- versus other-sport. The temporal congruence was calculated in the same manner as did in Zhang et al. (2018). A lower ratio score indicates better congruence between execution time and imagery time. Temporal congruence was calculated for each group on each task separately.

Functional Magnetic Resonance Imaging

The experiment was performed using a 2-group (basketball athletes, volleyball athletes; between-participant factor) × 2 task (basketball throw vs. volleyball serve; within-participant factor) factorial design. The experiment consisted of two runs: imagining a basketball throw with a basketball and imagining a volleyball serve with a volleyball. The order of the two runs was counterbalanced among the participants. Each run lasted 6 min, during which 180 volumes were acquired. Each run consisted of 25 trials (5 trials at each location presented in a random order). The participants watched a screen *via* a mirror mounted on the MRI head coil. Time course of the motor imagery trial was illustrated in **Figure 1C**. A 1-s fixation point appearing at the center of the screen indicated the start of a trial. The instruction for one of the five locations was subsequently presented to the participant. Participants pressed a button to mark the beginning and end of their motor imagery (E-prime 2.0, Psychology Software Tools Inc., Pittsburgh, PA). Two adjacent trials were separated by a resting state indicated by a black screen that lasted 3–7 s after the second button press (end of motor imagery). The resting state was used as a baseline measurement. Imaging was acquired using a 3.0 Tesla Siemens Trio Tim MRI scanner with a 12-channel head coil at Shanghai Key Laboratory of Magnetic Resonance. Functional images (repetition time = 2 s, one shot per repetition, echo time = 30 ms, flip angle = 90°, field of view = 240 mm^2 × 240 mm^2, slice thickness = 4 mm, voxel size = 3.3 mm^3 × 3.3 mm^3 × 4 mm^3, slices per volume = 33, volumes for 6 min = 180) were obtained as a gradient echo planar imaging sequence.

Post-scanner Imagery Questionnaires

Immediately after the participants were released from the scanner, the performance of motor imagery tasks was measured with self-evaluation using two questionnaires. The first questionnaire was developed based on that used in Wang et al., 2014 to assess if participants adhered to the experimental protocol. It included four introspective items and was scored on a 5-point Likert-type scale range from 1 (not at all) to 5 (greatly). The first question asked the participants to what extent they have used a first-person perspective during motor imagery. The second question asked the participants to what extent the motor imagery was easily controlled. The third question asked to what extent the first-person perspective motor imagery was clear. The fourth question asked to what extent the ease of performing first-person perspective motor imagery was different between the tasks (basketball throw vs. volleyball serve). The second questionnaire tested the vividness of motor imagery, was developed based on the MIQ-R (Hall and Martin, 1997) and included eight questions related to kinesthetic and visual properties (4 for each) during the motor imagery task. They were rated on a 7-point Likert-type scale ranging from 1 (very hard to see/feel) to 7 (very easy to see/feel).

Data Analysis

Mental Chronometry Test

Temporal congruence was tested with a two-way repeated measure analysis of variance (ANOVA), with the groups (basketball athletes and volleyball athletes) used as the between-participant factor and the tasks (basketball throw, volleyball serve) used as the within-participant factor.

Post-scanner Imagery Questionnaires

The vividness of motor imagery data was also analyzed with two-way repeated measure ANOVA. The use of first-person perspective motor imagery was tested with unpaired t test.

Functional Magnetic Resonance Imaging

The imaging data were preprocessed and analyzed with a general linear model (Friston et al., 1994) using Statistical Parametric Mapping version 8[1] implemented in MATLAB R2013a (MathWorks, Inc., Natick, MA). Preprocessing included slice time correction, realignment, normalization, and spatial smoothing in sequence. Normalization was performed by directly registering the mean functional image to the standard Montreal Neurological Institute template provided by SPM8. The resulting interpolated spatial resolution was 3 mm^3 × 3 mm^3 × 3 mm^3. The functional data were then smoothed with a Gaussian kernel of 6-mm full-width at half-maximum.

The first-level analysis was computed within-participant using an event-related approach in the context of the general linear model. Statistical parametric t-maps were generated for each participant. For each participant, the regressor of interest was defined to characterize cerebral responses to imagery for the four different conditions in the 2 × 2 factorial design. A regressor of no interest was used to model the cerebral responses to a button press. For the motor imagery regressor, onsets were time-locked to the button press that marked the onset of motor imagery, and durations corresponded to the mean motor imagery durations across all imagery trials of the participant. To address the effects of potential contamination by button pressing (Eden et al., 1999), button pressing was included as a condition in the design matrix to model the cerebral responses to button presses. In this way, the regressor of motor imagery would not pick up cerebral responses induced by button press, and this enabled us to regress out the effect of button presses (Bakker et al., 2008). For the button press regressor, onsets were time-locked to the time point each button press was made, and the duration was set at zero. Each effect was modeled on a trial-by-trial basis. Also, the head motion regressors derived from the spatial realignment procedure were included. The rest period was used as the baseline. The contrast images for cerebral responses to motor imagery were compared with those for the rest period and stored for a second-level group analysis.

For second-level group analysis, an SPM8 full factorial model was constructed using a two-way ANOVA model to test whether there were regions showing differences between the two participant groups (between-participant factor) and whether the differences in these regions between the groups were task-dependent. Contrast values for significant clusters were extracted from individual data obtained under the two experimental conditions to conduct correlation analyses. For each group, for each of the two experimental conditions, the mean contrast values and standard errors were calculated to characterize whether the pattern of interaction constituted an effect of expertise. Because there was variance in the duration of motor imagery time (**Table 1**) and

TABLE 1 | Duration of motor imagery.

Group	Basketball throw	Volleyball serve
Basketball athletes	4.17 ± 0.22 s	4.18 ± 0.19 s
Volleyball athletes	4.89 ± 0.15 s	4.54 ± 0.16 s

The durations of motor imagery shown in this table were measured during fMRI scanning. The values are expressed as the mean ± standard error of the mean.

that blood oxygenation level dependent (BOLD) signal changes occurred linearly with the duration of neural responses, the mean duration of motor imagery across all trials for each participant was added as a nuisance covariate to ensure that the main results were not affected by interparticipant variation (Dale and Buckner, 1997). Similarly, to make sure the comparability between tasks, the vividness of motor imagery of each participant was also added as a nuisance covariate. The false discovery rate (FDR) approach was used to correct for multiple comparisons (Genovese et al., 2002) at the cluster level with an extent threshold of 15 voxels per cluster ($p < 0.05$). All statistical maps were overlaid on the CH2 template (Holmes et al., 1998).

Parameter Analysis

For each significant cluster, the Pearson's correlation was tested for all athletes between the behavioral measure (the difference in the temporal congruence of motor imagery between self-sport imagery and other-sport imagery) and the functional measure (the difference in the contrast value between self-sport imagery and other-sport imagery). The threshold for significance was set at $p < 0.05$.

RESULTS

Expertise-Dependent Behavioral Performance During Motor Imagery

A two-way analysis of variance of temporal congruence revealed a significant interaction between group and imagery task [$F(1, 46) = 23$, $p < 0.001$]. Further t-tests revealed that in basketball athletes, congruence between motor imagery and motor execution was higher when imagining a basketball throw than when imagining a volleyball serve ($p < 0.001$), whereas in volleyball athletes, congruence was higher when imagining a volleyball serve than when imagining a basketball throw ($p < 0.01$) (**Figure 2A**).

According to the scores on the questionnaire aimed at examining first-person motor imagery, both groups performed the motor imagery task with a first-person perspective without group difference [basketball athletes, 14.92 ± 2.48; volleyball athletes, 15.79 ± 1.92; $T(46) = -1.37$, $p = 0.18$].

Two-way analysis of variation of the vividness of motor imagery revealed a significant interaction between group and imagery task [$F(1, 46) = 46$, $p < 0.001$]. Further t-tests revealed that basketball athletes imagined basketball throws more clearly than they imagined volleyball serves ($p < 0.001$), whereas volleyball athletes imagined volleyball serves more clearly than they imagined basketball throws ($p < 0.01$) (**Figure 2B**). No significant main effects were found for group or task.

[1]http://www.fil.ion.ucl.ac.uk/spm

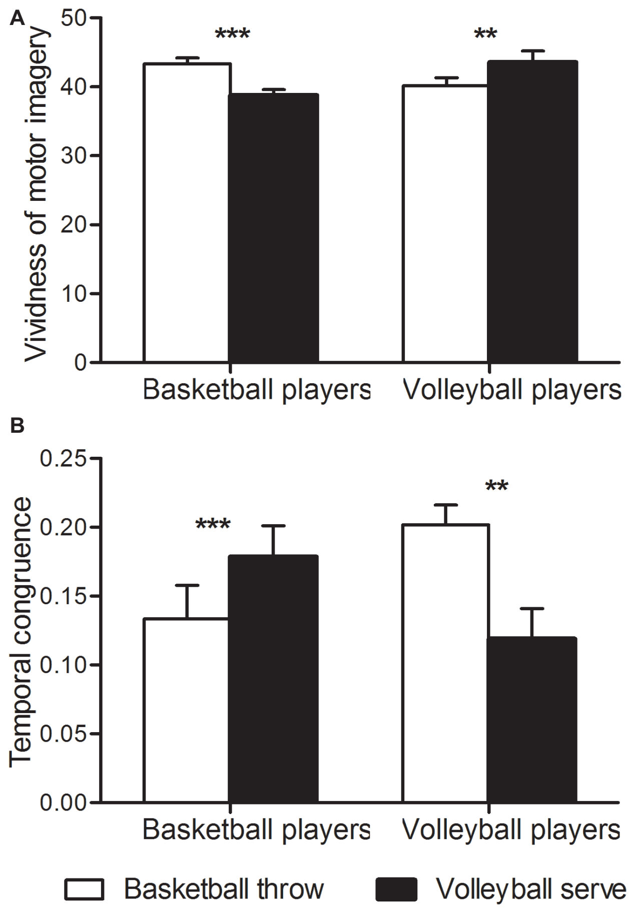

FIGURE 2 | Behavioral measures. **(A)** Temporal congruence. The ordinate shows temporal congruence. Congruence is expressed as [imagery time] minus [execution time] divided by [imagery time plus execution time]. **(B)** Vividness of motor imagery. $^{**}p < 0.01$; $^{***}p < 0.001$.

Expertise-Dependent Functional Activation of Motor Imagery

The differences in cortical activity between the two imagery tasks in the two groups of expert athletes were of more interest. *F* contrast revealed an interaction between these two main factors in the left putamen, the right insula, the left inferior parietal lobule, supplementary motor area and postcentral gyrus (**Table 2, Figures 3A–E**, left panel). The significant interaction was further investigated by examining the contrast values in the parameter estimate. Expert athletes showed less activation when imagining movements from their self-sport than when imagining movements from the other-sport, and there was a crossover pattern for the interaction between imagery task and group (**Figure 3**, right panel).

Parameter Analysis

Correlation analysis between behavioral measures and functional measures revealed a significant negative correlation in the left inferior parietal lobule ($r = -0285$, $p = 0.049$). No significant correlation was found for the left supplementary motor area ($r = -0.218$, $p = 0.137$), postcentral gyrus ($r = -0.129$, $p = 0.382$), putamen ($r = -0.143$, $p = 0.331$) and the right insula ($r = -0.043$, $p = 0.769$).

TABLE 2 | Expertise effect on motor imagery.

Brain area	Side	Cluster	MNI coordinate (mm)			*F*
			x	y	z	
Putamen	L	16	−27	−3	12	24.58
Insula	R	47	39	−27	21	25.28
Inferior parietal lobule	L	49	−48	−36	24	34.06
Supplementary motor area	L	125	0	−18	60	32.98
Postcentral gyrus	L	31	−15	−33	75	27.96

L = left. FDR-corrected to p < 0.05, extent threshold 15 voxels.

Discussion

The present study tested the neural efficiency hypotheses. Results showed that motor imagery performance was superior but cortical activation was decreased in athletes during imagining movements from their self-sport, suggesting a relatively facilitated motor simulation process for self-sport.

Expertise-Dependent Behavior of Motor Imagery

At the behavioral level, athletes showed better congruence in the time course between motor execution and motor imagery and greater vividness of motor imagery for the self-sport than for the other-sport. Both groups significantly overestimated the motor imagery duration for movements associated with the other-sport. This difference could be attributed to the extra effort required to represent the detailed movement components of unfamiliar movements (Guillot and Collet, 2005). The superior behavioral performance achieved in the self-sport indicated the presence of effective internal motor representation processes related to the self-sport (Guillot and Collet, 2005). Aspeculation is that this process is the mechanism underlying the effect of neural efficiency. This will be examined further in the next section from the neural representation level.

Expertise-Dependent Functional Activation of Motor Imagery

The experiment's factorial design revealed an interaction effect for group and task in the parietal-premotor cortical circuit. Besides, the left putamen and the right insula also showed the interaction effect. Neural activation in these regions was attenuated for the self-sport imagery compared with that for the other-sport imagery. This difference was interpreted as evidence of neural efficiency, i.e., motor imagery performance was superior for the self-sport, which required less energy consumption.

The findings of present study are consistent with those of a previous study which showed that there was left hemisphere dominance during the simulation of hand movements from a

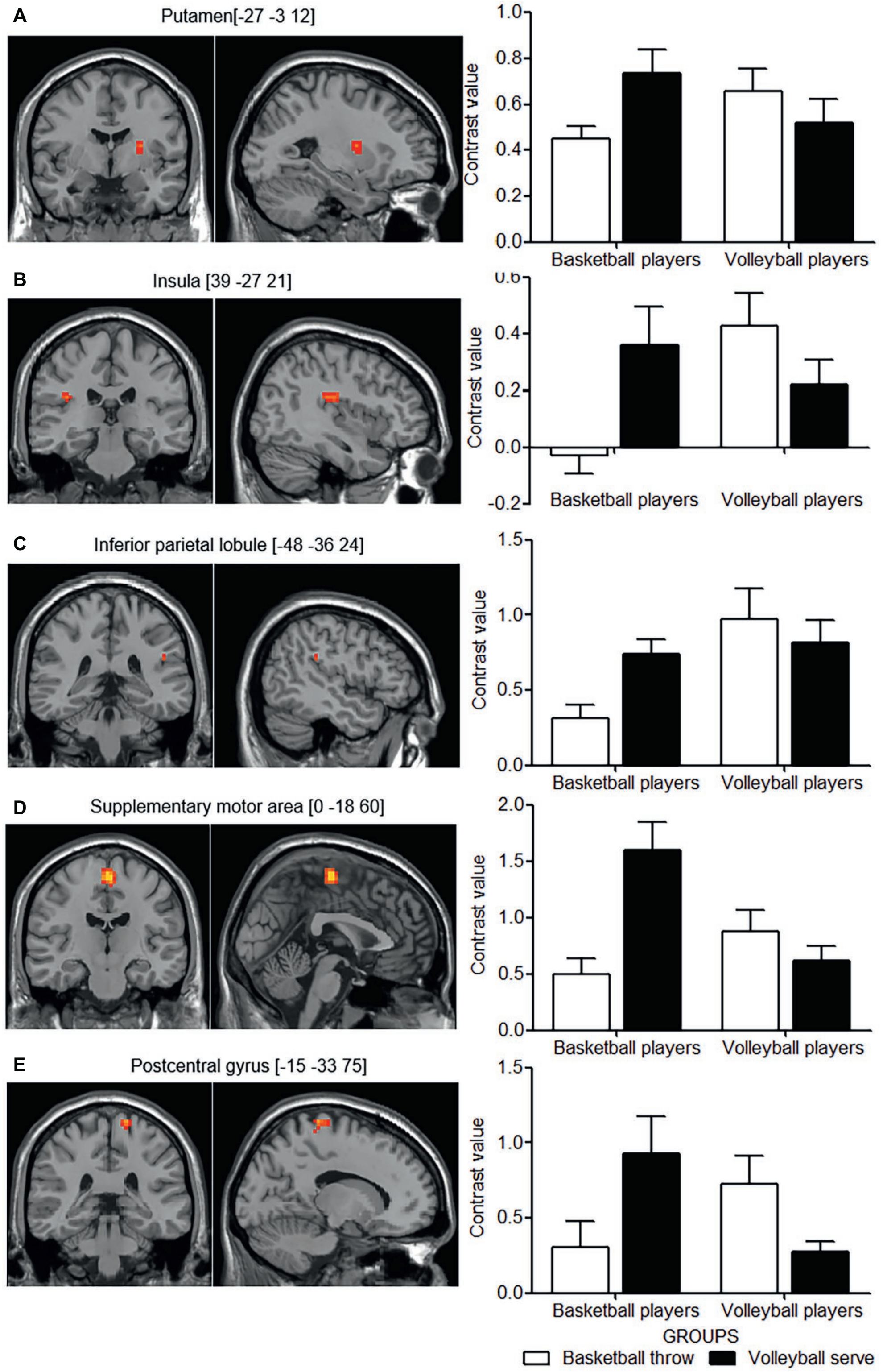

FIGURE 3 | Cortical areas showing interactions between group and motor imagery tasks. The left panel shows the cortical areas with activation in axial (z) and sagittal (x) views based on the interaction effect for group and motor imagery task. The right panel shows the mean contrast value for each activation cluster for each group in the two imagery tasks. **(A–E)** show the pair of left and right panels for each activation cluster of the interaction effect. White columns indicate basketball throws, and black columns indicate volleyball serves. Error bars indicate the standard error of the mean.

first person perspective (Lorey et al., 2009). This confirmed the embodied nature of the motor imagery paradigm used in the present study (i.e., the first-person perspective). This embodied process has in particular been associated with the left inferior parietal lobule. The inferior parietal lobule is a site associated with internal models and body representations (Macuga and Frey, 2011) that has been reported to be recruited when observing kinematic display of one's own movements (Bischoff et al., 2012) and during first-person perspective motor imagery (Lorey et al., 2009). The embodied simulation processes that occur in the inferior parietal lobule have also been emphasized by other studies (Keysers et al., 2004; Gallese, 2005). Furthermore, the inferior parietal lobule is related to the degree to which an action is embodied (Cross et al., 2006). The decreased activation during self-sport imagery is likely because that the internal representation of self-sport movements configured with the athletes' motor reservoirs that are shaped by long-term training and overpractice requires less neural resources to simulate the task. The inferior parietal lobule is also involved in pragmatic analysis related to action-oriented object manipulation (Jeannerod, 1994; Buccino et al., 2001) and codes for specific goals or intentions of motor acts (Fogassi et al., 2005). Together with the premotor areas, the parietal-premotor cortical circuit functions to build an integrated presentation of actions, objects acted on and locations toward which actions are directed (Gallese, 2005). Both tasks performed in the present study required participants to integrate their kinesthetic movements with their manipulation of the ball and to aim the ball at the target (basket/net). However, participants were more skilled in performing the integrated representation of the self-sport, which may have involved more efficient motor simulation and less neural effort.

The supplementary motor cortex is reported to be involved in motor planning, especially for the orderly performance of complex motor sequences (Hayes et al., 2012; Marchand et al., 2013). Patients with left supplementary motor area disorders showed impaired procedural learning (Ackermann et al., 1996). The activation in the supplementary motor area was also relatively lower when participants imagined movements from their self-sport relative to when they imagined movements from the other-sport. This finding is in accordance with that of Milton et al. (2007), who found that the level of supplementary motor area activity was lower in expert golfers than in novices. In the present study, both imagery tasks required coordination of different body parts to achieve a series of movements that were performed in a well-organized temporal order. Additionally, the supplementary motor area has been reported to play a leading role in the action-monitoring system that assesses ongoing actions and detects errors (Bonini et al., 2014) and to be involved in more extensive executive control activities, including reducing inference from irrelevant, distracting features in the environment (Nachev et al., 2008). The level of activation in the supplementary motor area was lower during imagery related to the self-sport, suggesting that the orderly representation of the movement components meant less effort and neural cost were needed (Shiffrin and Schneider, 1977).

The postcentral gyrus is classically associated with somatosensory processing (Iwamura et al., 1994; Tamè et al., 2016). This area is recruited even when athletes passively listen to sports sounds (Woods et al., 2014). Similar to the inferior parietal lobule and the supplementary motor cortex, the activation of the postcentral gyrus was also down-modulated for the self-sport. According to the somatosensory homunculus, this activation cluster was the trunk area. Trunk muscle function plays an important role in both sports but kinematic chains of the trunk differ (da Silva Santos et al., 2017; Sekiguchi et al., 2017). It is plausible that athletes from one domain were clearly aware of the different kinematic chains of the two different tasks and made different performance of them. Taken together, participants were able to generate automatic motor procedures related for self-sport as a result of long-term training. This may allow them to complete the motor task with least assistance from somatosensory inputs, resulting in a decrease in the activation of the postcentral gyrus. A similar reduction in cortical activation in the postcentral gyrus was observed in pianists, who may suppress sensory feedback to enable smooth and sequential motor behaviors (e.g., shifting from one key to another) (Oechslin et al., 2012).

Putamen, as part of the basal gangalia, supports willed, intentional movements (Groenewegen, 2003). In particular, putamen has been reported to be important for chucking movement sequences by concatenating movements at various stages (Wymbs et al., 2012). Chunking allows performance of a well learned motor sequence to be executed as a single unit of activity rather than multiple individual actions. Thus, decreased activity in putamen for self-sport imagery may reflect a more effective (chunked) representation that accompanies automatization as a result of extensive training for self-sport. Our findings were in line with a previous study which found training-related decrease in putamen even after a short time learning for a motor sequence task (Poldrack et al., 2005).

The right insula has been reported to be the seat of interoception (Critchley et al., 2004) or part of the pathway of interoceptive awareness (Khalsa et al., 2009). Either way, the right insula seems to play an important role in generating accurate predictions of the bodies' internal state in the next moment. The model of the body's future condition further instructs other brain areas to initiate actions that are more tailored to coming demands (Faull et al., 2018). It is plausible that predicting interception during other-sport imagery is more challenging than that of self-sport imagery, thus needs more efforts (increased activity in the right insula).

Relationship Between Behavioral and Functional Measures

A negative correlation was found between the behavioral measure and the functional measure for elite athletes. This finding suggests that greater neural efficiency underlies superior motor performance. In other words, better behavioral performance at less neural effort enables individuals to perform the internal processes associated with movements of high proficiency. This is plausible because well-established skills are believed to be based on automaticity and reduction in nonessential inputs of task-irrelevant processes (Logan and Crump, 2009; Rieger, 2012). Attention to such automatic processes can even undermine performance (Beilock et al., 2002). Neural efficiency may stem from the long-term training and be task-specific which enabled athletes to develop a focused and efficient organization of task-related neural networks.

Limitations

Our findings should be interpreted in light of the following limitations. The cross-sectional design of the present study, though articulate that neural efficiency is task-specific, is insufficient to impute that neural efficiency is training-induced. Further studies that randomly allocate naive participants to different sport interventions are expected to separate the effects of training and other confounding factors. Additionally, the correlation between behavioral measure and functional measure, although existed, was weak.

CONCLUSION

The present study revealed greater temporal congruence and vividness of motor imagery but attenuated activity in the parieto-premotor motor representation circuit and the insula interoceptive cortex when athletes imagined movements from the self-sport compared with when they imagined movements from the other-sport. Athletes were more effective in the representation of the motor sequences and the interoception of the motor sequences for their self-sport. The finding that elite athletes achieved superior behavioral performance with minimal neural energy consumption thus confirms the neural efficiency hypotheses.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

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

AUTHOR CONTRIBUTIONS

LZha concepted, drafted, and revised the work. FQ and HZ acquired and analyzed the data. LZho and MX concepted the work, intepreted the data, and revised the manuscript critically for important intellectual content. All authors approved the final version and agreed to be accountable for all aspects of the work.

FUNDING

This work was supported by the Local Innovation Grant (No. 5190080545) and the SSFC (No. 17BTY055).

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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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 17 January 2020
doi: 10.3389/fpsyg.2019.03025

Strategy and Decision Making in Karate

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Karate will be included in the 2020 Summer Olympics in Tokyo as an additional sport. The inner logic of this activity includes a specific scoring system and way of modeling. Three hundred and nine bouts were observed in the competition context, which resulted in new perspectives on training and competition. The scoring of punches (43.7% of total scored points) and face kicks (37.9%) appears to be more significant ($p \leq 0.01$) than that of body kicks (15.3%, $p \leq 0.01$) and leg-sweeping (3.1%, $p = 0.31$). Penalties appear to be very significant and associated with victory when "scored" by the competitor against himself or herself ($p \leq 0.01$). Competitors must score points and penalties. This zero-sum game induces a simple rivalry, whose purpose is domination and which must rely on a predefined strategy and initiative. Karatekas have to make decisions, such as when taking the risk to score points and penalties, whether or not they lead the score. Karatekas may decide to expose or protect themselves, create situations, or simply remain realistic and adhere to the plan. The question of decision making, which is central to this work, forces us to focus our future work on the notions of expectations and self-fulfilling prophecies.

Keywords: karate, modeling, inner logic, strategy, decision making

OPEN ACCESS

Edited by:
Donatella Di Corrado,
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *29 October 2019*
Accepted: *20 December 2019*
Published: *17 January 2020*

Citation:
Frigout J, Tasseel-Ponche S and Delafontaine A (2020) Strategy and Decision Making in Karate. Front. Psychol. 10:3025. doi: 10.3389/fpsyg.2019.03025

INTRODUCTION

Karate is a traditional martial art that originated in Japan. It is also a sport that will make its first appearance in the Olympic Games programme in Tokyo 2020.

According to the 2016 Referee rules (FFKDA, 2016) of the French Karate and Related Sports Federation [*Fédération Française de Karaté et Disciplines Associées* (FFKDA, 2016)], the bouts are managed by a central referee, who applies penalties, and by four judges seated at the corner, who record the points awarded. The different types of scores are as follows: *Yuko* for a 1-point awarding punch, *Waza ari* for a 2-points awarding upper body kick, and *Ippon* for a 3-points awarding face kick or a leg-sweeping technique followed by a punch or a kick. In the case of a tie at the end of the regular time, the referee and judges grant a flag in favor of the winner (fighting spirit and strength, superiority of tactics, and techniques displayed, initiative of actions). For a point to be awarded, four criteria must be met (potential effect, awareness, timing, distance), and at least two flags must be raised in favor of the competitor's colors (blue or red); the four judges may simultaneously award points to each competitor (for instance, two flags for the competitor with the blue belt, i.e., *ao*, and two flags for the competitor with the red belt, i.e., *aka*). The central referee may impose penalties (category 1 for excessive contact, category 2 for prohibited behavior), which must be confirmed by the four judges. When points are awarded or penalties imposed, the bout will stop. Thus, the fight occurs in segments, and the competitors take their original positions before the bout resumes. If a competitor has a clear lead of eight points, the bout is stopped, and victory is awarded.

Three additional rules must be followed: The "ten-second" rule allows the referee to withdraw a competitor from the tournament who is knocked down, who fell, or who is thrown, and who does not get back up on his or her feet within a maximum of 10 s. In addition, the use of video review allows the coach, seated in the corner of the competitor, to request a review of a decision and be awarded points despite the observation and confirmation of the judges. Finally, the *senshu* rule (the competitor who has obtained the first unopposed score advantage at time-up), which is currently being tested in international competitions, has just been introduced for the very first time at the 2017 Open Paris Karate–Premier League, held between 27 and 29 January at the Pierre de Coubertin stadium.

The goal of our study is to determine whether, beyond potentially modeling karate competitions, it would be possible to issue coaching requirements. We assume that the existing literature on the scoring system in karate must be supplemented by issue related to the expectations of the coaches (Fantoni, 2016) and the relationships between the coaches and their competitors (K/Bidy and Escalie, 2016). What types of motor decisions could karatekas make during a competition in an ongoing bout and in their relationship with their coaches (Biéchy, 2012; Fantoni, 2016)?

To achieve this goal, the authors carried out observations during four selective competitions at the French district level (in the cities of Rungis, Thiais, and Orly, all located near Paris, in the Val-de-Marne Department), which may lead competitors to participate in national championships in their own categories in case they are successful (FFKDA, 2016). Additionally, two competitions at international level were observed: the Open Paris Karate–Premier League, which is a ranking competition that allows competitors to score points to be qualified for the 2020 Olympics in Tokyo.

For instance, **Table 1** shows quantitative information on a bout that occurred at the 2017 Open Paris Karate–Premier League, on January 29, during one final bout.

This bout analysis is clearly in favor of the results presented by Vidranski et al. (2015) concerning the significant differences between actions attempted and points scored in competitive karate.

Thanks to this type of observation, we were able to define a performance model in karate competitions (Frigout et al., 2017, p. 75) by using Biéchy's (2012, p. 38) work: the technical and tactical paradox, which requires finding the right balance between "*exposing, realism, protecting, creativity*."

To this end, the coach must act as a researcher and try to be as objective as possible through observation.

Modeling in sports is the subject of several studies that have proven relevant: from Franks and Goodman (1986), who define the necessity of a systematic model and quantification, to Garganta (1998), who discusses game modeling in the context of better training, to Hughes et al. (2012) in the context of soccer.

TABLE 1 | Quantitative information on one final bout, 2017 Open Paris Karate–Premier League.

Anonymous final – 2017 Open Paris Karate-Premier League					
***Aka* (red color): victory 4**			***Ao* (blue color): defeat 1**		
Simultaneous actions	**Attempted**	**Scored**	**Simultaneous actions**	**Attempted**	**Scored**
Yuko	12	1/0	*Yuko*	14	1/0
Waza ari	3	0	*Waza ari*	1	0
Ippon	6	1/0	*Ippon*	5	0
Leg-sweeping *ippon*	0	0	Leg-sweeping *ippon*	4	0
Senshu	N/A	1	*Senshu*	N/A	0
Category 1	N/A	0	Category 1	N/A	0
Category 2	N/A	3	Category 2	N/A	0
Video review	1	0	*Video review*	1	1

These different works discuss how modeling "can be considered as a mediator between a theoretical and an empirical field (. . .) in order to analyse performance trends and to prioritize potential issue within the training structure" (Hughes et al., 2012, p. 403).

How should a coach choose a strategic training method specific to competition while implementing several tactical adaptation schemes? Should competitors try to simultaneously validate points to minimize both their gains and losses? Could the Nash (1950) be applied and used to model training sessions?

Let us remind ourselves that the *inner logic* (Parlebas, 2005) of sports relies, in regard to exclusive fighting sports, on the following relation: $R \cap S = \emptyset$ (Parlebas, 1986, p. 208). This relation reminds us that two opposing karatekas may not be simultaneously rivals and partners. This type of game where the scoring system is strictly contrary (Parlebas, 2005, p. 30) can be described by the following formula $M^{+} = \emptyset$. In a competition, karate is a zero-sum game (Rapoport, 1967). In addition, Nash (1950) provides evidence that there is no equilibrium in regard to pure strategy and that there is a need to rely on probabilities, i.e., a mixed strategy.

Thus, in relation to the new *senshu* rule mentioned in part 1, coaches and karatekas should not confuse an offensive with an initiative. Here, initiative in relation to formulating a strategy does not necessarily mean choosing to attack. Therefore, we must examine the notions of *decision making* and *rationality* (Shubik, 1971; Raïffa, 1973) and *expected utility* (Von Neumann and Morgenstern, 1944). These notions are linked to the concepts and possible scopes of game theory (Von Neumann and Morgenstern, 1944; Davis, 1973).

MATERIALS AND METHODS

Between January 24, 2016, and January 29, 2017, observations were carried out in real time by one of the authors, who is holder of a national degree (*BEES 2ème degré karaté*), by using and filling out the official FFKDA game sheets during the bouts.

The data collection method used by one of the authors is not subject to any objective errors, as the conclusions are supported thanks to the electronic device present in the competitions (computer, scoring and video screens, timer), which indicate, during and at the end of each fight, every element of the scoring: points scored, penalties, *senshu*, and in specific cases the victory by flag vote (when no points are scored).

Additionally, as karate fights are stopped to deal with points and penalties attributions, the scoring registered in the specific sheets was possible to make with no mistakes. Every time a point or a penalty had to be scored, the fight was stopped: at that precise time, the author used the scoring sheets.

This organization of karate competitions always uses these kinds of electronic devices. These facilitate the scoring for every observer (the coaches, of course, and also the authors).

The observations were made during six different competitions with various types of opponents, such as children, teenagers, adults and veteran athletes (more than 55 years old) of both genders. A significant proportion of international athletes, including the top eight ranking karatekas in the last world championships, in each weight division and of both genders (Linz, 2016), were observed for a total of 191 fights. In addition, 118 bouts in the children, teenage and veteran categories for both genders were examined. A total of 148 bouts in the male category and 161 bouts in the female category were attended. A total of 618 observations in 309 bouts were made of competitors involved in a fight.

Four competitions were followed in the national categories (October 9, 2016, in Rungis, during which 66 observations were made of children; January 15–22, 2017, in Thiais, during which 80 observations were made of teenagers and seniors and 66 of children; January 29, 2017, in Orly, during which 24 observations were made of veteran athletes) and 2 competitions in the international categories (January 24, 2016, and January 28, 2017, at the Open Paris Karate–Premier League, during which six observations and 376 observations were made of seniors athletes). The study complied with the standards established by the Declaration of Helsinki. The participants were fully informed about the protocol before participating in this study and signed an informed consent form.

The experiment was approved by the local ethics committee of the University Paris-Saclay (affiliations: EA 4532; CIAMS, Université Paris-Sud., Université Paris-Saclay, 91405 Orsay, France; CIAMS, Université d'Orléans, 45067 Orléans, France).

These observations represented a total of 38.187% of national categories, including children, veteran athletes, teenagers and adults (seniors), and a total of 61.812% of adult (senior) international categories (**Table 2**).

Observations were made of the different components of the scoring system and, in particular, the data that the judges and referees validate as part of this system: the date and location of the event, the observer, the category (age, gender, weight), the belt (blue or red), the points scored (simultaneously or separately), the category 1 or category 2 penalties, the possible flags (in case of a tie at time-up), the total number of points scored, the victory or defeat (including before time-up in case of a lead of at least 8 points between competitors), the potential disqualifications, the potential injuries, and the *senshu* (first unopposed point advantage).

The observations carried out during bouts between the abovementioned categories enabled us to determine whether the scoring system may significantly model karate techniques in competitions and the quest for performance and whether coaches and athletes should include additional data in their practice sessions on the basis of a performance model and regular observations: those related to the inner logic of the activity and their consequences for the purposes of scoring or achieving a flag. The significance threshold was set at $p < 0.05$. A chi2 test was performed over a series of the karatekas involved in competitions with Sphinx IQ2®, a quantitative data processing software.

RESULTS

The results described in the tables below specify the number of competitors involved. The losing competitor appears before the/symbol and the winner after. **Table 3** presents an overview of the points and penalties scored in relation to victory.

This table first shows the maximum number of occurrences by type of points scored and presents a significant link with the victory or loss. It appears that the number of points scored, expressed as a number of occurrences, is highly correlated with the use of punches.

The difference of results by category (all categories and seniors only) reveals that the victory is achieved by obtaining the seventh point, no matter the technique used (the total number of points scored). This trigger, which implies an irrevocable win, can be expressed by significance $p \leq 0.01$ TS (Khi2 = 311.75; ddl = 15) for all categories and by $p = 0.00$ TS (Khi2 = 205.26; ddl = 12) for the seniors only.

The results that relate to bouts won before time-up (8-point gap between the two competitors) show a significant difference between all the bouts observed and those with only seniors involved. The percentage of bouts won before time-up, which is low overall (10.7%), decreases even more (4.8%) in regard to seniors.

As for the type of points scored, and given that each technique grants a different number of points, we observe that punches account for 43.7% of points scored, body kicks for 15.3%, face kicks for 37.9% and leg-sweeping techniques followed by a kick or a punch when the opponent has fallen for 3.1%. Such information shows that punches and face kicks validate 4/5th of the points scored and that leg-sweeping techniques only represent a low percentage of total points scored.

This table also shows how category 2 penalties (prohibited behavior: grabbing without engaging in combat, escaping or stalling, exiting the competition area) are frequently used by competitors who have a significant advantage in the score to keep the opponent from engaging in viable combat or scoring back. These penalties are used by competitors until receiving three penalties (the fourth one means that they will be disqualified). A particular case, entitled *Mubobi*, is a warning about self-endangerment (for instance, a competitor who throws themselves at the opponent, by exposing his or her face to a counterattack without being able to block or avoid it). For seniors only, category 1 (a single penalty), i.e., excessive contacts and forbidden

TABLE 2 | Informations concerning the categories of competitors observed.

Categories	Male children	Female children	Male teenager	Female teenager	Male senior	Female senior	Male veteran	Female veteran	Total
Age	6–11	6–11	12–17	12–17	18–34	18–34	35+	35+	NA
National competitions	88	44	32	38	10	0	24	0	236
Weight categories (in kg)	Po −30 Po −25 Pu −35 Be −30 Be −40	Po −25 Po −30 Po −35 Pu −30	Mi −45 Mi −50 Ju −55 Ju −76 Ju +76 Ju Open	Mi −45 Mi −50 Ju −59 Ju +59	Se −84	/	Ve −75 Ve −84 Ve +84	/	NA
International competitions	0	0	0	0	142	240	0	0	382
Weight categories (in kgs)	/	/	/	/	Se −75 Se −84 Se +84	Se −50 Se −55 Se −61 Se −68 Se +68	/	/	NA

Poussin (6–7) = Po/Pupille (8–9) = Pu/Benjamin (10–11) = Be/Minime (12–13) = Mi/Cadet (14–15) = Ca/Junior (16–17) = Ju/Senior (18–34) = Se/Veteran (35+) = Ve

TABLE 3 | Points and penalties scored in relation to victory.

Points	0	1	2	3	4	5	6	7	8	9	10	11	p
Yuko	193/41 VS	71/74 VS	34/60 VS	7/51 VS	1/36 VS	1/23 VS	2/11 VS	0/5 VS	0/3 VS	0/1 VS	0/2 VS	0/2 VS	$p \leq 0.01$
Khi2 = 211.87; ddl = 11 **S, significant; FS, few significant; NS, non-significant; VS, very significant** **xxx/xxx = occurrences scored by *ao/aka* (the two opponents)**													
Waza ari	285/256 VS	10/40 VS	4/7 VS	0/5 VS	0/1 VS								$p \leq 0.01$
Khi2 = 27.58; ddl = 4													
Ippon	293/214 VS	15/69 VS	0/22 VS	1/4 VS									$p \leq 0.01$
Khi2 = 70.82; ddl = 3													
Leg-sweeping ippon	306/303 NS	3/6 NS											$p = 0.31$
Khi2 = 1.01; ddl = 1													

Penalties	0	1	2	3	4	p
Category 1	264/253 NS	45/56 NS* 14/23 VS**	12/17 NS	6/6 NS	3/0 FS	$p = 0.17$ *All categories **Seniors only
Khi2 = 6.44; ddl = 4 **Not significant relation with Khi2, but correlation between the number of penalties and victory**						
Category 2	154/140 NS	155/169 NS	87/107 FS	39/69 VS	6/0 S	$p \leq 0.01$
Khi2 = 20.87; ddl = 4 **Among the six competitors disbarred, two were for endangerment (*mubobi*) which resulted in injuries**						

techniques, also shows a significant link to victory. These results (**Table 4**) also highlight a small number of injuries (two in seniors) as well as a small proportion of disqualified competitors (those who received four penalties), both in categories 1 and 2.

The results that we observed for potential points simultaneously scored by the two competitors are not significant: $p = 0.85$ NS for punches (Khi2 = 0.32; ddl = 2), $p = 0.16$ NS for body kicks (Khi2 = 2.01; ddl = 1), $p = 0.16$ NS for face kicks

TABLE 4 | Points simultaneously scored and the *senshu* rule in relation to victory.

Points simultaneously scored	0	1	2	*p*
Yuko	295/292 NS	11/13 NS	3/4 NS	$p = 0.85$
Waza ari	307/309 NS	2/0 NS		$p = 0.16$
Ippon	307/309 NS	2/0 NS		$p = 0.16$
Leg-sweeping ippon				Ø

***Yuko* Khi2 = 0.32; ddl = 2/*Waza ari* Khi2 = 2.01; ddl = 1/*Ippon* Khi2 = 2.01; ddl = 1**

Flag rule	0	1	2	3	4	5	*p*
120 bouts analyzed	302/292 VS	3/0 VS	4/0 VS	0/4 VS	0/3 VS	0/10 VS	$p \leq 0.01$
***Senshu* rule**							
189 bouts analyzed	0/9 VS						$p \leq 0.01$

Flag rule Khi2 = 24.17; ddl = 5

Columns indicates the flag vote number (0 means inequality of scores at the end of bouts. 1 to 5 means draws at the end of bouts, and so flag votes)

Senshu rule Khi2 = 9.22; ddl = 2

Only nine bouts finished with draws and so victories due to *senshu* advantage

(Khi2 = 2.01; ddl = 1), and no occurrences for leg-sweeping techniques followed by a kick or a punch when the opponent has fallen. This is due to the number of points simultaneously scored, which is too low compared to all the points scored over all the competitions and bouts observed.

As for the *senshu* rule, we observed the following: before the rule was applied, only one competitor won his bout with the flags with a 0–0 score and another one only with the flags for an x–x score. A total of 120 bouts were analyzed in this case. With the *senshu* rule, no victory was awarded with the flags for an x-x score (a 0–0 draw or a draw with *senshu* scored simultaneously) and nine wins awarded with *senshu* for an x-x score. A total of 189 bouts were analyzed in the context of the application of this new rule. Additionally, no competitor lost this *senshu* advantage by being penalized in the last 15 s of the bout (this situation forfeits the *senshu* of the competitor who scores it). When *senshu* is awarded, at the end of a fight in an x–x situation (draw), the winner is the one who scored first, that is to say, he or she who obtained the *senshu* advantage. Each of these rules appears to be very significant in the way that it is applied: $p \leq 0.01$ TS (Khi2 = 24.17; ddl = 5) for the flag rule in the case of a tie, and $p = 0.01$ TS (Khi2 = 9.22; ddl = 2) for the *senshu* rule and the application of the first unopposed point advantage in the case of a tie.

DISCUSSION

Several profiles of karatekas, whether male or female, are likely to win and have repeatedly done so. The karatekas can engage in offensive, defensive or countering tactics.

Points Scored

There is a strong correlation between the number of *yuko* and victory. The more *yuko* a competitor wins, the larger the victory will be. This tendency reveals a possible paradox between fighting techniques that are based on single or cyclical (over two punches or kicks) actions and the tendencies observed, which show the significance of punches. What if the karateka had to combine two or three punches or kicks, just as boxers do, and only cease his or her sequenced cyclical actions and take his or her original position when the referee stops the bout?

In this scoring system, we notice that from 7 *yuko*, victory becomes certain in our entire sample. This certainty of scoring 7 *yuko* or more happened in this study to only 13 competitors (see **Table 3**). A *yuko* is a trigger in itself, both in terms of losses and gains.

Being awarded *waza ari* shows an even stronger correlation with winning than *yuko*. Surprisingly, the victory percentage is higher for 1 *waza ari* than for 2. From 3 *waza ari* scored, victory becomes certain. However, very few of these *waza ari* are scored. This could be explained by the body protection system the competitors use by placing their guards with their arms close to their bodies, which protects from body kicks and enables the opponent to counter the attack or to strike back. This could also be explained by the strong expectations of the referees and judges as to the scoring criteria (potential effect, awareness, timing, distance) or by a combination of these factors.

While only one competitor who was awarded 1 *ippon* lost in the entire sample of this study, managing to score with face kicking techniques significantly tends to lead to victory. This is something that coaches know in terms of points scored (3), and this imposes complex and hard work during physical training for athletes on one-foot postures when not protected against counterattacks or leg-sweeping techniques. This is also true for an *ippon* awarded for a leg-sweeping technique, which may lead to a loss in 33% of cases. This fact cannot be due to the risk of the technique itself, for if the *ippons* were scored, there would be no possibility of counterattacks because the bouts are stopped by the referee to score points. Rather, this must be due to other more complex relationships (i.e., were the sweeps tried as a desperate technical resource when a losing athlete tried to win back a losing match by earning the higher number of points with a single technique?).

In relation to the number of points scored, the results hold, yet again, few surprises: the more points that are scored, the most likely a victory is. A switch can be noted at 2 points. Defeat is then just as likely to occur as victory. A win becomes a certainty from 7 points, but there was 1 occurrence of 67 loses with at least 8 points (10–15). However, this result is significant.

Penalties

Observing category 1 penalties (for excessive contact) independently does not show any significant link with victory, except for the fact that the fourth penalty results in the competitor being disqualified. Further, the likelihood of victory for a disqualified competitor is zero.

Observing these penalties as a whole, as **Table 3** summarizes, is more interesting. Even if the link is not significant for khi2, there is an actual relation between the data. Victories are more or less frequent depending on the number of excessive contact penalties. The more contact penalties that are scored, the more victories that are obtained. Of course, the number decreases at 4 because of the resulting disqualification. However, the number of affected individuals is not high, as these penalties are moderately rare. As these components are not significant, looking for excessive contacts is not necessary, and we would rather elaborate on significant criteria that tend to lead to victory. By only examining the seniors and category 1 penalties (excessive contacts), it appears that contact penalties do not help competitors win, except for those who only receive penalty.

As for category 2 penalties (prohibited behavior), they become intricately linked to victory from the third penalty imposed. The penalties are not prior to the third strike and, because of the disqualification rule, automatically result in defeat when reaching the fourth penalty.

In all the results observed, only two competitors were disqualified because of prohibited behavior (exposing without protecting, called *mubobi*), which resulted in injuries. These two injuries affected karatekas who threw themselves into an offensive without protection to catch-up and who were hit by their opponents. These specific cases are among the few disabling actions authorized in karate competition (knock-out). In such circumstances, scoring a point requires meeting the four criteria (potential effect, awareness, timing, distance), as described in part 1, for the competitor who hit the wounded competitor. This is a situation that may happen to a led competitor. Thus, no tactics can effectively provoke the *mubobi* situation, which is almost always an accident, in which the motor control of one of the karateka is overwhelmed by an irrational action of the opponent.

Points Scored Simultaneously, Flags and *Senshu*

While karate is a zero-sum game (Rapoport, 1967), as Parlebas (2005) specifies, karate may also be exercised, in certain circumstances, according to a cautious strategy, based on observing and waiting for the opponent's moves. Attempting to minimize one's gains for the purposes of minimizing one's losses becomes a mostly defensive strategy. Can this be done?

If we agreed that such an exercise has already enabled an athlete to rise to the top of the world (for example : Nadége Aït-Ibrahim, karate World champion in 2012) or continental (for example : Anne-Laure Florentin, karate European champion in 2017) championships, i.e., that a Nash (1950) can be reached between two offensive strategies in a zero-sum game, the result would be considered suboptimal (Parlebas, 2005, p. 35) according to game theory.

Indeed, two of the rules of karate competitions result in cooperative strategies, thus becoming not significant: first, the stopping of the bout to award points to the first unopposed point advantage becomes a material standard, contrary to scoring simultaneous points, which, as we observed, is too rare of a situation to lead to any modeling that coaches and athletes could use. Scoring points during simultaneous actions is not enough to ensure a victory. Observations tend to lead to a contrary statement, although there are too few cases for that to be significant. Finally, the introduction of the *senshu* rule did not materially change the competitors' behavior by making them unflinching attackers. However, recent studies on the number of valid points scored in karate competition point to the fact that having to balance the risk of obtaining a double advantage with the first unopposed score versus the fact that the opponent could be the one who obtains the valid score if the attack is not precise enough and is counterattacked has led to a delay in the moment of the first combat attacking actions.

In addition, the low number of points scored during the bout should not hide the reality of interactions between the opponents: many decisions are made and many actions are attempted by competitors concerning "*realism, creativity, exposing, protecting*" (Biéchy, 2012) during fighting situations.

Points were scored by attacking, defending, or counterattacking, and very few of the points were awarded simultaneously.

Given the quantitative information described in **Table 1** of this article as to the bout between *Aka* (red color) competitor and *Ao* (blue color) competitor, we can highlight that *Aka* acts depending on what the scoring system analyzed considered significant (types of points, use of penalties, win at time-up) and is able to determine the errors that *Ao* makes (overuse of leg-sweeping techniques, failure to rely on penalties). *Aka* is well known for his *ippon* technics. Did *Ao* want to counter *Aka*'s work by using *ippon leg-sweeping* technics to prevent him from scoring with face kicks (even if he failed trying to do so)? Such quantitative information allows us to assume that there is a need for competitors to multiply social and motor actions. At that level of competition (finals of an international tournament), *Ao*'s fighting approach does not seem *realistic* enough and leads him to *expose* himself in vain. In contrast, *Aka*'s strategy, which is more appropriate considering the significance of the scoring system used, is closely related to the types of karatekas who often win. Additionally, in any combat, the technical level of both contestants might not be the same, and so one of them might have a clear advantage over the other, which cannot be reversed by any tactic.

The bout that we observed is a good representation of a zero-sum game, in which seeking an equilibrium between gains and losses is suboptimal.

These results may also be cross-checked with previous results from soccer (Hughes et al., 2012). Five purposes were discussed: "*movement analysis, educational use for coaches and players, tactical evaluation, database and technical evaluation.*" In comparison with the present work, the player roles were studied with educational and performance purposes, and we present the competitor roles concerning "*realism, creativity, exposing, protecting.*" Additionally, the significant results we present in this article concerning the scoring system in competitive karate and consequently the strategies that we propose next may be the first approach to identifying the Key Performance Indicators (KPI) used by Hughes et al. (2012). Indeed, further work may be engaged in to create a useful KPI for karate competitors.

Taekwondo researchers and trainers have already started working on modeling to "*provide objective data on competitive behavior*" (Menescardi et al., 2019). Their study focuses on technical and tactical behaviors and the regulations that need to be made concerning their inclusion in trainings, and of course, in bouts. The researchers assess that psychologists and coaches may help trainees pattern visualization plan sessions during training and thus elaborate on the tactical strategies to be used during competitions.

These previous studies may be of help for the continuation of this work.

On the basis of interactive logic, and as Conte and Lukonaitiene (2018) discussed regarding basketball and the case of different strategies, as to whether a team is winning or losing a match, we make some proposals that are the result of Biéchy's interpretations, in which penalties may be scored by a competitor because he or she has not yet scored 3 penalties (**Table 5**).

We also propose some different tactics when penalties may not be scored again by a competitor because this competitor has already scored 3 penalties (**Table 6**).

Before the end of the bout, when 15 s remain, the referee announces *Atoshi baraku*. This period immediately before the end of the fight is very important in terms of tactics, because *senshu* advantage can be lost during this period. The result of the fight could be reversed, and the competitors cannot avoid combat, which – to a certain extent – might give some small advantage to the competitor who is losing the fight, as his or her opponent is forced to confront the fight. Avoiding combat (retreats without effective counter, holds, clinches, or exits from the area) during *Atoshi baraku* is penalized with a category 2 penalty (3rd degree, or 4th if the competitor already scored 3 penalties, which means disqualification) and with the loss of this *senshu* advantage.

It appears, indeed more than ever, that the definition of strategies and the determination of possible tactical schemes occurs in the relationship between the trainer and the trainee and that the trainers rely on *rationality* (Shubik, 1971) in deciding how to train the trainee and compete.

For us, the main question to be asked is that regarding decision making, which was raised by Raïffa (1973). Coaches should help the trainees reach the relevant control and performance levels (Le Scanff and Legrand, 2004), i.e., to work toward improving their self-esteem. Self-esteem leads to the ability to set goals for oneself. Optimizing technical and tactical work for the purposes of reaching a certain level of performance will be, in close collaboration with the coach, one of the tools (Le Scanff, 2003)

TABLE 5 | Possible strategic options when penalties may still be scored by a competitor.

Current situation	Penalties	Possible strategic actions
Leading competitor: suppressing valid touch surfaces	Category 1: less than three penalties imposed	– Defending + face punch (*jodan uchi*)
	Category 2: less than three penalties imposed	– Grabbing (+defending with face punch – *jodan uchi*) – Exiting the area + counter face kick (*jodan geri*)
	Atoshi baraku (last 15 s): less than three penalties imposed	– Defending + grabbing + face punch (*jodan uchi*) – Exiting the area + counter body or face kick (*chudan geri* or *jodan geri*)
Led competitor: entering – exiting – re-entering the touch distance	Category 1: less than three penalties imposed	– Attacking with a face or body punch (*jodan uchi* or *chudan uchi*) + attacking (free technics) – Attacking with a face or body punch (*jodan uchi* or *chudan uchi*) + defending
	Category 2: less than three penalties imposed	– Attacking (free technics) + defending + grabbing
	Atoshi baraku: less than three penalties imposed	– Same tactic as above

Vocabulary used by referees (FFKDA, 2016): *jodan uchi* (face punch), *chudan uchi* (body punch), *jodan geri* (face kick), *chudan geri* (body kick), leg-sweeping technique
Strategic possible actions: attacking (attempt to hit an opponent by taking the initiative), counter (create an attack in an opponent attack to regain initiative and score points by hitting first), defending (block, dodge, parry an attack), existing the area (getting out the fighting area to win time, and cause a change of strategy of the opponent that he/she does not rationally decide), and grabbing (grab an opponent in order to prevent him/her to produce an attack/counter-attack that may score points).

TABLE 6 | Possible strategic options when penalties may not be scored because three are already scored.

Leading competitor: suppressing valid touch surfaces	Category 1: three penalties imposed	– Defending with body punch (*chudan uchi*) – Defending with face kick (*jodan geri*)
	Category 2: three penalties imposed	– Counter-attacking with face kick (*jodan geri*)
	Atoshi baraku: three penalties imposed	– Counter-attacking with body kick (*chudan geri*)
Led competitor: entering – exiting – re-entering the touch distance	Category 1: three penalties imposed	– Attacking (free technics) + defending on two sequenced height levels (mixing face and body technics)
	Category 2: three penalties imposed	– Same tactic as above
	Atoshi baraku: three penalties imposed	– Same tactic as above

Vocabulary used by referees (FFKDA, 2016): *jodan uchi* (face punch), *chudan uchi* (body punch), *jodan geri* (face kick), *chudan geri* (body kick), leg-sweeping technique
Strategic possible actions: attacking (attempt to hit an opponent by taking the initiative), counter (create an attack in an opponent attack to regain initiative and score points by hitting first), and defending (block, dodge, parry an attack).

for managing emotions and stress in the context of practice and in the bouts themselves. In this context, the trainer will have to work toward helping the trainee acquire new skills in relation to expectations, prophecies and a possible Pygmalion effect, as Fantoni (2016) showed. Determining the potential expectations of the coach will be a factor in the decision making for the athletes and will allow them to avoid the "*motor suicide*" obstacle (Fantoni, 2016, p. 155).

There are indeed "*interactive dynamics*" (K/Bidy and Escalie, 2016, p. 61) to be implemented by the trainer and the trainee once modeling is included in the practice process, in order to "*schedule ordinary training sessions*" and create a performance project.

According to Menescardi et al. (2019), "*objective data regarding successful behavioral patterns, (. . .) are important for coaches and psychologists to train and develop psychological strategies to prepare athletes. For instance, they can be used to individualize training sessions, including visualization of specific combat situations. (. . .) Coaches may use these findings for specific tasks related to technical-tactical improvement of scoring effectiveness.*"

The results of our analysis enable us to understand that an equilibrium between gains and losses is not relevant in a karate competition. As a zero-sum game, domination prevails.

The scoring system described in our analysis reveals that there is a need for karatekas to understand the wide variety of actions that can be used to score points. If competitors have to score points with punches as well as with face kicks, karatekas will have to make decisions depending on their opponent's level and will have to wonder if *realism* is to be favored over *creativity* or if they should rather *expose* or *protect* themselves. Far from being ignored and poorly considered, both categories of penalties should be used. Competitors must be acquainted with a possible scoring knockout if their opponents expose themselves. In all these different fighting scenarios, the sport is a lasting game, where the trainee has to expect fierce struggles that are rarely won before time-up.

CONCLUSION

The presentation of the technical and tactical paradox (which requires finding the right balance between "*exposing, realism, protecting, creativity*") in the context of the analysis of 309 karate bouts clearly indicates suggestions for coaches and athletes, for both training sessions and competitions, to avoid unsuccessful situations and to perform by winning fights, thanks to successful behavioral choices. The paradox concept is used to expose how the apparently sound principles of tactical options such as "*exposing, realism, protecting, creativity,*" which reason from acceptable premises, may be opposed to some of the techniques used to score and how this could lead to a conclusion that seems logically unacceptable or self-contradictory. These strategic choices are presented in this study. However, to pursue this research in future work, we could try establishing key performance indicators (KPI) to make the coach-trainee relationship even more efficient on the basis of significant technical and tactical decisions, leading to rationality. These future analyses may be realized for different competition issues and in different contexts, from national to international contexts and for different categories (age, sex, level).

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Paris-Saclay (EA 4532, CIAMS, Université Paris-Sud, Université Paris-Saclay, Orsay, France; CIAMS, Université d'Orléans, Orléans, France). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JF designed the study and collected, analyzed, and interpreted the data. JF, ST-P, and AD drafted and revised the manuscript and tables and gave the final approval.

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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.

frontiers in Psychology

BRIEF RESEARCH REPORT
published: 22 January 2020
doi: 10.3389/fpsyg.2019.02950

Heart Rate Kinetics and Sympatho-Vagal Balance Accompanying a Maximal Sprint Test

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When a maximal sprint starts, heart rate (HR) quickly increases. After the exercise ends, HR keeps high for seconds before recovering with a roughly exponential decay. Such decay and its time constant (τ_{off}) have been widely studied, but less attention was devoted to the time delay (t_{delay}) between sprint end and HR decay onset. Considering the correlation between sympatho-vagal balance and performance, as well as the occurrence of heart failure in cardiopaths during the post-exercise phase, we evaluated sympatho-vagal balance before and after sprint, trying to correlate it with both t_{delay} and τ_{off}. R-R intervals, recorded in 24 healthy adults from 5 min before to 5 min after a 60-m sprint-test (from Storniolo et al., 2017, with permission of all authors), were re-processed to extract HR variability power (LF and HF) in the low- and high-frequency ranges, respectively. The sympatho-vagal balance, evaluated in pre-test resting period $(LF/HF)_{REST}$ and at steady-state recovery $(LF/HF)_{RECOV}$, was correlated with t_{delay} and τ_{off}. Both $(LF/HF)_{REST}$ and $(LF/HF)_{RECOV}$ had a skewed distribution. Significant rank correlation was found for $(LF/HF)_{REST}$ vs. τ_{off} and for $(LF/HF)_{RECOV}$ vs. both τ_{off} and t_{delay}. The difference $(LF/HF)_{RECOV-REST}$ had a normal distribution and a strong partial correlation with t_{delay} but not with τ_{off}. Thus, a long t_{delay} marks a sympathetic activity that keeps high after exercise, while a high sympathetic activity before sprint leads to a slow recovery (high τ_{off}), seemingly accompanying a poor performance.

Keywords: R-R variability, heart rate recovery, maximal exercise, autonomic nervous system, human

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Specialty section:
This article was submitted to
Movement Science and Sport
Psychology,
a section of the journal
Frontiers in Psychology

Received: *09 October 2019*
Accepted: *12 December 2019*
Published: *22 January 2020*

Citation:
Storniolo JL, Esposti R and Cavallari P (2020) Heart Rate Kinetics and Sympatho-Vagal Balance Accompanying a Maximal Sprint Test. Front. Psychol. 10:2950. doi: 10.3389/fpsyg.2019.02950

INTRODUCTION

Current studies have widely reported the role of heart rate (HR) kinetics after exercise in predicting health issues such as cardiac disease, heart failure, and sudden death (Imai et al., 1994; Aeschbacher et al., 2016; Qiu et al., 2017). It is well known (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996) that the analysis of HR variability (HRV) needs a steady-state HR kinetic, or at least a linear trend of the signal, in order to reliably calculate variability indices like the SD of R-R intervals and the root mean square of successive differences (in the time domain), or the spectral components of HRV (in the frequency domain).

Concurrently, the specific analysis of the HR decay in the recovery phase from exercise has been as well accepted as a marker of the sympatho-vagal balance (Dimkpa, 2009; Billman, 2011). The advantage of this approach, compared to traditional HRV analysis consists of the possibility of calculating these parameters directly from HR time course (Peçanha et al., 2014; Watson et al., 2017). However, it should be taken into account that some studies reported controversial results when the analysis was restricted to a short part of the decay (commonly no more than 60 s), due to the non-linearity of the signal (Michael et al., 2017).

HRV is acknowledged as an indicator of the cardiac sympathetic and parasympathetic control (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). In particular, the fraction of the total power in the low-frequency range (LF, 0.04–0.15 Hz) reflects the sympathetic drive, while the fraction in the high-frequency range (HF, 0.15–0.4 Hz) unveils the parasympathetic drive through the *vagus* nerve. Accordingly, the LF/HF ratio quantifies the sympatho-vagal balance (Malliani et al., 1991). This balance has been shown to undergo significant changes at exercise transitions (basal to exercise to recovery) where its effects may be appreciated by rapid changes in HR (Michael et al., 2017). Fast feedbacks from muscle mechanoreceptors contribute to initial parasympathetic withdrawal as well as to its reverse process upon the exercise cessation (Pierpont et al., 2000; Dupuy et al., 2012). However, the speed of the process may vary in response to different factors, such as the exercise type and intensity, as well as the posture adopted in the baseline and recovery periods (Coote, 2010). It is also worth noting that a low LF/HF ratio, reflecting a generally high vagal tone, has been shown to be associated with a better cardiac adaptation to daily life exercise or activities (Peçanha et al., 2014).

HRV tests do not require expensive apparatuses, besides reliable HR monitors capable of beat-by-beat acquisition. However, its evaluation in exercise protocols commonly needs at least 25 min, spanned among baseline, exercise, and recovery acquisitions (Storniolo et al., 2017). Indeed, a quite long exercise is required to reach a stationary HR, from which HRV frequency distribution is calculated. However, it has been recently shown (Storniolo et al., 2017) that the maximal oxygen consumption, which correlates to the individual's adaptation to strenuous exercise, may be predicted also by measuring the HR decay after a 60-m sprint exercise, which is so short that the metabolic rate could not even approach the steady-state value.

In this perspective, we reprocessed HR data before, during, and after such sprint test, seeking for parameters of post-exercise HR kinetics that could correlate with sympatho-vagal balance, assessed through HRV frequency analysis in the pre-exercise and full-recovery periods. Should our search be fruitful, an important index could be easily derived from HR monitor data to estimate the individual adaptation to everyday life exercises. Among the HR recovery parameters, we considered the constant of the mono-exponential decay (τ_{off}), which is considered an indicator of higher aerobic and anaerobic power as estimated from different running protocols (Otsuki et al., 2007; Borresen and Lambert, 2008; Storniolo et al., 2017). Besides, we evaluated the period of time (t_{delay}) for which the HR plateaus between the exercise cessation and the onset of the exponential decay. Such delay in HR decrease has been observed in different physiological markers after exercises, including blood lactic acid concentration and oxygen consumption (Margaria, 1976; Bailey et al., 2018). Actually, t_{delay} in HR recovery has been repeatedly observed in the literature; nevertheless, many authors simply discarded it as a "confounding factor" for the kinetics analysis of HR exponential decay (Buchheit et al., 2007; Peçanha et al., 2014).

It is noteworthy to emphasize that t_{delay} is particularly evident after strenuous exercise, but to our knowledge, it was never correlated to sympatho-vagal balance, or discussed in physiological terms. Thus, given the proven correlation between the sympatho-vagal balance and the exercise performance (Michael et al., 2017), we evaluated HRV before and after a maximal sprint test, trying to correlate the sympatho-vagal balance with both t_{delay} and τ_{off}. Our hypothesis states that these parameters (particularly t_{delay}) might be associated with the sympatho-vagal balance since parasympathetic reactivation is notably impaired after high exercise intensity.

MATERIALS AND METHODS

Heart rate data analyzed in this study were originally collected by Storniolo et al. (2017), who also extracted the onset of the HR mono-exponential decay after exercise and its time-constant τ_{off}. Here HR data were re-processed, with kind permission of all co-authors, so as to measure HRV in pre-exercise and full-recovery periods, and correlate it with the time interval between the exercise end and the onset of HR decay, here called t_{delay}. Details of population parameters and data acquisition are thus reported in brief (for all details, see Storniolo et al., 2017).

Subjects

Out of the 25 subjects who attended the Storniolo et al. (2017) study, we excluded data from one subject whose t_{delay} was larger than the population mean + 2 SD. The resulting sample was composed of 24 subjects (7 women and 17 men, 25.0 ± 5.0 years, 1.77 ± 0.08 m height, 71.9 ± 8.5 kg body mass; mean ± SD). They were physically active, being involved either in recreational activity, or in amateur sport activity with a maximum of three sessions per week.

Experimental Protocol

Subjects performed a 60-m maximal sprint accomplished on an outdoor athletic track. They were instructed to get at the experimental session in a relaxed and fully hydrated state. In addition, they were told to avoid alcohol (24 h) and caffeine (6 h) intake before the test. Subjects were asked to perform the sprint at their best.

Data Acquisition

The 60-m maximal sprint trial was preceded by a short warm-up (5 min with jogging and stretching) and 10 min of resting period, 5 min in a seated and 5 min in a standing position. HR was recorded beat-by-beat throughout the 5 min of standing rest, the running phase and the 5 min of standing recovery, using a HR monitor with transmitter belt (Polar S410, Kempele, Finland). All tests were performed at the same time of the day (10–11 am) to limit the influences of circadian rhythm on muscle performance and HR response/variability (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996).

Sympatho-Vagal Balance

HRV was separately evaluated into the first 3 min of the standing rest and in the last 3 min of the recovery phases. R-R intervals were pre-processed so as to exclude those falling outside ± 2 SD with respect of the mean R-R duration, then the R-R time sequence was resampled at 10 Hz with spline interpolation. The RMS Power Spectral Density was extracted by the Least-Squares autoregressive method, setting the order parameter to the value that minimized the Akaike information criterion (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996).

The fractions of the total power in the LF and HF bands (LF: 0.04–0.15 Hz and HF: 0.15–0.40 Hz, approximately) were evaluated as the area under the respective spectral peaks, identified by means of the valleys between them. Then the ratio of LF/HF power was calculated before the sprint [$(LF/HF)_{REST}$] and at late recovery [$(LF/HF)_{RECOV}$], so as to evaluate the sympatho-vagal balance in the two phases (Malliani et al., 1991); the higher the ratio, the higher the sympathetic drive. The difference $(LF/HF)_{RECOV-REST}$ was also determined.

STATISTICS

Shapiro-Wilk test was used to assess the normal distribution of the data. Linear associations between $(LF/HF)_{RECOV-REST}$ with t_{delay} and τ_{off} were evaluated by Pearson partial correlation coefficients. Spearman's rank-order correlation was instead applied for $(LF/HF)_{REST}$ and $(LF/HF)_{RECOV}$ because their distribution deviated from normality. Statistical significance was granted at $p < 0.05$.

RESULTS

An example of HR time course during standing rest, 60-m sprint, and standing recovery is illustrated in **Figure 1**. It is apparent that HR started to rise in advance of the 60-m sprint, as the subject was readying itself to the effort. It is also apparent that after the end of the sprint, it took more than 1 min for the HR to regain a steady state. Thus, the last 2 min of standing rest and the first 2 min after sprint end were excluded from HRV analysis. Note that the HR exponential decay started about 10 s later than the end of the sprint (t_{delay}), a value that covered about 1/3 of the decay time-constant (τ_{off}). In the experimental sample, t_{delay} resulted to be 8.50 ± 1.98 s (mean ± SD), while τ_{off} was 27.85 ± 6.83 s. The 60-m sprint lasted 9.76 ± 1.37 s.

Figure 2 illustrates, in the experimental sample, the correlations between each of the HRV-based indicators of sympatho-vagal balance [$(LF/HF)_{REST}$, $(LF/HF)_{RECOV}$, and $(LF/HF)_{RECOV-REST}$] and the two parameters characterizing of HR recovery (t_{delay} in panel A, and τ_{off} in panel B). Since $(LF/HF)_{REST}$ and $(LF/HF)_{RECOV}$ significantly deviated from the normal distribution, Spearman's rank correlations (ρ) were calculated for these variables. Pearson's partial correlations (r) was instead used for $(LF/HF)_{RECOV-REST}$. A significant positive correlation between $(LF/HF)_{REST}$ and τ_{off} ($\rho = 0.42$, $p = 0.043$) was found, but not with t_{delay} ($\rho = -0.19$, $p = 0.37$); note, however, that this last correlation had a negative trend. Instead, $(LF/HF)_{RECOV}$ had a significant positive correlation with both t_{delay} ($\rho = 0.43$, $p = 0.035$) and τ_{off} ($\rho = 0.44$, $p = 0.030$). Therefore, while τ_{off} seems more linked to the sympatho-vagal balance in the rest and recovery time periods separately, t_{delay} seems to be a better indicator of the change in sympatho-vagal balance between these two periods. Indeed, the opposite ρ that $(LF/HF)_{RECOV}$ and $(LF/HF)_{REST}$ had with such delay resulted in a strong Pearson's partial correlation between the difference $(LF/HF)_{RECOV-REST}$ and t_{delay} ($r = 0.60$, $p = 0.002$), while the partial correlation with τ_{off} was at all marginal ($r = -0.038$, $p = 0.86$; **Figures 2A,B**).

DISCUSSION

In this study, we aimed to highlight the importance of t_{delay}, a representative parameter of the post-exercise HR recovery, as an important variable to assess the sympatho-vagal balance in that phase. In this aim, two time-domain parameters of the fast HR recovery after a maximal sprint-test (t_{delay} and τ_{off}) were tested for correlation with the HRV LF/HF ratio, at baseline before the sprint and at late recovery. To our knowledge, the present study is the first that correlates t_{delay} to sympatho-vagal balance and discusses it in physiological terms.

It was found that t_{delay} is a good candidate for indicating the changes in sympatho-vagal balance between resting baseline and late recovery, while τ_{off} seems more linked to the sympatho-vagal balance in each period separately. Indeed, τ_{off} was positively correlated with the sympatho-vagal balance both at rest and at late recovery; thus, it cannot be used to discriminate whether (i) the subject has an overall prevalence for the sympathetic vs. parasympathetic drive, or (ii) he strongly increases his sympathetic drive only after the exercise; in fact, τ_{off} would be high in both cases. On the contrary, the strong partial correlation between t_{delay} and $(LF/HF)_{RECOV-REST}$ clearly witnesses that t_{delay} selectively identifies a subject with problems in recovering his sympatho-vagal balance after a strenuous exercise.

Although t_{delay} has been frequently reported in the literature, it has been often dismissed from analysis due to the difficulty in inquiring the specific chemical dynamics involved during this period (Zhang et al., 2014). Besides that, the persistence of an high HR immediately after the end of an intense exercise might also depend on the high respiratory frequency (Pierpont et al., 2000; Borresen and Lambert, 2008). In accordance with Pierpont et al. (2000), a sustained tachycardia influenced by a high respiratory frequency may indicate a sympathetic predominance, despite the known re-activation of the parasympathetic system, during the fast phase of recovery. Even though some authors (Buchheit et al., 2007; Peçanha et al., 2014) excluded the very first seconds before the start of HR decay, so as to pinpoint the mono-exponential trend, such exclusion may hide part of the autonomic regulation of HR. Considering that a delayed HR recovery has been associated with the healthy and training status of the subject (Borresen and Lambert, 2008), it is of interest to understand whether this delay is secondary to a delayed HR decay (long t_{delay}) and/or a slower exponential phase (long τ_{off}).

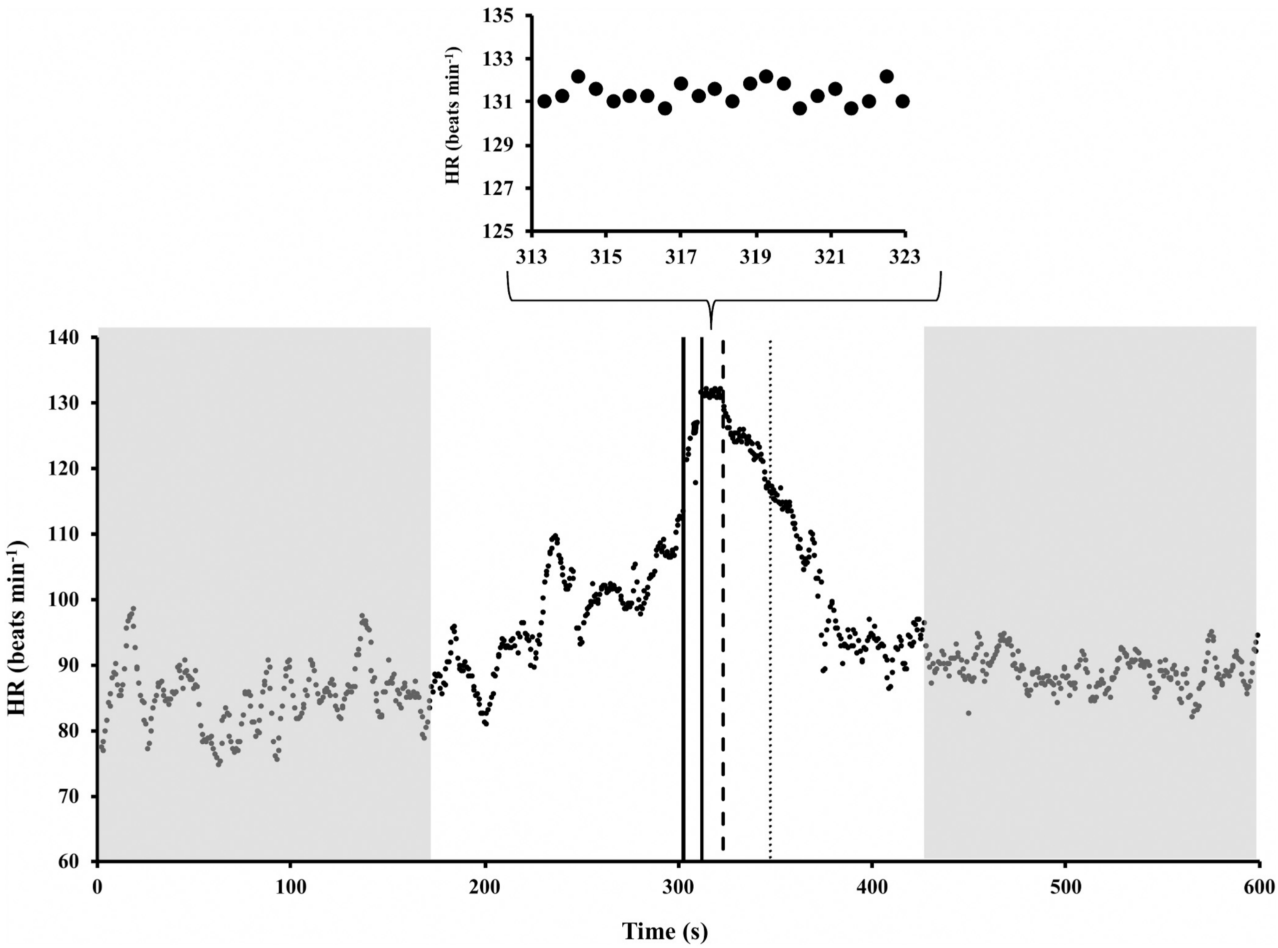

FIGURE 1 | Example of heart rate (HR) time course during standing rest, 60-m sprint, and standing recovery (redrawn from Storniolo et al., 2017). Shadow gray areas represent the time periods for HR variability analysis. It is apparent that in those periods HR was stationary. Solid vertical lines mark the start and end of the sprint. Dashed line marks the onset of HR exponential decay; thus, its distance from the last solid line represents t_{delay}. Dotted line is set at the time in which the HR decay was 63% completed, so that its distance from dashed line represents τ_{off}.

Moreover, it should be noted that "t_{delay}" after strenuous exercise has been previously reported not only for HR but also for other physiological markers, such as the lactic acid concentration in the blood, the oxygen uptake and the ventilation (Di Prampero et al., 1973; Margaria, 1976; Bailey et al., 2018). In fact, it is well known that during the exercise recovery phase, the muscle has to pay for the oxygen debt contracted at the beginning. When the load is kept below the maximum aerobic power, the oxygen debt is limited to that needed for phosphocreatine resynthesis, and the oxygen uptake (and the correlated variables) starts to decay as soon as the exercise ends. Instead, when the anaerobic threshold is crossed, also the lactic acid production should be added; therefore, the oxygen uptake should keep high for some seconds, so as to pay the lactacid debt. In this case, the oxygen uptake (and the correlated variables) shows a delayed exponential decay, which may be seen as a clipped exponential curve. Such curve would theoretically decrease immediately after the exercise, starting from the oxygen energetic equivalent of the load, but actually, it is clipped at the maximum oxygen uptake allowed by the cardiopulmonary limits. Acknowledging the correlation between the kinetics of oxygen uptake and HR, the statement mentioned above might explain the HR persistence after intense exercise. Considering that (i) the cardiac output is the product of stroke volume and HR, and that (ii) in exercises exceeding ~60% of individual's maximum HR the stroke volume stops raising, it follows that HR remains the only responsible for covering the need of a high perfusion after strenuous exercise (Zhang et al., 2014). In this perspective, our sprint exercise apparently crossed the anaerobic threshold; thus, no wonder that we could observe the clipping in HR recovery. It is then clear that the persistence of a high HR should be associated with a high sympathetic drive, influenced by the "payment" of the lactacid debt.

Notably, the delay in oxygen uptake recovery has been shown to be prolonged in heart failure individuals (Bailey et al., 2018). It is also known that a slow HR decay after exercise can be a good predictor of sudden deaths correlated to heart diseases (Huang et al., 2013; Bailey et al., 2018). In this regard, Huang et al. (2013) showed that in

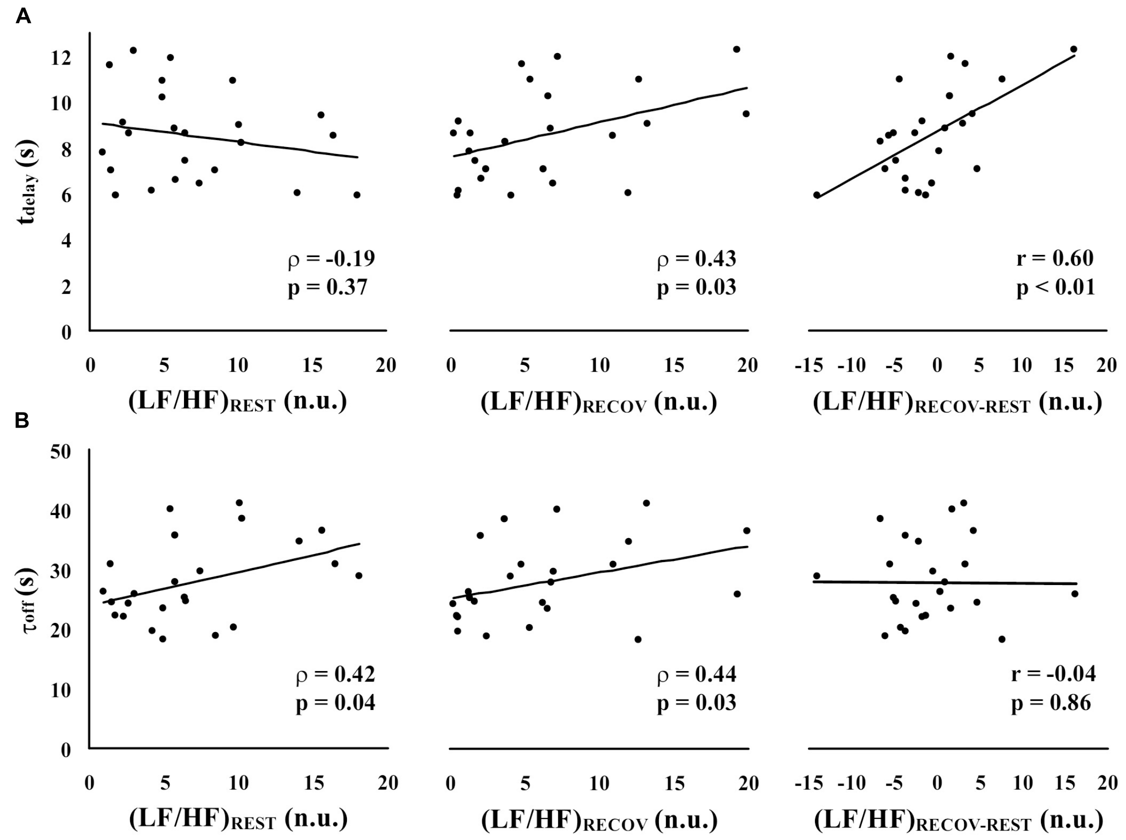

FIGURE 2 | Spearman's rank correlations (ρ) and Pearson's partial correlations (r) between each of the HRV-based indicators of sympatho-vagal balance [$(LF/HF)_{REST}$, $(LF/HF)_{RECOV}$, and $(LF/HF)_{RECOV-REST}$] and the parameters characterizing the time-course of HR recovery [t_{delay} in panel **(A)**, and τ_{off} in panel **(B)**].

elderly, in women, and in patients with normal chronotropic response during exercise, the slower the return of HR to baseline values, the higher is the probability of a vagal deficit. As justified in section "Introduction," our protocol may ensure the identification of potential risks in individuals attending the sprint test, with the advantage of a short-time requirement (approximately 10 min) and of the easiness of the measuring apparatus.

A short comment deserves the heterogeneous composition of the tested sample. Actually, we spanned on purpose different ages, training statuses, and days within the infradian cycle of interest (menstruation in women, see Schmalenberger et al., 2019, and testosterone seasonal secretion changes in men, see Smith et al., 2013). Indeed, all these aspects affect both HRV and exercise performance, therefore contributing to enhancing the inter-subject variability. In this way we effectively strengthened the reliability of the observed correlations.

A final note deserves the linkage between sympatho-vagal balance and training/emotional status. Our results also highlighted a predominance of the sympathetic drive [$(LF/HF)_{REST} > 1$, average HR ∼81 bpm] during pre-exercise rest, although we excluded the elevated HR values that preceded the sprint, thus limiting HRV analysis to the first 3 min of rest. Such result may come from the fact that subjects were resting in the orthostatic position, which promotes a higher sympathetic activation even in no exercise situations (Buchheit et al., 2009). However, this could also be linked to the emotional status related to mind-body preparation for the sprint (Choi et al., 2017). Indeed, it has been recognized how emotional factors, such as anxiety, can influence the sympatho-vagal balance mainly during stress situations (ChuDuc et al., 2013). From this perspective, Sanchéz-Conde et al. (2019) reported a high sympathetic drive in nurse students before their first clinical activities, associated with high subjective stress responses. The reason for such a behavior, as discussed by those authors, was the lack of habituation to the emotional stress of the work. Indeed, more experience could bring more adaptation, like in high-level sports athletes who show a lower sympathetic drive despite the stress situation preceding the competitions. Finally, such sympathetic predominance among our participants could also represent their sub-optimal fitness status. Indeed, the positive correlation we found between $(LF/HF)_{REST}$ and τ_{off} is in agreement with Danieli et al. (2014), who showed that the higher vagal predominance at rest in athletes vs. control subjects correlates with a faster HR recovery after sub-maximal exercise. In this regard, it was also reported that τ_{off} correlates with maximal aerobic capacity (Boullosa et al., 2014; Storniolo et al., 2017), a "gold standard" for assessing fitness level. As a whole, these observations stress the importance of a good preparation, both in terms of fitness and in terms of emotion control, to attain a fast recovery after strenuous exercise. Besides an appropriate physical training, it has been reported that mind activities, as yoga and meditation, drive improvements in parasympathetic reactivation through slow breathing techniques, without requiring the same energy expenditure of physical exercises (Adhana et al., 2013).

CONCLUSION

These results confirm our hypothesis that t_{delay} is a significant marker for the autonomic nervous system recovery after a sprint test. Still, further studies are needed to elucidate whether a diverse range of running intensities may influence the t_{delay} and τ_{off}, as well as the autonomic cardiac control.

DATA AVAILABILITY STATEMENT

Data analyzed in this study were obtained from Storniolo et al. (2017) and reprocessed with permission of all authors.

AUTHOR CONTRIBUTIONS

PC conceived the study. JS collected the data. JS, RE, and PC analyzed the data, drafted the manuscript, and revised the final version.

ACKNOWLEDGMENTS

Many thanks to Prof. Alberto Minetti and Dr. Gaspare Pavei for their kind permission to reprocess data from Storniolo et al. (2017).

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

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ORIGINAL RESEARCH
published: 04 February 2020
doi: 10.3389/fpsyg.2020.00130

Anxiety and Emotional Intelligence: Comparisons Between Combat Sports, Gender and Levels Using the Trait Meta-Mood Scale and the Inventory of Situations and Anxiety Response

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The present study compared emotional intelligence and anxiety between six combat sports of lower, intermediate and high-level female and male athletes. The sample was composed by 444 athletes (age: 24.7 ± 8.8 years, body mass: 72.4 ± 12.1 kg, height: 1.82 ± 0.3 m, and practice time: 13.1 ± 7.4 years) separated by sex (male n = 273, female n = 171) from different combat sports (jiu-jitsu n = 142, judo n = 137, karate n = 57, kendo n = 63, taekwondo n = 25, and freestyle wrestling n = 20) of three levels (high-level n = 57, intermediate n = 137 and low-level n = 142). Inventory of situations and anxiety response (ISRA) provided an independent evaluation for the three systems: cognitive, motor and physiological, as well as a total with four factors of analysis (anxiety before the evaluation, interpersonal, phobic and before habitual, and daily situations). Trait Meta-Mood Scale (TMMS-24) verified emotional intelligence scales. Descriptive results are demonstrated by percentage or median (first quartile Q1; third quartile Q3), Kruskal-Wallis and Mann-Whitney tests were conducted to compare groups, $p \leq 0.05$. The main results demonstrated 10% more total anxiety for wrestling and judo compared to the other groups ($p \leq 0.05$). Female athletes showed 15% more anxiety than men, while emotional attention demonstrated 10% better results for women. Significant differences were observed between high- versus low-level athletes in the total anxiety with 85 (44; 143) versus 122 (69; 186) of ISRA index and emotional repair with 30 (25; 34) versus 27 (22; 32) of TMMS-24 index. Emotional intelligence seems to be higher in female and in higher level, while anxiety appears to be prevalent in judo and wrestling, low-level and in female athletes. These outcomes provide support for the hypothesis that emotional abilities are an important contributor to emotional intelligence, particularly differentiating high level athletes than other levels. Results can be incorporated into strategies for reducing anxiety and improving emotional intelligence, considering particularities of gender and level groups.

Keywords: mood, martial arts, psychology, sports, sexual and gender disorders, anxiety

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *18 October 2019*
Accepted: *17 January 2020*
Published: *04 February 2020*

Citation:
Fernández MM, Brito CJ, Miarka B and Díaz-de-Durana AL (2020) Anxiety and Emotional Intelligence: Comparisons Between Combat Sports, Gender and Levels Using the Trait Meta-Mood Scale and the Inventory of Situations and Anxiety Response. Front. Psychol. 11:130. doi: 10.3389/fpsyg.2020.00130

INTRODUCTION

Anxiety is a sensation of uneasiness and worry, typically generalized and unfocused as an overreaction to a condition that is only subjectively seen as intimidating (Brandt et al., 2018; Tahtinen and Kristjansdottir, 2018). This feeling has been an essential concept for sports psychology and has demanded intensive investigation in combat sports for its effects on championship performance in karate (Friesen et al., 2018), judo (Matsumoto et al., 2000; Interdonato et al., 2013), kendo (Usui et al., 2018), jiu-jitsu (Andreato et al., 2014), taekwondo (Maloney et al., 2018), and wrestling (Bawa, 2010). Despite such well-known concern, martial arts and combat sports practices that originally bring philosophical aspects are supposed to assist practitioners in self-control, an aspect of inhibitory control, as the ability to regulate one's emotions, thoughts, and behavior in the face of anxieties and impulses.

One of the major difficulties confronting the researcher of combat sports in anxiety studies is the assessment of situational anxiety response or state anxiety. This assessment has been showed using behavioral (Tiric-Campara et al., 2012), physiological (Capranica et al., 2017), and/or with self-report techniques (Cerin and Barnett, 2011; Coswig et al., 2018). A variety of self-report procedures in combat sports has been used with a practical degree of success. A collective instrument to measure anxiety is the item response scale, in which the total item scores replied in the "anxious" way is the quantity of anxiety (Cheng and McCarthy, 2018). Preceding authors have developed anxiety traits questionnaires that were especially tailored to sports and was denominated as the sport competition anxiety test (SCAT) used in karate (Terry and Slade, 1995) and judo with higher values for female than male athletes (Wong et al., 2006; Interdonato et al., 2013). Recently, comparisons of mood states, using the Brunel Mood Scale (BRUMS), associated with outcomes achieved by female and male athletes in high-level judo and Brazilian jiu-jitsu (BJJ) championships demonstrated that female judo athletes had higher depression and vigor index than BJJ athletes (Brandt et al., 2019), while the logistic regression revealed that higher levels of anger and tension increased athletes' chances of performing well in a match by 23% and 13%, respectively (Brandt et al., 2019). Overall, authors observed a significant relationship between mood state and sports performance (Brandt et al., 2019).

Presently, two different lines of study can be found in meta-mood combat sports research. The first one is focused on insightful experience of mood as state, as BRUMS (Wong et al., 2006; Brandt et al., 2019). Much of this investigation is concerned in investigating how a fighter's thoughts may be affected by his/her mood state, and in considerate the various types of mood regulation (Jin, 1992; Terry and Slade, 1995). In addition, the second line is interested in more stable affective capacities that people routinely use to experience their feelings and moods (Salovey et al., 1995; Filaire et al., 2011; Espinoza-Venegas et al., 2015). This approach is denominated trait-meta mood research for which Salovey et al. (1995) developed the Trait Meta-Mood Scale (TMMS). In the present article we focused on this latter approach in combat sports, using a brief description of the TMMS-24, its three dimensions (Attention, Clarity, and Repair). Consequently, coaching staff and athletes should monitor athletes' mood and anxiety states to ensure that they are in optimal condition to perform and use psychological interferences to care athlete's preparation. However, more studies have compared gender differences, anxiety, and emotional intelligence levels between martial arts practice and combat sports.

Researchers recognize that any measure of sport anxiety must take into consideration cognitive anxiety (negative thoughts, worry) and somatic anxiety (physiological response) (Terry and Slade, 1995). The Competitive State Anxiety Inventory (CSAI-2) considers the difference between Anxiety state (i.e., momentary anxiety) and Anxiety trait (i.e., chronic anxiety) and distinguishes between cognitive and somatic anxiety (Smith et al., 2006). The CSAI-2 verified effects of anxiety in novice karate performers on visual search strategy, changing their peripheral narrowing or increasing susceptibility to peripheral distractors in response to taped offensive karate sequences (Williams and Elliott, 1999). Using CSAI-2, preceding authors demonstrated that cognitive and somatic anxiety were higher in interregional compared to regional judo championships with positive associations with cortisol (Filaire et al., 2001). Bringing together the behavioral and interactive approaches in the development of the Anxiety Situation and Response Inventory – ISRA (Miguel-Tobal and Cano-Vindel, 2002), an Inventory in the Situation-Response format, designed to assess the frequency with which manifests itself in a series of cognitive responses, physiological and motor disorders before different situations (i.e., of evaluation, interpersonal, phobic, and of the daily life). The ISRA psychometric properties, concerning convergent validity, as well as their capacity for discrimination, both between groups with various anxiety disorders, as between anxiety and depression (Miguel-Tobal and Cano-Vindel, 2002). Several adaptations of the original inventory have also been elaborated, oriented toward the valuation of anxiety in highly specific contexts, such as anxiety for medical revisions and to value the eagerness of the pilots of the Air Force (Miguel-Tobal and Cano-Vindel, 2002).The practical applications of these psychological instruments in combat sports are important to incorporate self-regulation strategies.

Self-regulation of anxiety plays an essential role in competitive and professional combat sport (Diamond, 2012; Breitschuh et al., 2018). During championship, for example, it is important to stick to one's competition plan and not give up when it gets tough but rather to mobilize additional energy (Alsamir Tibana et al., 2019). Self-regulation of anxiety is similarly a required condition for maintaining practice during long and exhausting periods of training that require concentration (Finkenberg et al., 1992; Lakes et al., 2013). This is particularly crucial if the training is under conditions of high demand and, in itself is not very motivating, but nevertheless active (Jin, 1992; Matsumoto et al., 2000). The contributions of preceding studies have shown anxiety as an eminent problem in different combat sports (Terry and Slade, 1995; Williams and Elliott, 1999; Tiric-Campara et al., 2012; Interdonato et al., 2013). However, the actual psychological distance between points or scores on these scales is typically unknown, while the Interval Scale of Anxiety Response

Scale (ISAR) can provide a sensitive instrument for measuring situational anxiety (Heaton et al., 2007).

Therefore, the aim was to compare emotional intelligence and anxiety between six combat sports of lower, intermediate and high-level female and male athletes. Based on these assumptions, our first hypothesis suggested that those athletes who perform combat sports and have a higher performance would show higher emotional intelligence and lower anxiety levels, measured by the ISRA than athletes of combat sports with a lower performance. The second hypothesis is regarding gender differences, being that female who train and compete in combat sports will have higher anxiety scores than male, as measured through the ISRA.

MATERIALS AND METHODS

Study Design

Present study is a cross-sectional study. We applied a descriptive method in which anxiety and emotional intelligence in athletes were analyzed according to their competitive levels. As dependent variables we used: emotional intelligence and anxiety; and as independent variables: competitive levels (low, medium and high) and gender (male and female). The measures were carried out in two situations: (a) competitions when the athletes were in qualification procedures and weighing (24-h before the competition); and (b) during national trainings. All measurements were performed by a single researcher, with ISRA applied first, followed by the TMMS-24. The aims and risks of the study were informed to the participants and they signed the Informed Consent Form. This protocol was approved by the Research Ethics Committee of the University in which it was performed.

Sample

The following inclusion criteria were applied: (a) be ≥15 years of age, (b) to practice and compete in jiu-jitsu, judo, karate, kendo, taekwondo and wrestling (≥5 years). 1,400 questionnaires were applied to carry out the study, of which 922 were returned, and 476 were rejected because they presented incomplete information, therefore the final sample was composed by 444 athletes (age: 24.7 ± 8.8 years, body mass: 72.4 ± 12.1 kg, height: 1.82 ± 0.3 m, and practice time: 13.1 ± 7.4 years) separated by sex (female = 171, male = 273) from different combat sports (Jiu-jitsu = 142, judo = 137, karate = 57, kendo = 63, taekwondo = 25, and freestyle wrestling = 20) of three levels (high level = 57, intermediate = 137, and lower level = 142). Regarding performance, the athletes were classified as: (a) low (compete, but without regional medals; female = 59 and male = 126); (b) medium (compete and own regional and national medals; female = 80 and male = 112); and (c) high (they compete and were classified in the top 5 in the continental or world championships; female = 33 and male = 36).

Measurements

The Trait Meta-Mood Scale (TMMS-24) (Salovey et al., 1995) or Emotional Intelligence Scale translated into Spanish (Fernández-Berrocal et al., 2004) was used. This inventory consists of 24 items that are subdivided into three subscales or dimensions: (a) emotional attention; (b) emotional clarity; and (c) emotional repair. The score for each of these subscales is classified into three ranges. For the emotional perceived subscale, the middle score range (22–32 in male; 25–35 in female) indicates adequate emotional attention, and scores in the high (>33 in male; >36 in female) or low (<21 in male; <24 in female) range indicate that emotional attention should be improved. In contrast, for the clarity subscale, scores in the low range indicate a need for improvement (<25 in male, <23 in female), those in the middle range (26–35 in male; 24–34 in female) indicate adequate clarity, and those in the high range (>36 in male; >35 in female) indicate excellent emotional clarity. Likewise, in the emotional repair subscale, low scores (<23 in male and female) indicate the need for improvement, scores in the middle range (24–35 in male, and 24–34 in female) indicate adequate repair, and high scores (>36 in male, >35 in female) indicate excellent emotional repair. In the questionnaire, individuals must rate each of their responses on a Likert scale from one to five points to indicate their level of agreement. The total score is obtained by adding the responses from each sub-scale, each of which ranges from eight to 40 points.

ISRA

Inventory of situations and anxiety responses provides an independent evaluation for the three response systems: cognitive, motor and physiological, as well as a total. It also includes four factors of analysis: anxiety before the evaluation (FI), interpersonal (F-II), phobic (F-III), and before habitual and daily situations (FIV). This enabled us to develop a profile of individual reactivity and measurements followed preceding protocol (Miguel-Tobal and Cano-Vindel, 2002). The athlete had to indicate the frequency with which each one of the anxiety responses appears in the proposed situation according to a Likert scale of 5 points. The original version of the ISRA was used consisting of 224 items in an open situation. These items are composed of an interaction of 22 situations and 24 responses. We obtained direct scores and subsequently calculated a percentile that offers a scale for each subject in each of the measures. The objective of passing this inventory was to see how the anxiety of the subjects was distributed in terms of the triple response system (motor, physiological, and cognitive) and to observe their general anxiety. Regarding the factors that it offers us, we consider the FI to be important since it measures the anxiety before the evaluation. In any case, the others were analyzed to see if there were any other differences. In the case of athletes, one of the factors that is indicated as causing anxiety is precisely the fear of being evaluated or doing it badly and failing (factor I of the ISRA measures the anxiety before the evaluation).

To estimate the internal reliability coefficient of the questionnaire items, the reliability used the Cronbach's alpha (a) coefficient, since an analysis based on internal consistency of the items (Artioli et al., 2010; Molanorouzi et al., 2014). The coefficient "alpha" is the designation of the statistical procedure using scales with Likert type items and this method was used because the responses to the items are distributed by an ordinal scale (Shojima and Toyoda, 2002; Okada, 2015). The methods based on the internal consistency of the items tend to supplant the stability-based coefficients, thus requiring higher than or equal to 0.70 (Moret et al., 1993; Sun et al., 2007). The reliability of the TMMS-24 instrument for the Spanish subscales were Emotional Attention α = 0.90, Emotional Clarity α = 0.90, and Emotional Repair α = 0.86 (Fernández-Berrocal et al., 2004). In addition, the spanish version of the Inventory of Situations and Responses of Anxiety (ISRA) (Miguel-Tobal and Cano-Vindel, 2002). The reliability of the TMMS-24 instrument for the Spanish subscales were α = 0.87 cognitive, α = 0.85 physiological, and α = 0.74 motor responses of anxiety (Martínez-Sánchez et al., 1995; Ziv and Lidor, 2013).

Statistical Analysis

Descriptive data is presented as median [25th percentile; 75th percentile] values and the Kruskal-Wallis One-way Analysis of Variance and pairwise Mann-Whitney tests were conducted to compare ISRA frequencies between groups. For the Kruskal-Wallis, the effect size was calculated as $ES = \sqrt{(chi^2/N)}$, where chi^2 is derived from the Kruskal-Wallis test results and N is the total number of observations (Rosenthal and DiMatteo, 2001). For the Mann-Whitney test, the effect size was calculated as $r = Z/\sqrt{N}$, where Z is derived from the Mann-Whitney test results and N is the total number of observations, and ES was interpreted as follows: small ($r = 0.1$), medium ($r = 0.3$), or large ($r = 0.5$). The significance level of $p \leq 0.05$ was used. All analyses were conducted using SPSS 20.0 for Windows.

RESULTS

Descriptive analysis of ISRA and TMMS-24 between combat sports are shown in **Table 1**. Jiu-jitsu athletes demonstrated lower values of cognitive anxiety than judo ($p = 0.26$) or kendo athletes ($p = 0.033$). The Judo group showed higher cognitive anxiety than karate ($p = 0.005$), and karate presented lower levels of cognitive anxiety than kendo ($p = 0.006$). Kendo was different from taekwondo ($p = 0.047$). Judo athletes presented higher ISRA T than Jiu-jitsu ($p = 0.040$) or kendo athletes ($p = 0.005$), while karate presented lower values of total anxiety than kendo ($p = 0.021$) and wrestling ($p = 0.038$).

The Jiu-jitsu group showed similar results of total anxiety from karate ($p = 0.17$), kendo ($p = 0.21$), taekwondo ($p = 0.65$), and wrestling ($p = 0.19$). Judo presented similar results of total anxiety when compared with kendo ($p = 0.57$), taekwondo ($p = 0.38$), and wrestling ($p = 0.87$). Karate presented similar results for total anxiety as taekwondo ($p = 0.19$). Total anxiety comparison for kendo, taekwondo and wrestling did not present a significant effect ($p = 0.532$ and $p = 0.85$). Similar results of total anxiety were observed between jiu-jitsu ($p = 0.52$), karate ($p = 0.20$), taekwondo ($p = 0.37$) and wrestling ($p = 0.87$); judo and kendo ($p = 0.75$), taekwondo ($p = 0.49$), and wrestling ($p = 0.28$).

Judo had higher motor anxiety than karate ($p = 0.015$) and Jiu-jitsu ($p = 0.047$), and karate had lower motor anxiety than wrestling ($p = 0.015$). Jiu-jitsu had similar motor anxiety to karate ($p = 0.32$), kendo ($p = 0.42$), taekwondo ($p = 0.85$), and wrestling ($p = 0.069$); karate was similar to kendo ($p = 0.13$) and taekwondo ($p = 0.60$), while kendo was similar to taekwondo ($p = 0.44$) and wrestling ($p = 0.14$); in addition, taekwondo and wrestling were similar ($p = 0.056$).

Judo demonstrated higher interpersonal anxiety than jiu-jitsu ($p = 0.016$) and karate ($p = 0.007$). Kendo showed higher values of interpersonal anxiety than karate ($p = 0.038$). Judo and wrestling presented a higher result of phobic anxiety than jiu-jitsu ($p = 0.02$ and $p = 0.019$). Jiu-jitsu presented similar results to karate ($p = 0.35$), kendo ($p = 0.2$), taekwondo ($p = 0.69$), and wrestling ($p = 0.20$). Judo had similar results of interpersonal anxiety when compared to kendo ($p = 0.32$), taekwondo ($p = 0.32$), and wrestling ($p = 0.91$). Karate demonstrated similar results for interpersonal anxiety when compared with taekwondo ($p = 0.44$) and wrestling ($p = 0.65$), and taekwondo had similar results of interpersonal anxiety as wrestling ($p = 0.7$). Wrestling presented higher phobic anxiety than karate ($p = 0.026$) and taekwondo ($p = 0.03$).

Jiu-jitsu presented similar result of phobic anxiety when compared with karate ($p = 0.88$), kendo ($p = 0.52$), and taekwondo ($p = 0.95$). Judo presented similar results for phobic anxiety to karate ($p = 0.056$), kendo ($p = 0.19$), taekwondo ($p = 0.15$), and wrestling ($p = 0.34$). Karate and taekwondo presented similar results ($p = 0.98$). No effects in TMMS-24 comparisons were observed between combat sports when compared to emotional attention ($p = 0.54$), clarity ($p = 0.39$) and emotional repair ($p = 0.90$). A descriptive analysis of ISRA and TMMS-24 between levels are in **Table 2**.

High level athletes presented lower values than lower level athletes in cognitive anxiety ($p = 0.002$), motor anxiety ($p = 0.028$), physiological anxiety ($p = 0.039$), total anxiety ($p = 0.003$), before the evaluation ($p = 0.024$), interpersonal anxiety ($p = 0.01$) and before everyday situations ($p = 0.031$). Regarding the interaction between level and combat sport groups, a main effect was observed in karate athletes ($X^2 = 6.468$, df = 2, $p = 0.039$), high level karate group had lower motor anxiety than the intermediate athletes ($p = 0.032$).

In addition, high level athletes presented lower values than intermediate athletes for total anxiety ($p = 0.028$), before the evaluation ($p = 0.003$) and phobic anxiety ($p = 0.011$). Concerning the interaction between level and combat sports, a main effect was observed in phobic anxiety of karate athletes ($X^2 = 6.193$, df = 2, $p = 0.045$), where high level group demonstrated lower phobic anxiety values than the intermediate athletes ($p = 0.045$). Significant differences in TMMS-24 comparisons between levels were observed in clarity ($X^2 = 7.444$, df = 2, $p = 0.024$) with higher scores for the high level group versus the low level group ($p = 0.013$), and in emotional repair ($X^2 = 12.794$, df = 2, $p = 0.002$) with lower scores to the low level group when compared with the intermediate group ($p = 0.003$) and high level group ($p = 0.002$). Regarding the interaction between level and combat sport groups, significant differences were observed in emotional repair ($X^2 = 8.943$, df = 2, $p = 0.011$) jiu-jitsu athletes presented lower values in lower level group than the intermediate athletes ($p = 0.01$), kendo also demonstrated differences between levels in emotional repair ($X^2 = 7.362$, df = 2, $p = 0.025$) with higher emotional repair on high level group

TABLE 1 | Descriptive and inferential analysis of combat sports anxiety and emotional intelligence comparisons (median, first, and third quartiles).

Factors	Jiu-jitsu	Judo	Karate	Kendo	Taekwondo	Wrestling	Statistical Inference			
	μ (25th; 75th)	μ (25th; 75th)	μ (25th; 75th)	μ (25th; 75th)	μ (25th; 75th)	μ (25th; 75th)	X^2	df	P	ES
ISRA C	55 (30; 70)	62 (35; 89)	44.0 (25.5; 68.5)	59 (38; 93)	66 (31; 80.5)	57.5 (35.5; 65.8)	134.245	5	0.04	0.17
ISRA M	24 (11; 43)	30 (12; 63)	20 (9.5; 39.5)	28 (10; 49)	22 (10.5; 40.5)	47 (27; 55)	10875	5	0.09	0.16
ISRA F	27 (12; 50)	29 (13; 58)	21 (9.5; 40)	24 (12; 48)	32 (11.5; 58.5)	39.5 (12.8; 55)	56.901	5	0.46	0.11
ISRA T	108 (56; 161)	125 (60; 214)	85 (45.5; 147)	113 (73; 181)	107 (56.5: 190.5)	153.5 (92.5; 171)	113.352	5	0.08	0.16
I F1	47 (25; 74)	60 (28; 88)	51 (22.5; 70)	48 (32; 78)	49 (28.5; 79.5)	56.5 (33.3; 77)	6.183	5	0.42	0.12
I F2	10 (4; 19)	13 (5; 27)	8 (4.5; 14.5)	10 (6; 21)	9 (3; 30.5)	18.5 (4.8; 22)	1167	5	0.09	0.16
I F3	14 (4; 30)	22 (6; 43)	13 (3; 30.5)	14 (4; 33)	13 (5.5; 31)	32 (23.5; 40.8)	115.400	5	0.07	0.16
I F4	5 (2; 16)	9 (3; 20)	6 (2.5; 13.5)	7 (3; 18)	7 (2.5; 14.5)	13.5 (3.3; 29)	8.600	5	0.23	0.13
IE 1	23 (19; 27)	23 (19; 28.5)	22 (18; 27)	21 (17; 29)	22 (18; 26)	21.5 (15.3; 25.8)	536	5	0.53	0.06
IE 2	28 (23; 32)	26 (22; 31)	30 (23; 32)	28 (23; 32)	31 (24; 33)	29.5 (20; 33)	6.284	5	0.39	0.07
IE 3	29 (25; 32)	28 (24; 33)	30 (25; 33)	26 (25; 32)	27 (23.5; 33)	28.5 (18.3; 36.3)	2.164	5	0.90	0.06

ISRA C, cognitive anxiety; ISRA M, motor anxiety; ISRA F, physiological anxiety; ISRA T, total anxiety; I F1, anxiety before the evaluation; I F2, interpersonal anxiety; IF 3, phobic anxiety; I F4, anxiety before habitual and daily situation; IE 1, emotional attention; IE 2, clarity; IE3, emotional repair; μ, median; 25th, 1st quartile; 75th, 3rd quartile; X^2, Chi-square; df, degrees of freedom; P, P calculated; ES, effect size.

TABLE 2 | Descriptive and inferential analysis of different levels anxiety and emotional intelligence comparisons (median, first, and third quartiles).

Factors	High level	Intermediate level	Low level	Statistical inferences			
	μ (25th; 75th)	μ (25th; 75th)	μ (25th; 75th)	X^2	df	P	ES
ISRA C	41 (22; 65.5)	54 (33; 80)	62 (35; 87)	11.524	2	0.003	0.16
ISRA M	21 (9.5; 30)	27 (10; 52)	28 (13; 53)	7.183	2	0.028	0.13
ISRA F	21 (10; 36)	26 (12; 51)	30 (13.5; 54.5)	6.225	2	0.044	0.12
ISRA T	85 (44.5; 143)	116 (60; 179)	122 (69; 186.5)	11.101	2	0.004	0.16
I F1	37 (24; 63)	52 (30; 79)	56 (27; 82.5)	7.448	2	0.024	0.13
I F2	6 (3; 15.5)	11 (5; 22)	12 (5; 25)	14.326	2	0.001	0.18
I F3	12 (3; 29.5)	15 (4; 35)	20 (6; 41)	7.531	2	0.023	0.13
I F4	5 (1; 12.5)	6 (3; 17)	8 (3; 17)	4.588	2	0.101	0.10
IE 1	22 (17; 27)	14 (19; 28)	22 (17.5; 27)	5.390	2	0.68	0.01
IE 2	30 (25; 32)	27 (23; 32)	27 (22; 32)	7.444	2	0.024	0.12
IE 3	30 (25; 34.5)	30 (25; 33)	27 (22; 32)	12.794	2	0.003	0.14

ISRA C, cognitive anxiety; ISRA M, motor anxiety; ISRA F, physiological anxiety; ISRA T, total anxiety; I F1, anxiety before the evaluation; I F2, interpersonal anxiety; IF 3, phobic anxiety; I F4, anxiety before habitual and daily situation; IE 1, emotional attention; IE 2, clarity; IE3, emotional repair; μ, median; 25th, 1st quartile; 75th, 3rd quartile; X^2, Chi-square; df, degrees of freedom; P, P calculated; ES, effect size.

compared with the lower level athletes ($p = 0.025$). Karate athletes demonstrated significant effects in emotional attention when compared level groups ($X^2 = 6.537$, df = 2, $p = 0.038$), high level athletes presented higher emotional attention than the lower level group ($p = 0.034$). No effects in emotional attention ($p = 0.068$) were observed. Descriptive analysis of ISRA and TMMS-24 between male and female athletes are in **Table 3**.

Female athletes presented higher cognitive, motor, physiological and total anxiety than male athletes ($p = 0.001$). Significant differences in TMMS-24 comparisons between genders were observed in clarity, with higher values for female compared with male ($p < 0.001$). When observed the interaction between sex and level groups in TMMS-24, comparisons indicated differences in the clarity dimension ($X^2 = 6.073$, df = 2, $p = 0.048$) with higher values by female and male high-level than female low-level athletes ($p = 0.044$). No effects were observed in clarity ($p = 0.95$) and emotional repair ($p = 0.57$) between male and female combat athletes.

DISCUSSION

This study examined the associations between important factors in the field of sports psychology (i.e., anxiety and emotional intelligence), comparing emotional intelligence and anxiety between six combat sports of lower, intermediate and high-level female and male athletes. The main results demonstrated higher values of cognitive and motor anxieties in judo, taekwondo and kendo than for jiu-jitsu, wrestling and karate groups. Judo athletes demonstrated higher phobic and interpersonal anxieties than the other groups. No difference in emotional intelligence was observed between modalities, which may suggest that anxiety is more associated with other factors such as gender

TABLE 3 | Descriptive and inferential analysis of gender anxiety and emotional intelligence comparisons (median, first, and third quartiles).

Factors	Female	Male	Statistical inferences			
	μ (25th; 75th)	μ (25th; 75th)	*U*	*Z*	*P*	ES
ISRA C	68 (43; 88)	46 (27; 71)	16833	4.997	0.001	0.24
ISRA M	35 (20; 55)	20 (8; 45.3)	16963	4.899	0.001	0.23
ISRA F	34 (20; 55)	20 (10; 45)	17597	4.419	0.001	0.21
ISRA T	138 (95; 194)	90 (48; 158.5)	16587	5.183	0.001	0.25
I F1	63 (38; 85)	42.5 (22.8; 68)	15932	5.680	0.001	0.27
I F2	10 (6; 25)	10 (4; 21)	21075	1.784	0.07	0.08
I F3	25 (6; 41)	13 (4; 31)	19109	3.274	0.001	0.16
I F4	10 (4; 18)	5 (1; 15)	1833.5	3.869	0.001	0.18
IE 1	24 (20; 28)	21 (17; 27)	1941.5	3.417	0.001	0.16
IE 2	27 (23; 32)	28 (23; 32)	23.646	1.323.2	0.62	0.06
IE 3	29 (24; 33.8)	29 (24; 33)	22.811	1.323.4	0.57	0.06

ISRA C, cognitive anxiety; ISRA M, motor anxiety; ISRA F, physiological anxiety; ISRA T, total anxiety; I F1, anxiety before the evaluation; I F2, interpersonal anxiety; IF 3, phobic anxiety; I F4, anxiety before habitual and daily situation; IE 1, emotional attention; IE 2, clarity; IE3, emotional repair; μ, median; 25th, 1st quartile; 75th, 3rd quartile; X^2, Chi-square; df, degrees of freedom; P, P calculated; ES, effect size.

and competitive level. Our data showed an inverse relationship between anxiety levels and expertise in combat sports practices, while females revealed higher anxiety than male athletes for all the analyzed variables. On the other hand, females demonstrated higher scores in emotional attention than male athletes, but both groups were classified as having low emotional attention, while high-level athletes showed better (classified as adequate) clarity and emotional repair than low-level athletes. Self-knowledge about the emotions, feelings, and moods together with the skill domain can help an athlete improve their performance (Cerin and Barnett, 2011; Tiric-Campara et al., 2012).

Emotional intelligence of applied psychology suggested the existence of three major conceptual models: (i) a transverse section of interrelated emotional and social competencies, abilities, and facilitator that influence intelligent behavior, called emotional clarity; (ii) a wide range of competencies and abilities that increase work performance, called emotional attention; and (iii) the ability to perceive, understand, manage, and regulate one's emotions, as well as the emotions of others, called emotional repair (Espinoza-Venegas et al., 2015). Despite the importance of emotional intelligence in combat sports, few studies have been conducted with this theme (Filaire et al., 2011).

Recently, in a randomized controlled trial, the effects of karate versus a mind-based stress reduction intervention on well-being and cognitive functioning in older adults demonstrated that both methods showed only small training effects concerning the assessed emotional and cognitive parameters (Jansen et al., 2017). This emotional self-control associated with anxiety levels has not been studied in different combat sports practices and in adults who are competitors in different levels until now. Assuming that combat sports present particular philosophies empirically associated with emotional control, it is significant to verify associations between expertise and controlled levels of anxiety.

The symptoms of anxiety can be recognized on different levels (Cheng and McCarthy, 2018), such as Cognitive (i.e., by a thought process), Somatic (i.e., by a physical response) and Behavioral (i.e., by patterns of behavior). For instance, a preceding report found that winning male college taekwondo athletes showed higher self-confidence and lower cognitive and somatic anxiety than their losing counterparts (Chapman et al., 1997). Although different studies have already verified the state and trait anxiety in combat sports, no studies have compared the symptoms of anxiety and emotional intelligence scale in different combat modalities.

Our gender comparisons shown larger effect sizes of anxiety variables and significant differences; female athletes had ∼35% more total anxiety than males who had ∼30% less cognitive anxiety characterized by indecision, sense of confusion, feeling heavy, negative thoughts, poor concentration, irritability, fear, forgetfulness, loss of confidence, and other negative factors. Furthermore, female presented ∼60% more physiological and ∼60% more motor anxieties. Female participants presented common indications of physiological anxiety such as increased blood pressure, respiration rate, sweating, adrenaline surge, needing to urinate, muscular tension, trembling, incessant talking and sleeplessness. In addition, motor anxiety was characterized by lethargic movements, inhibited posture and uncontrolled motor feeling. Females also had high scores of interpersonal and phobic anxieties which could be associated with presented symptoms. This outcome is consistent with an earlier study that suggested significant differences between male and female athletes during a judo championship (Interdonato et al., 2013).

To the author's knowledge, TMMS-24 was measured here for the first time in combat sports, with gender differences in emotional attention set shifting ability. Female athletes with higher total anxiety and worrisome thoughts did not associate difficulty in anxiety with emotional attention capacity; on the contrary, these results suggest that activation caused by anxiety may increase emotional attention. Although this study demonstrated that female athletes were related to anxiety and worry, it remains unclear whether female anxieties are related to a generalized mechanism of emotion repair. Regarding emotional intelligence differences between the level groups, TMMS-24 for the high-level group demonstrated ∼40% less total anxiety and

~10% more clarity and repair than the low-level group. This result demonstrated that emotional intelligence and expertise are associated in combat sports, as well as the anxiety reduction, especially cognitive anxiety, which is associated with negative thoughts, poor concentration, fear and loss of confidence. Coco et al. (2019) indicated that judo turns out to be a sport discipline useful to male athletes control their aggressiveness and to try of overcoming their limits. Another study recently showed a positive association between religious beliefs with anxiety in competitive judo athletes (Moghadam et al., 2015).

Although such settings have greater external validity, the variables of interest are more difficult to control and measure than in a laboratory environment. Present study indicated as a limitation the fact that information collected was a cross-sectionally design, occurring during an over short period of time, it did not show a long-term profile of combat athletes. No effects of age, body mass, height or practice time were observed in present research. However, preceding reports indicated that a rapid weight loss is associated with high anger, confusion and greater total mood disturbance at the official weigh-in in Mixed Martial Arts athletes (Brandt et al., 2018). Recently, findings indicated the association between obesity and hyperactivity and anxiety among female school students in Japan (Suzuki et al., 2019). Future studies would do longitudinal studies, conducting several observations of the same athletes over a period of time in combat sports, verifying the relationship between anxiety, emotional intelligence, and anthropometric factors.

The benefit of a longitudinal study is that researchers would be able to detect developments or changes in the anxiety and emotional intelligence characteristics of the combat sports over a year or during sequential championships, principally comparing levels of anxiety. Our study ensured that participants were of the same age range; even so, it is important to point out a limitation for non-comparisons between combat outcomes during championships. Preceding research indicated that better performance during judo championships was associated with significantly lower levels of cognitive anxiety or higher levels of confidence (Filaire et al., 2001). Chiodo et al. (2011) also demonstrated significantly higher post-match scores emerged for anger-hostility and depression-dejection, whereas the reverse was observed for vigor-activity. In particular, results discriminated observed parameters between different competition levels of each single combat sport and highlighted significant findings in jiu-jitsu, judo, karate and kendo. This approach clarified the findings of present study, as preceding reports indicated that different attention could emerge in the same combat sport group, because taekwondo athletes who train with different approaches had different session-RPE quantifying loads (Lupo et al., 2017).

Our results indicated higher values of cognitive and motor anxieties in judo, taekwondo and kendo than in other groups. These findings highlight that judo athletes demonstrated higher phobic and interpersonal anxieties than other modalities. Recent judo rules changes have reduced male combat time to 4 minutes and moments of low-intensity combat time during the approach and gripping time before the attack (Miarka et al., 2016; Brito et al., 2017). A recent study has shown blood lactate rates associated with a protective role against fatigue toward frontal cortex and defined worse performances in backward memory capacity by conditioning strategic ability of the athletes (Coco et al., 2019). Recent study in rodents compellingly supports the knowledge that the projection of neurons extending from the CA1 region of the hippocampus and from the subiculum to the prefrontal cortex, denoted to the H-PFC pathway, that is critically involved in aspects of cognition associated to the executive function, as to the repair (Godsil et al., 2013). Simultaneously, it is becoming evident that judo fighter suffering from depression, and post-traumatic stress could display structural anomalies and unusual functional coupling within the hippocampal–prefrontal circuit (Godsil et al., 2013). This overlap might similarly be intertwined with the pathway's evident susceptibility to stress and with its relationship to the amygdala, associated with anxiety and mood disorders (Kirkbride et al., 2012) in judo/Brazilian jiu-jitsu (Brandt et al., 2019) and MMA athletes (Brandt et al., 2018). In consequence, the H-PFC pathway could be a potentially crucial element of the anxiety in judo athletes.

Present study did not observed effects of interventions able to reduce anxiety levels and it could offer a specific target for therapeutic intervention in future studies. Furthermore, it has been shown that anxiety and stress responses to stressful motivations take account of coping strategies (Ursin, 1988). Coping depends on a positive response outcome expectancy, which again depends on a high emotional intelligence; our results of emotional clarity and repair were classified as adequate, while emotional attention had a low score. Filaire et al. (2001) indicated two styles of coping strategies that can be used when confronting an adverse event, being emotion-focused and problem-focused strategies, which could affect performance (Scanlan et al., 1991). The present findings help to create new strategies that can not only reduce the effects of anxiety, but also increase emotional intelligence, especially emotional attention, as well as creating strategies to reduce anxieties, particularly in judo, taekwondo and kendo. These modalities have meditation, as well as practicing forms that could be used as coping strategies for anxiety reduction and stress, especially in beginners and low-level competitive athletes.

Future studies could incorporate other measures, considering the limitations of the present study, as the answers that it gathers in the cognitive, physiological and motor systems allow only to obtain a general level of information, and little differentiated, of the existence of anxiety, since the sampling of responses that it contemplates is reduced; Practical applications could use our data, trying also to assess differential profiles of situational reactivity, since it does not take into account the continuous process of subject-situation-response interaction, and; in the clinical setting, to adapt the treatment to the specificity of the gender profiles of the specific combat sport and level that elicits emotional responses.

In fact, this study proposed a unique approach to characterizing the anxiety and emotional intelligence in gender, level, and combat sports. The presented results demonstrated higher values of cognitive and motor anxieties in judo, taekwondo and kendo, while judo athletes revealed higher phobic and interpersonal anxieties than other modalities. The findings indicated an inverse relationship between anxiety levels and expertise in combat sports, while females revealed higher anxiety than male athletes in all analyzed variables. Female athletes revealed higher emotional attention than male athletes, but both groups were classified with low emotional attention, while high-level athletes showed better and adequate clarity and emotional repair than the low-level athletes. These findings can be used in combination with the extensive knowledge of sport physiology as a means to support psychological preparation for combat sports, considering particularities of gender and level groups.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MF and AD conceived, planned, and carried out the study. CB and BM realized statistical analysis and wrote the manuscript with input from all authors.

FUNDING

This study was supported by FAPERJ E-26/202.810/2019 (247397).

ACKNOWLEDGMENTS

We thank all athletes, coaches, and federations for allowing and contributing to the accomplishment of this work.

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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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 05 February 2020
doi: 10.3389/fpsyg.2020.00074

The Psychophysiological Effects of Different Tempo Music on Endurance Versus High-Intensity Performances

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OPEN ACCESS

Edited by:
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University of Catania, Italy

Reviewed by:
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: 09 December 2019
Accepted: 10 January 2020
Published: 05 February 2020

Citation:
Patania VM, Padulo J, Iuliano E, Ardigò LP, Čular D, Miletić A and De Giorgio A (2020) The Psychophysiological Effects of Different Tempo Music on Endurance Versus High-Intensity Performances. Front. Psychol. 11:74. doi: 10.3389/fpsyg.2020.00074

The use of music during training represents a special paradigm for trainers to stimulate people undertaking different types of exercise. However, the relationship between the tempo of music and perception of effort during different metabolic demands is still unclear. Therefore, the aim of this research was to determine whether high intensity exercise is more sensitive to the beneficial effects of music than endurance exercise. This study assessed 19 active women (age 26.4 ± 2.6 years) during endurance (walking for 10′ at 6.5 km/h on a treadmill) and high intensity (80% on 1-RM) exercise under four different randomly assigned conditions: no music (NM), with music at 90–110 bpm (LOW), with music at 130–150 bpm (MED), and with music at 170–190 bpm (HIGH). During each trial, heart rate (HR) and the rating of perceived exertion (RPE) were assessed. Repeated analysis of variance measures was used to detect any differences between the four conditions during high intensity and low intensity exercise. RPE showed more substantial changes during the endurance exercises (11%), than during high intensity exercise (6.5%), between HIGH and NM conditions. The metabolic demand during the walking exercise increased between NM and HIGH bpm conditions. This study indicates the benefits of music under stress conditions as well as during endurance and high intensity training. The results demonstrate that the beneficial effects of music are more likely to be seen in endurance exercise. Consequently, music may be considered an important tool to stimulate people engaging in low intensity physical exercise.

Keywords: training and testing, rating perception effort, exercise, RPE, sport

INTRODUCTION

The psychophysiological effects of music have been widely investigated in both psychology (De Giorgio et al., 2017; Benke et al., 2018; Innes et al., 2018; Padovan et al., 2018) and in exercise and sport related fields (Jarraya et al., 2012; Terry et al., 2012). The effects of exercise on the brain are well known (for a review see De Giorgio, 2017, De Giorgio et al., 2018a), but the effect that music has on exercise and its cerebral counterpart has only recently been investigated (Bigliassi et al., 2017; Tabei et al., 2017). It has been demonstrated that music is able to trigger behavioral changes, i.e., there is an underlying modification of brain function which can induce people to increase their exercise adherence and participation (Altenmüller and Schlaug, 2012). Music has also been demonstrated to be effective in reducing fatigue and its related symptoms (Jing and Xudong, 2008), in emotional regulation (Hou et al., 2017), in regulating affective arousal (Hutchinson et al., 2018) and in improving the efficacy of the motor system (Bigliassi et al., 2017).

However, music remains a subjective experience and De Nora (2000) discussed how people select music in a subjective manner to improve mood and energy levels during physical activity. Furthermore, the influence of music is also associated with both its intrinsic elements, such as rhythm and musicality and extrinsic factors emerging from cultural and extra-musical associations (Zatorre et al., 2007; Koc and Curtseit, 2009; Karageorghis et al., 2012). Listening to a particular type of music has been found to improve subjective experience during low, moderate, and high intensity exercise (De Nora, 2000; Karageorghis and Priest, 2012a,b; Karageorghis et al., 2012).

In the neurophysiological context, it has been demonstrated that music influences processes in the autonomic nervous system and can even be used to regulate blood pressure and heart rate (HR) (Schneck and Berger, 2006; Karageorghis and Priest, 2012a,b). The central nervous system is highly sensitive to musical cues and its reaction is diverse, involving muscle activation, attention, thoughts, behavior, and executive functions (Thaut, 2005; Thaut and Abiru, 2010; Altenmüller and Schlaug, 2013).

With respect to attention, listening to music during physical activity has been described in the literature as a dissociative cognitive strategy that enables a shift in attention away from subjective experiences of discomfort or pain (De Nora, 2000; Rodriguez-Fornells et al., 2012; Altenmüller and Schlaug, 2013). It has been shown that as the intensity of exercise increases, discomfort and related bodily sensations increase, eliciting a greater awareness of fatigue-related symptoms (Karageorghis and Priest, 2012a). Conversely, when people are exposed to environmental sensory cues such as music, colors, or videos, these cues can divert attention and modify both behavior and bodily discomfort sensations during exercise or other tasks (Karageorghis and Jones, 2014; De Giorgio et al., 2018a,b).

As mentioned previously, the literature describes the capacity of music to shift the focus away from feelings of discomfort and fatigue and this has been demonstrated through the assessment of the rating of perceived exertion (RPE). In particular, it has been found that reduced RPE with music is associated with low to moderate intensity exercise, but not high intensity exercise (Harmon and Kravitz, 2007; Karageorghis and Priest, 2012b). The authors proposed that music seems unable to divert attention during exercise that is overly intense with a high degree of bodily discomfort (for a review see Karageorghis and Priest, 2012a,b). Despite this, it was found that while the RPE during high intensity exercise remained the same with or no music (NM), participants experienced more positive mood profiles when listening to music, regardless of exercise intensity. The authors suggest that this could have occurred because although the participants knew that they were exercising hard, they were happier about the activity (Karageorghis and Priest, 2012a,b). In their literature review, Karageorghis and Priest (2012a,b) also highlighted the finding that trained athletes are less influenced by the effects of music compared to those who are untrained. This could be a result of the practice athletes have in diverting their attention away from bodily discomfort in any situation.

However, to the best of our knowledge there have been no studies to date that have linked the effect of two different exercise types on the RPE under different music conditions. This study investigated the RPE after low intensity and high intensity exercise, conducted under different music conditions.

Participants

Nineteen female participants ranging from 24 to 31 years old were enrolled for the present study. All participants regularly performed physical activity three to five times a week and a good proportion of the participants were involved in physical fitness. The following participant information was collected: mass, height, BMI (body mass index, obtained by dividing the weight in kg of the participant with the square of the height expressed in meters), training experience [endurance intensive effort and/or high intensity effort (Chamari and Padulo, 2015)], and maximal HR. The participants' data are reported in **Table 1**. All participants gave written informed consent following verbal and written explanations regarding the study. All methodological procedures were approved by the local Ethics Committee.

Socio-Demographic Variables and Enrolment Process

The participants were enrolled in different fitness centers located in Rome using a convenience sampling based on the following inclusion criteria: (1) female gender; (2) age between 18 and 35 years old; (3) at least 1 year of experience in fitness training (minimum three to five session of training per week; and (4) at least high school graduation. To assure the safety of the procedure and the correct interpretation of the data the following exclusion criteria were instead applied: (1) presence of relevant disease or other condition (temporary or permanent) incompatible with the proposed interventions; (2) history of relevant cardiopulmonary disease; (3) BMI > 25 kg/m^2; (4) presence of relevant disease or other condition (temporary or permanent) potentially influencing the physical performance of the participant. The participants were all volunteers and were invited for an individual appointment in a Sports Science Laboratory in order to explain them the procedure of the study and in order to collect the information via survey. The survey aimed to investigate and collect the data reported in **Table 1**, the adherence to the inclusion criteria, and the absence of exclusion criteria.

Procedures

Each participant was asked to perform two different training sessions: (1) walking at 6.5 km/h (endurance exercise) on a treadmill for 10 min to reach a steady state (Padulo et al., 2014) and (2) high intensity exercise on leg press machine based on the one repetition maximum test (1-RM) (Padulo et al., 2015). Each exercise test was performed four times by each participant under four different tempo music conditions.

TABLE 1 | Characteristics of participants.

	Mass (kg)	Height (cm)	BMI (kg/m^2)	Age (years)	Theoretical maximal HR (bpm)	Training experience	Training experience (years)
Participant 1	67.2	175	22.0	24	187	EIE	16
Participant 2	61.3	168	21.7	26	186	EIE	13
Participant 3	63.8	170	22.1	24	190	EIE	12
Participant 4	67.5	177	21.6	26	175	EIE	15
Participant 5	56.6	167	20.3	29	186	HIE	7
Participant 6	63.9	175	20.9	31	184	EIE	3
Participant 7	62.0	173	20.3	25	185	EIE	14
Participant 8	48.9	160	19.1	24	179	HIE	2
Participant 9	61.3	169	21.5	24	177	EIE	1
Participant 10	57.4	165	21.1	24	190	HIE	5
Participant 11	53.0	170	18.3	24	170	HIE	1
Participant 12	62.9	164	23.4	25	185	HIE	3
Participant 13	70.0	170	24.2	29	184	EIE	11
Participant 14	53.7	170	18.6	31	187	HIE	7
Participant 15	61.3	157	24.9	27	187	HIE	0.6
Participant 16	57.3	177	18.3	31	178	EIE	2
Participant 17	54.5	170	18.9	27	184	HIE	1
Participant 18	55.0	168	19.5	26	184	EIE	4
Participant 19	54.5	173	18.2	25	188	EIE	3
MEAN	59.58	169.37	20.78	26.42	183.47	–	6.35
SD	5.65	5.30	2.02	2.57	5.31	–	5.39

Mean and standard deviation (SD) for the anthropometric measures and the training experience. EIE, endurance intensive efforts; HIE, high intensity efforts.

TABLE 2 | Results with pairwise comparisons among the four music conditions.

Dependent variables	Music conditions	Mean	SD	95% CI		Pairwise comparisons			
				Lower	Upper	NM vs.	LOW vs.	MED vs.	HIGH vs.
aHRwalking (bpm)	NM	83.37	4.166	81.360	85.376	LOW: $p < 0.0001$	NM: $p < 0.0001$	NM: $p < 0.0001$	NM: $p < 0.0001$
	LOW	95.79	4.237	93.747	97.832	MED: $p < 0.0001$	MED: $p = 0.001$	LOW: $p = 0.001$	LOW: $p < 0.0001$
	MED	99.47	3.289	97.888	101.059	HIGH: $p < 0.0001$	HIGH: $p < 0.0001$	HIGH: $p < 0.0001$	MED: $p < 0.0001$
	HIGH	110.11	4.054	108.151	112.059				
pHRwalking (bpm)	NM	95.95	4.731	93.667	98.228	LOW: $p < 0.0001$	NM: $p < 0.0001$	NM: $p < 0.0001$	NM: $p < 0.0001$
	LOW	104.37	4.044	102.419	106.318	MED: $p < 0.0001$	MED: $p < 0.0001$	LOW: $p < 0.0001$	LOW: $p < 0.0001$
	MED	109.05	4.020	107.115	110.990	HIGH: $p < 0.0001$	HIGH: $p < 0.0001$	HIGH: $p < 0.0001$	MED: $p < 0.0001$
	HIGH	125.37	4.044	123.419	127.318				
RPEwalking (Borg's scale score)	NM	9.26	0.653	8.948	9.578	LOW: $p = 0.002$	NM: $p = 0.002$	NM: $p < 0.0001$	NM: $p < 0.0001$
	LOW	8.58	0.692	8.245	8.913	MED: $p < 0.0001$	MED: $p = 0.049$	LOW: $p = 0.049$	LOW: $p < 0.0001$
	MED	8.05	0.848	7.644	8.461	HIGH: $p < 0.0001$	HIGH: $p < 0.0001$	HIGH: $p = 0.045$	MED: $p = 0.045$
	HIGH	7.47	0.772	7.101	7.846				
1RMlp (kg)	NM	133.26	41.777	113.127	153.399	LOW: p not sign.	NM: p not sign.	NM: p not sign.	NM: p not sign.
	LOW	133.26	41.777	113.127	153.399	MED: p not sign.	MED: p not sign.	LOW: p not sign.	LOW: p not sign.
	MED	133.26	41.777	113.127	153.399	HIGH: $p < 0.0001$	HIGH: $p < 0.0001$	HIGH: $p < 0.0001$	MED: p not sign.
	HIGH	136.47	43.004	115.746	157.201				
RPElp (Borg's scale score)	NM	16.26	1.447	15.566	16.961	LOW: p not sign.	NM: p not sign.	NM: $p = 0.002$	NM: $p = 0.002$
	LOW	15.89	1.595	15.126	16.663	MED: $p = 0.002$	MED: p not sign.	LOW: p not sign.	LOW: $p = 0.011$
	MED	15.53	1.541	14.784	16.269	HIGH: $p < 0.0001$	HIGH: $p = 0.011$	HIGH: p not sign.	MED: p not sign.
	HIGH	15.21	1.228	14.618	15.803				

Mean and standard deviation (SD) and 95% confidence interval (95% CI) for the aHRwalking (average HR during walking at 6.5 km/h); pHRwalking (peak of HR during walking at 6.5 km/h); RPEwalking (RPE during walking at 6.5 km/h); 1RMlp (One-repetition maximum at leg press); and RPElp (RPE during 1-RM at leg press) on four conditions: NM (no music), LOW (music with bpm between 90 and 110), MED (music with bpm between 130 and 150), and HIGH (music with bpm between 170 and 190).

The order of the four music conditions was randomly assigned in a counterbalanced way. Subsequently, in the other four experimental sessions (each conducted under different music conditions) each participant individually performed the two exercise sessions. The participant's HR was recorded during each endurance session (10 min for each one) and at the end of the test, the participant's average HR and peak HR were then calculated. Furthermore, immediately after the walking exercise, the participant was asked to express their perception of fatigue as a value based on the Borg scale ($0 < 20$). On a different day, each participant was assessed with regard to their maximal repetitions during the leg-press exercise (Padulo et al., 2017; Migliaccio et al., 2018) and the 1-RM based on the Brzycki method was calculated at the same time (Padulo et al., 2015). To ensure standardization of the procedure the following method was used. The participant began the leg-press exercise with a load equivalent to their body weight (measured in the preliminary session) and performed the maximal number of repetitions. When the participant reached 10 repetitions with the selected weight, the exercise was stopped and 20 kg was added for a further attempt after four minutes of rest. When the participant was unable to perform more than 10 repetitions with the selected load, the respective 1-RM was calculated using the Brzycki equation: 1-RM theoretical = lifted load/[1.0278 − (0.0278 × repetitions performed)]. Immediately after the last try, the participant was once again asked to express their perception of fatigue as a value based on the Borg scale (CR $0 < 20$). The four tempo music conditions were: NM, with music at 90–110 bpm (LOW), with music at 130–150 bpm (MED), and with music at 170–190 bpm (HIGH). During each music condition, five pop songs were used with increasing bpm (e.g., in the MED condition, the first song had 132 bpm, the second had 136 bpm, the third had 141 bpm, the fourth had 143 bpm, and the last song had 148 bpm). All sessions were conducted in the same Sports Science Laboratory of the enrolment process, and similar environmental conditions at each session were ensured (temperature and relative humidity for each session ranging from 22 to 24°C and 25 to 27%, respectively). All the sessions under different music condition were performed one week apart each other to avoid the influence of fatigue of each session on the subsequent ones. A reminder was sent to each participant 2 days before each session in order to assure the correct adherence to the study planning. No dropout or unavailability of the participants occurred during the study.

Statistical Analysis

The Shapiro–Wilk test was used to evaluate the normality of the data distribution. Successively, multivariate analysis of variance with repeated measures (RM-MANOVA) was conducted to determine whether significant differences existed between the four different music conditions. This was considered as the factor of the analysis (named CONDITION). The following five variables were considered dependent variables: aHRwalking (average HR during walking at 6.5 km/h); pHRwalking (peak HR during walking at 6.5 km/h); RPEwalking (RPE during walking at 6.5 km/h); 1-RMlp (one-repetition maximum during leg-press); and RPElp (RPE during leg-press). The alpha test level for statistical significance was set at $p < 0.05$ and η_p^2 was calculated as the index of effect size. The Bonferroni correction was used for pairwise comparison of the four music conditions. The reliability of the external load time (10′ on treadmill/leg-press machine) was assessed by calculating the intra-class correlations coefficient (ICC), according to the literature (Weir, 2005). The SPSS statistical software package (Version 25.0; IBM) was used for all statistical analysis.

RESULTS

On leg-press exercise the 1-RM was 133.26 ± 41.78 kg with the starting load of 62.11 ± 4.19 kg and concluded with 4.21 ± 1.90 sets/3.32 ± 0.89 reps. The ICC for external load time (treadmill/leg-press) on the four conditions was >0.985 for high intensity and endurance exercises, respectively. The results of the RM-MANOVA indicated significant differences between the four conditions ($F_{13,6}$ = 94,152; $p < 0.0001$; $\eta_p^2 = 0.995$). The univariate analysis showed significant differences with regard to all five dependent variables analyzed: aHRwalking ($F_{3,54}$ = 242.08; $p < 0.0001$; $\eta_p^2 = 0.931$); pHRwalking ($F_{3,54}$ = 631.38; $p < 0.0001$; $\eta_p^2 = 0.972$); RPEwalking ($F_{3,54}$ = 35.27; $p < 0.0001$; $\eta_p^2 = 0.662$); 1-RMlp ($F_{3,54}$ = 39.54; $p < 0.0001$; $\eta_p^2 = 0.687$); and RPElp ($F_{3,54}$ = 15.86; $p < 0.0001$; $\eta_p^2 = 0.468$). The results obtained for each condition and the pairwise comparisons between the four conditions are reported in **Table 2** and **Figure 1**.

DISCUSSION

The results of this study support the findings of other studies regarding the effects of music on cognitive motor processes (Bianco et al., 2017; Mohammad Alipour et al., 2019). This study is the first to link the effect of music with RPE and HR under different music conditions. The effects of music involve both unconscious sub-cortical areas and conscious cortical stimulation and the responses are highly complex (Zatorre et al., 2007; Levitin and Tirovolas, 2009; Rodriguez-Fornells et al., 2012; Altenmüller and Schlaug, 2013). Music can stimulate the human brain to such an extent that to ignore it is more difficult than interaction (Zatorre et al., 2007; Levitin and Tirovolas, 2009).

As mentioned previously, music perception involves both cortical and sub-cortical areas, but it has an effect on the whole brain. Music influences emotional responses (i.e., the limbic system), associate/automatic movements (i.e., the basal ganglia), coordination (i.e., the cerebellum), and the organization and planning of movements (motor, pre-motor, and supplementary motor areas). The rhythmic patterns of music facilitate error correction and the execution of movements (Levitin and Tirovolas, 2009). Indeed, repeated movements seem to be related to the phases between pulse music beats, stimulating a feedback/forward loop (Todd et al., 2002; Levitin and Tirovolas, 2009). In addition to the involvement of the whole brain, music also affects the whole body and this influence occurs through physiological arousal mediated by sub-cortical structures and bodily rhythms such as walking, breathing,

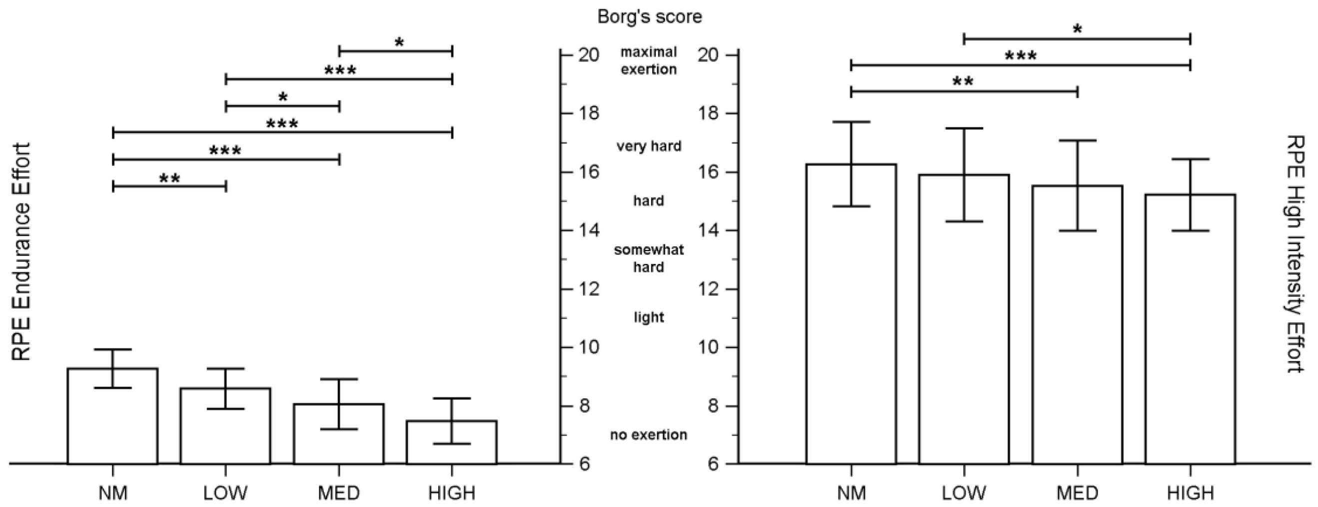

FIGURE 1 | Rating of perceived exertion (RPE) in both exercises during the four conditions. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

and HR (Schneck and Berger, 2006; Levitin and Tirovolas, 2009; Altenmüller and Schlaug, 2013). Previous studies have demonstrated that music regulates processes in the autonomic nervous system and can be used to regulate the cardiovascular system with regard to both HR and blood pressure (Harmon and Kravitz, 2007; Murrock and Higgins, 2009; Karageorghis and Priest, 2012a,b). Bodily activation is very important in feeling fatigue, as signals traveling from the body toward the brain inform the latter on the effort in progress, modulating physical activity as a result. These signals capture conscious attention and can change behavioral responses relating to exercise adherence. Becomes These signals capture conscious attention and can change behavioral responses (De Giorgio, 2016) also relating to exercise adherence. However, music can be considered a useful tool in regulating the intensity of physiological arousal and subjective experiences in order to improve levels of physical activity and exercise participation (De Nora, 2000; Zatorre et al., 2007; Karageorghis and Priest, 2012a,b; Altenmüller and Schlaug, 2013). Indeed, in the context of sport and exercise performance, De Nora (2000) discussed how music can be strategically chosen in order to induce physio-psychological responses that lead to better performance, experience, and adherence to exercise as well as regulating mood and shifting attention away from discomfort (De Nora, 2000). Our investigation showed the differences in the effects of listening to music during high intensity and low intensity exercise (i.e., endurance exercise). Endurance exercise seems more sensitive to external stimuli (Van Cutsem et al., 2017) due to the mental fatigue and perception of effort involved in endurance exercise. High intensity training (i.e., explosive effort) seems characterized by an all-out approach that is powered primarily by metabolic pathways through muscular simulation without the use of oxygen (Van Cutsem et al., 2017). As such, "anaerobic" high intensity training requires fewer decision-making processes compared to endurance exercise, due to the all-out strategy and the intrinsically shorter duration (Van Cutsem et al., 2017).

This study presents some limitations. First, the results refer to a physically trained adult female population. Consequently, these results need to be confirmed for other populations such as male subjects, untrained people, older people, or adolescents. Furthermore, music cannot be described only using tempo, but also other characteristics need to be considered such as lyrics, melody, and genre. These characteristics were not considered in this study, but they could influence the performance of the participant. Also, the preference of the participants concerning their musical preferences were not collected and considered in the present study. Finally, the effect in the different moments of the same exercise was not considered as in previous study (Di Cagno et al., 2016).

CONCLUSION

This study indicates the benefits of listening to music under physical stress conditions as well as during endurance and high intensity training. The results of this study demonstrate that the beneficial effects of music are more apparent for endurance exercise. Consequently, music may be considered an important tool to stimulate people engaging in physical exercise. The finding of this study underlines the efficacity of the tempo of music in improving the performance and simultaneously reducing the RPE during the exercises. With this in mind, it is important to understand how this music influence can be used to improve training load and performance in trained people, but also the risk of an "altered" RPE during the exercise (both endurance and high intensity) needs to be clarified.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the local Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

VP, JP, and AD: conceptualization and writing. JP and EI: methodology and formal analysis. EI and LA: validation. DČ, AM, and VP: investigation. LA, DČ, and AM: resources. EI: data curation. AD and JP: review and editing. AD: supervision.

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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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 14 February 2020
doi: 10.3389/fpsyg.2020.00193

A Qualitative Study on Pre-performance Routines of Diving: Evidence From Elite Chinese Diving Athletes

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Pre-performance routines (PPRs) are essential motor skills prior to a competition for athletes. But we believe that a specific kind of sport has its own PPRs. Using a qualitative research design, this study conducted in-depth interviews with 14 elite Chinese athletes in competitive diving and their coaches as well as observed and analyzed the behaviors of 13 athletes during diving competitions. The results showed that the divers' PPRs were constituted of four components (psychological skills, pace setting, mastering competition progress, and behavioral strategies), which could be divided into 20 core categories, with the entire diving process divided into three sections and ten stages, including 13 subcategories in off-platform, 12 subcategories in on-platform and the diving stage. Thus, patterns in the PPRs for divers were established and a clear and comprehensive picture of the diving process, as well as the psychological characteristics and behavioral patterns of athletes during the process, were obtained. The findings entail implications for developing PPRs for diving athletes and future studies on PPRs in other competitive diving and other sports.

Keywords: Chinese athletes, diving, grounded theory, pre-performance routines, qualitative research

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *04 November 2019*
Accepted: *28 January 2020*
Published: *14 February 2020*

Citation:
Yao Q, Xu F and Lin J (2020) A Qualitative Study on Pre-performance Routines of Diving: Evidence From Elite Chinese Diving Athletes. Front. Psychol. 11:193. doi: 10.3389/fpsyg.2020.00193

INTRODUCTION

Pre-performance routines (PPRs) are pre-arranged sequential thoughts and actions that help athletes stabilize and control their thoughts, emotions, and behaviors prior to a competition (Singer, 2002; Cotterill, 2010). Relevant studies and sports-related research tend to refer to PPRs as a plan, a strategy, a protocol, a technique, and even a ritual (e.g., Cohn et al., 1990; Foster et al., 2006; Lonsdale and Tam, 2008; Mesagno et al., 2019). PPRs involve a variety of psychological skills and behavioral responses, which are widely adopted in different sports; particularly, they are most commonly adopted in the preparation stage of self-paced events involving technical performance (e.g., Lonsdale and Tam, 2008; Clowes and Knowles, 2013). Scholars have suggested that PPRs are extremely important for high-performing or elite athletes; the motor skills of these athletes tend to be over-learned and the operation of the expected movements becomes mechanized, whereby they are executed without conscious attention (Cotterill, 2010). They are thus faced with an increased likelihood of being disturbed by internal and external non-task-related stimuli, which may negatively affect their athletic performance (Beauchamp et al., 1996; Jackson and Baker, 2001; Mesagno et al., 2015). The use of cognitive and behavioral procedures helps these athletes avoid interference and ensures smooth performance in the competition.

Singer (2002) conducted a general analysis of the pre-performance state in self-paced events and concluded that it should include the following steps: (1) self-regulation of thoughts and emotions to a status compatible with the expected movements; (2) narrow, dedicated, and sustained concentration; (3) attainable ideal self-efficacy; (4) appropriate distribution of activated locations in the brain to ensure a quiet mind; (5) maximal focus on the target (frequency and duration) to channel the direction of attention; (6) generating a set of simplified routine behaviors prior to and during the competition; and (7) automatic activation of the above processes to allow effortless, effective, and successful performance in the competition. The ultimate goal is to use the aforementioned steps to create individualized consistent PPRs that can be performed automatically regardless of the situation. The purpose of such routines is to ensure that athletes are continually in their best emotional state with high self-expectations, confidence, and concentration prior to and during the competition. Such self-regulatory techniques are essential as they are the driving force of athletes' performance during the competition, helping them control and regulate their emotions, thoughts, and attention to remain focused and self-controlled, and to ensure a state of flow (Jackson and Baker, 2001; Cotterill, 2010).

It is evident that athletes who have better motor skills and are able to perform effortlessly during competitions have more advantages than their opponents; however, it is a challenge to ensure effortless performance on a consistent basis during competitions. In order to achieve an optimal performance state, it may be a prerequisite to develop and master a set of effective PPRs. Systematic studies on athletes who could effectively perform PPRs have yielded that, regardless of being a conscious or subconscious behavior, PPRs are associated with motor skills, of which they have become an integral part. To a certain degree, PPRs directly affect athletes' readiness for their performance and results (Cotterill, 2010; Macnamara et al., 2016). Singer (2002) proposed a general five-step PPR approach applicable to different sports. However, empirical results showed that the proposed model was not specific and detailed enough to provide practical guidance for any given sport. Therefore, it would be theoretically and practically more useful if research could target PPRs with consideration of the characteristics of a specific sport.

The research interest of the present study is competitive diving. Patterns in PPRs in the context of diving have not been thoroughly studied. Since China is one of the leading nations in the sport of diving, this study recruited elite diving athletes and coaches of the Chinese national and provincial teams as research subjects. The qualitative research method was adopted to conduct comprehensive and in-depth investigations, interviews, and observations with the subjects. By analyzing their competition experience and behavioral patterns, a set of PPRs for diving was constructed in order to facilitate relevant studies and improve PPR interventions in the sport of diving.

MATERIALS AND METHODS

Research Subjects

Among the 14 athletes interviewed, 6 were from the national diving team and 8 from a provincial diving team. Among the 8 provincial athletes, 4 had previously been selected for the national team. Among the 4 remaining provincial athletes, 2 had previously received the title of "international professional athlete," and 2 had been granted the title of "national professional athlete." The athletes' mean age was 23 years (min = 15 and max = 39), with experience spanning, on average, 14 years as a professional athlete (min = 7 and max = 22). These athletes had collectively won 18 Olympic gold medals (two of them had won five Olympic gold medals each), 1 Olympic silver medal, and 6 gold medals in diving at the World Aquatics Championships. Three of the athletes had won two Olympic championships (see **Table 1**).

Six coaches (2 male and 4 female) were interviewed, among whom three currently coach in the national team and two had prior experience as a coach for the national team (**Table 2**).

Statistical Analysis Software

The QSR Nvivo 7.0 qualitative analysis software package was used to analyze the data collected during the interviews, while the data collected from the video recordings and observations were analyzed using Noldus' The Observer 6.0 behavioral analysis software package.

Data Collection

Collection of Interview Data

The purpose of this study was to identify PPRs for diving based on an investigation of Chinese elite diving athletes and their coaches. Based on the research objectives, a semi-structured interview outline was drafted. Next, a team of experts who are providing psychological services to the diving team preparing for the coming Olympic Games (experts, including a professor, a doctoral student, and two postgraduate students of athletic psychology) were invited to examine the coverage and contents of the drafted outline. The final outline was updated based on their suggestions and comments. A Behavioral Event Interview (BEI) was used to identify the characteristics of the skills mastered by the interviewed athletes during competitions. Data related to diving competitions were collected through interviews with the athletes, to determine their behaviors, moods, and psychological strategies at different stages of the diving competitions, as well as through interviews with their corresponding coaches. The interview outlines included items designed to collect the athletes' BEI data, behaviors during diving competitions, and viewpoints from their coaches.

In addition, a pilot study, based on the drafted outline, was conducted by the present researcher to interview two national team gymnastics athletes to improve the operational skills required for the interviews. The interviews were conducted face-to-face by the present author; the average duration was approximately 30 min, and all interviews were recorded.

TABLE 1 | Basic information of the interviewed athletes.

	Gender		Category		Professional level		# of Olympic gold medals	# of Olympic silver medals	Years of service	
	Male	Female	Platform diving	Springboard diving	International level	National level			<14	≥14
National athlete (*n* = 6)	4	2	2	4	6	0	5	1	1	5
Provincial athlete (*n* = 8)	3	5	2	6	6	2	0	0	7	1

TABLE 2 | Basic information of the interviewed coaches.

	Gender		Professional title		Years of service		Best achievement as a coach		
	Male	Female	National coach	Senior coach	<40	≥40	# of Olympic champion coached as the head coach	# of Olympic 1st runner-up coached as the head coach	# of Olympic champion coached as the 1st coach
Coach of the national team (*n* = 3)	2	1	2	1	2	1	2	1	0
Coach of the provincial team (*n* = 3)	0	3	2	1	1	2	1	0	2

Collection of Observed Data

The collection of observed data was completed by three people: the first person used a digital video camera to record the behavior of all participating athletes prior to ascending the platform or springboard (off-platform). The second person used a digital video camera to record the behavior of the participating athletes when they were on the platform or springboard (on-platform). The third person was expected to take a video camera and move between the various athletes' zones (such as coaches' stand, locker rooms, and warm-up areas) to observe and collect information that was not within the coverage of the other cameras.

Data Analysis

Analysis of the Interview Data

Grounded theory involves the development of a new theory based on raw data, to guide the development of theory driven by qualitative research (Glaser, 2001; Charmaz, 2006). The strategy proposed by grounded theory and the method of constructing theory using qualitative data have been widely applied to different fields and disciplines. Based on the results of comparative analysis, Charmaz (2006) suggested that we should regard grounded theory and corresponding methods as a set of principles and practices, rather than prescriptions or packaged procedures. On that account, a grounded-theory perspective that emphasizes the flexible use of coding guidelines is suitable for addressing the research questions of the present study. Therefore, this theory was employed as the data analysis method, based on the following process: open coding, axial coding, and selective coding were primarily applied; then, key behaviors were identified and a PPR model was developed. The coding system was developed strictly following the qualitative research process. First, two of the present researchers participated in the analysis of all of the collected data independently and established a preliminary coding table according to standard theoretical definitions in psychology. Next, a group discussion was conducted to resolve any disagreement on themes and groupings of behaviors until consensus was reached. Following the construction of the preliminary coding table, the researchers referred to the principles of thematic analysis and combined themes based on their similarities, so as to establish a more complex second-level coding table. Specifically, each theme was compared to each of the other themes, so that any themes with a similar meaning were combined, and themes with contrasting meanings were separated. Following the group discussion, the two researchers consistently agreed on the coding system to be applied.

All records of the interviews were first transcribed by the researcher. Next, the transcripts were checked against the records to ensure the accuracy of the information. Another member of the research team was also invited to conduct a second check of the transcripts to compare them against the records. The verified information was then imported into QSR Nvivo 7.0.

Analysis of the Observed Data

The recorded videos were imported into Noldus' The Observer 6.0. Firstly, the researcher conducted a preliminary coding table for the data, according to the research purpose. Next, a group discussion was conducted to resolve any disagreement on the theme and grouping of the behavior until a consensus was reached.

Test for Validity

The five types of validity standards include descriptive validity, interpretive validity, theoretical validity, generalizability, and evaluative validity and triangulation methods were used test the validity of the data.

Firstly, four strategies, used to improve the descriptive validity of the data, were adopted during the data collection process: (1) the interviewer ensured that the recording equipment was functional during the interview; (2) the transcriber ensured that the interviews had been transcribed verbatim; (3) the initial coding (components and categories) were sent to the interviewees for verification, and their suggestions were considered to ensure the accuracy of the terms; (4) finally, both athletes and coaches were interviewed to ensure that the collected data from the two groups complemented one another.

Secondly, two strategies were adopted to improve the interpretive validity of the data: (1) a group of experts, specialized in psychology, was recruited to provide suggestions and guidance throughout the entire research process, from preparation to implementation of the research; (2) during the transcription and coding process, the researcher maintained close communication with the interviewees (athletes and coaches) for advice and suggestions.

Thirdly, expert meetings were organized at each data analysis stage, and the OG-P experts were invited to evaluate the accuracy of the data coding.

Fourthly, the research results were sent to some interviewees, who confirmed that the results accurately reflected their situation and presented some abstract concepts in a more tangible manner, as well as confirming that the results could be internally generalized. This study also received recognition from target readers and relevant professionals, following communication with them; the constructed PPRs achieved acceptable external generalizability.

Fifthly, the researcher comprehensively reviewed and studied existing research and related theories on PPRs, from home and abroad, to gain a full understanding of the technical, psychological, and competitive characteristics of diving. In addition, the researcher also investigated the background of the interviewees in terms of years of service as an athlete or coach, as well as educational background. Expert meetings were held throughout the entire research process to improve its evaluative validity.

Lastly, triangulation, which refers to the use of different data sources, methods, analyses, and theories as a means of ensuring the accuracy of research results, was adopted. In this study, the findings from the interviews were further verified during the observation process, and the findings from the observations were compared with those from the interviews to ensure that the findings from the two methods matched, confirmed, and supplemented one another. Moreover, the study not only included athletes as interviewees but also coaches. During the observation process, both horizontal and vertical comparisons were conducted.

RESULTS AND ANALYSIS

Due to the word count restriction, the original quotes of the interviewees were only included for a limited number of topics.

Results of the Interviews

The analysis of the interview results with the athletes and coaches yielded four components and 16 categories of PPRs, as presented in **Table 3**.

Results of the Observation

Observation Results Off-Platform

The analysis of the behavior of 13 athletes off-platform showed that the athletes tended to exhibit the following behaviors: (1) climbing out of the pool to salute the referee and the audience; (2) listening to or checking the announced score of the dive; (3) showering with hot water and then drying off; (4) returning to the rest zone to rest; (5) warming up; (6) looking for the coach; (7) imitating the moves of the dive; (8) showering; and (9) waiting for their turn of the next dive. In addition, following a comparison between the observed behavior and the results of the interviews, three additional categories related to behavioral strategies emerged as follows: (1) climbing out of the pool to salute the referee and the audience; (2) listening to or checking the announced score of the dive; and (3) showering with hot water and then drying. These three categories were considered supplementary to the findings of the interviews.

Observation Results On-Platform

The analysis of the behavior of 13 athletes on-platform showed that the athletes tended to exhibit the following behaviors: (1) physical arousal behavior, such as clenching the fists, treading water, shaking and swinging the legs, bending the knees, rotating the head, and twisting the neck; (2) adjusting the springboard (springboard diving); (3) imitating the moves of the dive (platform diving); (4) throwing the towel; (5) adjusting breathing; (6) listening to the broadcast and the starting signal prior to beginning their dive; (7) habitual behavior, such as rubbing hands, squeezing wrists, touching hips, and rubbing face; (8) standing still; and (9) diving. A comparison of the observed categories with the results of the interview yielded one additional category related to behavioral strategies: standing still.

Observation of an Individual Case On-Platform

With the development of technological counseling services for the Olympic diving team, and the in-depth investigation of the present study, it was determined that certain associations existed between the behavior of outstanding athletes on the diving platform and their performance during competition. For that reason, the present researchers conducted an investigation on the behaviors of key athletes from the national team during major competitions. The athletes' habitual behaviors on the diving platform were categorized into movements of the hands, body, and head (including facial expressions). Physical arousal behavior on the platform was divided into upper limb movement and lower limb movement. In addition, habitual behavior that frequently occurred in the same dive group and the order of the movement of each action were analyzed and summarized. Cognitive processes and the stress levels of the athletes accompanying these frequently occurring habitual behaviors were further verified based on observation results and interviews. Since the goal of the present study was not to develop PPRs for a specific athlete or to establish a relationship between PPRs and competition performance, only the data of Athlete 5 (Olympic champion), who performed behavior 5253B in 10 major competitions, were presented and analyzed. The relationship between the frequency of the habitual

TABLE 3 | List of the components and categories of the PPRs collected through the interviews.

	Interviewees/meaning unit	Athlete (*n* = 14)			Total number of meaning unit	Coach (*n* = 6)			Total number of meaning unit
Component	**Category**	**On-platform**	**Off-platform**	**Total**		**On-platform**	**Off-platform**	**Total**	
Psychological Skills	Visualizing the moves of the dive	14	7	14	62	6	3	6	10
	Adjusting breathing	14	3	14	23	2	0	2	2
	Self-talk	5	2	5	13	0	0	0	0
	Concentrating	4	0	4	4	2	/	2	2
Pace setting	Pace setting	6	3	6	9	2	2	3	4
Mastering competition progress	Using the other participating athletes as a reference for the progress of the competition	/	8	8	11	/	4	4	4
	Listening to the broadcast and the starting signal prior to beginning their dive	7	/	7	10	1	/	1	1
Behavioral strategies	Warming up	0	14	14	21	0	6	6	11
	Habitual behavior	5	0	5	5	2	0	2	3
	Avoiding watching the dive of other athletes	/	4	4	4	/	2	2	2
	Imitating the moves of the dive	4	10	10	16	2	6	6	8
	Throwing the towel	2	/	2	2	1	/	1	1
	Adjusting the springboard (springboard diving)	5	/	5	5	4	/	4	9
	Looking for the coach	/	14	14	15	/	6	6	6
	Showering	/	9	9	9	/	2	2	2
	Resting	/	14	14	14	/	6	6	10

Unless specified otherwise, "on-platform" refers to the time period during which the athletes were on the platform or springboard, and "off-platform" refers to the time period during which the athletes were not on the platform or springboard.

behaviors, length of time standing still, and achievements in each competition are presented in **Table 4** and **Figure 1**. More data and behavioral analysis information on other athletes are not included in this paper, due to the word limit.

The frequency of habitual behavior of AI5 ranged between 4 and 7 times and the duration of standing still time ranged between 3 and 6 s prior to performing 5253B. In addition, the resulting score of the performance appeared to be higher when the frequency of the habitual behavior was 6 or 7 times and the duration of the standing still time ranged between 4 and 6 s.

TABLE 4 | Analysis of the on-platform behaviors of AI5 prior to performing 5253B.

	Scores	On-platform habitual behavior	Standing still (second)
Competition 1	93.8	5	4
Competition 2	96.9	7	4
Competition 3	102	6	4
Competition 4	96.9	7	6
Competition 5	95.2	6	4
Competition 6	91.5	5	3
Competition 7	90	4	3
Competition 8	97.4	6	5
Competition 9	95.6	7	4
Competition 10	98.3	6	4

A further interview with AI5 showed that the habitual behavior was usually accompanied by self-talk, intense concentration, and adjustment of breathing, while standing still was accompanied by visualizing the moves of the dive.

Analysis of Athlete 5's behaviors on the diving platform resulted in conclusions regarding their corresponding characteristics and patterns. In addition, different athletes tended to show unique behavioral characteristics and patterns on the diving platform prior to their dives. The characteristics and patterns not only provide the basis for constructing PPRs but also serve as a key reference for coaches and athletes to develop personalized PPRs. It should be emphasized that some of the habitual behaviors on the diving platform were associated with

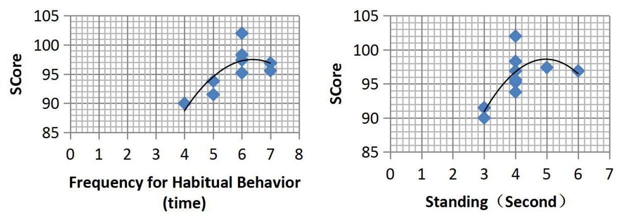

FIGURE 1 | Scatter plots of the relationship between scores and on-platform behaviors of interviewee 5 prior to performing 5253B.

athletes' psychological skills during the competition. Therefore, it is of great importance to elucidate such a relationship prior to developing PPRs.

Patterns in the Diving PPRs

The off-platform diving PPRs included the following:

(1) Psychological skills: (a) visualizing the moves of the dive, (b) adjusting breathing, and (c) self-talk; (2) pace setting; (3) mastering competition progress: (a) using the other participating athletes as a reference for the progress of the competition; (4) behavioral strategies: (a) climbing out of the pool to salute the referee and the audience; (b) listening to or checking the announced score of the dive; (c) showering with hot water and then drying the body; (d) returning to the rest zone to rest; (e) standing up and warming up; (f) looking for the coach; (g) imitating the moves of the dive; and (h) showering the body.

The on-platform diving PPRs included the following:

(1) Psychological skills: (a) visualizing the moves of the dive, (b) adjusting breathing, (c) self-talk, and (d) concentrating; (2) pace setting; (3) mastering competition progress: (a) listening to the broadcast and the starting signal prior to beginning their dive; (4) behavioral strategies: (a) physical arousal behavior, (b) adjusting the springboard (springboard diving), (c) imitating the moves of the dive (platform diving), (d) throwing the towel, (f) habitual behavior, and (g) standing still.

In order to present the distribution of the components and categories of the PPRs during the diving competition more clearly, the diving process was divided into three parts (**Figure 2**) and 10 stages. Each diving competition consisted of five (women's competition) or six (men's competition) such cycles. In light of the findings obtained through the interviews and observations, combined with the three-part model of the diving process, the diving PPRs were constructed (**Figure 3**).

Analysis of the Patterns in the Diving PPRs

Pace Setting

The category "pace setting" is involved in all parts of the diving PPRs, including the pace of off-platform preparation, the pace of on-stage preparation, and the pace of the dive. Pace setting during the competition is a very important step to ensure effective self-regulation during the competition. One of the interviewees explained "pace setting" as follows:

> *The behavior of athletes with more experience in competitions lends itself to a certain pace. For example, the usual pace during the Olympic Games is approximately one behavior per minute. The progress of the competitions is usually controlled by the corresponding TV stations, as they need time to broadcast other information, such as advertisements. There is a sense of rhythm in terms of when the athlete should ascend the stairs, when the broadcast announces the scores, when to adjust the springboard, when to throw the towel, when the broadcast announces his/her name, when to step onto the springboard, and when to jump (Coach Interviewee 1).*

Off-Platform Preparation

Stage 1: resting

During this stage, athletes use various strategies of self-regulation, such as visualizing the moves of the dive, adjusting breathing, self-talk, listening to music, and chatting with others, to rest. Other self-regulation strategies include not watching the dives of the other athletes and trying to avoid receiving information related to the performance of other athletes.

Stage 2: receiving the coach's instructions

When the athletes are preparing for the next dive, the coach usually gives instructions related to the essentials of the next dive and the moves that they should pay attention to. The athletes usually reinforce their understanding of the instructions by imitating or visualizing the moves of the dive. It was also found that the sequence of stage 2 and 3 (warm up) depends on the personal habits of the athletes rather than being fixed. Specifically, some of investigated athletes went directly to their coaches for instruction following the rest stage, while other athletes preferred to warm up prior to receiving instructions from their coach.

Stage 3: warm up

During this stage, common warm-up activities are carried out; the athletes tend to apply imitation and visualization of the dive moves to activate their body and mind and reinforce the essentials of the dive. In addition, athletes are required to shower and test the water to prepare their body for diving into the water. The time spent on showering and water temperature testing was believed by the interviewees to have a certain impact on the preparation of the dive.

Stage 4: waiting to ascend the platform/springboard

At this stage, the athlete waits for the completion of the previous athlete's dive prior to ascending the platform/springboard. Since the wait is usually not very long, the athlete is required to be alert and aware of when the previous athlete has completed the dive and he/she is able to ascend the platform/springboard. Therefore, the athletes tend to be nervous during this stage and usually adopt self-talk and breathing regulation to assist self-regulation.

Stage 10: transition and feedback following the dive

This stage is a transition stage between two dives. A certain number of behaviors is expected from the athletes, such as climbing out of the pool to salute the referee and the audience, listening to or checking the announced score of the dive, showering with hot water and then drying the body, looking for the coach, returning to the rest zone, putting on clothes, and resting. One other important aspect at this stage is to forget the result of the previous dive, regardless of it being good or bad, and swiftly adjust oneself for the next dive. One of the interviewees described this stage as follows:

> *Regardless of the result of the previous dive, [I] try not to think about it, but rather [I] clear my mind and try to calm down. Usually [my] heart beats fast during this time period, [so I] go and find a place to sit and rest (Athlete Interviewee 2).*

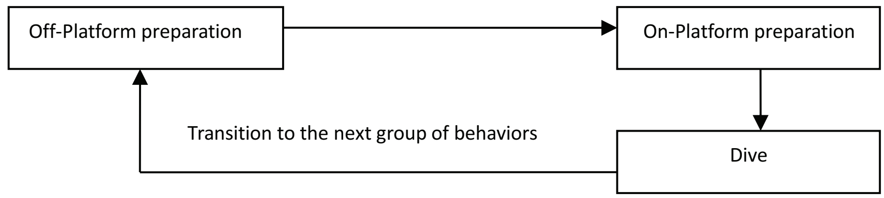

FIGURE 2 | The three diving stages.

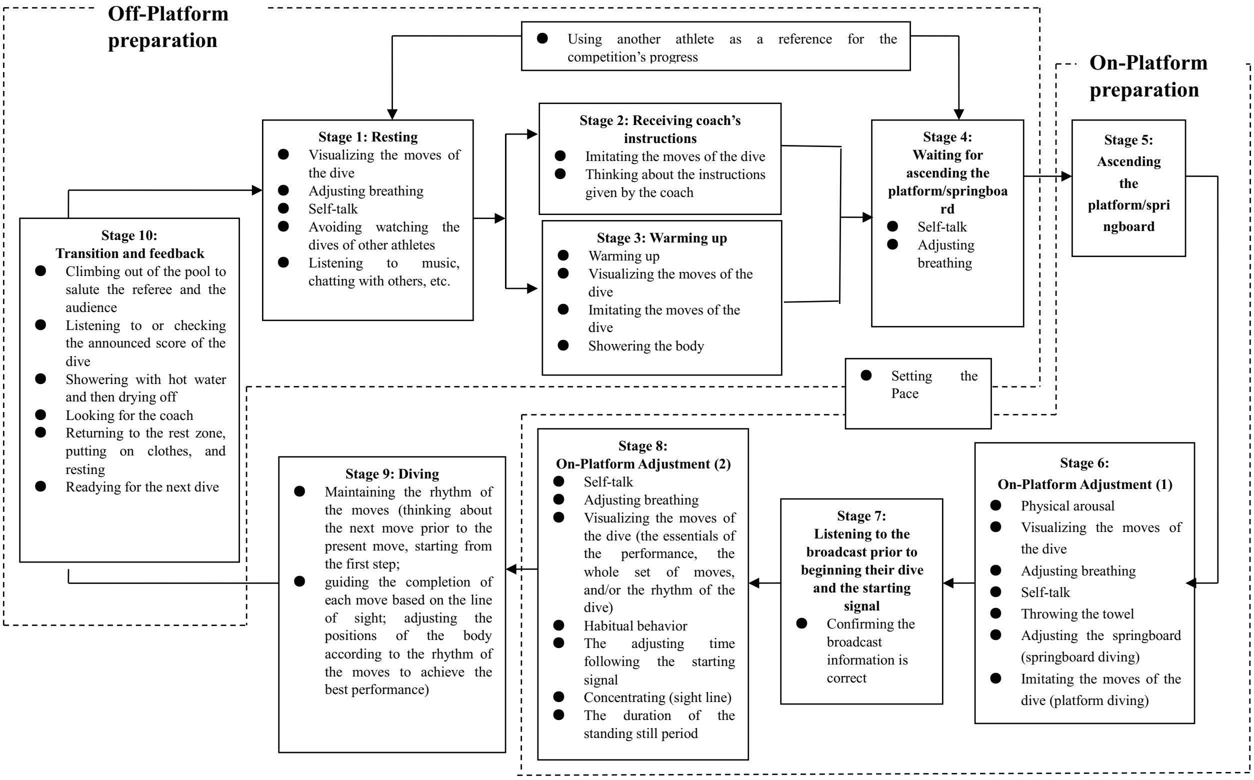

FIGURE 3 | The diving PPRs.

On-Platform Preparation

Stage 5: ascending the platform/springboard

This stage is a transition phase between off-platform and on-platform preparation. The ascent is usually too brief to allow for any other moves to be executed.

Stage 6: on-platform adjustment (1)

Athletes' appearance on the platform/springboard is similar to actors' appearance on the stage of theaters. Moving from "backstage" to being in front of the audience is likely to generate feelings of nervousness. Young and inexperienced athletes are likely to feel dizziness. In order to avoid potential negative effects of such pressure, athletes usually adopt strategies such as getting physically aroused, imitating the moves of the dive, and adjusting their breathing to alleviate the tension and ready themselves for the dive.

Stage 7: listening to the broadcast and the starting signal

At this stage, the athlete is expected to check the accuracy of the broadcast and the information displayed on the big screen. If the information does not match his/her personal information, he/she is supposed to raise his/her hand and ask for a correction. If no errors are identified in the broadcast and on the big screen, he/she is supposed to begin the dive after receiving the starting signal.

Stage 8: on-platform adjustment (2)

Although this stage lasts less than 1 min, it greatly affects the athletes' performance. The results showed that athletes tended to adopt self-regulation strategies such as self-talk, visualizing the moves of the dive, adjusting breathing, and concentrating. Habitual behaviors also occur during this stage and are usually accompanied by self-talk, concentrating, and adjustment of breathing, while standing still is usually accompanied by visualizing the moves of the dive.

Stage 9: diving

Very few interviewees mentioned self-regulation during this stage. In addition, the self-regulation strategies described by them appeared to be more abstract and highly personalized. Some examples of the responses are as follows:

> *[I] think about the essentials of a move prior to executing it. [I] find a good rhythm for the moves, such as [counting] "1, 2, 3" and complete the dive following my own pace. When [I] feel that a move was not executed smoothly, [I] try to think of ways to save it (Athlete Interviewee 8).*

> *[I] begin to think about the essentials of the moves after I take the first step, because that's when you develop the sense for the dive and think about what should be done (Athlete Interviewee 2).*

> *Once I stand there, the moves become a conditioned reflex in my mind. Once I jump, my mind automatically recalls which move/position is the most important to the dive and how I can optimize my performance. Maybe it's because I have been a diver for a long time that all the moves have become conditioned reflexes to me (Athlete Interviewee 4).*

DISCUSSION

Methodology

The advantage of qualitative research lies in the fact that it provides a profound, vivid, and comprehensive description of an object or phenomenon. The distinguishing characteristic of grounded theory is that researchers generally have no theoretical hypothesis prior to the research, but rather establish the theory using a bottom-up approach, by compiling and summarizing the concepts and propositions from the original data. The purpose of this study was to elucidate the PPRs of diving. It was expected that the findings would objectively present the experience of senior diving athletes in China and their existing PPRs and patterns so as to construct a PPR model for athletic diving. The choice of research methods in research generally depends on the research question and objectives. Considering the research questions and objectives of this study, the traditional quantitative research paradigm did not appear to fit the needs of the study. Therefore, the researcher chose the qualitative approach, combining interviews and observations (behavior analysis), to achieve the research objectives.

Nevertheless, there were certain limitations to the methodology of the study. Firstly, since this study mainly focused on the psychological training, behavioral strategies, and behavioral cues prior to and during past diving competitions, the responses of the interviewees were based on memory; hence, certain deviations from reality may have existed. Secondly, following the interviews, the researcher found that some of the concepts and responses required supplementary information for further clarification. Multiple rounds of interviews could have resolved the problem; however, due to several reasons, only a few of the interviewees were re-interviewed in this study. Thirdly, due to restriction of resources, the researcher was not able to conduct on-spot observations and timely interviews for each competition. The majority of the behaviors were recorded by video cameras and analyzed following the competition. Information that was not covered by the cameras was not included, which hindered in-depth revelations of the athletes' behaviors. Fourthly, only four interviewees were platform diving athletes (two males and two females). This was due to the fact that the majority of the platform-diving athletes were much younger, rendering it difficult to conduct in-depth interviews.

Research Content

Based on the five-step PPRs and related theory, as proposed by Singer et al., combined with the characteristics of the competitive sport of diving and diving athletes, this study divided the diving process into 10 stages and constructed a model of PPRs of diving. The off-platform preparation (stages 1, 2, 3, 4, and 10) in this study corresponded to the stages of "evaluating," "feedback," and "readying" of the five-step routines; the on-platform preparation (stages 5, 6, 7, and 8) corresponded to the stages of "imaging" and "focusing"; while diving (stage 9) corresponded to the stage of "starting the competition with a peaceful mind." In addition, this study also uncovered the behaviors, mental tactics, and patterns of top athletes in China during different stages of competition and proposed the concept of "pace-setting" of the competition, which was a dominant factor throughout the entire PPRs. Maintaining an appropriate rhythm for each movement during off-platform preparation, on-platform preparation, and the diving process was found to be a key measure in ensuring effective self-control and smooth performance during the competition itself. The model proposed in this study clearly and comprehensively revealed the diving process and the psychological and behavioral patterns of top diving athletes during the competition process, so that developers of PPRs, and other athletes, could accurately grasp the requirements of the competition process. However, in reality, the sequence and connection between some stages are not fixed, and athletes are required to adjust their preparation sequence according to their personal habits. Moreover, when applying the model to design PPRs for diving athletes, the specific behavioral procedures should be determined with consideration of the individual characteristics of each athlete. Training on psychological skills, such as how to adjust breathing, self-talk, visualizing the moves of the dive, and concentrating, should be provided to athletes on a regular basis to improve their ability to use the skills; the athletes should also frequently test and modify the skills with practical application.

Developing personalized PPRs that can be easily mastered by athletes is a difficult task. Each athlete has their own unique characteristics. In order to uncover the indicators and habitual behaviors suitable for each athlete, it is necessary to conduct in-depth interviews, repeated observation of large quantities of video recordings, and careful observation of the training and competition process, followed by further verification. In addition to collecting responses and viewpoints from the head coach, team coach, teammates, and athletes, it is also necessary to conduct research and analysis into the personality and characteristics of individual athletes. Furthermore, in the process of designing PPRs for diving athletes, it is also necessary to regularly conduct psychological skills training for athletes, such breathing control, use of self-talk, visualization of the moves of the dive, and concentration, so as to raise their ability to use these critical skills, and to continuously test and revise these skills during application.

The findings of the study also showed that some habitual behaviors (such as hand movements and hand-body movements) during the on-platform stage were accompanied by psychological skills (such as self-talk, concentrating, and adjustment of breathing), while standing still and looking forward and downward were accompanied by visualizing the moves of the dive. Uncovering the relationship between such behaviors and psychological skills is very important for the formulation of PPRs. It is likely that the PPRs of individual dives and synchronized group dives share some common characteristics as well as distinctive stages.

The present research mainly focused on the PPRs of individual dives; hence, the constructed model is suitable for individual diving athletes in the divisions of platform and springboard diving. However, the study did not collect or analyze data related to two-person synchronized dive teams. Since the PPR routines of synchronized diving are also important to the development of the sport, it is suggested that future studies include subjects from this area of the sport.

CONCLUSION

Based on the five-step PPRs and related theory proposed by Singer et al., combined with the characteristics of the competitive sport of diving and diving athletes, this study divided the diving process into 10 stages and constructed a model for diving PPRs. The model revealed the behaviors and psychological strategies and patterns of top diving athletes in China during various stages of the competition. In addition, the concept of competition "pace-setting" was proposed.

Off-platform preparation consisted of 13 categories, including: (1) visualizing the moves of the dive; (2) adjusting breathing; (3) self-talk; (4) pace setting; (5) tracking progress using other athletes as a reference; (6) climbing out of the pool to salute the referee and the audience; (7) listening to or checking the announced score of the dive; (8) showering with hot water and then drying off; (9) returning to the rest zone to rest; (10) standing up and warming up; (11) imitating the moves of the dive; (12) looking for the coach; and (13) showering.

On-platform preparation consisted of 12 categories, including: (1) visualizing the moves of the dive; (2) adjusting breathing; (3) self-talk; (4) concentrating; (5) pace setting; (6) listening to the broadcast and starting signal prior to the dive; (7) physical arousal behavior; (8) adjusting the springboard (springboard diving); (9) imitating the moves of the dive (platform diving); (10) throwing the towel; (11) habitual behavior; and (12) standing still.

The third part is diving. The three parts are connected to one another, forming a closed behavioral cycle that clearly and comprehensively demonstrates the diving process as well as the psychological characteristics and behavioral patterns of the athletes during the diving competitions. At the same time, "pace-setting" is the key to organically connecting various stages throughout the process of PPRs and clearly and comprehensively demonstrating the diving process, psychological characteristics, and behavioral patterns of top athletes during such a process. This research mainly focused on PPRs of individual diving divisions; hence, the constructed model is suitable for individual diving athletes in the divisions of platform and springboard diving.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors to any qualified researcher, if we do not utilize it for any other purpose.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Beijing Normal University. The ethics committee waived the requirement of written informed consent for participation.

AUTHOR CONTRIBUTIONS

QY designed the study. All authors analyzed the data, wrote and revised the manuscript, contributed to the manuscript revision, and approved the submitted version.

FUNDING

This research project is primarily supported by the Science Foundation of Beijing Language and Culture University (supported by the Fundamental Research Funds for the Central Universities) (Grant number: 19YJ120001, QY), the Natural Science Foundation of Guangdong Province (Grant number: 2018A0303130006, FX), and the Natural Science Foundation of China (Grant number: 71873047, JL).

ACKNOWLEDGMENTS

We express our deepest thanks to all the elite Chinese diving athletes and coaches involved in our study.

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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.

frontiers in Psychology

OPINION
published: 21 February 2020
doi: 10.3389/fpsyg.2020.00194

What Are We Doing Wrong When Athletes Report Higher Levels of Fatigue From Traveling Than From Training or Competition?

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OPEN ACCESS

Edited by:
Donatella Di Corrado, Kore University of Enna, Italy

Reviewed by:
Fabio Rubens Serpiello, Victoria University, Australia

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: 14 December 2019
Accepted: 28 January 2020
Published: 21 February 2020

Citation:
Calleja-Gonzalez J, Marques-Jimenez D, Jones M, Huyghe T, Navarro F, Delextrat A, Jukic I, Ostojic SM, Sampaio JE, Schelling X, Alcaraz PE, Sanchez-Bañuelos F, Leibar X, Mielgo-Ayuso J and Terrados N (2020) What Are We Doing Wrong When Athletes Report Higher Levels of Fatigue From Traveling Than From Training or Competition? Front. Psychol. 11:194. doi: 10.3389/fpsyg.2020.00194

Keywords: fatigue, competition, sport, TRIP, training, travel, recovery

Performance at the elite level in running-based team sports requires outlining the cyclical nature in which physiological and biomechanical loads lead to adaptation of the biological system as a whole (Vanrenterghem et al., 2017). Very commonly, there are congested fixture periods that seem to have no effect on physical activity, technical performance, and injury incidence (Dellal et al., 2015) injury rates or patterns (Carling et al., 2016), but do seem to decrease tactical performance, as measured by levels of movement synchronization (Folgado et al., 2015).

A very high traveling frequency is required to compete in elite professional sport. For example, the National Basketball Association's regular season consists of 82 games (41 home, 41 away) played over a 6-month period (Sampaio et al., 2015). This can have consequences for both physiological and psychological status and has the potential to impair performance, as seen in common anecdotal elite basketball player reports stating: *"I want to sleep," "I didn't sleep enough," "I slept poorly," "I get tired of traveling"; "I prefer to sleep at home even if it means getting home late."*

The sentiments and feelings like the aforementioned may clearly affect the balance between happiness and wellness (Calleja-Gonzalez et al., 2018). In that way, coaches focus on respecting, valuing, involving, engaging in dialogue with, listening to, and supporting players, as well as treating them as human beings, giving them the confidence and feelings of responsibility to try (Barker-Ruchti et al., 2014). There is a clear need for more research in this area, although some advances were already made by examining empathy using qualitative methods and identifying factors of empathy between athletes and coaches (David and Larson, 2018). Furthermore, a period of constructive reflection considering the relationship between performance analysis and recovery is strongly recommended (Calleja-González et al., 2018). Thus, there is a gap between research and reality (Buchheit, 2017), because players express that they are more fatigued from traveling than from training or competition, which is the focus of this letter.

A shift in the approach to sports performance research seems to be necessary. For example, sleep quality and quantity (Gupta et al., 2017), burden associated to traveling (Fowler et al., 2014), chronobiological disturbance (Drust et al., 2005) are often cited as limiting factors of performance in high level sport, and their impact should be considered and assessed. Further, the additive effect or the means by which one factor influence another should be taken into account (Tobias et al., 2013).

Elite athletes are exposed to substantial training loads (Soligard et al., 2016), however, that is only a (small) part of the key determinants of performance. Current trends in expertise describe the concept as a dynamically varying relationship captured by the constraints of the environment and those of the performer of a task (McGuckian et al., 2018). Using this approach, the context is key and should not be detached from the content, thus, the guidelines for designing and implementation of a training program will benefit from incorporating environmental information, integrated periodization, mental performance, skill acquisition, or nutrition (Mujika et al., 2018). In addition, using the aforementioned methods in combination with athlete monitoring of training, competition and psychological load, and pooled with assessments of recovery, well-being, and illness (Schwellnus et al., 2016). It may enable the achievement of enhanced performance levels.

Since extended traveling is common in elite sport (Flatt et al., 2019), it is recommended that coaches and applied sports scientists consider the following key points in order to minimize injury risk, enhance recovery, optimize performance and reduce the effect of traveling and sleep disturbance on performance with elite team sports players (Vitale et al., 2019):

- Monitoring external training load (before, during and after competition) using tracking systems (Fox et al., 2017) with the least possible invasion.
- Monitor Internal responses using heart rate measures and biomarkers in blood, saliva, and/or urine before, during and after competition (Halson, 2014).
- Monitor daily sleep quality, sleep duration, and player well-being to inform same day adjustments to training and competition workload (Fox et al., 2019).
- Arrive early to competition destination in order to include sufficient time on-site to recover from traveling and adjust to new time-zones, altitudes, climates, and environments (Lastella et al., 2019).
- Avoid environmental changes because changing physical sleep environments may increase susceptibility to altered sleep responses, which may negatively affect performance (Pitchford et al., 2017).
- Develop and apply consistent strategies (pre, during and post-traveling) that may help prevent or ease jet lag (Fowler et al., 2014).
- Develop and apply an *ad-hoc* nutrition plan for traveling (Halson et al., 2019).

Stress on the body is probably cumulative (Issurin, 2009). Therefore, the development of new variables, such as ratios, that might relate player's fatigue, training demands, match performance, environmental conditions, at home or away, could be an interesting open window to explore. Further, the creation and validation of a travel fatigue scale would enhance an understanding of the traveling effect. Also, a scale of mental fatigue (Russell et al., 2019) that informs about the stress derived from training, competition and environmental stress would be most useful.

With the increasing popularity of sport, number of contests, and travel demands on the rise, the importance of athlete load monitoring in combination with nutritional programming, implementation of recovery methods, and proper sleep practices cannot be underestimated. Taking these steps will make for a more effective travel experience and support athlete health and playing career longevity. In the same way, rationalizing the use of measurement instruments and procedures seems also a need, as anecdotally suggests that "strict data-led regimes undermine trust and stifle creativity, shackling a player's natural empathy with the game," thus, "it is vital that those who oversee performance in elite sport consider the consequences on players of such intense surveillance."

Finally, novel scientific studies examining the impact of air traveling direction, flight time, flight duration, average flight altitude (above sea level), frequency and magnitude of height changes during flight, air cabin conditions, oxygen saturation levels, and athlete chronotype are warranted to help painting a clearer picture on how different stressors impact wellness and performance due to traveling. Athlete monitoring tools may help to understand how each of the above-mentioned variables play a role on the accumulation of both acute and chronic fatigue in elite athletes. However, common wearable technologies and test procedures may still present a burden in terms of practicality, time efficiency, reliability, and/or validity. Therefore, novel easy-to-use methodologies such as the critical fusion threshold (Clemente-Suarez and Diaz-Manzano, 2019) and Ruler Test (Eckner et al., 2015; van Schooten et al., 2019) may facilitate our ability to measure and monitor the rigors of traveling on a daily basis, specifically pertaining to its consequences on the central nervous system and psychophysics in elite athletes. However, further research and clinical trials are needed to validate its applicability. Additional topics should be considered in future researches and practical solutions such as:

- Bus/plane traveling (seats ergonomic, number of disposable seats in bus/plane) (Menegon et al., 2019).
- Seating positions/dangerous seating positions (players education and control).
- Muscle activation during traveling (Smulders et al., 2019).
- Intellectual activity during traveling.
- Problem with sleep medicaments (hypotonic effects) (DeKosky and Williamson, 2020).
- Sleep banking between travels and games (Roy and Forest, 2018).
- Designing individual players traveling profile.
- Plane/bus vibration effect on athlete's bodies (Blake et al., 2018).
- Plane/bus engine noise stressor effect (Hede, 2017).

AUTHOR CONTRIBUTIONS

JC-G: original idea and conception and design. DM-J: analysis and interpretation. MJ and JS: critically reviewed. TH, FN, AD, IJ: drafting the paper. SO, PA, and NT: final approval. XS and JM-A: approved the final version. FS-B and XL: interpretation. All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: DM-J was employed by company Deportivo Alavés, Spain.

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

frontiers in Psychology

ORIGINAL RESEARCH
published: 23 March 2020
doi: 10.3389/fpsyg.2020.00400

Former Road Cyclists Still Involved in Cycling Report Lower Burnout Levels Than Those Who Abandoned This Sport

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OPEN ACCESS

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: 10 December 2019
Accepted: 21 February 2020
Published: 23 March 2020

Citation:
Sors F, Tomé Lourido D, Damonte S, Santoro I, Galmonte A, Agostini T and Murgia M (2020) Former Road Cyclists Still Involved in Cycling Report Lower Burnout Levels Than Those Who Abandoned This Sport. Front. Psychol. 11:400. doi: 10.3389/fpsyg.2020.00400

Despite the numerous benefits associated with sport practice, many children and adolescents end up quitting it year after year, with a stable dropout rate between 10 and 19 years of age. Among the causes of sport abandonment, the scientific literature highlights the presence of burnout as a fundamental factor. In this regard, the aim of the present study was to investigate the levels of the three components of sport burnout–emotional and physical exhaustion, reduced sense of accomplishment, and sport devaluation–reported by a sample of young (former) athletes, depending on whether their sport abandonment was relative (i.e., change to another sport modality) or definitive. In particular, participants were former agonist road cyclists, who have been divided into three groups on the basis of what they did after abandoning road bicycle racing, namely: (a) those still involved in cycling, either in a different specialty (e.g., mountain bike) or with a different role (e.g., coach for kids); (b) those who started practicing a different sport; and (c) those who definitively abandoned sports. The general hypothesis was that, with respect to those who changed sport and those who definitively abandoned it, those still involved in cycling would report experiencing lower levels of the three burnout components during the last year practicing it. To test this hypothesis, the Athlete Burnout Questionnaire (ABQ; Raedeke and Smith, 2001) was administered to 85 young former road cyclists. The results seem to support the hypothesis for two out of the three components, namely, emotional and physical exhaustion and sport devaluation; on the other hand, for reduced sense of accomplishment, no difference among the three groups emerged. Further research is needed to deepen the understanding of such processes, also in relation with other relevant constructs; yet, the results of the present study should already raise the awareness of sport organizations on the need to deal with this and related phenomena by adopting appropriate strategies to ensure the well-being of young athletes, thus trying to reduce early dropout.

Keywords: burnout, cycling, sport abandonment, young athletes, emotional/physical exhaustion, reduced sense of accomplishment, sport devaluation

INTRODUCTION

The practice of physical activity and sports has been considered as a healthy habit for many decades (e.g., Tušak and Blatnik, 2014; Di Corrado, 2017; Petralia et al., 2018; Coco et al., 2019). Currently, there is consolidated evidence about how increasing exercise promotes self-esteem and cognitive functioning, as well as relieving depression levels in children and adolescents (Biddle et al., 2019). As long as the training load is appropriate for the maturation level of minors, it is unlikely that negative consequences for young athletes–such as injuries–can occur (McKay et al., 2019). However, despite the benefits undoubtedly associated with sport practice, many children and adolescents end up abandoning it year after year, with a stable dropout rate between 10 and 19 years of age (Møllerløkken et al., 2015). Crane and Temple (2015) conducted a systematic review on the issue of youth abandonment in organized sports, identifying five major areas related to it: lack of fun; perception of competence; social pressures; competitive priorities; and physical factors, such as maturation and injuries. Among the causes of sport abandonment, the scientific literature highlights the presence of burnout as a fundamental factor (e.g., Gustafsson et al., 2014; Isoard-Gautheur et al., 2016a; Larner et al., 2017).

The conceptualization of burnout arises in the clinical setting (Freudenberger, 1974). However, it is of great importance to contextualize it also in the sports environment; indeed, although most athletes do not experience this syndrome to a significant degree, it can lead to serious consequences for the physical and mental well-being of people who practice sports (Eklund and DeFreese, 2015). Burnout was defined in the sports context by Raedeke (1997), through a three-dimensional conceptualization, characterizing this syndrome by emotional and physical exhaustion, reduced sense of accomplishment, and sport devaluation. As a complement to this sports burnout model, and seeking to create a valid and reliable instrument, Raedeke and Smith (2001) developed the Athlete Burnout Questionnaire (ABQ) to measure the three postulated dimensions. This scale has shown good validity and reliability properties in different languages and cultural contexts (e.g., Arce et al., 2012).

In addition to the aforementioned sport abandonment, burnout syndrome has a series of negative consequences, such as depressed mood, psychological stress, or negative affect (De Francisco et al., 2016; Gustafsson et al., 2017a). The causes of burnout syndrome and the consequent abandonment of sports practice in young athletes are often related either with dispositional variables such as low levels of resilience and fear of failure (Gustafsson et al., 2017b; Sorkkila et al., 2019) or with motivational variables, linked to the non-satisfaction of the athlete's basic psychological needs (Sorkkila et al., 2018; Lonsdale et al., 2009). Concerning the latter, according to the self-determination theory (Ryan and Deci, 2017), intrinsic motivation would be determined by the satisfaction of the psychological needs of autonomy, perceived competence, and relatedness with others. Such postulations have been corroborated in the sports context (Gustafsson et al., 2017a), with the observation that when athletes have a high intrinsic motivational profile, they have lower levels of burnout (Gustafsson et al., 2018a). In a complementary way, other researchers postulate that sport motivation is also determined by the achievement goal theory (Nicholls, 1984; Ames, 1995); in particular, intrinsic motivation would be linked to the task goals–those goals depending on the athlete's effort–rather than to the ego goals, whose achievement is related to comparison with others in a range of superiority–inferiority (Lochbaum et al., 2016; Balaguer et al., 2017). The establishment of task-oriented goals, as well as of an empowering climate that favors athletes' self-determination, is related to a lower presence of burnout (Lonsdale and Hodge, 2011; Vitali et al., 2014).

The fact that athletes are able to maintain a high intrinsic motivation–through the satisfaction of basic psychological needs and effort goals–depends also on other variables, such as family and/or coach support, which become crucial to prevent burnout (Isoard-Gautheur et al., 2016b; Ingrell et al., 2018). Focusing on the effects that these variables have on young athletes, it was found that those who receive greater social support from their team or have higher levels of sports competence and autonomy have lower levels of burnout and higher levels of intrinsic motivation (DeFreese and Smith, 2013; Rottensteiner et al., 2015; Jowett et al., 2016). On the other hand, the absence of fun or the establishment of ego goals is closely related to the presence of burnout symptoms, as well as to sport dropout (Gardner et al., 2017; Sorkkila et al., 2018).

To contribute to this line of research, the aim of the present study is to investigate the levels of the three components of sport burnout–emotional and physical exhaustion, reduced sense of accomplishment, and sport devaluation–reported by a sample of young (former) athletes, depending on whether their sport abandonment was relative (i.e., change to another sport modality) or definitive. Specifically, as concerns relative sport abandonment, we separately considered those who remained in the same sport–either in a different specialty or with a different role (e.g., as coaches for kids)–and those who started practicing a different sport. No previous studies investigated burnout with a similar approach; however, it is reasonable to put forward the general hypothesis that, with respect to those who changed sport and those who definitively abandoned it, those who remained in the same sport would report experiencing lower levels of the three burnout components during the last year practicing the specialty they then abandoned. As previous research highlighted a potential role of gender in quitting physical activity (e.g., Labbrozzi et al., 2012; Crane and Temple, 2015), we also tested for gender differences in reported burnout levels (regardless of the sport activity participants have undertaken after abandoning the specialty they practiced).

MATERIALS AND METHODS

Participants

Eighty-five former agonist road cyclists (40 females, 45 males) were recruited as participants. At the moment of data collection, their age ranged between 18 and 25 years ($M = 20.49$, $SD = 1.71$). On average, they abandoned road bicycle racing when they were 16.35 years old ($SD = 1.45$); on average, the abandonment occurred 4.62 years ($SD = 1.71$) before data collection.

Participants were divided into three groups on the basis of what they did after abandoning road bicycle racing: (a) those still involved in cycling, either in a different specialty (e.g., mountain bike) or with a different role (e.g., coach for kids); (b) those who started practicing a different sport; and (c) those who definitively abandoned sports. From now on, the three groups will be called "Cycling other" ($N = 33$), "Different sport" ($N = 29$), and "No sport" ($N = 23$), respectively. **Table 1** summarizes the descriptive data of the three groups; as can be noticed, the groups did not differ in terms of age at data collection, age at road bicycle racing abandonment, and years between abandonment and data collection.

Informed consent was obtained from each participant prior to the beginning of the data collection. The protocol was approved by the Ethics Committee of the University of Trieste, and the study was carried out in accordance with its recommendations.

Questionnaire and Procedure

The ABQ (Raedeke and Smith, 2001) is a self-report inventory consisting of 15 items, equally distributed among the three subscales of emotional and physical exhaustion, reduced sense of accomplishment, and sport devaluation. In the present study, the Italian translation used by Vitali et al. (2014) was administered. With respect to the original version, we modified the general request to refer to the last year participants practiced road bicycle racing, that is, "Thinking about your last year practicing road bicycle racing, rate how often you experienced the following situations"; accordingly, the tense of all items was changed from present to past. Items were to be answered like in the original version, that is, on a five-point Likert scale, with the following anchors: (1) almost never, (2) rarely, (3) sometimes, (4) frequently, and (5) almost always. For each participant, the score of each subscale corresponds to the average of the responses given to the five items characterizing it.

In addition, participants were asked to specify the following information: their sex, their current age, and their age when they abandoned road bicycle racing, the year they abandoned road bicycle racing, and what they did at a sport level after abandoning road bicycle racing.

For data collection, a digital survey was prepared by means of Google Forms, including both the ABQ and the personal questions mentioned above. Such a survey was preceded by the description of relevant information about the study, to allow participants to express their informed consent. The form was structured in such a way that when consent was expressed, the browser automatically redirected to the survey; on the other hand, when consent was denied, the browser automatically redirected to a standard exit page.

As concerns the procedure, in a preliminary phase, young former road cyclists from the Italian regions of Friuli Venezia Giulia and Veneto were contacted and informally asked for their availability to participate to the study. Those who agreed (>98%) were sent the link to the form described above.

TABLE 1 | Descriptive data of the three groups of participants.

Group	Sex	Age at data collection (M ± SD)	Age at road bicycle racing abandonment (M ± SD)	Years between abandonment and data collection (M ± SD)
Cycling other	F = 12, M = 21	20.67 ± 1.65	16.64 ± 1.25	4.58 ± 1.46
Different sport	F = 15, M = 14	20.48 ± 2.05	16.00 ± 1.63	4.97 ± 1.95
No sport	F = 13, M = 10	20.26 ± 1.32	16.39 ± 1.44	4.26 ± 1.71

Statistical Analyses

Preliminarily, we calculated Cronbach's alpha for each subscale of the ABQ. Then, to address the main research question of the study, a multivariate analysis of variance (MANOVA) was conducted, considering each of the three subscales of the ABQ in relation with what participants did after abandoning road bicycle racing; *post hoc* comparisons were run using the least significant difference (LSD) correction. Finally, to investigate for potential gender differences in reported burnout levels, another MANOVA was performed, considering each of the three subscales of the ABQ in relation with gender. The analyses were run using the statistical software SPSS 25.0 for Windows.

RESULTS

Cronbach's alpha values were 0.87 for emotional/physical exhaustion, 0.81 for reduced sense of accomplishment, and 0.80 for sport devaluation.

With regard to the main research question, the MANOVA revealed a significant main effect for the subscales "emotional and physical exhaustion" [$F(2,82) = 3.96$; $p < 0.05$; $\eta^2 = 0.09$; power = 0.70] and "sport devaluation" [$F(2,82) = 4.16$; $p < 0.05$; $\eta^2 = 0.09$; power = 0.72]. Conversely, the analysis did not reveal a significant value for the main effect of the subscale "reduced sense of accomplishment" [$F(2,82) = 0.11$; $p = 0.90$].

As for emotional and physical exhaustion, the *post hoc* analyses highlighted: (a) a significant difference between the group *Cycling other* and the group *Different sport*, with lower levels for the former group ($p < 0.05$; *Cycling other*: M = 1.68, SD = 0.62; *Different sport*: M = 2.22, SD = 0.91); (b) a significant difference between the group *Cycling other* and the group *No sport*, with lower levels for the former group ($p < 0.05$; *No sport*: M = 2.11, SD = 0.89); and (c) no difference between the group *Different sport* and the group *No sport* ($p = 0.88$).

As for reduced sense of accomplishment, the *post hoc* analyses revealed no difference in the three comparisons between pairs of groups (*Cycling other* versus *Different sport*: $p = 0.81$; *Cycling other* versus *No sport*: $p = 0.80$; *Different sport* versus *No sport*: $p = 0.64$). In particular, the scores for each condition were the following: *Cycling other*: M = 3.28, SD = 0.80; *Different sport*: M = 3.23, SD = 0.84; and *No sport*: M = 3.34, SD = 0.94.

As for sport devaluation, the *post hoc* analyses highlighted: (a) a significant difference between the group *Cycling other* and the group *Different sport*, with lower levels for the former group

($p < 0.05$; *Cycling other*: M = 2.00, SD = 0.82; *Different sport*: M = 2.48, SD = 0.93); (b) a significant difference between the group *Cycling other* and the group *No sport*, with lower levels for the former group ($p < 0.05$; *No sport*: M = 2.67, SD = 1.00); and (c) no difference between the group *Different sport* and the group *No sport* ($p = 0.45$). All results are summarized in **Figure 1**.

With regard to the potential gender differences in reported burnout levels, the MANOVA revealed no differences between females and males in any of the subscales (emotional/physical exhaustion: $p = 0.21$; reduced sense of accomplishment: $p = 0.08$; sport devaluation: $p = 0.60$). In particular, for emotional/physical exhaustion, the score for females was M = 1.86, SD = 0.75, while for males, M = 2.09, SD = 0.89; for reduced sense of accomplishment, the score for females was M = 3.11, SD = 0.94, while for males, M = 3.43, SD = 0.72; for sport devaluation, the score for females was M = 2.40, SD = 1.05, while for males, M = 2.29, SD = 0.84.

DISCUSSION

The aim of the present study was to investigate the levels of the three components of sport burnout–emotional and physical exhaustion, reduced sense of accomplishment, and sport devaluation–reported by a sample of young (former) athletes, depending on whether their sport abandonment was relative or definitive. The general hypothesis was that, with respect to those who changed sport and those who definitively abandoned it, those who remained in the same sport (in a different specialty or with a different role) would report experiencing lower levels of the three burnout components during the last year practicing the specialty they then abandoned. The results seem to support this hypothesis for two out of the three components, namely, emotional and physical exhaustion and sport devaluation. Indeed, the group *Cycling other*–that is, former agonist road cyclists still involved in cycling, either in a different specialty (e.g., mountain bike) or with a different role (e.g., coaches for kids)–reported experiencing lower levels of these two components during the last year practicing road bicycle racing with respect to both those who started practicing a different sport from cycling and those who definitively abandoned sports. Instead, for reduced sense of accomplishment, no difference among the three groups emerged. Interestingly, between the groups of those who changed sport and those who definitively abandoned it, no difference emerged also for the other two components. Moreover, as a secondary result, no gender differences emerged in any of the three burnout components.

There are two potential explanations for the main results. On the one hand, we can speculate that, during the last year practicing road cycling, participants had actually experienced the different burnout levels they have reported in the present study, and (also) based on these, they decided to remain in cycling or to abandon it. On the other hand, we can speculate that such differences did not actually exist, but the fact of remaining in cycling versus abandoning it has influenced participants' memories about the burnout levels experienced during the last year practicing road cycling, with a softening effect for those who remained in cycling and a worsening effect for those who abandoned it. Of course, it is also possible–and reasonable–to think about a combination of these two explanations: some differences in burnout levels may have actually existed (contributing to the decision of remaining in cycling or not), and they could have been magnified by the subsequent experiences of participants.

As for the first potential explanation (i.e., the actual experience of different burnout levels), the establishment of a sport identity specifically associated with cycling might have occurred. The establishment of such an identity would be promoted by the satisfaction of the basic psychological needs in that sport in particular and by the resulting intrinsic motivation (Reifsteck et al., 2016). As children and adolescents play a particular sport, they develop an identity associated with their role as an athlete, as part of their self-concept (Brewer et al., 1993). However, if this identity is mono-dimensional–focusing only on sport practice and excluding other personal aspects–when sport abandonment occurs, it can lead to the suffering of psychiatric symptoms and burnout, both in young people and in adults (Giannone et al., 2017; Chang et al., 2018; Gustafsson et al., 2018b). As a consequence, especially for children and adolescents, on the one hand, it is essential to develop an identity as an athlete that allows them to feel competent and autonomous and maintain positive relationships with their peers; on the other hand, to prevent negative consequences in case of sport abandonment (either relative or definitive), such an identity should not be mono-dimensional, being preferably focused on their overall development as athletes rather than exclusively linked to their competence in a specific sport (Coakley, 1992). To evaluate the appropriateness of this interpretation, future studies aimed at investigating similar issues should take into consideration the potential mediating effects that the (non-)satisfaction of basic psychological needs could have on burnout levels. From a broader perspective, in future studies, former athletes from sports other than cycling should also be involved, in order to evaluate the degree of generalizability of the results that emerged from the present investigation. In particular, it would be interesting to see whether, when considering also former athletes from other sports, the absence of a difference concerning reduced sense of accomplishment, as well as the absence of a difference between those who changed sport and those who definitively abandoned it, is confirmed.

As for the second potential explanation (i.e., the influence of participants' subsequent experiences on their memories), there are two aspects to be considered in this regard. On the one hand, it is well known that explicit memory is reconstructive, namely, people's current thoughts and feelings influence the recall of their past thoughts and feelings (e.g., Levine, 1997; Ross and Newby-Clark, 1998); in particular, memories of emotional states are updated in light of subsequent experience (e.g., Safer et al., 2002; for a review, see Levine and Safer, 2002). On the other hand, people typically exaggerate the intensity of past emotions, overestimating the intensity of both the positive and negative emotions actually experienced (e.g., Wirtz et al., 2003; for a review, see Levine et al., 2006). In light of these two mechanisms–which are not mutually exclusive–and considering the fact that

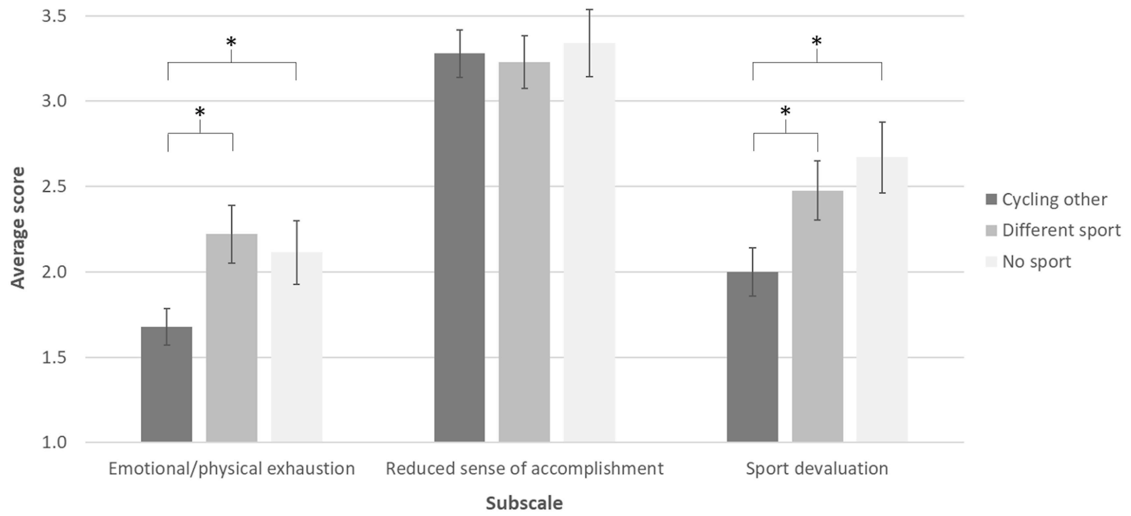

FIGURE 1 | Average scores of the three groups for the three subscales of the Athlete Burnout Questionnaire (ABQ); error bars show the standard error of the mean; $^*p < 0.05$.

both those who remained in cycling and those who abandoned it had experienced negative emotions during their last year practicing road cycling, it is reasonable to hypothesize that all participants overestimated such negative emotions, but those still involved in cycling did it to a minor extent with respect to those who abandoned this sport. The experimental design used in the present study did not allow us to test this hypothesis; to evaluate its appropriateness, future studies on this topic should adopt a design typically used to investigate memories of emotional states, with repeated measurements during and after the event(s) of interest. However, identifying in advance athletes who are willing to abandon the sport they are practicing is not easy; a possible strategy is to start "monitoring" some teams toward the end of a sport season to identify the missing athletes at the beginning of the new one, so that the first measurement can occur only a couple of months after the abandonment (relative or definitive).

To sum up, the present study revealed that former agonist road cyclists still involved in cycling (either in a different specialty or with a different role) reported that they had experienced lower levels of emotional and physical exhaustion and sport devaluation during the last year practicing this specialty, with respect to both those who started practicing a different sport and those who definitively abandoned it. Interestingly, the presence of differences in these two burnout components, as well as the absence of differences in reduced sense of accomplishment, is coherent with a recent study by Gerber et al. (2019), which highlighted greater emotional/physical exhaustion and sport devaluation in young elite athletes reporting high compared to low burnout symptoms. A reasonable explanation for the results observed in our study is that some differences in burnout levels actually existed (contributing to the decision of remaining in cycling or not), and these differences have been magnified by the subsequent experiences of participants. Further research is needed to deepen the understanding of such processes, also in relation with other relevant constructs, like for example, the (non-)satisfaction of basic psychological needs. The secondary result of the absence of gender differences in the reported burnout levels suggests that burnout itself would not contribute to gender differences in the early dropout phenomenon.

Interestingly, the present study adds to the literature of psychology in the domain of cycling; previous psychological studies addressed other aspects related to cycling, such as mood (e.g., Murgia et al., 2016), recovery–stress balance (e.g., Filho et al., 2013, 2015), attentional focus (e.g., Bertollo et al., 2015; di Fronso et al., 2018), and psychobiosocial states (e.g., Robazza et al., 2017). As concerns psychobiosocial states, other studies highlighted their potential role as mediators of the relationship between the perceived motivational climate by young athletes and their motivation to continue playing sports (e.g., Bortoli et al., 2009, 2011, 2014); thus, psychobiosocial states also could be taken into consideration by future studies aiming to better understand the role of burnout in sport abandonment.

From an applied perspective, the results of the present study highlight two important aims to be pursued by sport organizations to prevent young athletes from experiencing negative emotions potentially leading to burnout and, consequently, to sport abandonment (relative or definitive): on the one hand, avoiding the exasperation of emotional and physical components of sport practice, and on the other hand, maintaining positive and meaningful feelings associated to it. It is quite intuitive that in this process, among all the figures populating sport organizations, a key role is played by the coaches; however, in dealing with these issues, young athletes may significantly benefit also from the interventions and the support provided by sport psychologists. From a broader perspective, findings deriving from studies on similar issues should raise the awareness of sport organizations on the need to deal with this and related phenomena by adopting appropriate strategies to ensure the well-being of young athletes, thus trying to reduce early dropout.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

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

AUTHOR CONTRIBUTIONS

FS, IS, and MM conceived the idea. FS, DT, SD, IS, AG, TA, and MM designed the study. FS, SD, and AG prepared the digital form for data collection. SD recruited participants and collected the data. FS, MM, and TA analyzed the data. FS, DT, and MM wrote the first draft of the manuscript. SD, IS, AG, and TA revised 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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 17 April 2020
doi: 10.3389/fpsyg.2020.00633

Mental Imagery Skills in Competitive Young Athletes and Non-athletes

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Mental imagery is a fully immersive multi-sensory procedure that associates as numerous senses to create a mental image and process it without the presence of external stimuli. In the sport situation, imagery has been designated as the state in which people imagine themselves while effecting abilities to deal with the forthcoming duty or improve performance. Methodical analyses have revealed that imagery increases performance in motor tasks. This study aims at observing not the vividness of image but the cognitive abilities useful for the inspection, maintenance, generation, and manipulation of dissimilar classes of images, investigating modifications in mental imagery skills in competitive athletes and non-athletes. Participants were competitive athletes (n = 48) and non-athletes (n = 48) between the ages of 8 and 13 years (M_{age} = 10.50, SD = 1.73). The athletes had a minimum of 5 years of training skill in the sport. They completed the Mental Imagery Test (MIT). Competitive athletes showed higher scores on mental imagery skills than non-athletes. The study contributed to increase the exploration in the definite area of mental imagery, supplying an added support for the pluridimensional nature of mental imagery and for its practicality in motor and sport sciences.

Keywords: mental imagery, children, athletes, sport, cognitive performance

OPEN ACCESS

Edited by:
Mauro Murgia, University of Trieste, Italy

Reviewed by:
Selenia Di Fronso, Università degli Studi G. d'Annunzio Chieti e Pescara, Italy
Tommi Sipari, University of Jyväskylä, Finland

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *19 February 2020*
Accepted: *17 March 2020*
Published: *17 April 2020*

Citation:
Di Corrado D, Guarnera M, Guerrera CS, Maldonato NM, Di Nuovo S, Castellano S and Coco M (2020) Mental Imagery Skills in Competitive Young Athletes and Non-athletes. Front. Psychol. 11:633. doi: 10.3389/fpsyg.2020.00633

INTRODUCTION

Mental imagery is the reproduction of perceptual experience (Kosslyn et al., 2001; Pearson, 2007) across multisensory ways and the processing of images in the absence of external stimuli. Mental imagery is a significant element in human functioning.

In the sport situation, imagery has been designated as the state in which people imagine themselves while effecting abilities to deal with the forthcoming duty or improve performance. Imagery may be a consequence from both thoughtful and unconscious recall procedures; an individual sees an image, or experiences a movement as an image, without experiencing the real thing through a process. Imagery plays a significant role in this context, improving performance in motor tasks (Di Corrado et al., 2014, 2019).

It is usually assessed in relations of its mental and emotional characteristics, as well as motivational competence (Cumming and Williams, 2012). Owing to the gains of imagery, it is, nowadays, included in numerous mental skills line-ups, in addition to physical preparation.

Various overlying terms have been utilized to refer to several sides of mental imagery in sports (Hale et al., 2005; Cumming and Ramsey, 2009; Collet et al., 2013). Morris et al. (2005) proposed that a further complete description of sports imagery is "*the intentional or unintentional conception or regeneration of an experience produced from memorial information, concerning quasi-affective and quasi-sensorial features that may occur in the absence of the tangible stimulus antecedents usually associated with the real experience*" (p. 19).

Within the mental mode, kinesthetic (i.e., perceptual involvement of the body while executing a movement) and visual (i.e., what a person sees) are the most usual sensory tested mentally approaches of creating images (Guarnera et al., 2016).

However, imagery is a complex construct. In the several explorations of mental imagery, researchers have investigated equally *imagery use* and *imagery ability*. The capability of creating vivid images is different from the competence in controlling and manipulating the created images (Morris et al., 2005). Cognitive psychology designed instruments to measure imagery ability into two aspects: controllability, i.e., "*manipulate mentally an image in precise way*" (Guillot and Colle, 2010; Pirrone and Di Nuovo, 2014), and vividness, i.e., "*the sensory richness of an image*" (Murphy, 2005). Murphy and Martin (2002) defined imagery use as the "*use of imagery to reach a variety of cognitive, behavioral, and affective changes*" (p. 418). Hall et al. (1998) underline that images address distinct motivational and cognitive aspects, both on a common and definite level. Consequently, differentiations in the use of imagery occur: cognitive specific (e.g., movements), cognitive general (e.g., tactics), motivational general, motivational specific (e.g., aims), motivational general–affective (e.g., anxiety), and motivational general–mastery (e.g. self-confidence).

In addition to the aforementioned considerations, the model of imagery suggested by Kosslyn et al. (2006) established which cognitive procedures are required in order to generate the configurations of behavior related with the everyday use and experience of mental imagery (Slotnick et al., 2012). These processes consist of generation, inspection, maintenance, and manipulation of visual images, in the lack of visual input. In detail, generation is the ability to generate mental representations deprived of a perceived stimulus. Maintenance is the capacity to maintain images in the short-term memory. Inspection describes the capacity to explore a generated image to interpreting a spatial property or an object-based characteristic of the image. Manipulation is the capacity to modify a mental image in some manner. Individuals can manipulate, transform, or rotate objects in visual imagery much like real objects, in their mind (Pearson and Kosslyn, 2013). This component of "controllability" of the images has been less studied in athletes.

Although previous investigation on mental imagery has principally concentrated on adult athletes, fewer studies have examined the young athlete population. Ashby (1983) have showed that imagery ability does not grow completely until 7 years of age. Parker and Lovell (2009) discovered high improvement in imagery ability in athletes between 7 and 17 years of age. Regarding the imagery use, previous studies showed that young athletes, competing at different levels, obviously use all components of imagery (Munroe-Chandler et al., 2007a; Parker and Lovell, 2012).

Comparing athletes' imagery with that of non-athletes, Isaac and Marks (1994) investigated whether distinctions in movement and visual imagery vividness can be assessed in 16 different sporting disciplines. Results showed that elite athletes had significantly higher vivid imagery than non-athlete controls. Williams and Davids (1995) compared the soccer knowledge base of three groups of participants: highly skilled, lower skilled, and controls (who had never played the game). Results showed that the highly skilled participants scored considerably higher than the others did on the ability to recognize and recall soccer movements. Moreau et al. (2011) investigated whether the level of expertise in a particular sport is related to better motor performance and spatial abilities, such as mental rotation, in particular. The findings indicated that young elite athletes reported consistent high performance in the spatial ability.

In a research on high school athletes, Godoy-Izquierdo et al. (2007) described more levels of imagery in elite athletes compared with non-elite ones. Mohammadzadeh and Sami (2014) investigated some psychological skills such as motivation, imagery, arousal, focus, self-confidence, and goal setting of elite and non-elite volleyball players (N = 60). Regarding imagery as the usage of all the senses to recreate or make an experience in mind, the results indicated that elite volleyball players had superior performance than non-elite ones.

Nevertheless, little investigation has been conducted on younger athletes comparing imagery—i.e., perception without present stimuli—with other cognitive abilities (e.g., spatial perception and visual memory).

The aim of the current study is to investigate the ability of children to engage in visual and spatial mental imagery (image maintenance, image inspection, image generation, and image manipulation), and to compare these processes between athletes and non-athletes (8–13 years of age). This age range has been selected as it is recommended that children aged 7 and over can form kinesthetic and transformational images (Piaget and Inhelder, 1971). In fact, although in disagreement with Piaget's theory, much research has demonstrated that under certain conditions, children younger than 7 years of age can transform visual mental images (Quaiser-Pohl et al., 2010; Guarnera et al., 2017, 2019). There is general agreement that children over 7 years of age improve their imagery ability, as they move from perceptual to conceptual activity (Munroe-Chandler et al., 2007b).

We expected athletes to show greater ability in controlling mental images than non-athletes.

MATERIALS AND METHODS

Participants and Procedure

The participants Were competitive athletes (n = 48) and non-athletes (n = 48) Between the ages of 8 and 13 years. the groups Were matched so they Had the same mean and standard deviation (M_{age} = 10.50, SD = 1.73, t = 0).

The athletes had a minimum of 5 years of training skill in the sport, and they were all associates of sport clubs. These athletes had different competitive sport backgrounds (e.g., soccer, karate, gymnastics, dance, and handball). Their hours of exercise per week ranged from 3.0 to 21.5 h (M = 7.39, SD = 3.41). Forty-eight students who had no experience in any sport represented control participants. Participants did not obtain before mental abilities or imagery training. Measurements were carried in clusters of four participants. Athletes were tested in an isolated place near the training accommodations. The control group was from dissimilar classes and was tested in a separate place near the school at the end of the educational activities. Prior to the beginning of the study, ethical approval was granted from the first author's university ethics committee. The study obtained ethical permission from the University Enna Kore Internal Review Board for psychological research (September 26, 2019).

Before starting the protocol, parents signed a consent form, and were informed about the processes of the study and the anonymity of their answers, in accordance with the Declaration of Helsinki.

Measures

Imagery Assessment

A sequence of tasks evaluating mental imagery skills including maintenance, inspection, generation, and manipulation of different categories of images was administered. Eight tasks are incorporated in the Mental Imagery Test (MIT) and standardized for usage in childhood (Di Nuovo et al., 2014):

Visualizing letters

The individuals are invited, without seeing the stimuli and spending only imagination, to say which upper-case letters have curled parts (e.g., A, P, or R; not L, M, or N).

Brooks "F" test

With their imagination, the individuals are asked to walk along the delineation of a large upper-case letter F earlier viewed for 30 s on a reproduced card. The individual is asked to say whether the limits encountered when moving from the lower left corner in a counter-clockwise direction are external or internal.

Clock

The task necessitates imagining a clock with hands indicating 10 min past 10:00, then imagining the clock reproduced in a mirror and saying what time the mirrored clock will show after 10 min.

Cube

The image of a large cube is shown for 30 s; it is collected of nine small cubes per face (3 × 3), and the external faces are colored. After the stimulus is detached, the subject is asked to state how many small cubes have three, two, one, or none external (colored) faces.

Subtraction of parts

A digital display with the number 88 collected of small segments is shown for 10 s. Then, another digital display with designated segments of a two-digit number is shown for 10 s. The individual is asked to imagine what two-digit number will remain after deducting the parts of the new figure from the figure with all digits seen beforehand.

Mental exploration of a map

The individual is presented with a map of an island, with a house, a church, a lake, and a wood located on it. The instructions ask to look with attention at the map, staring at the distances among the elements located. After the map is detached, the individual is asked to answer four questions about the comparative distance between couples of the earlier seen components.

Imagined paths

The individual is asked to imagine a small ball moving in dissimilar directions, succeeding a suggested path in the imagined space, and saying if at the end of the route the ball will end up above or below the initial point, or at the similar level.

Mental representation of shapes of objects

The individual hears the names of 20 concrete objects (e.g., bottle, pizza, candle, tower, and bed) and is asked to imagine them and select if the object has a taller or larger form.

A total score of mental imagery can be found by the sum of the scores in the single subtests. Cronbach's alpha for this

TABLE 1 | *T*-test results.

Variables		Controls	Athletes	*T*	P
Mental imagery abilities					
Visualizing letters	M	10.02	11.88	−6.22	< 0.001
	SD	2.04	0.33		
Brooks "F" test	M	4.10	7.44	−6.43	< 0.001
	SD	2.42	2.66		
Clock	M	1.29	0.08	5.00	< 0.001
	SD	1.62	0.40		
Cube	M	1.15	1.71	−1.40	0.17
	SD	1.53	2.33		
Subtraction of parts	M	5.04	10.04	−8.65	< 0.001
	SD	3.23	2.37		
Mental exploration of a map	M	4.00	5.23	−4.64	< 0.001
	SD	1.49	1.08		
Imagined paths	M	4.29	7.48	−6.03	< 0.001
	SD	2.56	2.62		
Mental representation of shapes of objects	M	14.13	18.54	−7.24	< 0.001
	SD	4.12	0.94		
Memory and visual perception					
Forward digit-span	M	3.87	5.10	−4.07	< 0.001
	SD	1.95	0.75		
Backward digit-span	M	1.88	3.79	−7.56	< 0.001
	SD	1.45	0.99		
Visual–spatial memory test	M	2.29	15.35	−16.39	< 0.001
	SD	2.93	4.68		
Memory of objects	M	5.12	6.63	−5.73	< 0.001
	SD	1.67	0.70		
Memory of position of objects	M	6.15	9.56	−6.30	< 0.001
	SD	3.05	2.20		
Mirror reproduction of spatial position	M	9.58	15.31	−6.38	< 0.001
	SD	5.80	2.25		

score of imagery is 0.75. A confirmatory factor analysis showed the monodimensionality of the measure containing the eight tasks, in a sample of 556 participants aged 8 to 13 years (chi-square = 186.28, $p < 0.01$; Root Mean Square Error of Approximation (RMSEA) = 0.09, $p < 0.01$; Comparative Fit Index (CFI) = 0.90; Standardized Root Mean (SRM) = 0.05; Goodness of Fit Index (GFI) = 0.93 (Di Nuovo et al., 2014).

The selection of the tasks, resulting from the preceding literature on mental imagery, was designed at expressing all the functions implicated in imagery, agreeing to the classification proposed by Pearson et al. (2013).

Comparison Tasks

With the aim of discriminating mental imagery abilities from those based on memory and visual perception—without necessitating active generation and/or alteration of mental images—some other cognitive standardized tasks are proposed.

Forward and backward digit span

The individual hears gradually increasing digit series, and has to repeat them in direct or backward order. Verbal working memory is implicated in these attentive tasks.

Memory of objects and of position of objects

The individual, after seeing seven concrete objects for 30", is invited to evoke as many of them as possible in a free recall. Subsequently, the individual has to recall the position in a matrix of six objects before seen for 30".

Visual–spatial memory test

Individuals are presented for 10" with a matrix in which a number of cells are completed and, after, are required to recall where they were located using a blank matrix. Six matrices are presented, and completed cells increase gradually from 2 to 4.

The tasks of memory of position, for both objects and matrices, necessitate a passive maintenance of spatial position in working memory and, consequently are useful to differentiate this skill from active elaboration of mental images.

Mirror reproduction of spatial position

The individual is requested to copy a model in a mirror position, though really seeing the model. This task of copy includes spatial perception without active alteration of images.

Statistical Analyses

Differences between the two groups of participants were assessed by t-test comparisons. Moreover, Pearson correlational analyses were completed to explore possible existing relationships between mental imagery abilities, and memory and visual perception within each group of participants. Statistical analyses were performed using SPSS version 23 Statistical Software Package for Windows (SPSS Inc., Chicago, IL, United States).

RESULTS

Preliminary, for the global score of imagery, we verified that the general difference due to the gender was non-significant: males' mean = 53.27, SD = 13.74; females' mean = 53.15, SD = 12.24; t = 0.05; p = 0.96. For this reason, the subsequent analyses were carried out without taking into account gender.

The analyses of differences in the performances of controls and athletes in the specific tasks are shown in **Table 1**.

Results showed high significant differences in all mental imagery abilities (except the "cube" test) and, in memory and visual perception with athletes. The only task showing a different trend is "clock," the performance being better in the control group.

In addition, the difference in the total score of imagery is highly significant: for the athletes group, mean = 62.40, SD = 7.13; for the controls group, mean = 44.02, SD = 10.74; t = −9.87, $p < 0.001$.

Correlational analyses between imagery tasks and perceptual and memory tests were performed separately for the two groups of athletes and controls (**Tables 2**, **3**). Bonferroni confidence interval adjustments were used throughout.

Results showed that the mental imagery performances are differently correlated with perceptual and memory ones. As for

TABLE 2 | Pearson correlation matrix between imagery subtest and perceptual and memory tasks—athletes.

Athletes	Forward digit-span	Backward digit-span	Visual–spatial memory test	Memory of objects	Memory of position of objects	Mirror reproduction of spatial position
Visualizing letters	0.31*	0.11	0.27	0.16	0.27	0.08
Brooks "F" test	0.19	0.13	0.38**	0.01	0.27	0.19
Clock	0.25	0.15	0.14	0.11	0.14	−0.08
Cube	−0.10	0.32*	−0.08	−0.07	−0.09	0.15
Subtraction of parts	0.32*	0.22	0.05	0.32	0.14	0.37**
Mental exploration of a map	0.05	0.07	−0.02	0.34*	0.16	−0.10
Imagined paths	0.37**	0.34*	0.22	0.22	0.00	0.42***
Mental representation of shapes of objects	0.25	0.37**	0.21	0.22	0.27	0.35*

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 3 | Pearson correlation matrix between imagery subtest and perceptual and memory tasks—controls.

Controls	Forward digit-span	Backward digit-span	Visual-spatial memory test	Memory of objects	Memory of position of objects	Mirror reproduction of spatial position
Visualizing letters	0.26	−0.09	0.32*	0.16	0.10	0.24
Brooks "F" test	0.45***	0.30*	0.60***	0.48***	0.60***	0.10
Clock	−0.07	−0.04	0.08	−0.06	−0.01	0.01
Cube	−0.25	−0.07	0.29*	0.08	0.17	0.06
Subtraction of parts	0.31*	0.55***	−0.09	0.32*	0.04	0.32*
Mental exploration of a map	0.25	0.20	0.34*	0.42***	0.35**	0.31*
Imagined paths	0.49***	0.49***	0.46***	0.63***	0.57***	0.32*
Mental representation of shapes of objects	0.56***	0.61***	0.30*	0.61***	0.62***	0.57***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

group differences, an interesting exception to the general trend is the "clock" task, which is positively (although not significantly) correlated with memory and perception tasks in athletes, while in the control group, these correlations are null or inverse.

DISCUSSION

The present study aimed to assess the ability of children to engage in visual and spatial mental imagery (image maintenance, image inspection, image generation, and image manipulation), and to compare these processes between athletes and non-athletes.

Results showed high significant differences in all mental imagery abilities (except the "cube" test) and, in memory and visual perception with athletes. According to Moreau et al. (2011), imagery ability is known to be closely related to visual perception and to be determinant in learning, memory, and motor processes.

The only task showing a different trend is "clock": the performance being better in the control group. This suggests that image maintenance abilities depend on stimulus complexity, according to previous research (e.g., Kosslyn, 1994; Frank et al., 2016). Children are better able to recall an image with specific features than an image with a more abstract pattern (Simonsmeier and Buecker, 2017). We, therefore, determine that the image generation task reasonably plays a significant role in reversal ability: the ability to form an image of another interpretation and impose this imagined assembly onto the figure.

Correlational analyses showed that the mental imagery performances are differently correlated with perceptual and memory ones. In the group of young athletes, the significant correlations are few and with lower size, indicating that in this group, the imagery functions are more independent from perception and memory than in non-athletes, and this independence could justify the overall better performance. We know that having solid mental imagery is an advantage to resolving visual and spatial tasks; nevertheless, our results propose that persons might use diverse cognitive approaches to resolve the similar visual memory task.

An interesting exception to this general trend is the "clock" task, which is positively correlated with memory and perception tasks in athletes (not significantly, although the size of the correlation with the forward digit span is relevant, i.e., 0.25), while in the control group, these correlations are null or inverse. In this task, the performance of the group of athletes is worse than that of the non-athletes; it could be influenced by the integration between memory and perceptual abilities, differently from controls. In fact, this task—being the most difficult—requires more than others to join visualizing and remembering the position in the space (of the hands of the visualized clock) and, therefore, an integration between imagery and other cognitive function, less present in the group of athletes as demonstrated in the other tasks. Probably, the young athletes are less able in the clock task for their less familiarity with analogical clocks, since they have more practice with digital clocks (e.g., for monitoring functioning during training and performances). For the same reason, in this task, the influence of the perceptual and memory abilities is more relevant in the athletes.

Despite the strengths of the current study, which include novel findings for a young population, there are several limitations that should be noted. For one, the ability of children to engage in visual and spatial mental imagery could be resulted with a longitudinal design. The relationship between the variables could be identified through since to start sport. Future research should investigate the mechanism more specifically, for example, investigating the association between cognitive-specific imagery ability and learning development of athletes.

CONCLUSION

In conclusion, it can be determined that imagery seems to be an instinctive psychological ability, which grows in early years of life. This finding is in line with previous studies, which showed that children often use imagery to acquire skills in a natural way (Wolmer et al., 1999; Munroe-Chandler et al., 2007a). Consequently, to improve learning, performance, and other results related with imagery (such as self-efficacy, anxiety regulation, and cognition), athletes and coaches should incorporate the regular practice of mental imagery in their training programs.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University Enna Kore Internal Review Board for psychological research (September 26, 2019). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

DD, MG, SD, and MC contributed to the conception and design of the study. CG and SC were responsible for testing. MC, MG, SD, DD, and NM were responsible for data collection and statistical analysis. DD, MG, and MC were responsible for drafting and finalization of the manuscript. All authors contributed to manuscript revision and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.00633/full#supplementary-material

DATA SHEET S1 | Datasets for this study.

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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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 23 April 2020
doi: 10.3389/fpsyg.2020.00628

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Stress and Coping in Esports and the Influence of Mental Toughness

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This study explored stress and coping in electronic sports (esports) athletes and the influence of mental toughness (MT), as defined by two prominent conceptualizations: the 4/6Cs and Mental Toughness Index (MTI) frameworks. Participants were 316 esports athletes, ranked in the top 40% of one of five major esports: Defense of the Ancients 2, League of Legends (LoL), Counter Strike: Global Offensive, Overwatch and Rainbow Six: Siege. Participants completed the MTI, Mental Toughness Questionnaire 6 (MTQ6), Stress Appraisal Measure, and Brief COPE inventory. Results showed that MT (via both MT frameworks) was associated with perceived control, and MTQ6 subscales were associated with stress intensity. Mental toughness (both frameworks) was associated with the selection of more problem-focused and emotion-focused coping strategies and less avoidance coping strategies. The results indicate there is some overlap between the MT and stress-coping process in high-performing traditional sports and competitive esports athletes. These results suggest that esports athletes could benefit from sports psychology interventions designed for traditional sports athletes. Finally, the MTQ6 and MTI had low shared variance (20%), suggesting that the two questionnaires appear to measure different aspects of MT.

Keywords: electronic sport, threat, challenge, control, intensity appraisal

OPEN ACCESS

Edited by:
Alessandro Quartiroli, University of Wisconsin–La Crosse, United States

Reviewed by:
Mark J. Campbell, University of Limerick, Ireland
Ismael Alfonso Pedraza Ramirez, German Sport University Cologne, Germany

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *19 December 2019*
Accepted: *16 March 2020*
Published: *23 April 2020*

Citation:
Poulus D, Coulter TJ, Trotter MG and Polman R (2020) Stress and Coping in Esports and the Influence of Mental Toughness. Front. Psychol. 11:628. doi: 10.3389/fpsyg.2020.00628

INTRODUCTION

Electronic sports (esports) is the term used to describe the casual or organized playing of video games in a way that provides professional or personal development to the player (Pedraza-Ramirez et al., 2020). While there is still definitional debate around what is an esport and what is a video game, this study will be adopting the definition proposed by Pedraza-Ramirez et al. (2020). Esports is beginning to see increased attention from researchers (Reitman et al., 2019). One topic of interest and debate has been the comparison esports has with traditional sports (Bányai et al., 2018). This debate mainly centers on whether esports can be classified as a "sport" and if its players can be treated as traditional "athletes." Jenny et al. (2017) identified that esports fitted well within the sociological and philosophical definitions of sport (e.g., it involves play, competition, and skill). Total prize pools for esports competitions are predicted to reach more than US $413 million by 2020 (Goldman Sachs, 2018). In 2019, the Defense of the Ancients 2 (DOTA 2) major tournament, "The International 9," had a total prize pool of US $34 million, with the winning side (Team OG) collecting US $15 million (*The International, 2020*). Growth in viewership and prize pools has led to the development of professional players/teams competing in regular professional esports leagues (Taylor, 2012). Furthermore, talent development pathways for esports players are becoming more common with a number of governments and American (Conditt, 2016) and Australian student sporting portfolios (Lace, 2019) now recognizing esports athletes. As such, it would be important to examine some of the psychological factors that might determine success in esports.

On a psychological level, it has been suggested that the competitive and cooperative nature of esports requires similar mental skills as traditional sports (Murphy, 2009; Campbell et al., 2018). Supporting this idea, Himmelstein et al. (2017) qualitatively examined the mental skills and obstacles encountered by five League of Legends (LoL) athletes. To achieve optimal performance, 11 mental skills were identified (e.g., staying in the moment, utilizing preperformance routines, adapting to competition). Himmelstein et al. (2017) also identified four ways esports athletes acquired their skills (i.e., setting goals, analyzing performance, practicing individual skill, and maintaining a growth mindset). Smith et al. (2019), through interviews, investigated the stressors experienced and the associated coping strategies used by seven professional esports competitors. The associated coping strategies identified in the data supported the existing stress-coping literature (Polman, 2012). Emotion-focused (EFC), problem-focused (PFC), avoidance (AC), approach, and appraisal coping strategies were all employed by esports athletes (Smith et al., 2019). The studies by Himmelstein et al. (2017) and Smith et al. (2019) are limited by small samples sizes. Toth et al. (2019) explored esports players of different skill levels on tests of cognitive functioning. Results showed that elite esport athletes (based on in-game rankings) displayed faster response times and higher accuracy for simple choice reaction time stimuli (control trials), but that there were no differences between groups in cognitive inhibition. Clearly there is a need for more research on the psychological determinants of success for esports players (Pedraza-Ramirez et al., 2020).

A factor that has been shown to influence performance in sport is the way athletes cope with stressors they encounter (Lazarus, 2000). Considering esports has some similarities to traditional sport, it is timely to examine the stress and coping process in esports athletes to explore whether performance and well-being could be enhanced through established or new psychological interventions or training programs (Polman et al., 2018). An athlete's ability to cope with stress has been shown to be important to success in traditional sport (Lazarus, 2000; Polman, 2012). The main framework adopted by researchers has been the cognitive–motivational–relational theory of stress and coping (Lazarus, 2000). According to this framework, appraisal of stressors, coping, and consequences are viewed as a dynamical and recursive process between the individual and his/her environment. Specifically, the person appraises events through primary (something at stake) and secondary (available coping options in relation to the event) appraisals (Lazarus, 2000). Following appraising an event as stressful, an individual invokes a voluntary coping response to manage the stress. Coping responses have been identified as falling into three common, higher-order dimensions (Nicholls and Polman, 2007): PFC (strategies aimed at changing stressful situation), EFC (strategies to regulate emotions associated with a stressful situation), and AC (physical or cognitive efforts to disengage from the stressor).

Studies have indicated that stable personality factors can directly or indirectly influence the stress-coping process (Polman et al., 2010). A disposition considered to be influential in sporting success is mental toughness (MT) (Coulter et al., 2018). There is ongoing debate around the conceptualization and definition of mental toughness (Gucciardi et al., 2015). This debate largely stems from two main perspectives that have recently emerged in the sport psychology literature.

The first perspective originated in Clough et al.'s (2002) work, who proposed the 4/6Cs model of MT. This model builds on Kobasa's (1979) conceptualization of hardiness, a stress buffering personality trait. Based on interviews with coaches, athletes, and sport psychologists, Clough and colleagues added *confidence* (interpersonal and in one's ability) to Kobasa's (1979) three-factor hardiness construct: challenge, commitment (to one's goals), and control (emotions and life). From this 4/6C model, Clough et al. (2002) developed a 48-item Mental Toughness Questionnaire (MTQ-48). While the MTQ-48 has been used extensively in the literature, several research teams have reported equivocal results about its psychometric properties (Gucciardi, 2017). To improve the factorial validity of the MTQ-48, Kawabata et al. (under review) recently refined the MTQ-48 to create a statistically and conceptually rigorous six-item multidimensional model of the 4/6Cs – the Mental Toughness Questionnaire 6 (MTQ6).

The second notable approach to the conceptualization and psychometric assessment of MT derives from qualitative methods to understand people's perceptions of MT and its core attributes. Gucciardi et al. (2015) recently synthesized this body of research to identify several core properties of MT. Based on this work, the Mental Toughness Index (MTI) was developed (Gucciardi et al., 2015), which assesses seven core constructs: generalized self-efficacy, buoyancy, success mindset, optimistic style, context knowledge, emotion regulation, and attention regulation. According to Gucciardi et al. (2015), the MTI is a unidimensional measure that treats MT as a trait construct with state-like properties (i.e., it can fluctuate across time and context).

While similarities and differences exist across the two conceptualizations of MT, the current study aims to incorporate both perspectives into its research design, as an opportunity to explore the relationships and comparative explanatory impact the two perspectives have with stress and coping. In addition, the team-based nature of many esports requires its athletes to engage in interpersonal interactions. The 4/6C model (via the MTQ6) includes an interpersonal aspect to being mentally tough (interpersonal confidence), hence the decision to include it in the current study.

The relationship between MT and the stress and coping process has been researched in traditional sport. A study by Kaiseler et al. (2009) found that higher levels of MT were associated with lower levels of perceived stress and higher levels of emotional control. Furthermore, Nicholls et al. (2008) found that athletes who were more mentally tough used more PFC strategies and less AC strategies. Nicholls et al. (2012) also found that an athlete's perception of challenge and threat was associated with one's perceived control of the stressor. Higher levels of control were associated with perceiving the stressor as a challenge, and lower levels of control were associated with perceiving the stressor as a threat.

To better understand the relationship between MT and the stress and coping process in competitive esports players, this study will target players in the top 40% of their chosen esport. Esports games that use an in-game ranking system calculate players' level of competence. The top 40% of competitors (according to in-game ranking) represents a large ability range and is more likely to capture players who play regularly and at a higher competency level. Esports players from five major team based esports will be selected in this study: DOTA 2, LoL, Counter Strike: Global Offensive (CS: GO), Overwatch (OW), and Rainbow Six: Siege (R6) (Pedraza-Ramirez et al., 2020). The games were chosen because of their popularity, prize pool (tournaments), in-game ranking system, and accessibility of participants (Goldman Sachs, 2018; Pedraza-Ramirez et al., 2020). Each of the five esports explored in this study have a competitive or ranked game play mode where an in-game ranking system sorts players into rankings based on their in-game competence.

The aim of the present study is to examine stress and coping in competitive esports athletes and explore how this regulatory process may be influenced by MT. To that end, it is predicted that esports athletes with higher MT scores will report lower levels of stress intensity and higher levels of perceived control, see stressors more as a challenge than a threat, and use more PFC and less EFC and AC (e.g., Nicholls et al., 2008, 2012; Kaiseler et al., 2009). Esports athletes who scored higher MT (total and item) will have higher levels of achievement (determined by in-game rank). Finally, the potential similarities or differences across the two MT conceptualizations were explored; no explicit *a priori* predictions were made.

METHODS

Participants

Participants were 316 esports athletes (283 Males, 33 Female) aged 18–41 (M = 22.61, SD = 4.35). **Table 1** provides descriptive statistics for gender, age, in-game rank, percentile group, and the frequency of professional players for each esports game. **Table 2** shows the distribution of participants' in-game ranks across each of their chosen esports and how in-game ranking was standardized and grouped into achievement levels across esports for statistical analysis.

Measures

Demographics

The first part of the questionnaire pack for this study included completion of some demographic information including type of esport played, in-game ranking, age, and gender. The questionnaire allowed only players in the top 40% of their chosen esports (as determined by self-reported in-game rank) and players who played on a desktop computer, to continue through the questionnaire. In-game rank cutoffs were as follows: DOTA 2 ≥ Archon 3, LoL ≥ Silver 1, CS: GO ≥ Master Guardian 1, OW ≥ Platinum 1, R6 ≥ Gold3 (**Table 2**). No participants who met the in-game ranking cutoff were excluded. Players were also asked if they had ever competed in a professional esports tournament.

Stress Appraisal

To measure how esports athletes appraise stress, participants were asked to report a stressor that they recently encountered while playing their esport. On analog scales, participants rated the intensity of the stressor (Kowalski and Crocker, 2001) (1 = not stressful, 10 = extremely stressful), how much control they felt they had over the situation (1 = no control at all, 10 = full control), how much of a threat they felt the situation was (1 = not at all threatening, 10 = extremely threatening), and how challenging they felt the situation was (1 = not at all challenging, 10 = extremely challenging) (Kaiseler et al., 2012; Britton et al., 2019).

Coping

Coping was assessed by using the 28-item Brief COPE inventory (Carver, 1997). Using a four-point scale, the Brief COPE assesses how a participant has been dealing with the stressors in his/her life. The Brief COPE has 14 factors that can be classified into three higher-order dimensions: PFC, EFC, and AC coping (Dias et al., 2012). The Brief COPE has good psychometric properties (Carver, 1997). In the current study, reliability for 13 of the 14 factors was satisfactory (**Table 3**). Although one of the scales of the Brief COPE did not reach acceptable levels of internal consistency, it was included in the statistical analysis because estimates of internal consistency have limited applicability when assessing psychometric properties of measures of coping

TABLE 1 | Frequency of gender, average age, average in-game rank, and frequency of professional players by esport game.

Esport	Gender		Average age		Level of competition		Average in-game rank
	Male	Female	Mean	*SD*	Professional	Nonprofessional	
DOTA 2 (n = 18)	18	0	21.67	4.20	2	16	Ancient 1
LoL (n = 118)	105	13	23.78	4.61	8	110	Platinum 2
CS: GO (n = 61)	56	5	21.38	3.60	16	45	Distinguished Master Guardian
OW (n = 84)	71	13	22.75	4.47	6	78	Diamond
R6 (n = 35)	33	2	21.00	3.05	8	27	Platinum 2
Total (n = 316)	283	33	22.61	4.35	40	276	-

TABLE 2 | In-game ranking standardized into achievement level groups across esports.

DOTA 2

Group	Rank	Percentage
5	Archon 4	(58.17–63.61)
5	Archon 5	(63.61–68.96)
5	Legend 1	(68.96–74.11)
4	Legend 2	(74.11–78.73)
4	Legend 3	(78.73–82.78
3	Legend 4	(82.78–86.24)
3	Legend 5	(86.24–89.19)
3	Ancient 1	(89.19–91.60)
2	Ancient 2	(91.60–93.52)
2	Ancient 3	(93.52–95.05)
2	Ancient 4	(95.05– 96.25)
2	Ancient 5	(96.25–97.56)
2	Divine 1	(97.56–98.19)
2	Divine 2	(98.19–98.64)
2	Divine 3	(98.64–99.0)
1	Divine 4	(99.0–99.26)
1	Divine 5	(99.26–99.45)
1	Immortal	(99.45–100)

League of legends

Group	Rank	Percentage
5	Silver 1	(56.3–62.18)
5	Gold 5	(62.18–73.62)
4	Gold 4	(73.62–79.26)
4	Gold 3	(79.26–83.28)
3	Gold 2	(83.28–85.92)
3	Gold 1	(85.92– 89.7)
3	Platinum 5	(89.7–93.02)
2	Platinum 4	(93.02–94.72)
2	Platinum 3	(94.72–96.19)
2	Platinum 2	(96.19–97.37)
2	Platinum 1	(97.37–98.01)
2	Diamond 5	(98.01–99.25)
1	Diamond 4	(99.25–99.6)
1	Diamond 3	(99.6–99.78)
1	Diamond 2	(99.78–99.88)
1	Diamond 1	(99.88–99.95)
1	Master	(99.95– 99.98)
1	Challenger	(99.98–100)

Counterstrike: global offensive

Group	Rank	Percentage
5	Master Guardian 1	(66.61–74.16)
4	Master Guardian 2	(74.16–80.77)
3	Master Guardian Elite	(80.77–86.01)
3	Distinguisher Master Guardian	(86.01–90.16)
2	Legendary Eagle	(90.16– 93.41)
2	Legendary Eagle Master	(93.41–96.61)
2	Supreme Master First Class	(96.61–99.25)
1	The Global Elite	(99.25–100)

Overwatch

Group	Rank	Percentage
5	Platinum (>2588)	60.0–77.7
4	Diamond	77.8–91.2
2	Master	91.3–96.7
2	Grandmaster	96.8–99.9
1	Top 500	99.9–100

Rainbow six: siege

Group	Rank	Percentage
5	Gold 3	(64.89–73.64)
4	Gold 2	(73.64–81.81)
3	Gold 1	(81.81–88.06)
3	Platinum 3	(88.06– 95.52)
2	Platinum 2	(95.52–98.1)
2	Platinum 1	(98.1–99.11)
1	Diamond	(99.11–100)

Achievement Level Groups	Ranking Percentage
5	∼ 60–70
4	∼ 70–80
3	∼ 80–90
2	∼ 90–99
1	∼ 99–100

Note: The ranking percentages above were gather at below times and location.

DOTA 2	Based on June 2018	Cutoff rank: > Archon 3	https://www.esportstales.com/dota-2/seasonal-rank-distribution-and-mmr-medals
League of legends	Based on august 2018	Cutoff rank: > Silver 1	https://www.esportstales.com/league-of-legends/rank-distribution-percentage-of-players-by-tier
Counter strike	Based on August 2018 data	Cutoff rank: > Master Guardian 1	https://totalcsgo.com/ranks
Overwatch	Based on August 2018 (season 11)	Cutoff rank: Platinum (> 2588SR)	https://www.esportstales.com/overwatch/competitive-rank-distribution-pc-and-console
Rainbow six siege	Based on July 2018 data	Cutoff rank: > Gold 3	https://www.esportstales.com/rainbow-six-siege/seasonal-rank-distribution-and-percentage-of-players

TABLE 3 | Mean, standard deviation, Cronbach α for stressor appraisal, coping strategies, mental toughness index, and mental toughness questionnaire.

Stress appraisal	Mean	*SD*	α
Perceived stress intensity	6.42	2.27	
Perceived control	3.86	2.92	
Perceived threat	4.07	2.97	
Perceived challenge	6.19	2.62	
Coping strategies			
Problem-focused coping	**2.47**	**0.63**	**0.81**
Active coping	2.79	0.79	0.72
Use of instrumental support	2.03	0.88	0.70
Positive reframing	2.42	0.92	0.81
Planning	2.65	0.83	0.70
Emotion-focused coping	**2.23**	**0.49**	**0.75**
Use of emotional support	1.99	0.89	0.83
Venting	2.06	0.81	0.63
Humor	2.67	0.83	0.84
Acceptance	2.99	0.78	0.60
Self-blame	2.39	0.90	0.72
Religion	1.29	0.63	0.71
Avoidance coping	**1.64**	**0.45**	**0.68**
Self-distraction	2.47	0.89	0.61
Denial	1.37	0.61	0.53
Substance use	1.19	0.47	0.87
Behavioral disengagement	1.53	0.71	0.68
Mental toughness			
Mental Toughness Index (MTI)	**5.23**	**0.95**	**0.86**
Mental Toughness Questionnaire (MTQ6)	**4.18**	**0.37**	**0.61**
Challenge: Challenges usually bring out the best in me.	4.16	0.67	
Commitment: I don't usually give up under pressure.	4.29	0.63	
Emotional control: Even when under considerable pressure, I usually remain calm.	4.15	0.65	
Life control: I generally feel that I am in control of what happens in my life.	4.04	0.65	
Confidence in abilities: I am generally confident in my own abilities.	4.16	0.62	
Interpersonal confidence: I usually take charge of a situation when I feel it is appropriate.	4.33	0.62	

(Billings and Moos, 1981). Confirmatory factor analysis (CFA) was conducted, using AMOS 25, to explore the psychometric properties of the Brief COPE. This showed an excellent fit (CMIN/DF = 1.57, CFI = 0.95, RMSEA = 0.04, PCLOSE = 0.94).

Mental Toughness

The two MT questionnaires administered were the MTI (Gucciardi et al., 2015) and the MTQ6 (Kawabata et al., under review). The MTI has eight items and is scored on a seven-point Likert scale. The MTI has shown good psychometric properties across a range of independent samples (Gucciardi et al., 2015) and measures overall MT. CFA for the present sample showed a good fit (CMIN/DF = 1.55, CFI = 0.99, RMSEA = 0.04, PCLOSE = 0.66).

The MTQ6 has six items and is scored on a five-point scale. Initial results have shown good factorial structure for the MTQ6 (Kawabata et al., under review). In the current study, CFA showed an adequate fit (CMIN/DF = 2.76, CFI = 0.92, RMSEA = 0.08, PCLOSE = 0.12).

Procedure

The study received institutional ethical approval. Participants provided informed consent before participation in the study. Participants were recruited to the study through two methods, either online (n = 314) or in-person (n = 2) at esports events. Online participants were directed to a URL where they could complete the questionnaire pack (developed and managed by Qualtrics). The URL was distributed via email and online via social media (Twitter and Facebook) and YouTube.

Data Analysis

Esports classify their players into levels, based on a percentage range. The number of levels differs across esports. To standardize in-game ranking across five esports into achievement level, five group classifications were developed: level 1 = 99–100%, level 2 = 90–98%, level 3 = 89–80%, level 4 = 79–70%, and level 5 = 69–60% (**Table 2**). Before the main analysis, a Shapiro–Wilk test was used to examine the distribution of each variable. All study variables were normally distributed, and skewness and kurtosis were not breached. Cronbach α's and descriptive statistics were obtained for all study variables (**Table 3**). Pearson product–moment correlations between the variables were then calculated. Initial analysis compared differences between gender (Kaiseler and Polman, 2010) and game across stress appraisal, coping, and MT. No significant differences were found (all $P > 0.05$), and the data were collapsed across game and gender.

To determine whether MT was associated with perceived stressor intensity, stressor control, stressor threat, and stressor challenge, several separate linear regressions were run with the MTQ6 items (1–6), MTQ6 total, or MTI total, as predictor variables. To assess whether MT was associated with coping strategy selection, linear regressions were used. The 14 factors of the Brief COPE were entered as the dependent variables, whereas the MT measures represented the predictor variables. Similarly, regression analysis was conducted to explore the association between MT and coping at the dimensional level.

We first calculated Pearson product–moment correlations between the variable in this study. To investigate if achievement level was associated with participant's stressor appraisal and selection of coping strategies, a number of multivariate analyses of variance (MANOVAs) were run. In the instance of significant main or interaction effects, follow-up analysis of variance (ANOVA) was conducted. Analyses of variance were conducted to explore if achievement level was associated with participants' total MT levels. *Post hoc* comparisons were conducted using Sidak.

RESULTS

Correlation Analysis of Study Variables

The means, standard deviations, and Cronbach α for stressor appraisal, coping strategies (dimensional and strategy level), and both MT questionnaires are reported in **Table 3**. The results of the correlational analysis of the study variables are shown in **Table 4**. Contrary to predictions, correlational analysis demonstrated that there was no association between overall MT level (both frameworks) and stressor intensity. However, there were small significant inverse relationships between MTQ6 dimensions, emotional control (r = -0.11), life control ($r = -0.12$), and stressor intensity. In terms of perceptions of control, only a small, significant positive correlation was identified with the MTI ($r = 0.12$).

For threat perceptions, a small significant inverse correlation with emotional control ($r = -0.13$) (MTQ6) was found, whereas for challenge perceptions, there was a negative correlation with MTQ6 total score ($r = -0.11$) and life control ($r = -0.14$). For PFC, there were small to moderate positive correlations with both the MTQ6 total ($r = 0.26$) and MTI ($r = 0.35$). In addition, small significant correlations were identified with challenge ($r = 0.17$), commitment ($r = 0.18$), confidence ability ($r = 0.17$), and interpersonal ($r = 0.18$) items of the MTQ6. Similarly, small significant inverse correlations were found between the MTQ6 total ($r = -0.20$), MTI ($r = -0.27$), and AC. The MTQ6's commitment ($r = -0.22$), emotional control ($r = -0.15$), confidence ability ($r = -0.12$), and confidence ($r = -0.14$) interpersonal items also showed small significant negative associations with AC. Finally, there were no associations between MT (both frameworks) and EFC (all $P > 0.05$). See **Table 4** for full results of the correlational analysis.

Associations Between Coping Strategies and MT Measures

Regression analysis was run to explore the association between coping strategies and the six items of the MTQ, the MTQ6 total score, and MTI total score (**Table 5**). The PFC strategy, active coping, was associated with commitment ($\beta = 0.16$), confidence ability ($\beta = 0.13$), and interpersonal confidence ($\beta = 0.13$), explaining 11% the variance in the use of this strategy. Similarly, MTQ6 and MTI total scores respectively explained 9% ($\beta = 0.30$) and 15% ($\beta = 0.38$) of the variance in active coping. The use of instrumental support was only predicted by the MTI, which explained 2% of the variance in using instrumental support as a coping strategy. Higher levels of positive reframing and planning were also associated with higher levels of total MTQ6 (2%, $\beta = 0.14$; and 7%, $\beta = 0.27$) and MTI (4%, $\beta = 0.20$; and 10%, $\beta = 0.31$). Higher levels of challenge ($\beta = 0.12$) and interpersonal confidence ($\beta = 0.17$) also predicted increased use of the coping strategy planning (9%).

Regarding EFC, acceptance was the only strategy associated with MT. In particular, the MTQ6 (5%, $\beta = 0.24$) and MTI (2%, $\beta = 0.14$) showed small but significant associations. In addition, challenge ($\beta = 0.13$) and emotional control ($\beta = 0.16$) (MTQ6) had a significant positive association with acceptance (7%). No associations were observed between the MTQ6 items, MTQ6 total, MTI, and the EFC strategies venting, humor, self-blame, or religion.

For AC, self-distraction ($\beta = -0.15$) was negatively associated with MTI total score (2%), whereas substance use and behavioral disengagement were negatively associated with both MTQ6 (2%, $\beta = -0.16$; and 6%, $\beta = -0.24$, respectively) and MTI (2%, $\beta = -0.13$; and 12%, $\beta = -0.35$) scores. Also, commitment ($\beta = -0.17$) (MTQ6) was associated with substance abuse

TABLE 4 | Correlational analysis of the study variables.

Stress appraisal measure	Stressor intensity	Stressor control	Stressor threat	Stressor challenge	Problem-focused coping	Emotion-focused coping	Avoidance coping
Stressor intensity							
Stressor control	−0.24*						
Stressor threat	0.44*	−0.19*					
Stressor challenge	0.48*	−0.13*	0.39*				
Coping strategies							
Problem-focused coping	0.08	0.21*	0.24*	35			
Emotion-focused coping	0.11*	0.04	0.19*	0.10	0.57*		
Avoidance coping	0.18*	−0.07	0.08	0.08	0.08	0.43*	
MTQ6 total	−0.08	0.05	0.07	−0.11*	0.26*	0.10	−0.20*
MTQ 1 – challenge	0.04	0.05	0.02	0.02	0.17*	0.07	0.02
MTQ 2 – commitment	−0.02	0.05	0.00	−0.09	0.18*	0.03	−0.22*
MTQ 3 – emotional control	−0.11*	0.05	−0.13*	−0.09	0.11	0.07	−0.15*
MTQ 4 – life control	−0.12*	−0.01	−0.07	−0.14*	0.09	0.04	−0.08
MTQ 5 – confidence in abilities	−0.01	0.00	−0.00	−0.05	0.17*	0.09	−0.12*
MTQ 6 – interpersonal control	−0.06	0.04	−0.07	−0.04	0.18*	0.06	−0.14*
MTI total	−0.06	0.12*	0.02	−0.01	0.35*	0.08	−0.27*
Game rank	0.16	0.03*	0.56	0.19	0.49	0.61	0.27

*$p < 0.05$.

TABLE 5 | Regression analysis to explore the association between mental toughness and coping strategies.

Construct	Construct – MTQ6 (Items 1–6)			Construct – MTQ6 Total			Construct – MTI		
Coping strategies	R^2	$F(6, 309)$ =	Six MTQ 6 (1–6) – β significant predictors	R^2	$F(1, 314)$ =	Six MTQ 6 total – β significant predictor	R^2	$F(6, 309)$ =	Six MTI total – β significant predictor
Problem-focused coping	0.07	4.02**		0.7	22.04**	0.26**	0.12	42.30**	0.36**
Active coping	0.11	6.45**	Q2 = 0.16**; Q5 = 0.13*; Q6 = 0.13*	0.9	30.96**	0.3**	0.15	54.16**	0.38**
Use of instrumental support	0.01	0.336		0.00	1.28		0.02	6.1*	0.14*
Positive reframing	0.02	1.16		0.02	6.09*	0.14*	0.04	13.18**	0.201**
Planning	0.09	5.19**	Q1 = 0.12*; Q6 = 0.17**	0.70	24.56**	0.27**	0.10	33.12**	0.31**
Emotion-focused coping	0.01	0.70		0.01	3.14		0.01	2.02	
Use of emotional support	0.02	1.21		0.01	2.79		0.01	2.54	
Venting	0.04	1.98		0.01	2.12		0.01	1.59	
Humor	0.02	1.24		0.01	3.24		0.00	0.41	
Acceptance	0.07	3.89**	Q1 = 0.13*; Q3 = 0.16**	0.05	18.88**	0.24**	0.02	5.81*	0.135*
Self-blame	0.01	0.64		0.00	0.02		0.00	0.03	
Religion	0.01	0.42		0.00	0.02		0.01	3.01	
Avoidance coping	0.08	4.63**	Q1 = 0.14**; Q2 = −0.20**	0.40	12.44**	-0.2	0.07	24.87**	-0.27**
Self-distraction	0.02	1.15		0.01	1.99		0.02	7.2**	-0.15**
Denial	0.02	1.19		0.01	1.71		0.00	1.37	
Substance use	0.04	2.33*	Q2 = −0.17**	0.20	5.9*	-0.16*	0.02	5.75*	-0.13*
Behavioral disengagement	0.10	5.43**	Q2 = −0.21**; Q6 = −0.16**	0.06	18.63**	-0.24**	0.12	42.84**	-0.35**

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

(4%), whereas commitment (β = −0.21) and interpersonal confidence (β = −0.16) (MTQ6) were associated with behavioral disengagement (10%). There was no association between MT and denial. **Table 5** provides details of the regression analysis.

Influence of Achievement Level on MT, Stressor Appraisal, and Coping

Multivariate analyses of variance were used to test the influence of achievement level on MT, stressor appraisal, and coping (**Table 6**). Perceived stressor control was influenced by achievement level. Although there was a trend for higher-achieving players to perceive more control over the stressor, *post hoc* comparisons only showed that the 99th–100th percentile scored significantly higher than the 70th–80th percentile in levels of perceived control. There was no association between achievement level, perceived stressor intensity, threat, and challenge. Similarly, at both the strategy (Wilks' λ = 0.80, P = 0.36, η_p^2 = 0.05) and dimensional (Wilks' λ = 0.96, P = 0.45, η_p^2 = 0.01) levels, coping was not influenced by rank.

Achievement level was significantly influenced by MTQ6 items. *Post hoc* comparisons showed lower challenge scores for the 60th–70th percentile group compared to the 90th–99th and 99th–100th percentile groups. For commitment, the 80th–90th percentile group scored lower compared to the 90th–99th and the 99th–100th percentile groups.

One-way ANOVA showed significant differences between achievement level and both MTQ6 and MTI totals. *Post hoc* comparisons only showed that, for the MTI total, the 99th–100th and 80th–90th percentile participants scored higher than the 60th–70th percentile group.

There was a significant positive correlation between MTQ6 total and MTI (r = 0.45). The MTI positively correlated with all items of the MTQ6, except for life control. However, the shared

TABLE 6 | MANOVA between achievement level and stressor appraisal, coping strategies, Mental Toughness Index, and mental toughness questionnaire.

MANOVA	Wilks'	p	η_p^2
Stress appraisal	0.91	0.74	0.02
Coping dimensions	0.96	0.45	0.01
Coping strategies	0.80	0.36	0.05
MTQ6 item (1–6)	0.86	0.17	0.04
ANOVA	$F(4, 277)$	p	η_p^2
MTQ6 total	2.70	0.03	0.04
MTI	4.14	0.003	0.06

variance between the MTQ6 and MTI was only 20% and lower between the items of the MTQ6 and MTI. See **Table 7** for full results of the correlational analysis.

DISCUSSION

The main purpose of this study was to examine stress and coping in esports athletes and explore how this regulatory process is influenced by MT. Results suggest that the MTI was associated with perceived control, and MTQ6 subscales were associated with stress intensity. Furthermore, MT was associated with how stress was perceived as being a challenge or threat (both inversely) and the selection of coping strategies.

Association Between Stress Appraisal and MT

Results did not support the *a priori* prediction that esports athletes with higher overall levels of MT would report lower levels of stress intensity and higher levels of stress control. This observation contradicts previous findings by Kaiseler et al. (2009) and Levy et al. (2012), who found that higher levels of MT, using the MTQ-48, were associated with lower levels of perceived stress. This result might be explained due to esports athletes experiencing different types of stressors to traditional sports athletes (Nicholls and Polman, 2007). For example, esports athletes in the present study reported technical issues and antisocial behavior as stressors that have not been reported previously, however, further research is needed to understand this. Providing partial support for this study's prediction, small significant negative associations were observed between emotional control and life control and stress intensity, indicating that esports athletes, with higher levels of emotional control, rated the intensity of the self-reported stressor lower. It appears that only those esports athletes, who reported to have higher levels of emotional control, were able to reduce the intensity of the perceived stressor.

In support of the initial hypothesis, a positive association was observed between overall MT (MTI) and stress control. Similar to previous findings (Kaiseler et al., 2009; Levy et al., 2012), those esports athletes higher in MT (MTI) reported more control over the self-reported stressor. Literature on MT has described more mentally tough people as having an unshakable faith in their abilities to control their own destiny and an increased ability to remain in control under pressure (Clough et al., 2002; Nicholls et al., 2008). The result here appears to match this description of mentally tough people and suggest that more mentally tough esports athletes have increased levels of perceived control over a stressor.

The present study did not support previous findings (Kaiseler et al., 2009; Levy et al., 2012) and the *a priori* prediction that MT would be associated with lower threat and higher challenge appraisal. There was only a small negative correlation between emotional control and threat perception. In addition, overall score of the MTQ6 and the life control subscale had a negative association with challenge. Previous studies have found athletes with higher overall MT perceive stressors more as a challenge than a threat (Nicholls et al., 2012). First, the present findings suggest that the relationship between challenge and threat appraisal is not dichotomous (Britton et al., 2019). Esports athletes appear to appraise stressors as both a threat and challenge at the same time. This finding might be explained through the use of a single item to measure threat and challenge. Second, differences in threat and challenge perception between esports and traditional sports athletes could be explained due to the online nature of esports. Nonprofessional play is largely done online through ranked or competitive play; players may not be able to choose all their teammates. Players are often randomly grouped with different teammates (this varies between esports), and the only outcome at stake is their in-game rank. When playing in a professional tournament, often in front of a live audience for a cash prize, the stakes could be comparable to traditional sports. This study, having less professionals (n = 40) than nonprofessional (n = 276) players, could account for the difference in threat and challenge perceptions.

Associations Between Stress Coping and MT

Correlational and regression analysis showed support for the hypothesis that PFC, at both the dimensional and strategy levels (active coping, use of instrumental support, positive reframing, and planning), was positively associated with total MT (both frameworks). Higher levels of the MTQ6 subscales commitment,

TABLE 7 | Correlational analysis the mental toughness inventory, mental toughness questionnaire 6 total, and mental toughness questionnaire 6 subscales.

Construct	MTQ6 total	MTQ 1 challenge	MTQ 2 commitment	MTQ 3 emotional control	MTQ 4 life control	MTQ 5 confidence in abilities	MTQ 6 interpersonal confidence
MTQ6 TOTAL							
MTQ 1 – challenge	0.60**						
MTQ 2 – commitment	0.62**	0.33**					
MTQ 3 – emotional control	0.59**	0.24**	0.35**				
MTQ 4 – life control	0.52**	0.06	0.08	0.17**			
MTQ 5 – confidence in abilities	0.61**	0.19**	0.21**	0.17**	0.31**		
MTQ 6 – interpersonal control	0.57**	0.24**	0.20**	0.11	0.20**	0.28**	
MTI total	0.45**	0.33**	0.41**	0.18**	0.10	0.25**	0.30**

$^{**}p < 0.05$.

confidence in abilities, and interpersonal confidence predicted increased active coping, and higher levels of challenge and interpersonal confidence predicted increased planning. These results are consistent with previous research, which has shown that mentally tough athletes are more likely to use PFC strategies, suggesting that esports athletes in the top 40% cope with stressors similarly to high-performing sports athletes and that mentally tougher esports athletes appear to want to actively deal with their stressors (Nicholls et al., 2008).

Like previous research, mentally tougher esports athletes reported less use of AC and AC strategies (e.g., self-distraction, substance use, and behavioral disengagement; Nicholls et al., 2008; Kaiseler et al., 2009). Such associations were also observed for some of the factors of MT (MTQ6). Specifically, higher levels of commitment were associated with less substance use and behavioral disengagement, and interpersonal confidence with less use of behavioral disengagement. This finding suggests that athletes who have lower levels of MT, and who employ more AC strategies, may be less skillful and may not perform as well as athletes with higher levels of MT. These results also suggest that competitive esports and sports athletes with high levels of MT (both frameworks) cope similarly by employing less AC strategies.

Contrary to the hypothesis, MTI, MTQ6 total, challenge, and emotional control all positively predicted the use of acceptance (EFC strategy). This observation suggests that acceptance could be important for competitive esports athletes. The use of acceptance could be explained through the match-making algorithm used in solo queue. When playing ranked or competitive play, many factors can be out of the player's control, which includes teammates, opponents, and character selection. Although these issues might result in stress, being able to accept that these factors are beyond a players control could be associated with performing more highly in esports.

Because this is the one of the first studies exploring stress and coping in an esports population, scores obtained for the Brief COPE were compared to those obtained in the sport domain. To this end, Dias et al. (2010) explored coping in a team sport setting using the Brief COPE. At the dimension level, traditional sports athletes reported the use of more PFC and EFC, and on a strategy level, they reported a higher use of instrumental and emotional support. Such differences between traditional sport and esports might be due to the fast-paced nature of esports. As such, esports athletes might have less time to invoke PFC strategies. Also, esports athletes used more acceptance and self-distraction strategies compared to the team athletes in Dias et al. (2010) study. These differences could be explained by the online nature of esports requiring acceptance or ignoring of stressors to perform at the highest level.

Associations Between MT and Achievement Level

The current study found partial support for the notion that achievement level was associated with MT. In particular, those with higher ranks tended to have higher total and subscale MT scores, with a number of significant differences for challenge and commitment (MTQ6). Similar to traditional sport, these findings suggest there could be an association between esports performance and MT levels (Cowden, 2016). It would appear that those who are more successful esports athletes have higher levels of MT.

Similarities and Differences Between the MTQ6 and MTI8

There were interesting similarities and differences that emerged from the results of the MTQ6 and MTI. Regression analysis shows that both MT measures predicted the use PFC and AC at a dimensional level, and active coping, planning, acceptance, substance use, and behavioral disengagement at a strategy level. Correlational analysis from the MTQ6 and MTI showed differences in stress appraisal. The MTQ6 was associated with perceived stressor intensity, threat, and challenge, whereas the MTI was associated only with perceived stressor control. Mixed results are not surprising considering each questionnaire represents a different, yet partly similar, framework. Furthermore, correlational analysis showed that the MTQ6 and MTI had low shared variance (20%). This would suggest that the two questionnaires measure different aspects of MT. Overall, these findings represent the ongoing debate surrounding the conceptualization of MT.

Practical Implications

While further research is needed, the findings of the present study could be beneficial for sport psychologists working with esports athletes. Interventions to increase emotional control may help lower perceived stress intensity, potentially improving performance and quality of life. Furthermore, results suggest that acceptance coping is an important strategy used by esports players. Esport athletes who more effectively utilize acceptance coping may better deal with stressors caused by factors outside of their control (i.e., teammates and opponents). Based on the notion the esports athletes are more likely to report the use of PFC strategies and less AC strategies, it would be suggested that coaches, team managers, and/or sport psychologists help their athletes to actively deal with the stressors they experience, although future research should examine coping effectiveness.

Limitations and Future Research Direction

The present study is not without limitations. A cross-sectional design was used, meaning that causality cannot be inferred. The constructs were measured using self-reported questionnaires. Data collected were retrospective and collected from players only in the top 40% of their esport, which limits the generalizability of the findings. Moreover, stress appraisal was assessed in relation to one specific stressful event, and the potential baseline differences in stress reactivity were not controlled for. One coping strategy measured by the Brief COPE showed low reliability, however, it was included in the analysis because previous research has indicated that estimates of internal consistency have limited applicability when assessing psychometric properties of measures of coping (Billings and Moos, 1981). Standardizing rankings across games means that the study could not control for differences in skill distribution or game difficulty between esports. Future research could investigate the relationship between MT and stress coping in one game and across all game ranks (Pedraza-Ramirez et al., 2020). In addition, it could be beneficial to explore how esports athletes cope over time and across multiple stressful events.

CONCLUSION

The present study suggests that MT may influence the stress and coping process in esports athletes. There is an overlap between the MT and stress-coping processes in traditional sports and esports athletes. These similarities appeared more in the selection of coping rather than the appraisal process. This result suggests that esports athletes could benefit from traditional sports psychology interventions in MT and stress coping and that further research is required into the psychological determinants of success for esports athletes. Finally, low correlations between the MTQ6 and MTI – representing two of the fundamental and most popular models of MT in current literature – indicate that further debate is encouraged on how best to conceptualize MT.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Queensland University of Technology Office of Research Ethics and Integrity. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The study was designed by DP, TC, and RP. The data were collected by DP and MT. The data were analyzed by DP and RP. The manuscript was written by DP, TC, and RP. All authors read and approved 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.

frontiers in Psychology

MINI REVIEW
published: 06 May 2020
doi: 10.3389/fpsyg.2020.00857

Antidepressant Drugs and Physical Activity: A Possible Synergism in the Treatment of Major Depression?

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Specialty section:
This article was submitted to
Movement Science and Sport
Psychology,
a section of the journal
Frontiers in Psychology

Received: 23 March 2020
Accepted: 06 April 2020
Published: 06 May 2020

Citation:
Guerrera CS, Furneri G,
Grasso M, Caruso G, Castellano S,
Drago F, Di Nuovo S and Caraci F
(2020) Antidepressant Drugs
and Physical Activity: A Possible
Synergism in the Treatment of Major
Depression? Front. Psychol. 11:857.
doi: 10.3389/fpsyg.2020.00857

Major depressive disorder (MDD) is a severe mental illness that affects 5–20% of the general population. Current antidepressant drugs exert only a partial clinical efficacy because approximately 30% of depressed patients failed to respond to these drugs and antidepressants produce remission only in 30% of patients. This can be explained by the fact that the complex pathophysiology of depression has not been completely elucidated, and treatments have been mainly developed following the "monoaminergic hypothesis" of depression without considering the key role of other factors involved in the pathogenesis of MDD, such as the role of chronic stress and neuroinflammation. Chronic stress acts as a risk factor for the development of MDD through the impairment of neurotrophins signaling such as brain-derived neurotrophic factor (BDNF) and transforming-growth-factor-β1 (TGF-β1). Stress-induced depressive pathology contributes to altered BDNF level and function in MDD patients and, thereby, an impairment of neuroplasticity at the regional and circuit level. Recent studies demonstrate that aerobic exercise strongly increases BDNF production and it may contribute as a non-pharmacological strategy to improve the treatment of cognitive and affective symptoms in MDD. Here we will provide a general overview on the possible synergism between physical activity and antidepressants in MDD. Physical activity can synergize with antidepressant treatment by rescuing neurotrophins signaling in MDD patients, promoting neuronal health and recovery of function in MDD-related circuits, finally enhancing pharmacotherapeutic response. This synergism might be particularly relevant in elderly patients with late-life depression, a clinical subgroup with an increased risk to develop dementia.

Keywords: depression, physical activity, stress, affective symptoms, cognition, brain-derived neurotrophic factor, transforming-growth-factor-β1

INTRODUCTION

Major depressive disorder (MDD) is a severe and a common mental illness affecting more than 264 million people worldwide (Gbd 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). The World Health Organization (WHO) describes depression, also indicated as MDD or clinical depression, as a mental disorder characterized by sleep and appetite disturbances, variation of mood, loss of energy, and psychomotor retardation[1].

Among the different hypotheses that have been proposed to explain MDD pathophysiology, the "monoaminergic hypothesis" has been initially validated with the development of monoaminergic antidepressants. Based on this hypothesis an impairment of monoaminergic systems [serotonin (5-HT), noradrenaline, and dopamine] has been considered a primary event for the onset of affective and cognitive symptoms in MDD (Hirschfeld, 2000; Hamon and Blier, 2013). Therefore, the majority of antidepressant drugs have been developed according to this hypothesis, representing a useful therapeutic tool (Lopez-Munoz and Alamo, 2009); unfortunately around 30% of depressed patients are considered treatment resistant (Caraci et al., 2018a), probably because emerging additional factors involved in the pathophysiology of MDD, such as chronic stress and neuroinflammation, should be considered (Caraci et al., 2018b). The pathological effects of stress on hippocampus have contributed to the development of the so-called "neurotrophic hypothesis" according to which neurotrophic factors play a key role in the etiology of depression (Altar, 1999; Duman and Li, 2012; Jaggar et al., 2019). This hypothesis suggests that depression derives from decreased neurotrophic support resulting in neuronal atrophy, decreased hippocampal neurogenesis, and loss of glial cells (Duman and Monteggia, 2006). A hyperactivation of the hypothalamic-pituitary-adrenal (HPA) axis has been found in the 50% of depressed patients (Krishnan and Nestler, 2008) and several evidences identify chronic stress, linked to an impairment of neurotrophins such as brain-derived neurotrophic factor (BDNF) and transforming-growth-factor-β1 (TGF-β1) (Caraci et al., 2018b), as a risk factor for the development of MDD (Pittenger and Duman, 2008; Caraci et al., 2010). A significant decrease of BDNF levels has been demonstrated in animal models of depression stress-induced (Berry et al., 2012) as well as in depressed patients (Angelucci et al., 2005). Likewise, a decrease of TGF-β1 levels has been observed in hippocampus and cortex of animal models of depression (Yu et al., 2011); furthermore, several studies carried out in depressed patients have demonstrated that plasma TGF-β1 levels are reduced and correlate with depression severity (Myint et al., 2005; Rush et al., 2016). A chronic treatment with first- and second-generation antidepressants rescues BDNF levels in different preclinical models of depression (Duman and Monteggia, 2006), while selective serotonin reuptake inhibitors (SSRIs) drugs and the new multimodal antidepressant vortioxetine are able to reverse the depressive-like phenotype and memory deficits induced by amyloid-β (Aβ) in mice by the rescue of TGF-β1 (Torrisi et al., 2019). Furthermore, antidepressant drugs exert immunoregulatory effects reducing the production of pro-inflammatory cytokines and stimulating the synthesis of TGF-β1 in depressed patients (Sutcigil et al., 2007).

Noteworthy, it has been shown that epigenetic mechanisms such as DNA methylation, microRNAs, and histone modifications are able to influence the development of depression (Lin and Tsai, 2019) and, with specific regard to BDNF, their altered activity can in turn affect the expression and the activity of this neurotrophic factor (Hing et al., 2018).

Several studies have demonstrated that aerobic exercise (AE) could represent a non-pharmacological strategy to improve the treatment of depression, decreasing, at the same time, the burden of somatic comorbidity of this pathology (Mura and Carta, 2013; Josefsson et al., 2014). Since the 1980s, several papers have reported on the beneficial effects played by exercise and physical activity in the treatment of depression, effects comparable to those of antidepressants (Martinsen et al., 1985; Babyak et al., 2000; Belvederi Murri et al., 2018; Lopez-Torres Hidalgo, 2019). This increased interest in this field has led to the proposal that physical exercise may serve as an alternative or integrative approach in combination with monoaminergic drugs for the treatment of MDD (Martinsen, 2008).

In the present review we will provide a general overview on the possible synergism between physical activity and antidepressants in treatment of MDD, analyzing the possible benefits of physical activity both at a neurobiological level and clinical level focusing in particular on the treatment of affective and cognitive symptoms in MDD.

THE PATHOPHYSIOLOGY OF DEPRESSION: THE ROLE OF NEUROTROPHIC FACTORS AND THE POSSIBLE IMPACT OF PHYSICAL ACTIVITY

MDD shows a complex pathophysiology that has been only partially elucidated in the last 10 years (Caraci et al., 2018a). Chronic stress, reduced synaptic plasticity, impairment of adult hippocampal neurogenesis, and hippocampal neurodegeneration along with the well-known dysregulation of the monoaminergic system contribute to explain the pathophysiology of MDD (Jaggar et al., 2019; Vu, 2019). Epidemiological studies support the pivotal role played by chronic stress in MDD (Pittenger and Duman, 2008); in fact, the exposure to stressful life events contributes to the development of this disease (Czeh and Lucassen, 2007). Chronic stress leads to an impaired negative feedback of glucocorticoids (GR) on the activity of HPA axis, which results in elevated cortisol levels (de Kloet et al., 2005). Excess of GR is able to induce neuronal death at hippocampal level (Yu et al., 2008) as well as dysfunctional changes in the prefrontal cortex (PFC), two regions critically involved in the cognitive symptoms of depression (Krishnan and Nestler, 2008). Stress also exerts its effects by reducing the synthesis of factors essential for neuronal homeostasis such as BDNF

[1] https://www.who.int/health-topics/depression#tab=tab_1

(Nowacka and Obuchowicz, 2013), a neurotrophin fundamental for the maintenance of dendritic spines (Vigers et al., 2012), the regulation of adult hippocampal neurogenesis (Vilar and Mira, 2016), cognitive and mood-related behavior and aging (Castren and Kojima, 2017). Reduced levels of BDNF have been connected to dendritic atrophy, neuronal apoptosis, and inhibition of neurogenesis in MDD (Nowacka and Obuchowicz, 2013). Stress decreases BDNF concentrations in hippocampus and PFC of animal models of depression (Smith et al., 1995; Duman and Monteggia, 2006; Filho et al., 2015), in line with the reduced expression of this neurotrophic factor observed at cortical, hippocampal, and peripheral level of depressed patients (Thompson Ray et al., 2011; Reinhart et al., 2015). Stress exposure also leads to an impairment of TGF-β1 signaling in different brain regions (hippocampus, cortex, and hypothalamus) (You et al., 2011; Caraci et al., 2015). This impairment has been connected to the onset of a depressive-like phenotype in mice (Torrisi et al., 2019). Lastly, a correlation between reduced TGF-β1 plasma levels, depression severity, and treatment resistance in MDD has been proved (Sutcigil et al., 2007; Caraci et al., 2018a).

In addition to HPA axis hyperactivation, immune system dysregulation and neuroinflammation play a central role in the pathophysiology of depression (Caraci et al., 2010), underlining the great impact of immune system activation on the central nervous system and in particular on the overall activity of monoaminergic systems (Caraci et al., 2018a). An increase of two well-known pro-inflammatory cytokines, called interleukin (IL)-1β and tumor necrosis factor-α (TNF-α), as well as a decrease of anti-inflammatory cytokines (e.g., IL-10, IL-4, and TGF-β1) have been observed in hippocampus and cortex of animal models of depression (You et al., 2011) and MDD patients (Farooq et al., 2017; Caruso et al., 2019).

Antidepressant drugs, such as sertraline and fluoxetine, exert immunomodulatory effects, reducing the production of pro-inflammatory cytokines and stimulating the synthesis of TGF-β1 in depressed patients (Sutcigil et al., 2007; Maes et al., 2016; Caraci et al., 2018a). Furthermore, the ability of some antidepressant drugs to induce the synthesis and the release of BDNF and TGF-β1 has been demonstrated both *in vitro* and *in vivo* studies (Caraci et al., 2010), suggesting that the long time required for BDNF restore could, at least in part, contributes to explain the therapeutic latency (2–4 weeks) of these drugs (Racagni and Popoli, 2010). Recent studies have demonstrated the rapid and long-lasting antidepressant effects of TGF-β1 as well as the key role of TGF-β1 released from microglia in mediating the antidepressant activity of (R)-ketamine (10 mg/kg) in a mouse model of depression (Zhang et al., 2020). (R)-ketamine is a novel drug under study for treatment-resistant MDD patients. Interestingly this drug rescued the expression of TGF-β1 and its receptors in the PFC and hippocampus, whereas inhibition of TGF-β1 signaling (i.e., SB431542) or neutralizing antibody of TGF-β1 blocked the antidepressant effects of (R)-ketamine, thus suggesting the essential and novel role of TGF-β1 as antidepressant.

According to the neurotrophic hypothesis of depression, which could be the impact of physical activity on the neurobiology of depression considering recent evidence in MDD patients?

Physical activity as an add-on strategy to the traditional treatment of depression is able to reduce the relapse risk, increase adherence to pharmacological treatment, and promote the management of side effects with a 60–80% of success (Neumeyer-Gromen et al., 2004; Silveira et al., 2013; **Figure 1**).

Interestingly a recent study conducted by Murri et al. (2018), has demonstrated that physical exercise, in combination with the SSRI sertraline, reduces affective symptoms and psychomotor retardation in MDD. Furthermore, the beneficial effects of AE as an add-on strategy in the treatment of moderate to severe depression has been shown in a study carried out by Imboden et al. (2019), considering different psychological and biological variables (e.g., BDNF, HPA axis activity, cognitive symptoms) besides depression severity.

Physical activity exerts beneficial effects on pre- and postnatal brain development (Gomes da Silva and Arida, 2015), stimulates neurogenesis and synaptic plasticity by increasing BDNF synthesis and release (Walsh and Tschakovsky, 2018), and reduces HPA axis hyperactivation (Nabkasorn et al., 2006). In particular, it has been proposed, as a proof of muscle-brain crosstalk, that irisin, produced during exercise through the cleavage of fibronectin type III domain-containing protein 5 (FNDC5) membrane protein and able to cross the blood-brain barrier, induces BDNF expression at brain level, which in turn will lead to an increased hippocampal neurogenesis, and therefore to enhanced learning, memory, and mood (Pedersen, 2019). With regard to TGF-β1, the plasma concentration of this neurotrophin increases in response to exercise (1 h of treadmill running) (Heinemeier et al., 2003). In a different study enrolling healthy people and Parkinson subjects, the immunomodulatory effects of moderate intensity on plasma neurotrophins levels was investigated (Szymura et al., 2020). Szymura et al. (2020) demonstrated that after completion of the 12 weeks training program the concentration of TGF-β1 as well as of other neurothophic factors (nerve growth factor and BDNF) were found to be increased only in training groups. Furthermore, in a study considering a total of 29 athletes, the serum levels of TGF-β1 were higher in athletes with high relative Vo_2peak (relVo_2peak) values, a measure of the athletes' cardiovascular fitness and aerobic endurance, compared to low relVo_2peak (Weinhold et al., 2016). No studies have been conducted yet in MDD patients to assess whether SSRIs can synergize with AE to increase TGF-β1 signaling, although preliminary available evidence suggests the existence of common biological targets.

All together, the above mentioned evidence suggests a synergistic effect between AE and antidepressant drugs for the treatment of depression (**Figure 2**), reducing the cognitive deficits that compromise the working activities of MDD patients and influence their relapse risk (Albert et al., 2016). This synergism might be particularly relevant in elderly patients with late-life depression (LLD), a clinical sub-group with an increased risk to develop dementia, improving patients' cognitive outcomes (Neviani et al., 2017).

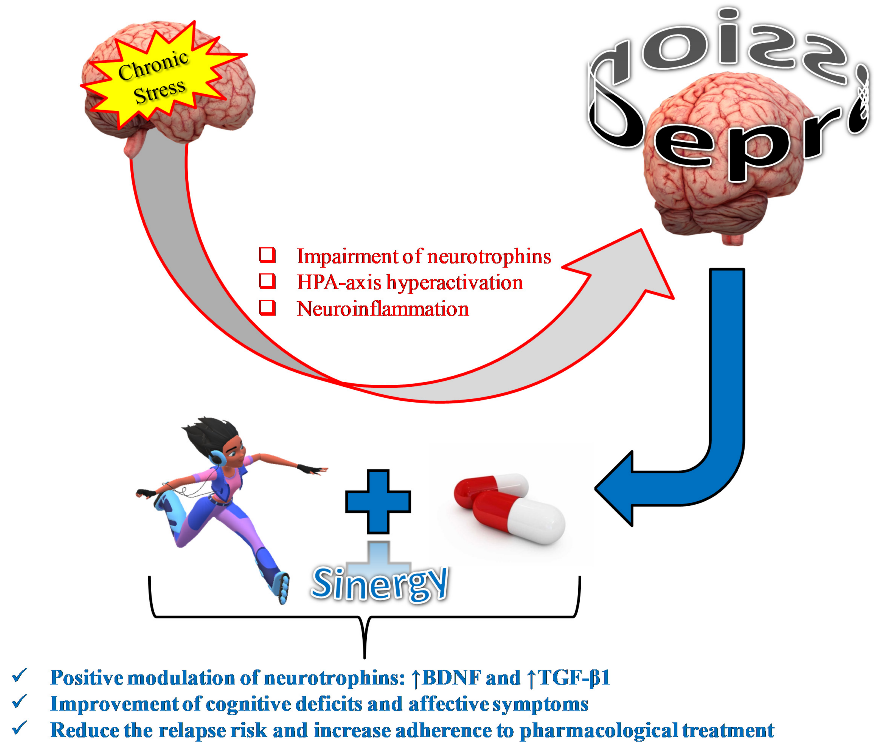

FIGURE 1 | Physical activity as an add-on treatment strategy to antagonize stress-induced depression.

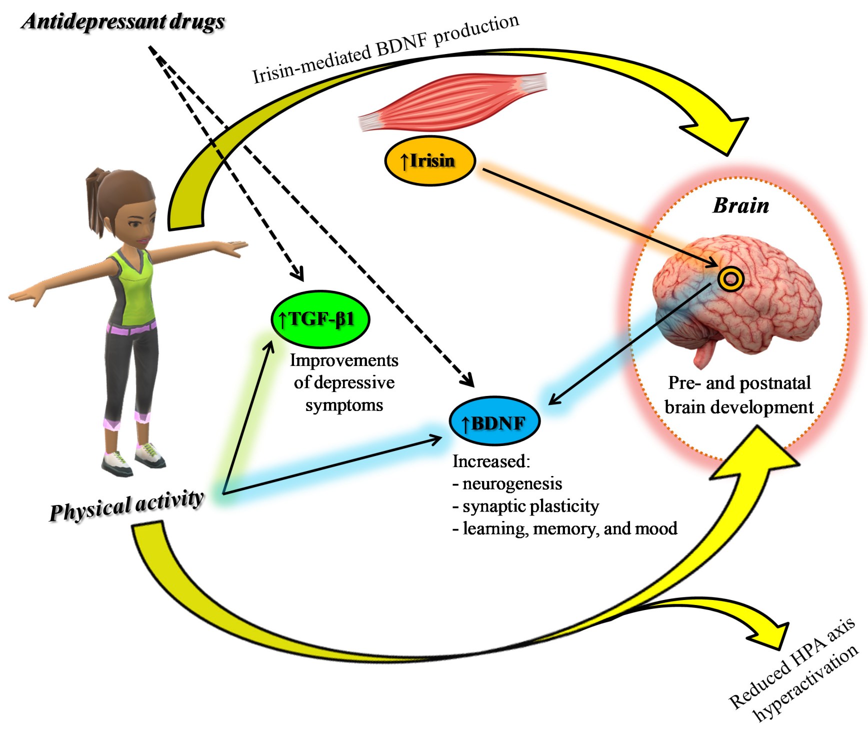

FIGURE 2 | Synergic effect between physical activity and antidepressants: positive modulation of neurotrophic factors.

IMPACT OF PHYSICAL ACTIVITY ON AFFECTIVE SYMPTOMS IN MDD

Apart from biological and genetic risk factors (Hammen, 2018), physical inactivity has been identified as a risk factor for the development of depression (Adamson et al., 2016; Hammen, 2018). Along this line different studies have shown that physical activity is able to provide mental health benefits in patients with severe mental illness, reducing depressive symptoms and improving social and cognitive functions (Rosenbaum et al., 2014). In a recent global systematic review and meta-analysis including 69 studies, Vancampfort et al. (2017) have examined sedentary behavior and levels of physical activity in patients with MDD or other severe mental disorders. After the analysis of the studies, it was clear as the physical activity was connected to health benefits in healthy controls while the level of activity as well as the related benefits were low in people with severe mental illnesses (Vancampfort et al., 2017). Indeed, as confirmed in different studies, regular physical activity of moderate intensity, such as walking or cycling, is enough to give significant benefits for health and plays a protective role in preventing different mental disorders (Ashdown-Franks et al., 2019); whereas lack of exercise represents a major cause of chronic diseases, including depression (Booth et al., 2012). Several studies have focused their attention on the potential benefits of physical activity to prevent the development of this disease. The "HUNT Cohort Study" investigated whether exercise provides protection against new-onset depression, the importance of both intensity and amount of physical activity and existing associations between them (Harvey et al., 2018). The results based on a healthy cohort of 33,908 adults followed for 11 years suggested that regular leisure-time exercise of any intensity provides protection against future depression development. Very recently Bennie et al. (2020) showed in a study employing a large sample (23,635) of German adults that AE is associated with a lower likelihood of depressive symptoms severity, as assessed by eight-item Patient Health Questionnaire depression scale (PHQ-8). In a case report published by Büyükturan et al. (2017), AE was able to improve physical conditions and to dramatically decrease depressive symptoms (sadness, anhedonia, reluctance to getting out of house, memory complaints) in a 76 years old female patient. Before enrollment in the study, she followed a 6-months treatment with antidepressants without getting any improvement. She followed a special 4-weeks exercise program consisting of 10 min warm-up (jogging, breathing, upper, and lower extremity active exercises), 20–25 min flexibility, balance and strengthening exercise, and 10 min cool-down exercise periods.

It has been shown that regular physical activity is able to reduce sleep disturbances (Chen et al., 2010) and improve somatic, affective, and cognitive symptoms in depressed patients, especially by enhancing the psychological health and social relationships (Babyak et al., 2000). Netz (2017), by the analysis of different randomized controlled trials in which physical exercise and pharmacologic treatment were compared, found in all studies considered, except one, that patients performing physical activity as an adjunctive treatment for depression have a significant improvement of depressive symptoms and a better clinical response after the exercise period.

An additional meta-analysis, carried out by Kvam et al. (2016), shows as different types of exercise (e.g., walking, running, cycling) could represent a viable adjunct treatment in combination with antidepressants. They demonstrate that the effects of exercise as an independent treatment were evident, with maximum efficacy showed when compared to no intervention, suggesting that physical activity may represent an alternative approach in non-responder patients.

As discussed above, a regular physical activity is also able to reduce depressive symptoms by different neurobiological mechanisms. In fact, it can increase monoaminergic neurotransmission (Stenman and Lilja, 2013), reduce cortisol levels simultaneously increasing hippocampal neurogenesis (Rethorst et al., 2009; Blake, 2012; Niwa et al., 2016), and increase β-endorphin and BDNF levels (Ernst et al., 2006). Since in the brain, neurons are a significant source of BDNF, whose synthesis occurs in regions fundamental for emotional and cognitive functions (Sasi et al., 2017), these preliminary evidence suggests that physical activity, when performed in combination with pharmacological antidepressant treatment, may improve affective symptoms in MDD patients.

IMPACT OF PHYSICAL EXERCISE ON COGNITIVE SYMPTOMS IN MDD

MDD could be considered as the most common mental illness among elderly people with an estimated prevalence ranging from 4.6 to 9.3% (Luppa et al., 2012). Rates of MDD are by and large lower in healthy community-dwelling elderly people than in younger adult populations, in a range from 1 to 3% (Kessler et al., 2010). However, these rates can increase on the basis of increasing medical and psychiatric comorbidity as well as in relation to various social conditions (Espinoza and Kaufman, 2014). LLD, occurring in people with an age ≥60 years, is often associated to cognitive dysfunction (Taylor, 2014). Cognitive dysfunction can affect one or multiple cognitive domains such as attention, working memory, verbal fluency, visuospatial abilities, and executive function (Murrough et al., 2011). Furthermore, this clinical sub-group presents a higher risk to develop dementia, in particular Alzheimer's disease and vascular dementia (Caraci et al., 2010; Diniz et al., 2013). LLD clinical manifestations are individual suffering, increased morbidity, premature mortality, and greater healthcare utilization (Diniz et al., 2013; Meijer et al., 2013), compromising the geriatric patients' life quality (Morimoto et al., 2015). Moreover, LLD is a condition often accompanied by significant impairment in physical and social functioning as well as disability (Blazer, 2003; Chang et al., 2016). Longitudinal studies have shown that LLD worsens the outcomes of physical illnesses and the likelihood of frailty in elderly people (Butters et al., 2008; Vaughan et al., 2015). Research community has focused its attention on physical exercise as a potential non-pharmacological treatment to improve cognitive function in depressed elderly patients. Since 1990s, several studies have been carried out to demonstrate the efficacy of physical exercise as an intervention for clinical depression in these patients (Dupuis and Smale, 1995; Blumenthal et al., 1999). In a randomized controlled trial, Singh et al. (2001) demonstrated the effectiveness of a 20 weeks physical exercise program as a long-term treatment for clinical depression in elderly patients. The same year, in a different study, the effectiveness of a structured exercise program on specific areas of cognitive functioning (e.g., attention, concentration, executive processes, figural memory) compared to antidepressants treatment has been proved (Khatri et al., 2001). In 2012, Bridle et al. (2012) showed that structured physical exercise tailored to individual ability reduces depression severity in older people with clinically significant symptoms of depression. More recently, Heinzel et al. (2015) demonstrated that all investigated types of physical exercise, such as AE, resistance training, dancing, and alternative forms of exercise (Qi Gong and Tai Chi), may serve as a feasible and additional intervention for depression in elderly people. This preliminary evidence was strengthen by a meta-analysis of randomized controlled trials carried out by Schuch et al. (2016), suggesting that previous meta-analyses have underestimated the benefits of exercise and therefore structural physical exercise should be considered as a routine component of the management of depression in older adults.

This evidence shows how physical exercise could improve the effectiveness of pharmacological treatments in elderly depressed patients (Mura and Carta, 2013; Murri et al., 2015). An improvement in memory and executive functions that persists for up to 24 months was demonstrated in elderly depressed patients who followed an integrative approach consisting of combined physical activity and pharmacological treatment (Bragin et al., 2005). Murri et al. (2015), in a study of 24 weeks employing 121 primary care patients (>65 years) with major depression, demonstrated the synergism between the antidepressant sertraline and two different types of physical exercise in improving the outcomes related to LLD. In particular, a higher remission rate (primary outcome) was observed for the higher intensity, progressive AE plus sertraline group (81%), showing an increment of +8% (and shorter time to remission) and +36% compared to lower-intensity, non-progressive exercise plus antidepressant and sertraline alone, respectively.

Neviani et al. (2017) performed secondary analyses on data from the Safety and Efficacy of Exercise for Depression in Seniors study, a trial comparing the effectiveness of sertraline, in the absence or in the presence of progressive or non-progressive exercise. The results of 121 patients (mean age 75 years) showed improvements of Montreal Cognitive Assessment (MoCA) total scores and visuospatial/executive functions for sertraline plus progressive exercise group, showing how the addition of aerobic, progressive exercise to antidepressant drug treatment may offer significant advantages over standard treatment with regard to cognitive abilities and disability (Neviani et al., 2017).

CONCLUSION

Physical activity stimulates neurogenesis and synaptic plasticity through BDNF synthesis and release, induces physiological changes in endorphine and monoamine levels, increases the plasma concentration of TGF-β1, and reduces cortisol levels; it can also act as an "anti-inflammatory factor" increasing IL-10 levels and suppressing TNF-α production, thus exerting "antidepressant-like effects". Therefore, we can assert that physical activity modulates many mechanisms and systems involved in the pathophysiology of depression. Physical activity has also proved able to act on the core symptoms of depression, decreasing sadness, anhedonia, and sleep disturbances, improving metabolic control and cognitive functions such as attention and concentration, and also decreasing the risk of depression and dementia development. Lastly, different clinical trials have highlighted the effects of physical activity as add-on treatment for MDD patients with moderate to severe depression, underlining the existing synergism between AE and the traditional pharmacological treatment. This synergism might be particularly relevant in elderly patients with LLD, a clinical sub-group characterized by an increased risk to develop dementia.

AUTHOR CONTRIBUTIONS

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

FUNDING

This work was supported by PRIN2017 (Program of Relevant National interest- 2017AY8BP4_004) from the Italian Ministry of University and Research.

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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.

frontiers in Psychology

ORIGINAL RESEARCH
published: 26 May 2020
doi: 10.3389/fpsyg.2020.00932

What Brings Out the Best and Worst of People With a Strong Explicit Achievement Motive? The Role of (Lack of) Achievement Incentives for Performance in an Endurance Task

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An explicit achievement motive is intuitively related to good performance. In contrast, the present paper directs attention to conditions where individuals with a strong explicit achievement motive display poor performance. We hypothesized that participants with a strong achievement motive perform worse in a bicycle ergometer task when task instructions lack achievement incentives than when the instructions include achievement incentives. Furthermore, we expected that, when achievement incentives are lacking, they show even worse performance than participants with a weak achievement motive. For the latter, we assumed that they are relatively unaffected by the achievement incentive content of the instructions. In a within-subject experimental design ($N = 55$) with two blocks (achievement incentives vs. lack of achievement incentives; each block consisted of three trials), our hypotheses were partly supported. The lack of achievement incentives brought out the worst (regarding performance), but the presence of achievement incentives did not bring out the best of participants with a strong achievement motive. In the discussion, we suggest how to improve future experimental achievement settings and reflect the results within the framework of the differentiation into implicit and explicit motives.

Keywords: explicit achievement motive, motives, incentives, motor performance, underperformance

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *19 February 2020*
Accepted: *15 April 2020*
Published: *26 May 2020*

Citation:
Schüler J and Wolff W (2020) What Brings Out the Best and Worst of People With a Strong Explicit Achievement Motive? The Role of (Lack of) Achievement Incentives for Performance in an Endurance Task. Front. Psychol. 11:932. doi: 10.3389/fpsyg.2020.00932

INTRODUCTION

That a strong achievement motive, defined as "the capacity to derive satisfaction from the autonomous mastery of challenging tasks" (Schultheiss, 2008, p. 603), which in turn encourages people to seek out situations that allow measuring one's standards of excellence (McClelland et al., 1953), is associated with high performance is not only intuitively plausible but also supported by research in sports (Elbe et al., 2005; Wegner et al., 2014; Gröpel et al., 2016) and in several other domains of life, for example, at the workplace (e.g., Andrews, 1967; McClelland and Franz, 1992), in learning contexts (e.g., McKeachie, 1961; O'Connor et al., 1966; Dahme et al., 1993; Schultheiss and Köllner, 2014), and in research laboratories with a broad variety of achievement tasks (to name but a few examples: Thurstone, 1937; Lowell, 1952; Biernat, 1989; Puca and Schmalt, 1999; Fodor and Carver, 2000; Brunstein and Hoyer, 2002; Brunstein and Maier, 2005; Pang, 2010).

In the present paper, we focus on *explicit* achievement motive, which has to be differentiated from *implicit* achievement motive due to differences in the behavior it influences, in the incentives that arouse the motives, and in motive development, to name a few examples. (For a detailed differentiation into implicit and explicit motives, see McClelland et al., 1989; see also discussion below.) The explicit achievement motive is a consciously represented part of one's self-concept ("I am a person for whom it is important to perform well," "It is important for me to demonstrate good performance"). According to previous theoretical considerations, the explicit achievement motive is highly relevant for performance in general (McClelland, 1980; Brunstein and Maier, 2005), as well as for performance in the sports and exercise context (Elbe and Wenhold, 2005; Elbe et al., 2005).

Motivation researchers share the view that the link between achievement motivation and performance stems from the interaction between the person's achievement motive and characteristics of the situation (e.g., performance feedback), which is associated with the possibility to satisfy the achievement motive and, as a result, promises the experience of positive affects (for achievement: feelings of pride, being satisfied because one acts in accordance with one's self-concept) (Brunstein and Heckhausen, 2008). In brief, the achievement motive is aroused by corresponding achievement incentives (Beckmann and Heckhausen, 2018a,b; McClelland, 1980).

The explicit achievement motive is incited in situations in which *social* incentives are present. Social incentives are characteristics of the situation such as demands and expectations that come from outside the task (e.g., from experimenters, teachers, coaches) rather than from the task itself (activity incentives) (for details about social and activity incentives, see McClelland et al., 1989). Further typical social achievement incentives, which we will also utilize in our study, are *verbal stimuli*. Bargh et al. (2001), for example, found that achievement-related words such as "win," "master," and "achieve" enhance performance. Also supporting this so-called "behavioral priming effect" (see also Breidebach and Gruber, 2019), Engeser et al. (2016) used excerpts from mathematics (Experiment 1) and language (Experiment 2) schoolbooks and found that semantic achievement primes enhanced performance in an arithmetic task and an anagram task, respectively. Following our line of argumentation that verbal stimuli leave *implicit* motives unaffected, the implicit achievement motive did not moderate the priming effect. In another series of studies, Engeser and Baumann (2014) found that verbally presented achievement primes indeed arouse explicit, but not implicit, achievement motivation (for further examples of achievement motive priming, see Breidebach, 2012, 2017).

A further example of verbal stimuli is achievement-related instructions in an experiment (McClelland et al., 1953; French, 1958). In the present study, we use task instructions for our experimental manipulation that stress the personal importance of performing well and demonstrating one's competence.

The *presence* of achievement incentives is one "side" of the achievement motive × incentive interaction. But what about the other side of the interaction: How do people behave, when achievement incentives are *absent*? When social extrinsic incentives are missing, and when people do not feel responsible for the performance outcome (e.g., when performance depends on a device's technical properties rather than on their performance; see calibration task below), then achievement behavior is not stimulated, and people with a strong achievement motive might perform even worse than people with weak achievement motives. The reason is that the explicit motives are built on the self-image of a person: "It operates as a cognitive regulator that shapes voluntary behavior in accordance with a person's motivational self-view, mainly through its influence on cognitively based choices and explicit responses to social–extrinsic cues" (Brunstein and Maier, 2005, p. 206). One possible choice or explicit response is to put no effort in tasks that do not satisfy the achievement motive, for example, in a task without individual performance feedback, because this makes it impossible to assess and demonstrate one's ability. In accordance with most motivation theories' assumption, that goal characteristics and needs have a direct (McClelland et al., 1953; Wigfield and Eccles, 2000) or indirect (Brehm and Self, 1989; Wright, 2008) crucial role for investing energy in goal pursuit, people with a strong achievement motive are effective in effort regulation in the sense that they put the effort in tasks that are "worth" it (worth concerning motive-satisfying potential). When performance has consequences for one's self-concept as an achievement-oriented and successful person, more effort should be mobilized to achieve high performance (Brunstein and Maier, 2005; Gendolla and Richter, 2010). They do not, however, waste time and effort in tasks that are "worthless" (= unable to satisfy the achievement motive). In sum, we assume that a strong achievement motive is associated with strategic effort investment. In contrast, for people with a weak achievement motive, achievement incentives are irrelevant, and their task performance might depend more strongly on other factors (e.g., compliance with the experimenter's instructions).

In the present study, we experimentally designed instructions that either contain (achievement condition) or lack (calibration condition) achievement incentives to test the following interaction hypotheses concerning motor performance in a strenuous motor task: Participants with a strong achievement motive are expected to perform worse in an experimental condition that lacks achievement-related incentives than in a condition that includes achievement incentives. We furthermore assume that when a condition is void of achievement incentives, they perform even worse than participants with a weak achievement motive. When achievement incentives are present, they should perform better than the latter. We chose an endurance task (cycling on a bicycle ergometer) because physical performance can be accurately and continuously measured, and performance can be visualized to participants in real time. Further, as physical exertion creates a strong sense of effort, strategic effort investment (i.e., pacing) occurs even during short experimental tasks. We varied the difficulty of the endurance task (low, moderate, and hard levels of load) referring to an established power table (Coggans power table)[1] and

[1]https://www.trainingpeaks.com/blog/power-profiling/

exploratorily examined whether load influences the hypothesized effect reported above.

MATERIALS AND METHODS

Participants

Fifty-five students (31 women) from different faculties of a German university with a mean age of 23.67 years (*SD* = 5.09) participated in an experiment that was announced as a study that allegedly tested emotional well-being during an ergometer endurance task. We recruited participants using a university-internal platform, postings on blackboards, and advertisement in lectures. As exclusion criteria, we defined consumption of caffeine and tobacco less than 2 h before the experiment and alcohol or other drug intakes less than 12 h before the experiment. Further exclusion criteria were lower limb injuries and strenuous workouts in the last 12 h. Participants were informed that they will receive 10 Euros and that the study will last about 1 h.

Procedure

The study design and material (e.g., information sheet, debriefing form) met the standards of the Ethics Committee of the authors' university and were in line with the Declarations of Helsinki (World Medical Association, 2013). Participants were tested individually in a laboratory at the authors' university. After being greeted by a female experimenter, participants read the information sheet and filled in the informed consent form. Then their height and body weight were assessed. While the experimenter prepared the bicycle ergometer (e.g., chose a load profile that fit participant characteristics, e.g., profile for men and women depending on body weight; see below), participants filled in a questionnaire containing the achievement motive measure (Unified Motive Scale, UMS, Schönbrodt and Gerstenberg, 2012) and a questionnaire that was used to test a hypothesis irrelevant for the present research (Self-Regulation Scale, Schwarzer et al., 1999)[2].

After that, the experimenter adjusted the parameters on the bicycle according to the participants' comfort (i.e., pedal and crank arm are parallel to the floor, while the knee and shank are perpendicular to the floor). Participants were then asked to start pedaling to familiarize themselves with the bike. They learned that they are expected to practice maintaining a given cadence that allegedly will be computed later from their individual scores (in fact, all cadences were 70 rpm) and tried it out during a familiarization phase. The cadence was displayed continuously on a screen in front of the participants while they were pedaling. The given cadence was clearly marked by a line so that participants could continuously observe deviations from the target cadence. It was explained that being precise – that is, keeping a specified cadence of 70 rpm – represents good performance. This should also include the reverse conclusion that poor performance is indicated by deviations from cadence (no matter whether higher or lower scores were achieved). A warm-up phase lasting 3 min followed. Participants were requested to inform the experimenter in case of any pain or discomfort during the course of the test and had the opportunity to ask questions about the whole procedure.

Then the actual test that consists of two blocks with three levels of load started. The first block consisted of half of the participants in the calibration condition and the other half in the achievement condition (random assignment to the order of condition). After a 5 min break, the groups received the respective other condition. The experimental conditions were implemented using written instructions for the cycling task. The achievement instructions contained positive evaluations of performance (which is a scoring category for the achievement motive in Winter's scoring manual, Winter, 1994) (e.g., "optimal cadence," "accuracy of your performance") that unambiguously can be attributed to participants (it is about "YOUR individual performance"). As the incentive for people with a strong achievement motive is "to do something better" (McClelland, 1985), they need a tool to assess performance, for example, by receiving feedback on how well they are doing. In accordance with these theoretical considerations, previous research supported that people with a strong (implicit and explicit) achievement motive benefit more from feedback than participants with weak achievement motives (Fodor and Carver, 2000; Brunstein and Maier, 2005). We, therefore, announced an "individual performance log" in the instructions of the achievement condition. In contrast, in the calibration task, performance was framed as an accuracy assessment of the ergometer. With this, we intended to make participants feel responsible for their performance outcome in the achievement, but not in the calibration, condition (for a similar procedure, see McClelland et al., 1949). The concrete instructions for the achievement and calibration conditions are displayed in **Table 1**.

The two ergometer blocks consisted of three levels of loads (low, moderate, hard) lasting 2 min each with a break of 1 min between each run. We used the Coggans power table[3] to determine gender-specific power/weight (p/w) ratios for the low, moderate, and hard load levels. Female participants had to pedal at a p/w ratio of 1.6 for the easy, 2.1 for the moderate, and 2.6 for the hard load levels, and male participants pedaled at 2.4, 3, and 3.6 p/w for the easy, moderate, and hard levels. The loads were calibrated in such a way that even untrained participants would be able to complete 2 min of the hard load. After the cycling part, the participants answered two questions checking whether they were aware of the hypotheses (What do you think was the real aim of the study? How do you think the two sessions were connected?). No participant realized the study's intention. Then they stated whether they consumed any drugs, caffeine, or alcohol prior to the study (exclusion criteria). They then received a debriefing form and their payment and were thanked and dismissed.

[2]Further variables were assessed that are not relevant for the present research question (weight, height, perceived exertion).

[3]https://www.trainingpeaks.com/blog/power-profiling/

TABLE 1 | Wording for the achievement and calibration conditions in the two separated blocks of the experiment.

	Block 1: Achievement		Block 2: Calibration
1.1	Let's start with the test.	2.1	The ergometer needs a new calibration. Like this, we can be sure about the accuracy of the ergometer.
1.2	First of all, we will do three runs with different levels of difficulty	2.2	We are again performing three runs with different levels.
1.3	With these runs, we will measure the accuracy of YOUR task PERFORMANCE.	2.3	We will perform the same as before. But this time, we will test the ERGOMETER instead of you.
1.4	We can measure your performance accurately in the course and compare it to the rest of the participants.	2.4	This time, we are measuring the accuracy of our ergometer. We have to calibrate the ergometer to make sure it measures accurately.
1.5	Here you can see your personal performance line, which we have calculated for you during the pre-test (warming-up). The optimal cadence per minute for you is 70. This line here displays the 70 rpm cadence line. Your task is to keep the cadence of 70 rpm as constant as possible around (above or below) this line. Like this, we can exactly figure out your precision of riding a specific cadence. Go for it!	2.5	Here you can see a calibration profile presented by the software of the ergometer. The cadence is 70 rpm. This line here displays the 70 rpm cadence line. Your task is to keep the cadence of 70 rpm as constant as possible around (above or below) this line. Like this, we can figure out the accuracy of our ergometer. The calibration is starting soon!
1.6	*Afterward, you will receive your individual performance log. Here, you can see an example of an ergometer protocol. The performance log will look like this. It shows your performance over time and in comparison to the other participants.	2.6	*This time, this will be the test report for the ergometer. So, we will get a log with the deviation of the ergometer from its calibration line. Roughly the same will be our performance log for the ergometer. It shows the deviation of the ergometer compared to the calibration line.

*The numbering is just for illustration of the experimental manipulation; participants read a running text. *A profile example was presented to show how the participant's profile (/the bicycle ergometer's profile) could look at the end. Participants were told that they would receive a printed version of their own profile (/the ergometer's profile) at the end of the study.*

Measures

We used a German version of the Unified Motive Scale (UMS-10, 54 items, Schönbrodt and Gerstenberg, 2012) that assesses a broader range of self-attributed motives. Reports about the UMS reliability and validity can be found in Schönbrodt and Gerstenberg (2012); see also Sariyska et al. (2019). The **achievement motive** scale, which is relevant for our research question, consists of two statements (i.e., "I am appealed by situations allowing me to test my abilities, "My goal is to do at least a little bit more than anyone else has done before"), which require an agreement rating on a six-point rating scale ranging from 1, strongly disagree, to 6, strongly agree, and eight goals (e.g., "continuously improve myself," "personally producing work of high quality," "opportunities to take on more difficult and challenging goals and responsibilities," "personally doing things better than they have been done before," "opportunities to create new things," "projects that challenge me to the limits of my ability," "continuously new, exciting, and challenging goals and projects," "maintaining high standards for the quality of my work"), which require an importance rating (1, not important to me, to 6, extremely important to me).

We used a Cyclus2 ergometer (by RBM Elektronik-automation GmbH, Leipzig, Germany) to assess **motor performance**. Cycling data were measured at a sampling rate of 2 Hz and with a set true gear ratio of 53/14. Participants were asked to keep the cadence as close as possible to around 70 rpm. In asking participants to keep this pre-defined cadence, we used accuracy rather than a "the more the better" (e.g., higher cadence indicates better performance) criterion of performance. We therewith ensured that the participants could not overspend themselves at the beginning (and have to abort their participation in the rest of the experiment due to physical exhaustion). In addition to these laboratory experimental reasons, motor precision is important to be analyzed, because it is crucial for an accurate execution of movement, which is important for injury prevention (for a similar reasoning, see Hirsch et al., 2020, March 17). A further reason is that motor response precision requires high exertion of self-control. Manohar et al. (2015, p. 1707) called this fact "cost of control," which means that exerting control to improve response precision itself comes at a cost (the costs to attenuate a proportion of intrinsic neural noise) (Giboin et al., 2019). Furthermore, keeping a specific cadence comes closer to Brunstein and Maier (2005) findings that the explicit achievement motive predicts the continuation of a task (keep on going) rather than the performance itself (e.g., peak performance).

Our choice of the level of cadence that we asked participants to keep (70 rpm) was based on studies that analyzed what cadence non-cyclists prefer when they are free to choose (Whitty et al., 2009). Non-cyclists freely chose levels of the cadence of about 80 rpm that they report to be comfortable, which, however, were significantly higher than the most economical cadence (in terms of metabolic economy, 50 rpm). Cycling at a cadence above or below the most economical cadence of 50 rpm was experienced as strenuous, indicated by higher ratings of perceived effort (RPEs). We chose a cadence (70 rpm) that deviates from the expected preferred cadence of 80 rpm, to ensure that participants were not likely to automatically gravitate to our target cadence.

In our experiment, deviations from a cadence of 70 rpm were squared and averaged for each load and condition. Thus, higher scores in "Cadence" represent poorer performance.

RESULTS

Description of Data and Their Relationships

Table 2 depicts means and standard deviations for participants' motor performance (Cadence) for the achievement goal and calibration conditions, each for an overall score and for low,

TABLE 2 | Means and standard deviations (in brackets) for Cadence for the Achievement and Calibration Conditions separated for different levels of load.

	Achievement condition				Calibration condition			
Load	**Overall**	**Low**	**Moderate**	**Hard**	**Overall**	**Low**	**Moderate**	**Hard**
Cadence	2.27 (4.21)	2.24 (3.95)	2.13 (4.37)	2.45 (4.32)	4.07 (8.82)	2.97 (5.66)	4.14 (9.1)	5.09 (11.7)

Cadence means squared deviations from a cadence of 70 rpm, and thus, higher scores mean poorer performance.

moderate, and hard loads. The achievement motive (M = 3.48, SD = 0.723) is positively correlated with deviation from cadence in the achievement condition (r = 0.31, p = 0.021) as well as in the calibration condition (r = 0.38, p = 0.004). Cadence scores of both conditions were highly related with r = 0.37, $p < 0.005$.

Testing the Hypotheses

To test the hypothesis that participants with a strong achievement motive perform worse in the calibration condition than in the achievement condition (goal conditions were nested within participants), we conducted a hierarchical multi-level regression analysis using the statistical software R (R Core Team, 2017) and the lme4 package (Bates et al., 2015). We chose a hierarchical multi-level model to better account for the fact that people differ but that these differences do not stem from the experimental manipulation. The regression model was built by sequentially adding predictors after an intercept-only model, and its random intercept had been specified (*baseline model*). To create the *main effect model*, we added the single predictors (Condition, ACHmotive) to the baseline model with Condition allowed to vary between participants. The *interaction model* consists of the single predictors and the two-way interaction (Condition × ACHmotive). This procedure allowed us to compare all stages of model specification and figure out whether the interplay between ACHmotive and Condition can explain variance in addition to the single variables.

The interaction model summary showed that the ACHmotive significantly [b = 1.538, $t(53)$ = 2.371, p = 0.021, d = 0.320] and the interaction marginally [b = 2.755, $t(53)$ = 1.973, p = 0.054, d = 0.266] predicted performance. Condition was not a significant predictor [b = −7.800, $t(53)$ = −1.571, p = 0.122, d = 0.212]. An ANOVA testing the *main effect model* against the *interaction model* revealed a significant effect [$\chi^2(1)$ = 3.898, p = 0.048] indicating that the interaction model significantly improved the fit over the main effect model. **Figure 1** illustrates the nature of the interaction.

In accordance with the hypothesis, participants with a strong achievement motive (blue lines and dots) performed worse in the calibration than in the achievement condition. Also as expected, in the calibration condition, they performed worse than participants with a weak motive (red lines and dots). Unexpectedly, however, participants with strong and weak achievement motives did not significantly differ in the achievement condition.

Exploratory Analyses

To examine whether the load of the task (easy, moderate, high) could improve the fit of the model, we examined a *main effect model* (Condition, ACHmotive, Load), a *two-way interactions model* (main effect model plus the three two-way interactions), and a *three-way interaction model* (two-way interaction model plus Condition × Load × ACHmotive interaction). Neither the three-way interaction nor the two-way interactions were significant[4].

DISCUSSION

We aim to make use of the primacy effect (Ebbinghaus, 1913; Murdock, 1962) and start our discussion with the results that support our hypotheses. A hierarchical linear regression analysis revealed that considering the interaction between incentive content of task instruction and participants' achievement motive contributes to explain performance. The interaction itself was only marginal, but the interaction model contributes significantly when compared to the main effect model. To sum, although we assumed this interaction effect to be stronger, it is a least partly in conformity with the fundamental hypothesis in motive research that motives interact with characteristics of the situation to predict behavior (Brunstein and Heckhausen, 2008). However, the pattern of the interaction only partly supported our assumptions. In line with the hypotheses, participants with a strong achievement motive performed worse in an experimental condition that lacks achievement incentives (calibration condition) than in a condition that includes achievement incentives (achievement condition). Also as expected, in the calibration condition, they performed worse than participants with weak achievement motives. This supports our assumption that people with strong achievement motives perform badly when the effort that has to be invested in a task is not worth the effort because it does not promise motive satisfaction. We speculate that this "lazy" behavior is a clever strategy to invest one's effort efficiently, for example, by not "wasting" it on an unrewarding task (but saving energy for highly rewarding tasks).

Also in accordance with our hypotheses, people with a weak achievement motive, who are not dispositionally interested in demonstrating performance, showed relatively robust performance across the two experimental conditions. Their performance behavior was fully in line with the instructions given by the experimenter. It seems that agreeableness and

[4]We conducted a power analysis (using GPower 3.1; Faul et al., 2009) for a design with lower statistical power (no multi-level design). This analysis for an ANOVA with repeated measures testing a 2 (condition vs. achievement) * 3 (easy vs. moderate vs. high) design (effect size = 0.25, alpha = 0.05, power = 0.80) revealed an ideal sample size of 44 participants (actual power: 0.9557).

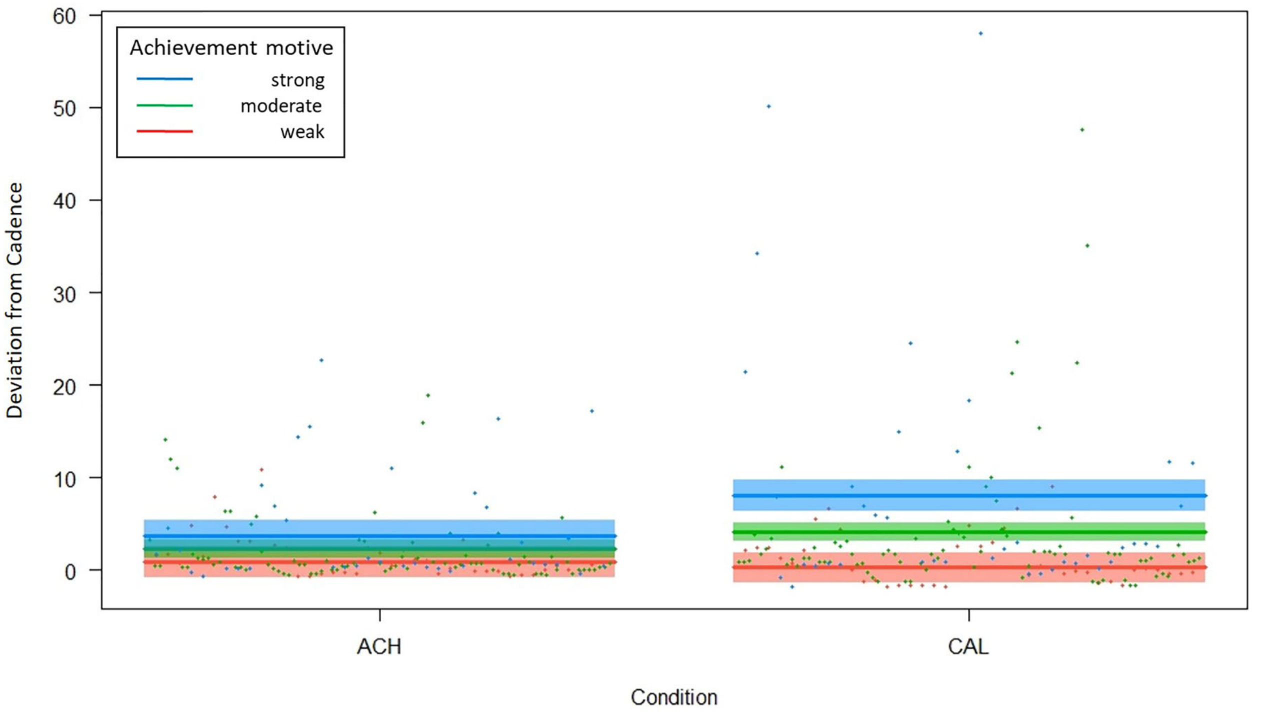

FIGURE 1 | Illustration of the Condition × Achievement Motive interaction. Note. Cadence means squared deviations from a cadence of 70 rpm, and thus, higher scores mean poorer performance. ACH: Achievement condiction, CAL: calibration conditions.

compliance with experimental instructions had guided their behavior. This is in contrast to participants with a strong achievement motive who appear to have regulated their effort depending on the incentive content of the instructions. Unexpectedly, the assumption made for the achievement condition was not supported by the data. Here, participants with a strong achievement motive did not perform better than participants with a weak achievement motive. An obvious reason is that participants with a weak achievement motive performed extremely well (very small deviations from cadence), and surpassing this level is virtually impossible. However, people with strong achievement motives should at least show the same performance. One explanation why they don't might be that – although we derived the components of the task instructions theoretically – we failed to create an experimental setting that incites the explicit achievement motive well. It might be that announcing an individual performance log did not directly promise to fulfill the desire to demonstrate one's performance. We should have extended the announcement by adding the information that their ergometer protocol would be published and therefore would be visible for others. Furthermore, as has been shown in the literature of achievement goal priming, using words as primes is not always effective (Harris et al., 2013). In addition, the effects of self-set goals might outweigh those of the priming, or stronger effects would be revealed from field rather than from laboratory settings (Chen et al., 2020).

It could also be that we did not only fail to incite the achievement motive in the achievement condition but that we even demotivated people with a strong achievement motive (as the positive correlation between achievement motive and deviation from cadence would support) by accidentally restricting their autonomy. Although the following considerations about autonomy and achievement motive refer to the implicit achievement motive, they could also apply to the explicit achievement motive: The incentive for people with a strong achievement motive is the autonomous mastery of challenging tasks (McClelland et al., 1953). As pointed out by Schultheiss (2008, p. 603), however, if people with a strong achievement motive "cannot chose and solve such tasks on their own terms, but are given explicit advice and direction on how to do it, they are likely to leave the field and invest no effort in the task" (see also Spangler, 1992). Reconsidering the instructions in the achievement condition, we might have put too much pressure on them by clearly directing them ("Your task is to keep the cadence of 70 rpm") and by demonstrating control by announcing that the experimenter monitors compliance with the instruction ("We can exactly figure out your precision of riding a specific cadence"). Future studies should give people with a strong explicit achievement motive more scope to choose the challenging task themselves. Most importantly, speculations about if and how the experimental manipulation had worked can be simply avoided by manipulations checks (e.g., asking participants how motivated they felt in each condition).

Furthermore, physical performance is only one single aspect of one's capability, and some (rather untrained) participants with strong achievement motives might not feel incited by this domain-specific performance setting. To avoid possibly domain-specific arousal of the achievement motive, we suggest adding the information to future study instructions that showing good performance in this endurance task is known to be an indicator of good performance in other domains of life (academia, workplace).

Limitations and Further Research Tasks

Our research leaves further open research questions that we aim to address in the following. In our study, we assessed explicit achievement motives because they are known to be triggered by social achievement incentives such as expectations from the experimenter, coaches, sport education teachers, and fitness instructors. However, next to the explicit achievement motive, the implicit achievement motive (unconsciously represented, based on affects), which is characterized by the enjoyment of challenging tasks and the anticipation of feeling proud after success (McClelland et al., 1953; Brunstein and Heckhausen, 2008), also plays a crucial role in sport performance (Gröpel et al., 2016). Implicit and explicit motives differ, among other things, in the incentives (social vs. activity incentives) that trigger them and lead to motive-relevant behavior. On the theoretical level, there is a clear-cut differentiation in regard to what type of incentives arouse which type of motive. Experimentally (and in everyday life), it is challenging to create incentives that map perfectly on this differentiation. Social and activity incentives cannot easily be isolated from each other. In the present laboratory study, it is highly probable that not only the result of the motor task motivated people to perform well or to save energy (explicit incentive) but also characteristics of the task itself. People with a strong *implicit* achievement motive might have been also attracted by, for example, the possibility to exceed their physical comfort zones and master a physically challenging task, regardless of the outcome of the activity (and therefore also regardless of being in the achievement or control group). We did not assess the implicit achievement motive and therewith cannot control for its influence on performance. A second way in which the implicit achievement motive might have undermined the hypothesized results is by being incongruent with the explicit achievement motive. The disconcordance between implicit and explicit motives causes impairment of well-being and motivation (Brunstein et al., 1998; Brunstein, 2010; Schüler, 2010) and requires self-control (Kehr, 2004; Schüler et al., 2019). However, all these are crucial for high performance in a strength endurance task.

Schüler (2010) took an even more extended perspective and examined the interplay between implicit and explicit achievement motives as well as achievement incentives. She found that achievement motive incongruence exerted stronger negative effects when individuals act in situations in which achievement incentives are present and arouse the conflict between the two motives. For the present study, this applies to the achievement condition but not the calibration condition. In brief, it might be that motive incongruence undermined the expected results only in the achievement condition (in which we found unexpected results) and left performance in the control condition (in which we found expected results) unaffected. Schüler (2010), however, analyzed effects on flow experience, and it is pure speculation (although theoretically plausible) that her findings also apply to motor performance. If we briefly accept this speculation as true, it still has to be explained why in the achievement condition, the motive incongruence reduced performance of people with a strong explicit achievement motive (and a weak implicit motive, Type 1 of motive incongruence) but not performance of people with a weak explicit achievement motive (and a strong implicit achievement motive, Type 2 of motive incongruence), who maintained their performance (see **Figure 1**). This can only be answered with another speculation. If a strong explicit achievement motive is not supported by the energy that is exerted in connection with a high implicit motive (Type 1 of incongruence), but this "energizing function" of implicit motives (McClelland et al., 1953) is needed for a strenuous endurance task, performance should be reduced. Type 2, in contrast, is characterized by a high implicit motive that remains unsatisfied, because a corresponding high explicit motive is lacking that elicits achievement-relevant behavior. In our laboratory session, however, the "achievement behavior" (holding a specific cadence) is pre-defined by the experimenter rather than initiated by the explicit achievement motive. The explicit achievement motive might not come into play here, and thus, the negative effects of this type of incongruence might therefore not be evinced. This explanation, however, is built on two speculations and has to be tested empirically.

Also, in reality, sport and exercise settings probably require a mixture of "respondent behavior" (McClelland, 1980) triggered by explicit motives and "operant behavior" triggered by implicit motives so that high standards of excellence can be achieved. Performance in a marathon race, for example, depends on the choice to participate in a large city marathon, for example, to fulfill the expectations of the running group and to demonstrate one's high-performance capacity to the public (social incentives, respondent behavior), and it depends on activity-inherent incentives, such as liking to run and enjoying that one's performance improves over time, that ensure long-term adherence to one's training program (activity incentives, operant behavior). Therefore, one imperative for future research is to assess behavior in settings that are closer to sports reality and allow, for example, spontaneously generated behavior (operant behavior) and examine its interplay with respondent behavior. Furthermore, more complex incentive patterns (e.g., social and activity incentives) and the assessment and arousal of implicit and explicit achievement motives have to be considered to overcome the artificiality of the laboratory and to better understand the complex interplay of implicit and explicit motives.

A further task for future research is to assess the mechanism that we assume to underlie the underperformance of people with strong achievement motives. The "worth" of performance behavior outcome can be assessed by asking participants how much they value the calibration task and the achievement task, respectively. Additionally, the willingness to invest effort has to be assessed with objective measures (cardiovascular effort indicators) or by assessing the self-reported willingness to invest effort.

CONCLUSION

To make use of the recency effect (Ebbinghaus, 1913; Murdock, 1962), we would like to close with a positive statement. Experimenters, coaches, sport education teachers, and fitness instructors can easily assist people by paying careful attention to the instructions they give. Although our study has not figured out what brings out the best from people with a strong achievement motive, it shows what instructions should be avoided because they harm people with a strong achievement motive. Practitioners in the sport context, for example, are recommended to avoid task instructions that do not contain any achievement incentives. They might function for some people who might exercise only to meet the expectations of others (in our study, people with a weak achievement motive who complied with instructions of the experimenter) but would discriminate against people with a strong achievement motive. But also for the former, the longer-term perspective does not look good: According to Self-Determination Theory (Deci and Ryan, 1985), external regulation (perform a behavior because somebody else wants me to do it) and introjected regulation (do it because you feel obligated) are less good predictors for the maintenance of sport and exercise over a longer time (for an overview, see Hagger and Chatzisarantis, 2008). We encourage researchers and people in the applied setting to consider individual differences in motives. This might help to better understand phenomena such as the assumed unwillingness to invest effort and the underperformance of people who are expected to perform well.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

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

AUTHOR CONTRIBUTIONS

JS and WW conceived the study design, conducted the study, and performed the statistical analyses together. JS wrote the first draft of the manuscript. WW revised and finalized 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.

frontiers in Sports and Active Living

HYPOTHESIS AND THEORY
published: 29 May 2020
doi: 10.3389/fspor.2020.00020

Memory Reactivation and Its Effect on Exercise Performance and Heart Rate

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Neuronal ensemble and brain plasticity both play an important role in memory consolidation and subsequently memory reactivation. To date, many studies have been designed to study the effect of exercise, heart-rate variability, and other factors on brain plasticity and memory. Here, we present a case study in which we have demonstrated the effect of neuronal ensemble and memory formed during High-intensity aerobic training (VO2 max) and Target Heart-Rate (THR) training and the effect of reactivation of same memory on THR and performance. Of note is the fact that the reactivation and recreation of memory stimulus learned and formed during High-intensity training, such as place, time, odor, and other conditions, can elevate the THR to the same previous peak zone even at low intensity. This demonstrates that reactivation of previously acquired memory or using the stimulation from the neuronal ensemble of consolidated memory during the specific event of training may exert similar physiological effects on exercise or the body to those that are learned during the memory acquisition phase. Hence, as exercise has an effect on memory, the memories may have an effect on exercise performances.

Keywords: neuronal ensemble, memory reactivation, THR, peak heart rate, exercise, aerobic

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Sports and Active Living

Received: *28 December 2019*
Accepted: *25 February 2020*
Published: *29 May 2020*

Citation:
Dhawan AG (2020) Memory Reactivation and Its Effect on Exercise Performance and Heart Rate. Front. Sports Act. Living 2:20. doi: 10.3389/fspor.2020.00020

INTRODUCTION

Memories play an important role in cognitive as well as functional behavior. Exercise and memories have been an important part of studies in recent years. The effects of exercise on memory consolidation, Neurogenesis, and Neuroplasticity have been observed on a different scale. The paradoxical relationship has not been thoroughly observed or studied. The memory consolidation and reactivation incorporate neuro-cortical paradigms as well as physiological shifts. As motor and sensory inputs play an important role in memory formation, the studies on memory reactivation and its physiological effects on biological systems need to be understood as part of learning during memory encoding. To begin the case study, we have created an overview of the fundamentals of exercise and memory.

MEMORY AND NEURONAL ENSEMBLE

The memory is a collection of neurons and can be classified as declarative, procedural, or cognitive memory. The basic unit of memory in the brain is depicted as an Engram. An Engram is a unit of cognitive facts inside the brain, theorized to be representative of how memories are stored as biophysical or biochemical changes in response to sensory stimuli (Ungerleider et al., 2002; Herz et al., 2004; Moehring, 2019). The formation of memory is not just the acquisition of information, but it is more profoundly a three-step process: acquisition, consolidation, and reactivation. The neurons involved in memory formation are populated across the brain space, forming a neuronal ensemble. A neuronal ensemble (Qin et al., 1997; Sutherland and McNaughton, 2000) is a population of nervous system cells involved in a particular neural computation where computation could be a complete path of a different set of neurons involved in memory. Memory is often imbued with multisensory richness; the recall of an event can be endowed with the sights, sounds, and smells of its prior occurrence (Musso et al., 1999; Ramachandran and Rogers-Ramachandran, 2000; Flor et al., 2013). All types of sensory inputs are encoded in memory learned during acquisition. Memory Consolidation is the process of stabilizing a memory trace after the initial acquisition and making it available for long term archive and reactivation (Moorman and Miner, 1997; Lundborg, 2000; Banks, 2016). It is usually considered to consist of two specific processes: synaptic consolidation and systemic consolidation. It can be considered an interplay between multiple cortical brain regions, and it has a prominent role in the hippocampus.

The reactivation of memory triggers the whole path of an ensemble: neurons that wire together fire together. The retrieving of these memories involve the reactivation of neural ensembles that were established during learning (Kolb and Whishaw, 1998; Lane et al., 2009; Flor et al., 2013). The well set of an experiment performed using optogenetics demonstrates that reactivation of a set of neurons reactivates the same encoded emotional set (Laubach et al., 2000; Critchley et al., 2002; Sumbre et al., 2008; Smith et al., 2009). Any trigger to the partial sensory group may trigger the whole set of the ensemble, resulting in the complete retrieval of state or emotion.

When it comes to exercise, in this context, we have looked at aerobic exercise. *Aerobic exercise* mainly involves aerobic energy-generating process or exercise that involves primarily aerobic or free oxygen metabolic processes. This aerobic exercise could be categorized ranging from low intensity to high intensity. High-intensity exercises involve the peak performance of cardiorespiratory capacity. Peak Heart rate involves reaching above 85% of one's cardio capacity depending on age (Stiedl et al., 2004; Mahncke et al., 2006).

Training Methods and Settings

The person involved in the case study was a 28-year-old male with a BMI of 20. The program was adapted for Target heart rate (THR) training by High-intensity Interval training-based treadmill running. The training aimed to achieve the THR in peak HR for the maximum time possible, thus improving VO2 max (Tayler et al., 2013; Thomas et al., 2016). The device used to track the Heart rate and Program data was a Fitbit Charge 2. The case study divided training into five phases, namely, the initial training phase, training phase, peak phase, weight training/detraining phase, and memory reactivation phase.

The maximum aerobic capacity or max heart rate (HR) was calculated by a formula created by Nes et al. (2013): HRmax = 211 – (0.64 × age), which is 193 bpm. The peak zone or maximum THR to peak zone (i.e., 85% and above of the maximum aerobic capacity) is >85% of 193. The training type used was High-Intensity Interval training (HIIT). High-intensity Interval training is built upon alternating between short, high-intensity bursts of energy with slower recovery phases throughout a single workout. Initially starting with steady-state cardio, this method gradually progresses to HIIT. It starts with an initial warm-up phase followed by alternating high-intensity running and slow walking recovery bursts; lastly, there is a cool-down phase. The aerobic detraining phase was achieved by inducing weight training. The weight training work out was low to mid-intensity weight training.

The main parameters considered for evolution were the heart rate zone and graph, the number of steps per exercise session, the calories burnt, and the duration of the exercise. The conditions set for training were considered to be the timing of training and the intensity of the treadmill, including speed in km/hr and inclination. The training was done in the morning session. Before training, the subject was regularly exercising/running for 20–30 min a day for 6 months. The average foot stride was of 2.5ft. The average room temperature varied from (22 ± 2) Celsius in winter to (31 ± 3) Celsius in summer. The activity tracker data report consists of the date, time, HR graph, Calorie burn graph, step count, HR zone, etc.

CASE STUDY

Initial Training

This consisted of 5 km running on a treadmill within approximate 40 (±5) min. The initial warm-up burst was 3 KM/Hr to 6 KM/Hr walk for 5–7 min. The maximum speed of highest intensity per burst was 12 KM/Hr with every burst of 1 min, and the lowest was 6 KM/Hr for a low-intensity bout with every burst of 1 min. Total High- and Low-intensity alternating bursts was on average 25–29 min. The last 2–3 min phase consisted of the cool down. As shown in **Figure 1**, the average step count was (5,200 ± 400) steps per exercise session, summating to an average of 5 km on the ground running. The average calorie burn was (400 ± 30) calories. The peak heart zone (85 to 100 percent of the maximum HR) maintained was 4 (±2 min). The maximum maintained zone was the cardio zone (70 to 84 percent of your maximum heart rate). This training was varied to 4–5 days a week for nearly 7 months. The treadmill inclination varied by 2% (±1).

Peak Phase

After the initial training, the peak performance stage was reached. As shown in **Figure 2**, the average step count was 5,600 (±500) steps per exercise session, resulting in an average of 5.5 (±0.5) km on the ground running. The average calorie burn was 470/±30 calories. The enhancement to VO2 Max was seen. The peak heart zone (85 to 100 percent of your maximum heart rate) that was maintained for 15 min (±4). The maximum maintained zone was the peak heart rate zone. The cardio zone was maintained for an average 15 (±4) min (70 to 84 percent of your maximum heart rate). All treadmill training parameters were, on average, the same as the initial phase.

Post Peak Phase

After the peak performance stage was reached, the subject maintained a regular training schedule for 3–4 days a week,

FIGURE 1 | Analysis report during one of the initial training months.

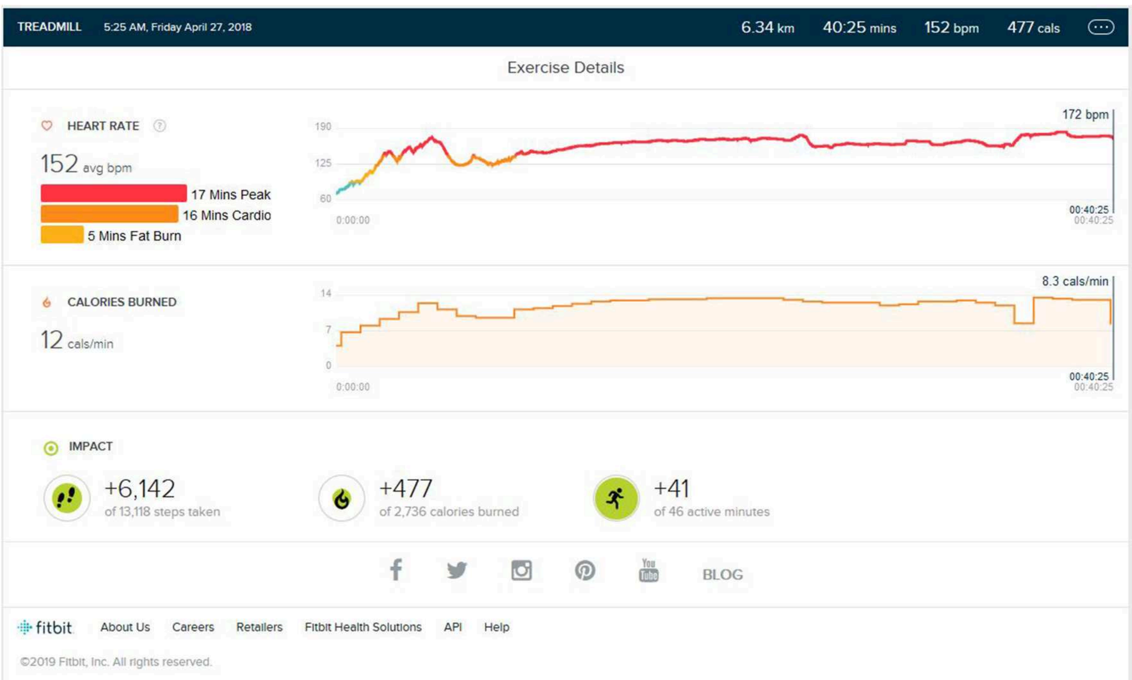

FIGURE 2 | Analysis report during one of the Peak phase achieved months.

with a reduction in treadmill training parameters concerning the intensity of bursts, number of bursts per exercise, and high burst time duration. The main aim of the schedule was to maintain the peak heart performance achieved during training. As shown in **Figure 3**, the maintained VO2 Max was seen. The peak heart zone (85–100% of your maximum heart rate) maintained was 14 min

FIGURE 3 | Analysis report during on one of the days of the maintenance phase months after months of peak phase being achieved.

(±4). The maximum maintained zone was the peak heart rate zone. The cardio zone was maintained for an average of 16 (±4) min (70 to 84% of your maximum heart rate).

Weight Training Phase/Aerobic Detraining

Following continuous induction of high-intensity aerobic exercise for almost 1.5 years, remarkable weight loss (10 ± 0.5 Kg) and subsequent muscle loss was seen. So, the partial detraining from aerobic exercise and added weight training was achieved. Weight training consisted of 2 days of weight training followed by cardio training for 1 day and a following 2 days of weight training. Weight training was low to mid intensity supplemented by a protein diet with 1–1.2 gm protein per kg in the natural form. No as shown in **Figure 4**, peak HR zone was maintained. The maximum HR zone maintained was the fat burn zone for an average of 22 (±10) min. Average exercise lasts for 40 min (±5). The average step count was 2,100 (±500) steps per exercise bout, coming to an average of 1.5 (±0.5) km. The average calorie burned was 250/±30 calories.

Memory Reactivation

This was very important phase to be noted. After 3 months of treadmill activity of regular steady sate jogging/walking was added at a speed of 6 km/Hr for just 10 min (±3) at the end of weight training without any HIIT or high intensity burst, the heart rate suddenly peaked to the peak HR zone. The place and the time spent on the treadmill were all similar stimuli to that used during peak HR training. There was no high inclination of increment in the speed to reach peak HR. As shown in **Figure 5**, even the average distance covered after 10 min on the treadmill was not more than the 1.2 km average, and that is despite the total steps taken being close to 3,000 in the whole session.

To cross verify whether this was the effect of memory reactivation, i.e., the same stimulus as time, odor, temperature, place, and equipment, four different settings were tested. First, the treadmill session was added to the first part of weight training. Second, we tested the effect of running the whole session outdoors or in a completely different environment. Third, we changed the treadmill environment by changing the complete stimulus other than that previously used. Last, we carried out reverification after a few months under the same stimulus.

In the first trial, the result was the same as with the stimulus that was used during training when added at the start of weight training instead of at the end; HR was easily raised to the peak zone. It was tested for an average of 15 min. The heart rate was triggered to reach toward the peak HR zone in just couple of minutes. During the weight training session, it varied in the fat burn zone.

As shown in **Figure 6**, during the second verification trial, the subject was made to run for 38 min (±2) in an outdoor non-similar stimulus environment with HIIT-type running. Of note was the fact that the heart rate remained in the cardio and fat burn zone and did not reach the peak HR. The distance was 4.6 km, and the step count was 4,870. Looking at distance covered, the step count, and the calorie burn graph, we can see that it was similar to the training or peak phase data, but changes in the environment resulted in different HR zones, and this was after nearly 5 months of aerobic partial detraining.

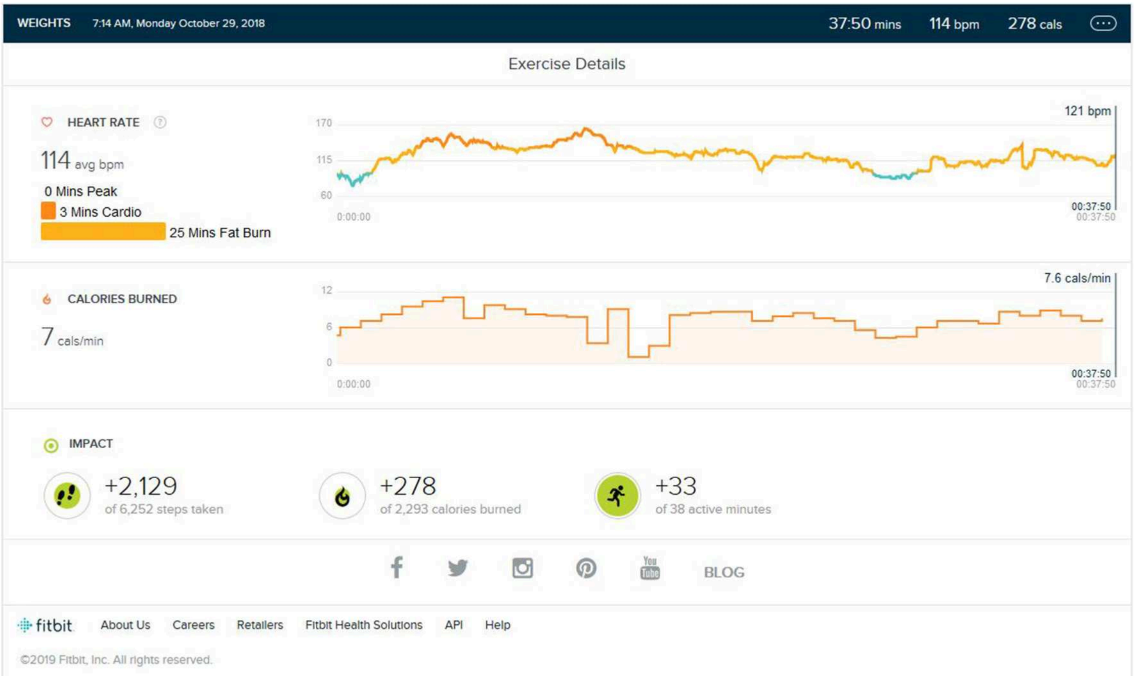

FIGURE 4 | Analysis report on one of the days during weight training phase.

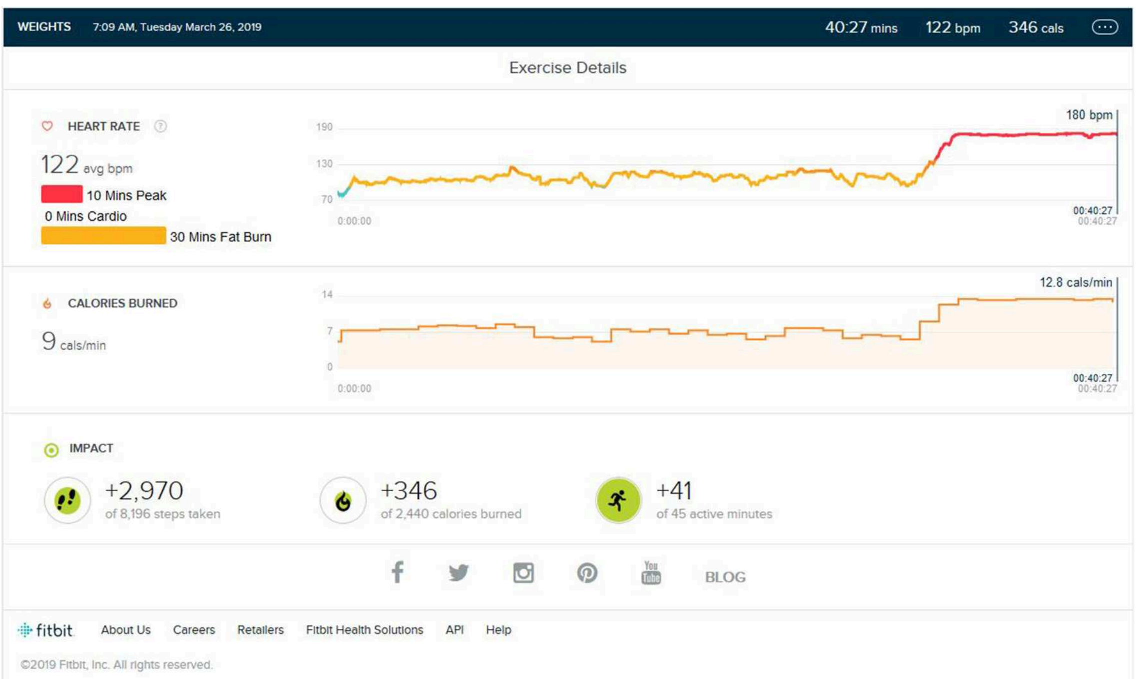

FIGURE 5 | Analysis report on the addition of the same environment stimulus of treadmill jogging to weight training and HR raising to peak phase.

As shown in **Figures 7**, **8**, during the third verification trial, yjr subject was made to run for 12 min (±2) in a non-similar treadmill stimulus environment with HIIT-type running during his weight training session of an average of 37 min. The location, equipment, and environment (Rasch and Born, 2007) was changed completely.

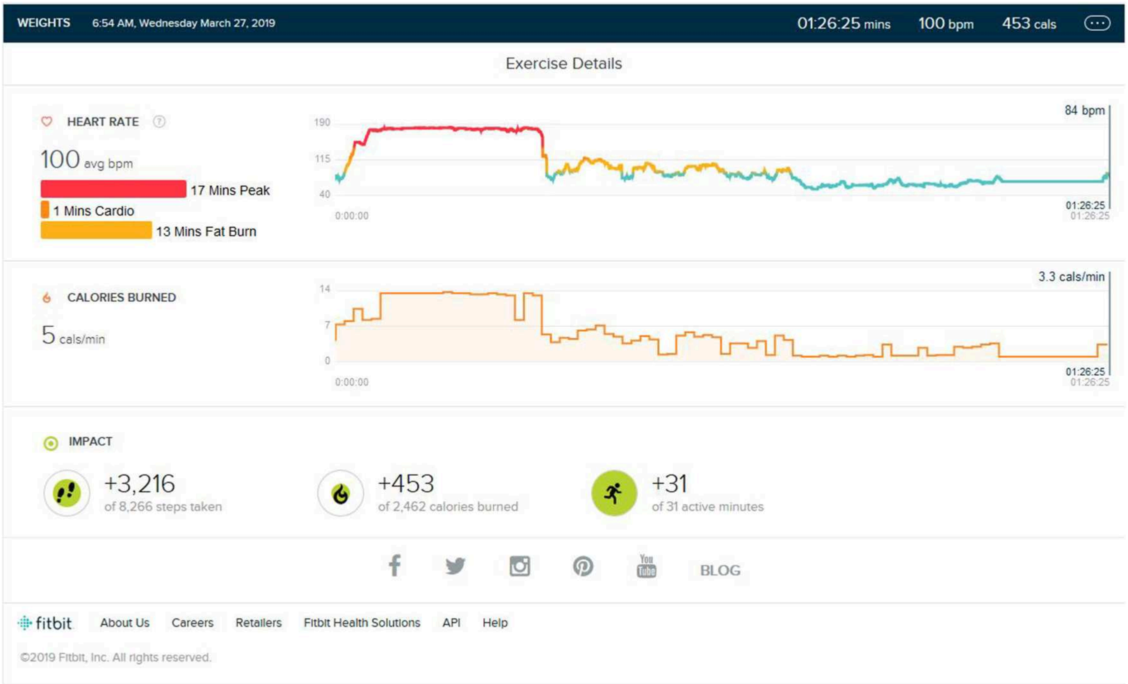

FIGURE 6 | Analysis report on the addition of same environment stimulus of treadmill jogging at the start of weight training instead of the end of weight training and HR raising to peak phase.

FIGURE 7 | Analysis report on the addition of different environment stimulus in cardio training and HR not raising to the peak zone.

Of note was the fact that the heart rate remained in the cardio and fat burn zone and did not reach the peak HR.

In the fourth trial, the subject was weight trained in the same environment (Rasch and Born, 2007; Van Someren et al., 2011; Schedlbauer et al., 2015) after a few days of

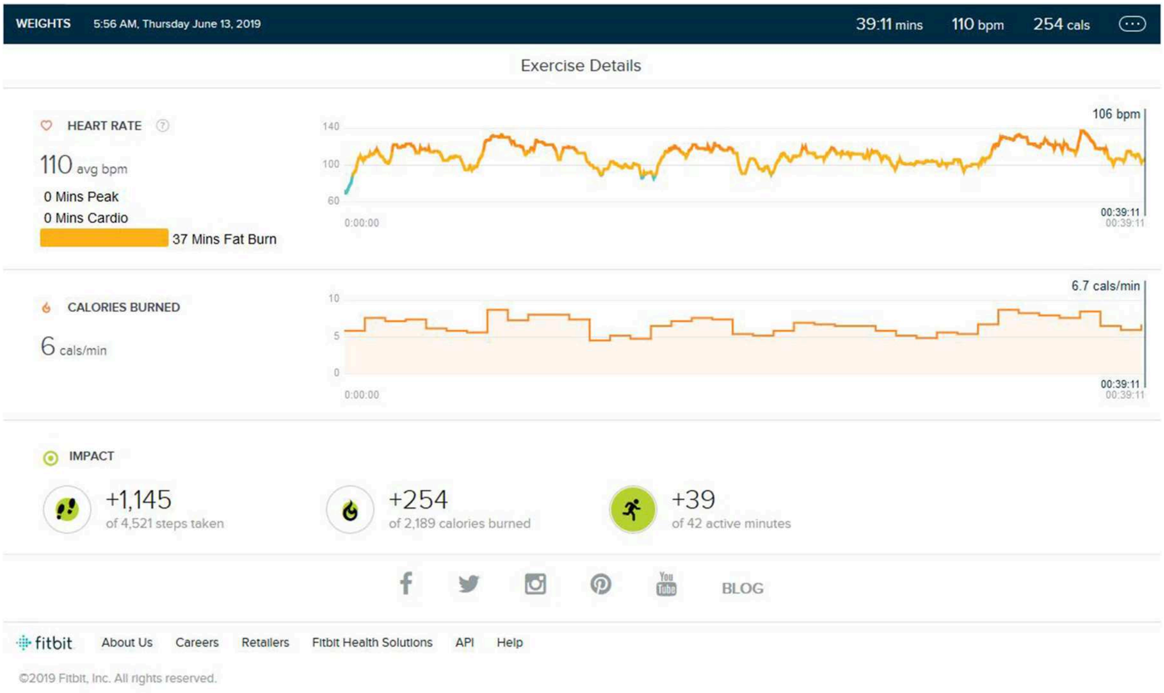

FIGURE 8 | Analysis report on the addition of different environment stimuli to weight training and the HR not raising above the peak zone.

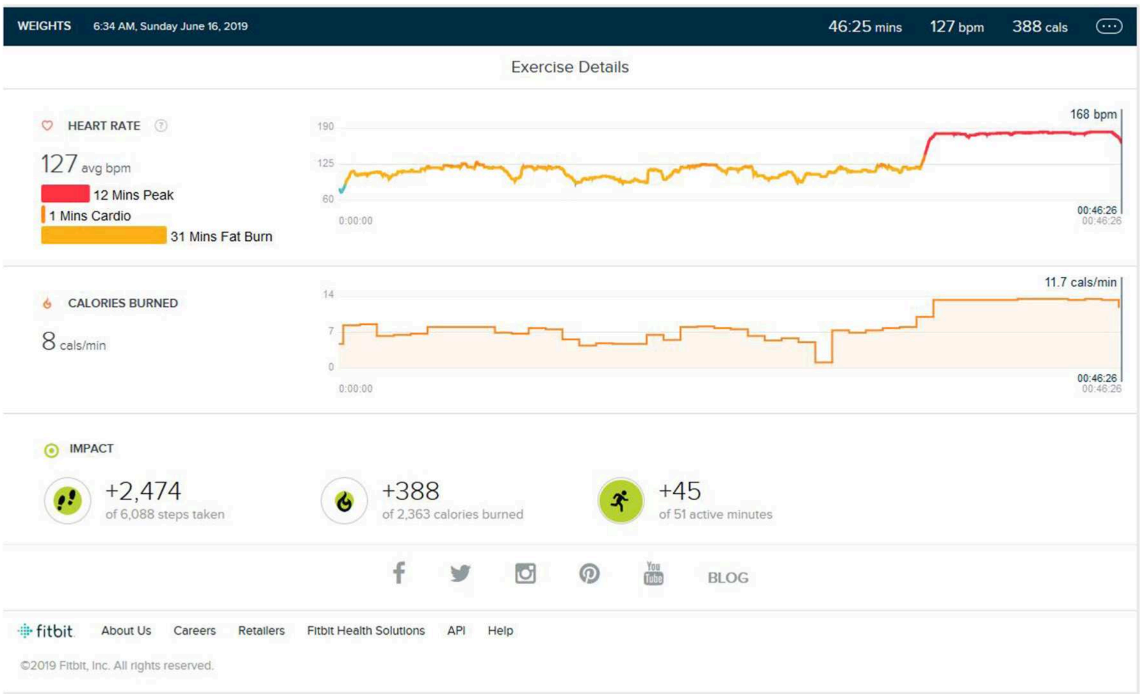

FIGURE 9 | Analysis report reactivation of memory/environment stimulus during weight training and HR raising to peak zone, similarly to how it does during the memory acquisition phase.

discontinuation with the addition of cardio training at the end of session, i.e., a similar treadmill stimulus environment with slow jogging of 6 km/Hr during the weight training session with the same place, time, equipment, etc, As shown in **Figure 9**, the heart rate was easily raised to the peak zone. It was tested for 12 min average. Heart rate was triggered to reach the peak HR zone in just a couple of minutes.

DISCUSSION

From this case study, it is of note that whenever the subject was in an environment (Rasch and Born, 2007; Wimmer and Büchel, 2015; Yanagisawa et al., 2016) that was similar to during training, the physiological response—in this case, the peak heart rate—was elevated to the same intensity zone, i.e., peak HR even with less or minimal physical effort, which was quite unexpected. The loss of efficiency after detraining was an expected factor that was observed in outdoor running after detaining, but the above result is opposite when it comes to peak HR during simple walking/jogging after weight training under the same stimulus. After partial detraining or weight training of about 6 months, as seen in second trial, the subject was not easily able to reach peak HR in a non-stimulus environment. The distinguishable thing is that, when the subject is confronted with same stimulus, even after same detraining phase, the subject was easily able to reach the peak HR. This is indicative of the predictable idea that the memory or neuronal reactivation may have physiological effects on the body that can extend to exercise performance. Many recent studies have linked the effect of memory reactivation to the physical responses (Hall et al., 1990; Flor et al., 2013; Banks, 2016) of body. Some studies, including that of V. S. Ramchandran et al., demonstrate that the pain acquired in disease and its memory during the pain phase have the same trigger effect, even after amputation of that part, e.g., phantom limbs (Gottfried et al., 2004; Flor, 2008) (the physiological effect of memory and pain). Brain plasticity is an important aspect of human physiological adaption (Rasch et al., 2007; Guan et al., 2016; Forte et al., 2019). Neural plasticity plays an important role in making the adaption of training into reflexes. Rigorous training for days results in improved cognitive reserve and elevated neuronal synaptic plasticity (Aglioti et al., 1994). Many recent studies have correlated the link between olfactory and other stimulus during memory consolidation to memory reactivation (Banks, 2016) by same stimulus (Armstrong and Maresh, 1998; Nyberg et al., 2000; Herz et al., 2004). The more intense the training, the stronger its memory formation. Fear or stress memories activate sympathetic responses in the body that include HR, dilation of the pupil, etc. (Cotman and Berchtold, 2002; Chamine and Oken, 2016; Corder et al., 2019), and, correlating all the above literature, it can be said that the memory reactivation could trigger the same physiological responses consolidated during acquisition. This demonstrates that reactivation of previously acquired memory or using stimulation of neuronal ensemble of consolidated memory during the specific event of training may exert similar physiological effects on exercise or the body that are learned during memory acquisition phase. Hence, as exercise has effect on memory, the memories may have an effect on exercise performances.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Agricultural Development Trust. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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

frontiers in Psychology

ORIGINAL RESEARCH
published: 18 June 2020
doi: 10.3389/fpsyg.2020.01091

The Psycho-Physiological Profile of Adolescent Elite Sailors: Testing a Three-Way Moderation Model

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The present study aimed at extending the work on individual differences, in the relationship between personality traits and the cortisol response, by examining the interaction effects of sex and the role category of Italian adolescent elite dinghy sailors. Seventy athletes completed a self-reported questionnaire including socio-demographic data, information about the role played on board (helmsmen or bowmen) and the Big Five Questionnaire-2. Salivary cortisol samples were collected at 30 min after awakening the day before competitions. Main findings from bivariate correlations showed positive associations among cortisol levels, extraversion and consciousness in both male and female bowmen groups. The moderation and moderated moderation analyses further indicated (1) a three-way interaction effect in the relationship between extraversion and salivary cortisol, (2) a marginal significant three-way interaction effect in the relationship between neuroticism and salivary cortisol, and (3) no other personality dimensions were significantly predictive of the outcome variable. Our results provided evidence not only about sex differences, but also about the role played on board by the sailors in the linkages between personality traits and the biomarker of the trait component of HPA axis functioning.

Keywords: Personality traits, individual differences, salivary cortisol, psycho-physiological profile, adolescent elite sailors

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *31 January 2020*
Accepted: *29 April 2020*
Published: *18 June 2020*

Citation:
Valenzano AA, Monacis L, Ceglie F, Messina G, Polito R, Sinatra M and Cibelli G (2020) The Psycho-Physiological Profile of Adolescent Elite Sailors: Testing a Three-Way Moderation Model. Front. Psychol. 11:1091. doi: 10.3389/fpsyg.2020.01091

INTRODUCTION

An increasing number of studies investigated the individual differences in psychological and physiological responses to stressors and challenging environments. Among psychological factors, personality constructs, rather than environmental factors, have been proposed as major variables in identifying and impacting on biomarkers of stress-sensitive biological systems, such as the hypothalamus-pituitary adrenal (HPA), as indexed by the cortisol response. Indeed, based on theoretical arguments and research showing the substantial heritability of personality (Heath et al., 1992; Bouchard and McGue, 2003), previous investigations tried to uncover the plausible linkages between personality traits and the trait components of the HPA axis functioning, i.e., basal cortisol, and the state components of HPA, i.e., the cortisol awakening response (CAR), yielding, however, inconclusive results (e.g., Evans et al., 2016).

The personality construct has generally been analyzed by the following psychological models: Model of psychosocial characteristics, Model based on Rumination and Emotional Inhibition, Eysenck's biopsychological model and the Five Factor Model (FFM; Soliemanifar et al., 2018). The last two models have been conceptualized as trait approaches to personality, focused on bio-physiological correlates. Eysenck's framework comprises three dimensions: extraversion, neuroticism and psychoticism; while, the FFM identifies five dimensions: neuroticism, extraversion, openness, agreeableness, and conscientiousness (Costa and McCrae, 1992; Hartmann, 2006). Within the psycho-physiological research, neuroticism has been one of the most studied traits. Referring to feelings of vulnerability and the negativity of emotional reactions to social stressors (Lahey, 2009), it was found to be positively, negatively, or not related at all to cortisol. Specifically, no associations were reported between neuroticism and cortisol levels, either measured as a baseline, or as the change after a stressful event (Schommer et al., 1999), as the CAR (Chan et al., 2007; van Santen et al., 2011; Hill et al., 2013), or as the change at noon and later in the afternoon (Ferguson, 2008). Conversely, significant associations were reported between this trait and the HPA functioning, usually measured through the area under the curve, with respect to the increase (AUCI; Zobel et al., 2004), or through the difference in cortisol concentrations between the time of awakening and 30–45 min later (Portella et al., 2005; Mangold et al., 2012).

A further complex matter concerns the effects of sex on HPA functioning, within the above mentioned associations; different sex patterns were reported to be close to significance only in women (DeSoto and Salinas, 2015; Puig-Perez et al., 2016), whereas the absence of sex differences occured after controlling the luteal phase (Kajantie and Phillips, 2006; Poppelaars et al., 2019).

Extroversion, indicating individuals who enjoy being with people and are full of energy, contrary to introverts who are less involved in social activities and tend to keep to themselves, is the second well-investigated trait in relation to HPA functioning, although inconclusive results have been yielded. No association was found between extraversion and the variability in early morning salivary cortisol levels (Munafò et al., 2006; van Santen et al., 2011) and between higher mean scores on extraversion and lower cortisol reactivity to a social stress response in adolescents (Evans et al., 2016). Significant associations were shown between high introversion and low CAR levels among both male and female adolescents, even if no significant associations emerged in the awakening cortisol levels or in the diurnal cortisol slope (Hauner et al., 2008). Conversely, positive associations occurred between higher extraversion and greater CAR levels in females exhibiting greater cortisol output (Hill et al., 2013) or when considering basal cortisol levels in adolescents (Laceulle et al., 2015). Puig-Perez et al. (2016) reported mixed results, from no association when considering the total sample or the 2-Day CAR group, to a negative association when including the data of only one day CAR measurement. With regard to the remaining personality traits of the FFM, no significant associations were found with any kind of cortisol response (Hill et al., 2013).

In light of the inconsistency of these results, the current research sought to examine the individual differences in the relationships between personality traits and the salivary cortisol in adolescent elite sailors. According to the authors' knowledge, the relevance of this research is that the psycho-physiological profile of dinghy sailors has not yet been empirically analyzed. Only Manzanares Serrano and colleagues distinguished, although theoretically, bowmen' and helmsmen' profiles: the former are more extrovert and the latter more determined and introverted with higher levels of self-control (Manzanares Serrano et al., 2012). Consequently, it was expected that the helmsmen should be characterized by higher levels of consciousness and lower levels of openness, agreeableness, neuroticism, and extraversion; whereas, the bowmen should be characterized by lower levels of consciousness and higher levels of openness, agreeableness, neuroticism, and extraversion. Being responsible for maneuvering and handling the boat in all environmental conditions and situations including emergencies and being conscious of the safety of the crew at all times, the helmsmen should tend to be less emotionally instable and more conscious and introverted. Controlling sails, spinnakers, etc., the bowmen tend to be more extroverted, action-oriented, and sociable with the other members of the crew and with the helmsman. Following Kern and Friedman's assumption that extroverts are characterized by a "biologically-based drive for activity" being oriented to the surrounding environment, bowmen were expected to exhibit elevated cortisol levels, in contrast to the lower cortisol levels of introverted helmsmen (Kern and Friedman, 2011). In addition, as cortisol is the hormone most closely associated with a biological reaction to a stressor, a positive relationship was hypothesized between cortisol and neuroticism, a trait that ought to characterize the bowmen's profile. Finally, it was supposed thea moderated role of sex in the linkages of cortisol levels with extraversion and neuroticism and a stronger effect of this association in female bowman was supposed. This idea is rooted in the notion that women deal with stressors differently from than men do, including the hormonal levels (Kirschbaum et al., 1992) and their lower coping ability.

MATERIALS AND METHODS

Participants and Procedure

The sample was composed of 70 sailors (48 males and 22 females), with 27 in the under 16 category (15–14 years) and 43 in the under 19 category (16–18 years), all participants of the Italian Youth Two Crew Members Dinghy Classes Championship, held in Bari, Italy, in September 2019. Exclusion criteria were the presence of any form of contraception and a menstrual cycle outside the range of 28 ± 1 days. The cultural and the socioeconomical background of the athletes was homogenous. The research proposal was submitted to the Italian Sailing Federation Committee for approval. In addition, the Regional Committee for Medical and Health Research Ethics approved the study, which was conducted in accordance with the Helsinki declaration. Since most of the athletes were under the legal age of consent, only their attorney/legal representative provided

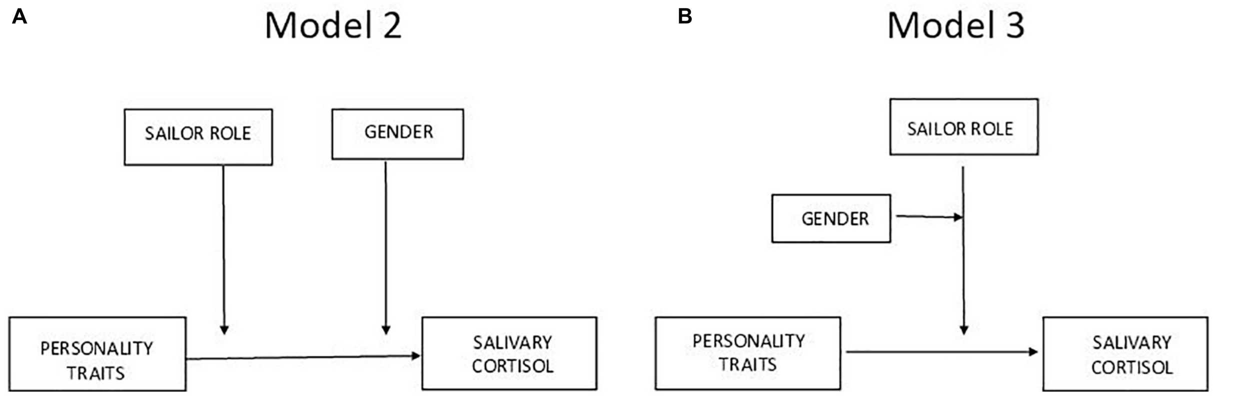

FIGURE 1 | Moderated analyses computed using both moderators, simultaneously **(A)** and the moderated moderation **(B)**.

written informed consent for participation. All results were treated anonymously.

Data Collection

All the data were collected the day before the competitions. Initially, a questionnaire was applied, containing information regarding sailors' practical experience: dinghy class, role on board, and years of practicing.

Salivary Cortisol Assay

Saliva collection and cortisol assays were performed as previously described (Capranica et al., 2017). Briefly, the saliva specimens were collected the day before the competitions, within 30 min after awakening, by participants, under parents' or coaches' supervision, using cotton swabs and saliva collecting tubes (Salivette, Sarstedt, Germany). The samples were kept in a portable cooler during sampling and then, once returned, were stored at −70°C, until use. A commercially available enzyme immunoassay kit (Salimetrics LLC, State College, PA, United States) was used to analyze salivary cortisol, according to the manufacturer's instructions.

Personality Traits

To assess the sailors' personality characteristics, the Big Five Questionnaire-2 (BFQ-2, Caprara et al., 2007) was used. The BFQ-2 is a phrase-based self-report inventory, comprising 134 items that identify five dimensions (extroversion, agreeableness, consciousness, neuroticism, openness to experience) to describe and assess the personality of adolescents aged over 14. Each dimension included 24 items on a 5-point Likert-type scale, ranging from 1 (*strongly agree*) to 5 (*strongly disagree*). In the current research, alpha coefficients ranged from 0.81 to 0.83.

Data Analysis

Descriptive statistics and zero-order correlations between the variables of interest were applied to the total sample, sex, and sailor roles on board. Age, sex, roles, and salivary cortisol differences for the variables' scores were analyzed using independent samples t-tests.

A multiple regression analysis was performed to identify the best predictors for cortisol levels. The SPSS PROCESS macros version 3.1 (Hayes, 2018) was used for bootstrapping analyses to determine the significance of moderation. The interaction effects of personality traits on cortisol levels, *via* the moderators, were considered significant if 95% bootstrap confidence intervals from 10,000 bootstrap samples did not include zero. Single moderation models were first conducted to test whether the influence of each personality trait (X) on cortisol levels (Y) was moderated by sailing category and sex (W and Z, respectively) (**Figure 1**). To this purpose, moderated analyses were computed using both moderators, simultaneously (Model 2, **Figure 1A**) and the moderated moderation (Model 3, **Figure 1B**).

RESULTS

The physical and technical variables analyzed in this study are shown in **Table 1**. It is worth noting that the number of male sailors exceeded that of female sailors, either in the total sample, or in each category, while, with regard to the role held on board, the helmsmen were slightly more numerous than the bowmen. No differences were found in the years of practicing, either between male and female sailors, or between helmsmen and bowmen, confirming that this variable did not influence the result.

The impact of athletes' personality on the biological trait models of stress reactivity was indexed by cortisol reactivity. The total and detailed awakening cortisol analyses are shown in **Table 2**. The results showed that there were no differences among athletes in the cortisol awakening levels, measured the day before competition, in relation to age, sex, and role on board, even though bowmen showed an increasing trend in cortisol reactivity, compared to helmsmen (p = 0.068), which did not reach significance, probably because of the small sample size (n = 70) included in the analysis.

With regard to the total sample, sex differences emerged only in the mean scores of openness to experience, $t(68) = -2.053$, p = 0.047, where females obtained higher mean scores (M = 88.92) in comparison to males (78.48). On the other

TABLE 1 | Descriptive statistics: Mean and standard deviation for each variable in the total sample, male and female group, helmsmen and bowmen group.

	Total sample	Male group	Female group	Helmsmen	Bowmen
	***n* = 70**	***n* = 48**	***n* = 27**	***n* = 37**	***n* = 33**
			Mean (SD)		
Age	15.95 (1.28)	15.74 (1.20)	16.38 (1.39)	15.84 (1.38)	16.13 (1.13)
C (μg/dl)	3.93 (1.24)	4.14 (1.07)	3.49 (1.48)	3.86 (1.11)	4.50 (1.37)
E	82.97 (12.63)	83.22 (12.61)	82.46 (13.16)	83.96 (12.88)	81.33 (12.45)
A	84.73 (11.81)	84.37 (10.81)	85.46 (14.12)	84.56 (10.24)	85.00 (14.44)
C	82.65 (11.22)	81.15 (9.97)	85.77 (13.36)	81.20 (11.20)	85.07 (11.22)
N	65.88 (14.64)	68.52 (14.77)	60.38 (13.23)	64.16 (14.20)	68.73 (15.42)
O	81.22 (12.67)	78.48 (12.15)	88.92 (12.24)	80.40 (12.05)	82.60 (13.98)

C (μg/dl), cortisol; E, extroversion; A, agreeableness; C, consciousness; N, neuroticism; O, openness to experience.

TABLE 2 | Bivariate correlations between personality traits and levels of cortisol in the total sample, sex group, sailing group, and the sailing role within sex groups.

	Total Sample	M	F	H	B	H		B	
					Cortisol levels				
						M	**F**	**M**	**F**
E	0.200	0.080	0.381	0.010	0.516*	0.175	−0.275	0.160	0.920*
A	0.173	0.074	0.300	0.051	0.269	−0.131	0.288	0.302	0.361
C	0.266	0.352	0.307	−0.105	0.583*	0.058	−0.251	0.201	0.745
N	0.164	−0.025	−0.341	−0.153	0.430	−0.318	−0.046	−0.064	0.797
O	0.226	0.245	0.427	0.155	0.266	0.206	0.197	0.236	0.655

$^*p < 0.05$. E, extroversion; A, agreeableness; C, consciousness; N, neuroticism; O, openness to experience; M, males; F, females; H, Helmsmen; B, Bowmen.

hand, when considering the role, sex effects emerged in the mean scores of consciousness in helmsmen, $t(68) = -2.568$, $p = 0.017$, a category in which females obtained higher mean scores ($M = 88.75$), compared to males ($M = 77.61$).

Moreover, sailing role effects were also examined in the total sample. Significant differences emerged in the mean scores of cortisol levels, $t(68) = -2.065$, $p = 0.046$, among sailors. Bowmen obtained higher mean scores ($M = 4.50$) in comparison to helmsmen ($M = 3.86$). When considering this effect within sex groups, significant differences were observed in the mean scores of cortisol levels, $t(35) = -3.565$, $p = 0.002$, and consciousness, $t(35) = -2.638$, $p = 0.014$: male bowmen obtained higher scores compared to male helmsmen in both variables of interest ($M = 4.93$ and 3.67, $M = 87.10$ and 77.85, respectively). No significant differences emerged within female bowmen and helmsmen.

Table 2 provides a first picture of the interrelationships between cortisol levels and personality traits in the total sample, male and female groups, and helmsmen and bowmen. No significant association emerged between cortisol levels and personality traits in the total sample and in the sex groups, whereas positive associations between cortisol levels, extraversion, and consciousness in the bowmen group were shown. Furthermore, a positive association between levels of cortisol and extraversion was also confirmed in the female bowmen group. A series of moderation analyses and moderated moderation analyses were performed to examine whether the relationship between personality traits and cortisol levels was influenced by sailing role and sex, and how these moderators changed the strength (stronger or weaker) of the linkage in predicting the levels of salivary cortisol. To this purpose, sailing role and sex were computed simultaneously (Model 2). It was further examined whether the effect of personality traits on the cortisol response was a function of the conditional effects between personality traits and sailing role by sex ($X \times W \times Z$) (Model 3).

Table 3 shows the results of the analyses in both models. With regard to the relation of extraversion with salivary cortisol levels, Model 2 indicated no statistical interaction effects of both moderators. Conversely, Model 3 showed a significant three-way interaction effect and is plotted in **Figure 2A**. When looking at the regression coefficient for XWZ, i.e., $b = 0.142$, $t(32) = 2.596$, $p = 0.014$ with a 95% CI of 0.031 to 0.252, the magnitude of the moderation by sailing role of the effect of extraversion on cortisol, depended on the sex category. The effect of extraversion on cortisol was positive, but the difference of this effect between helmsmen and bowmen was stronger in female bowmen. This moderated moderation accounted for 10% of the variance in support of the cortisol levels. With regard to the traits of agreeableness, consciousness, and openness to experience, both models indicated no significant direct effect or interaction effect in the relationship with cortisol levels, whereas the association between neuroticism and cortisol levels was moderated by sailing role (Model 2; $b = 0.05$, $t(34) = 2.204$, $p = 0.034$ with a 95% CI of 0.004 to 0.105) and by the product of the two moderators (Model 3; $b = -8.054$, $t(32) = -2.228$, $p = 0.033$ with a 95% CI of -1.419 to -0.690). Finally, in this relationship a three-way interaction effect

TABLE 3 | Unstandardized beta coefficients and model indices.

Predictors	Model 2 $R = 0.568$ $R^2 = 0.323, p = 0.016$	Model 3 $R = 0.696$ $R^2 = 0.485, p = 0.001$
E	−0.091	0.019
Role	−3.870	13.975 ($p < 0.05$)
Sex	−2.794	15.90 ($p < 0.05$)
E × Role	0.058	−0.132
E × Sex	0.026	−0.179 ($p < 0.05$)
Role × Sex		−12.956 ($p < 0.01$)
E × Role × Sex		0.142 ($p < 0.05$)
	Model 2 $R = 0.567$ $R^2 = 0.322, p = 0.017$	**Model 3 $R = 0.651$ $R^2 = 0.424, p = 0.008$**
N	−0.138 ($p < 0.05$)	0.066
Role	−2.789	8.431
Sex	−3.774 ($p < 0.05$)	6.954
N × Role	0.055 ($p < 0.05$)	−0.098
N × Sex	0.052	−0.097
Role × Sex		−8.054 ($p < 0.05$)
N × Role × Sex		0.112 ($p = 0.054$)

E, Extroversion; N, Neuroticism.

was close to being significant (Model 3; $b = 0.112$, $t(32) = 1.998$, $p = 0.0543$ with a 95% CI of -0.002 to.226), thus indicating a slight significant moderated moderation of sailing role, by sex category. The positive relationship between neuroticism and salivary cortisol tended to be stronger in female bowmen. The three-way interaction is plotted in **Figure 2B**.

DISCUSSION

The current study examined the individual differences in the relationships between personality traits and the trait components of HPA axis functioning, i.e., the awakening cortisol, in a sample of adolescent elite sailors. Moreover, given the lack of empirical evidence for the different psychological profiles of helmsmen and bowmen, this investigation sought to fill this gap by exploring whether the different roles played by these athletes could moderate the linkages between personality traits and awakening cortisol levels. It was also explored whether sex could influence the moderated associations. With regard to the trait components of HPA axis functioning, we found evidence that cortisol awakening levels were not significantly influenced by the physiological response of the training load imposed on the athletes, with respect to age, sex, and years of practicing. Notably, we might speculate that cortisol awakening levels are positively influenced by the role played on board. However, these findings posit the possibility that such a different response detected in both helmsmen and crew members were consistent with the different training loads, related to the role. Our findings further corroborated those studies that showed significant relationships of awakening cortisol levels with extraversion (Schommer et al., 1999; Oswald et al., 2006; Hauner et al., 2008; van Santen et al., 2011; Hill et al., 2013) and neuroticism (Zobel et al., 2004; Portella et al., 2005; Laceulle et al., 2015). Interestingly, descriptive statistics indicated sex effects in the sailor category, that is, female helmsmen tended to be more conscious in comparison to their counterparts. This result not only confirmed the above-mentioned hypothesis of helmsmen' tendency to obtain higher scores for consciousness, as this role is related to the responsibility of the safety of crew and boat, but it also shed light on sex differences in sailing roles. In this vein, the bio-psychological linkage between sex and personality characteristics could suggest to coaches how sailor roles should be selected. When considering the biomarker factor, the obtained higher mean scores of salivary cortisol in bowmen could be explained properly by the sailing role, given bowmen's tendency to be more action-oriented

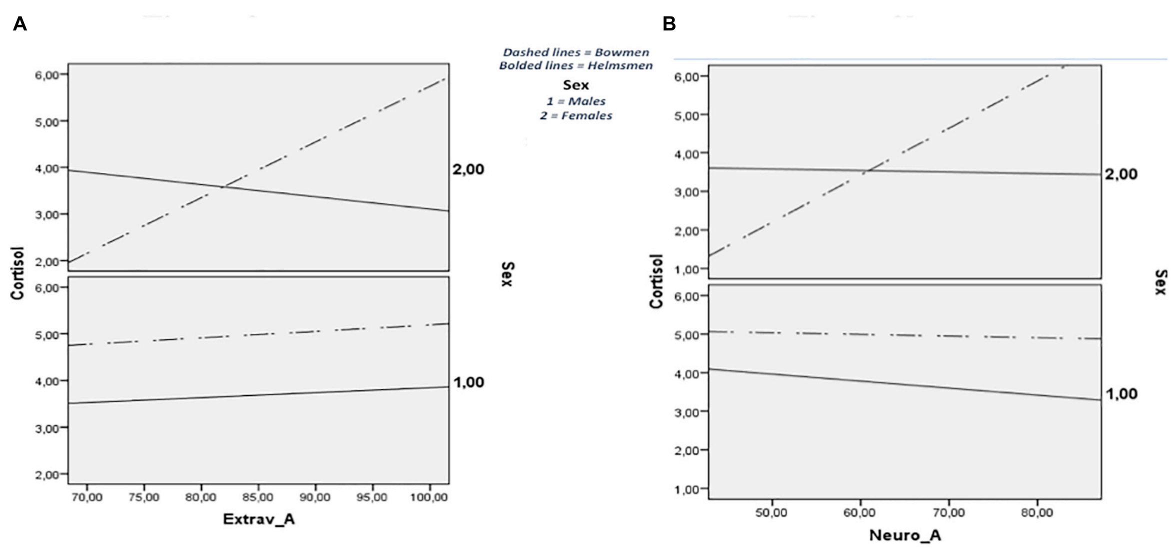

FIGURE 2 | A three-way interaction effect, Extraversion **(A)**, Neuroticism **(B)**.

and to show higher cortisol levels. However, an unexpected result was the sailor role effect on consciousness; in fact, compared to male helmsmen, male bowmen obtained higher scores on this trait, which was contrary to the hypothesized assumption. A possible explanation may be inferred from a lacking psychological assessment of the specific profiles during athletes' selection.

In alignment with some other studies (Hauner et al., 2008; van Santen et al., 2011; Hill et al., 2013; Laceulle et al., 2015), extraversion was significantly associated with cortisol levels. Specifically, the positive association that supported Kern and Friedman's idea of the biological drive for activity, emerged in the bowmen category (Kern and Friedman, 2011). When stratified by sex, the same association was confirmed only in female bowmen, consistent with previous research (Kunz-Ebrecht et al., 2004; Wright and Steptoe, 2005; Almeida et al., 2009) and with the assumption that females are more likely to report chronic stress than males (McDonough and Walters, 2001), which may impact neuroendocrine functioning (Pruessner et al., 1997; Wüst et al., 2000). The three-way interaction observed in the moderated moderation further proved these sex differences in the HPA system.

When looking at neuroticism, findings corroborated the significant trend of elevated cortisol levels, that is, higher levels of neuroticism were positively associated with higher baseline levels of cortisol (Portella et al., 2005; Nater et al., 2010; Oishi et al., 2012; Garcia-Banda et al., 2014; Miller et al., 2016). Such a trend was consistent with the assumption that individuals high in this trait tend to have an increased magnitude of cortisol secretion during the day, reflecting greater frequency and intensity of HPA stimulation from the psychosocial domain. Following the suggestion to check whether males and females differ in HPA activation in the neuroticism-cortisol relationship (DeSoto and Salinas, 2015), a further aim of the current research was to examine the key role of sex. Results provided the existence of a gender specific interaction: neuroticism and cortisol levels were noted to be positively related among females. This finding was in line with Puig-Perez and colleagues' investigation, but in contrast to Oswald's research group and DeSoto and Salinas, who found negative relationships, and with Zobel et al., too, who reported a positive association among males (Zobel et al., 2004; Oswald et al., 2006; DeSoto and Salinas, 2015; Puig-Perez et al., 2016).

Other important information from the current research, concerned the hypothesized positive relationship between cortisol and neuroticism, which was yielded in the bowmen's category. As such, the empirical evidence took a first step in addressing sport research (e.g., Frenkel et al., 2019) in the examination of the dispositional psychological factors in stressful situations before a competition. Despite this strength, our study was not without limitations. The sample size was modest (but sufficient for the analysis carried out) and the cortisol survey pertained only a single awakening time, without taking into account cortisol changes in response to a stressor or individual differences in diurnal variations. Consequently, the comparability of the current findings to prior findings were, therefore, restricted. Further work should be carried out to clarify the existing inconsistent data and to generalize the present findings.

CONCLUSION

The current research examined the psycho-physiological profile of adolescent elite sailors by focusing on individual differences in the relationships between personality traits and the salivary cortisol response. To this purpose, two models were tested: in the former model sailing role and sex were computed simultaneously when considering the linkages between personality traits and cortisol levels; whereas, in the latter model, the function of the conditional effects between personality traits and sailing role by sex was taken into account when considering the effect of personality traits on cortisol response. In summary, these findings suggested that the effect of extraversion on cortisol was positive in female bowmen. Likewise, the effect of neuroticism on cortisol tended to be marginally significant and positive in female bowmen. No other personality traits were significantly predictive of cortisol levels. Therefore, our results extended the knowledge on previous contrasting findings, shedding light on the importance of sex differences and the role of adolescent dinghy sailors, when examining the relationships between personality trait and the HPA system.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Regional Committees for Medical and Health Research Ethics. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

GC and LM: conceptualization, LM: methodology and formal analysis. FC, GM, AV, and RP: investigation. LM and MS: writing-original draft preparation. LM and MS: writing-review and editing. MS: supervision. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

We acknowledge with gratitude the athletes and coaching staff who contributed to this project. A special thanks to the local organizers for the hospitality and logistics, and to the President and Members of the VIII Zone Committee of the Italian Sailing Federation for communication promotion in support of the research.

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

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ORIGINAL RESEARCH
published: 30 October 2020
doi: 10.3389/fpsyg.2020.537922

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Executive Functions During Submaximal Exercises in Male Athletes: Role of Blood Lactate

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: 25 February 2020
Accepted: 01 October 2020
Published: 30 October 2020

Citation:
Coco M, Buscemi A, Cavallari P, Massimino S, Rinella S, Tortorici MM, Maci T, Perciavalle V, Tusak M, Di Corrado D, Perciavalle V and Zappalà A (2020) Executive Functions During Submaximal Exercises in Male Athletes: Role of Blood Lactate. Front. Psychol. 11:537922. doi: 10.3389/fpsyg.2020.537922

The present study was carried out among 20 healthy young male athletes to determine whether aerobic exercise performed at two different intensities is able to affect executive functions. For this purpose, we used the Stroop Color Word Test (SCWT) to evaluate the ability to inhibit cognitive interference and the Trail Making Test (TMT) to assess organized visual search, set shifting, and cognitive flexibility. Simple Reaction Time (RT), as a measure of perception and response execution, was also evaluated. The experimental protocol included the measure of blood lactate levels with the aim of assessing possible relations between lactate blood values and selected executive functions after a 30-min steady-state test performed at 60% and at 80% of VO_{2max}. The results showed that a 30-min aerobic exercise is not associated with a worsening of executive functions as long as the blood lactate levels stay within the 4 mmol/l threshold.

Keywords: submaximal exercise, blood lactate, executive function, man, sport

INTRODUCTION

It has been observed that acute but submaximal exercise facilitates inhibitory control (e.g., Hillman et al., 2003; Drollette et al., 2014), working memory (e.g., Coles and Tomporowski, 2008; Pontifex et al., 2009), and cognitive flexibility (Bae and Masaki, 2019). These abilities fall within those cognitive capabilities called executive functions (Diamond, 2013), a term used to designate the set of cognitive abilities that allow us to plan, control, and regulate behaviors advantageous to accomplishing a certain result (Miller and Cohen, 2001).

On the contrary, some data lead to the conclusion that exhaustive exercise has the opposite effect on some executive functions and that this negative influence seems to be related to the increase of blood lactate levels (Coco et al., 2009, 2016, 2020; Perciavalle et al., 2015, 2016a,b; Coco et al., 2018; Itagi et al., 2018; Moreira et al., 2018).

Moreover, studies related to attentional processes (Coco et al., 2009, 2019b; Pellerone et al., 2017; Petralia et al., 2018; Santisi et al., 2018) have observed the negative effects of high blood lactate levels on cognition, even when induced through an intravenous infusion of lactate solution.

However, it has been observed (Perciavalle et al., 2014) that the negative effects of acute exercise on attentional processes only occurred when the intensity of the exercise exceeded 80% of maximal oxygen consumption (VO_{2max}). We therefore wanted to verify whether it is possible to detect negative effects of aerobic exercise on executive functions with an intensity of more than 80% of the VO_{2max} and the concentration of blood lactate above 4 mmol/l. This value is a standard marker, called Onset of Blood Lactate Accumulation (OBLA), defined as the point when blood lactate starts to accumulate, and represents the transition from aerobic to anaerobic work (see Faude et al., 2009).

Therefore, we performed a study on healthy young athletes to determine whether submaximal aerobic exercise, carried out at two different intensities, is capable of influencing executive functions. For this purpose, we used the Stroop Color Word Test (SCWT) to evaluate the ability to inhibit cognitive interference (Strauss et al., 2006) and the Trail Making Test (TMT) to assess organized visual search, set shifting, and cognitive flexibility (Tombaugh, 2004). Simple Reaction Time (RT), a measure of perception and response execution (Woods et al., 2015), was also evaluated.

Our working hypothesis was that the possible influences exerted by aerobic activity on executive functions were linked to an increase in blood lactate values. For this purpose, the experimental protocol included the measure of blood lactate levels with the aim of assessing possible relations between lactate blood values and the selected executive functions after a 30-min steady-state test performed at 60% and at 80% of VO_{2max}.

MATERIALS AND METHODS

Participants and Procedure

The study was made possible by the voluntary participation of 20 male athletes from the Track and Field Team of the University. They had a mean age of 23.9 years (±2.25 Standard Deviations, SDs), a mean height of 125.8 cm (±4.09 SDs), a mean body mass of 74.1 kg (±4.49 SDs), a mean Body Mass Index of 24.8 (±0.79 SD) and a mean VO_{2max} of 63.9 ml/kg/min (±2.92 SDs). The protocol of the study was approved by the Ethical Committee of the University of Milan (number 15/16). All tests were performed under close clinical supervision. The athletes were fully informed about the purpose of the study and the possible risks before signing the informed consent form, in accordance with the ethical standards laid down in 1964 by the Declaration of Helsinki. **Figure 1** summarizes the experimental protocol.

Measure

Exercises

The experimental protocol required each athlete to perform two different aerobic exercises, with an interval of 1 week apart from each other, respectively, at 60% VO_{2max} and at 80% VO_{2max}, randomly selected. Each athlete was instructed not to perform aerobic activities in the 24 h preceding the experimental session and to fast for 3 h before the exercise. The exercise, to be performed between 9 and 12 a.m., consisted of pedaling for 30 min on a cycle-ergometer (Ergomedic 828E, Monark, Sweden) at 60 or 80% VO_{2max}, at a constant pedaling rate of 60 rpm (Perciavalle et al., 2015). Each athlete initially cycled without load for 3 min; then the load was increased by 30 Watt every 3 min until 60 or 80% of VO_{2max} was reached.

VO_{2max}

VO_{2max} of each subject was calculated before the experimental sessions as previously described (Perciavalle et al., 2014). The subjects were asked to pedal continuously on the cycle ergometer throughout the experimental session, with the workload being progressively increased every 3 min for an overall duration of 30 min. Achievement of VO_{2max}, defined as the highest value of VO_2 reached during the exercise, was confirmed by the following criteria: (1) exceeding 90% of the maximum heart rate expected for the age of the athlete and (2) plateau of VO_2 (cfr. Howley et al., 1995). Metabolic parameters were collected and assessed by using an open circuit spirometer Fitmade MED (Cosmed s.r.l. Italy), and heart rate was measured with a heart rate monitor Polar (Gays Mills, Wisconsin, United States).

Blood Lactate

Blood lactate levels were quantified before the exercise (pre), every 10 min during the exercise (during), immediately at the end of the exercise (end), and finally, 10 min after the exercise was completed (post). Lactate measurements were taken using a "Lactate Pro 2" portable lactate analyzer (Arkray Inc, Japan), which has proven to be highly reliable (Buckley et al., 2003).

Simple Reaction Time

The method for quantifying RT, a task that demands an intense simple attention, was the same one previously used (Coco et al., 2009). The volunteer was asked to press, as quickly as possible, the space bar on a computer keyboard when the "star" symbol appeared on the screen. To avoid habituation, the frequency of the appearance of the "star" symbol was randomly changed between 1 and 3 s. The evaluation was carried out immediately at the end of the exercise (end) and 10 min after the exercise was completed (post).

Stroop Color Word Test

The golden version of the SCWT was used in the present study (Strauss et al., 2006). The test consisted of three successive moments. Initially, the volunteer had to read a list of 50 names written in black ink. Subsequently, the subject had to indicate the color of 50 circles painted with different colors. Finally, the subject was given a list of 50 colors dyed with a color that was different from what the name indicated and asked to indicate the color of each word. The number of correct answers the subjects gave within the first 45 s of the third test represented the "interference" factor of the SCWT. The evaluation was carried out immediately at the end of the exercise (end) and 10 min after the exercise was completed (post).

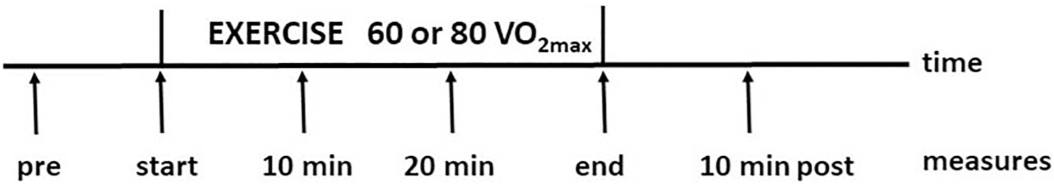


FIGURE 1 | Schematic representation of the experimental protocol. Blood lactate levels were quantified before the exercise (pre), every 10 min during exercise (during), immediately at the end of exercise (end), and finally, 10 min after exercise was completed (post). The Simple Reaction Time, Stroop Color Word Test, and Trial Making Test were measured immediately at the end of the exercise (end) and 10 min after the exercise was completed (post).

Trial Making Test

TMT was chosen to assess organized visual search, set shifting, and cognitive flexibility (Tombaugh, 2004). The TMT is typically designed in two parts. In TMT-A the subject must use a continuous line to connect with 25 numbered circles in numerical order, distributed on a sheet of paper. In TMT-B the subject must use a line to connect 25 circles that carry letters and numbers, distributed on a sheet of paper, alternately following alphabetical and numerical order. In each of the two tests the time required for completion and the number of errors were measured.

The B/A ratio of performance on the TMT was also measured since it provides an index of executive function (Arbuthnott and Frank, 2000).

The evaluation was carried out immediately at the end of the exercise (end) and 10 min after the exercise was completed (post). The order of cognitive tests was randomly selected.

Participants were familiarized with the cognitive test procedures before the actual experiment starts in order to minimize practice effects (Theisen et al., 1998; Oberste et al., 2019), during the VO_{2max} testing day. The aim was to allow the subject to complete the cognitive tests in less than 10 min.

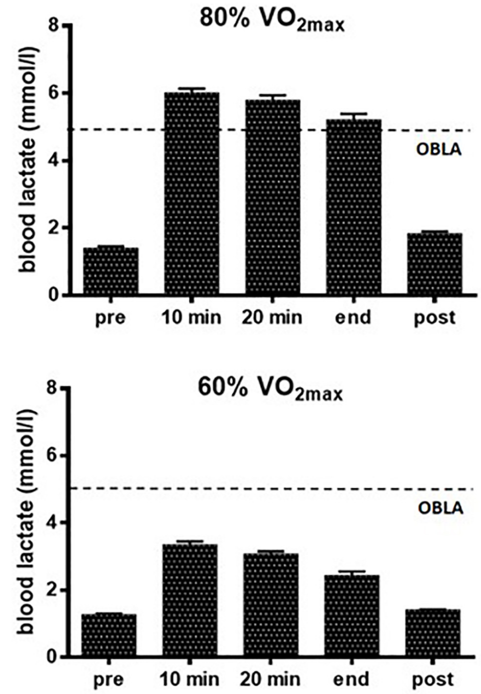
Statistical Analysis

After data collection, the mean value (±SD) of each measured parameter was calculated. Data were compared with one-way repeated measures analysis of variance (ANOVA; Friedman test), followed by Tukey's Multiple Comparison Test. The presence of possible correlations between parameters was verified by means of two-tailed Pearson's correlation. Significance was established at $p < 0.05$. The analyses were carried out by using GraphPad Prism version 6.03 for Windows (GraphPad Software, San Diego, CA).

RESULTS

Figure 2 shows the mean values of blood lactate measured in the 20 athletes in the two different motor tasks (60 and 80% VO_{2max}). Blood lactate levels were quantified before the exercise (pre), every 10 min during the exercise, immediately at the end of the exercise (end), and finally, 10 min after the exercise was completed (post).

One-way ANOVA, followed by Tukey's Multiple Comparison Test, performed on data displayed in **Figure 2**, shows that at both 60 and 80% of VO_{2max} the levels of blood lactate exhibits a significant ($p < 0.001$) increase, compared to the pre-exercise



Tukey's test	60%	80%
pre vs. 10 min	***	***
pre vs. 20 min	***	***
pre vs. end	***	***
pre vs. post	ns	*
10 min vs. 20 min	ns	ns
10 min vs. end	***	***
10 min vs. post	***	***
20 min vs. end	***	**
20 min vs. post	***	***
end vs. post	***	***

FIGURE 2 | Blood lactate levels (mean values ± SD) of the 20 participants performing a voluntary 30-min exercise at 60 and 80% VO_{2max}. Measurements were carried out every 10 min before the exercise (pre), during the 30-min exercise, and 10 min after the conclusion (post). The dotted line indicates the level (4 mmol/l) of the Onset of Blood Lactate Accumulation (OBLA). Results of Tukey's Multiple Comparison Test carried out on data are also presented. ANOVA with Tukey's multiple comparison test are the following: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

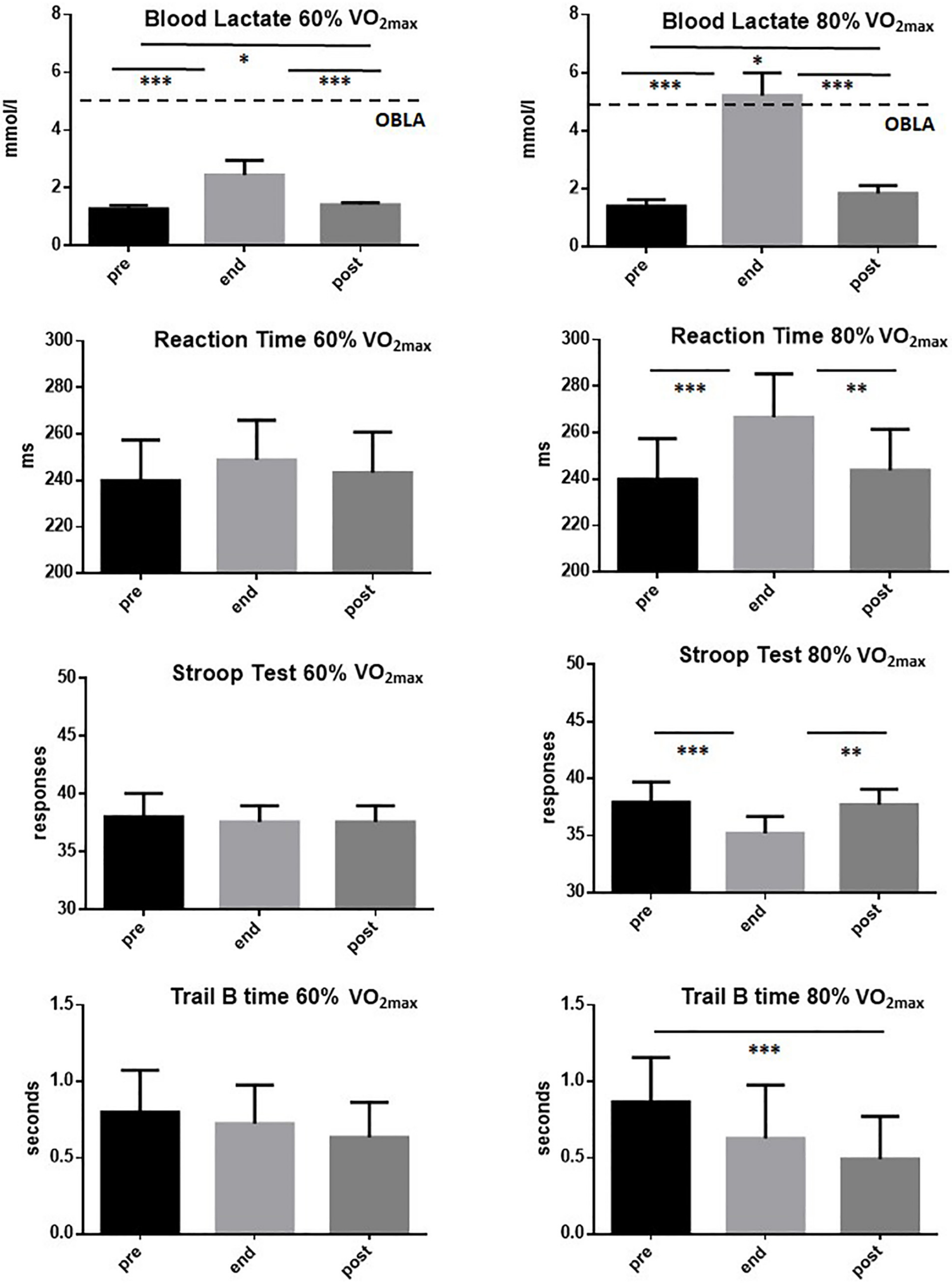


FIGURE 3 | Mean values (±SD) of blood lactate, reaction time, Stroop test, and time for execution of Trial Making Test B of the 20 participants performing a voluntary 30-min exercise at 60 and 80% VO_{2max}. Measurements were taken 10 min before (pre) the beginning of exercise (gray area), at its end and 10 min after the conclusion (post). The dotted line indicates the level (4 mmol/l) of OBLA. Symbols from ANOVA with Tukey's multiple comparison test: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

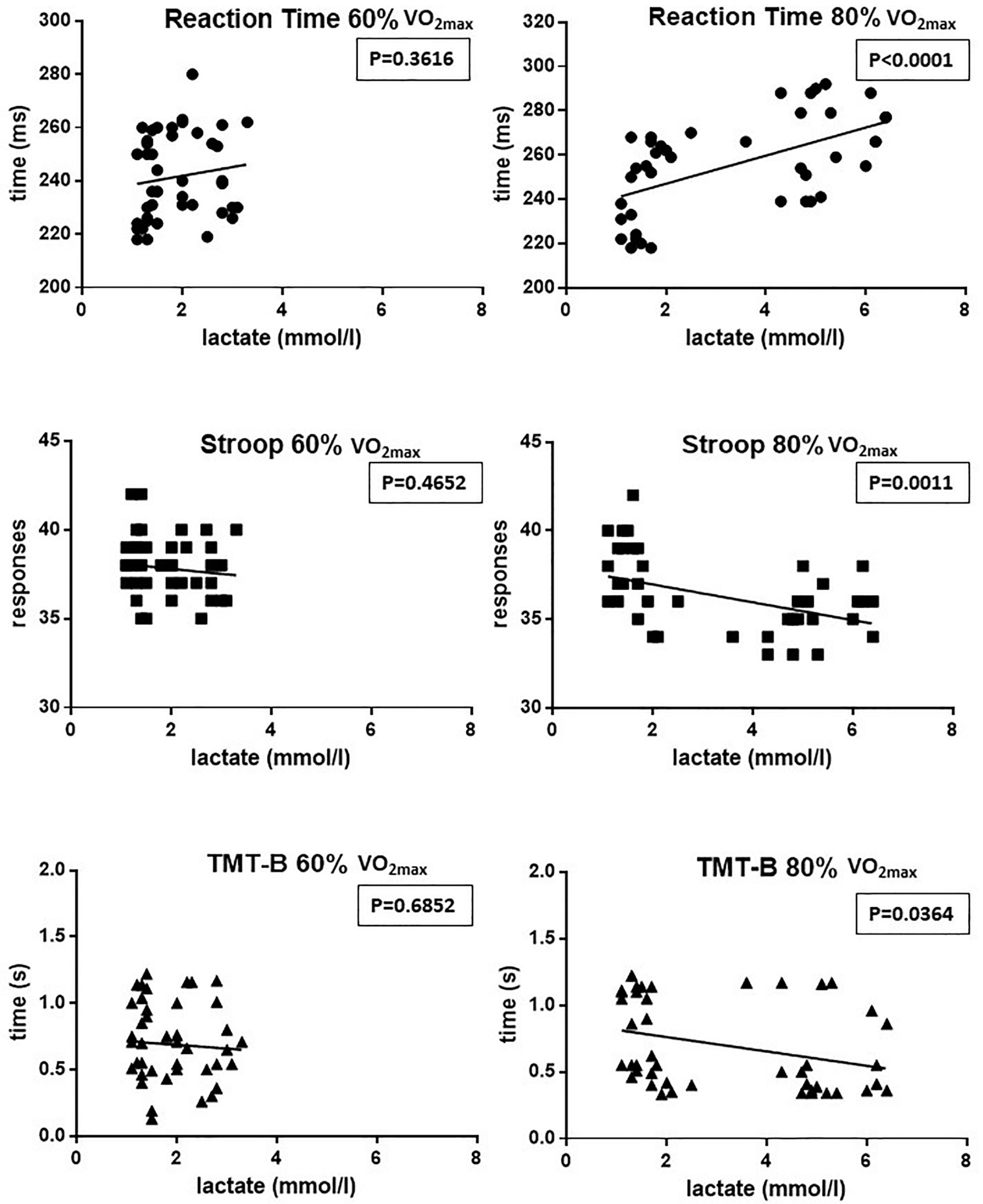


FIGURE 4 | Correlations between blood lactate levels and performance measured for RT, SCWT, and TMT-B in the two different exercise intensities (60% of VO_{2max} on the left and 80% of VO_{2max} on the right). As can be seen, while at 60% of VO_{2max} none of the correlations reaches statistical significance, at 80% of VO_{2max} the 3 correlations are statistically significant ($P > 0.05$).

(pre) and post-exercise (post) values, immediately after the beginning of the exercise. During the exercise at 60% of VO_{2max} the blood level of lactate reached a maximal mean value of 3.35 mmol/l (±0.97 SD), whereas during exercise at 80% of VO_{2max} the blood level of lactate reached a maximal mean value of 6.02 mmol/l (±0.52 SD), thus overcoming the OBLA (4 mmol/l). At 80% of VO_{2max} the level of blood lactate remained over the OBLA throughout exercise, and the blood lactate returned to pre-exercise values after 10 min from its end.

With respect to executive functions, as can be seen in **Figure 3**, it was found that while exercise performed at 60% of VO_{2max} does not change any of the parameters studied, exercise performed at 80% of VO_{2max} negatively affects RT, SCWT, and the time for execution of TMT B. No effect has been detected at either 60 or 80% of VO_{2max} on TMT-A and on the number of errors in TMT-B (data not shown). It is important to note that exercise performed at 60% of VO_{2max} caused only minimal increases in blood lactate levels, while the exercise performed at 80% of VO_{2max} caused an increase in blood lactate values above 4 mmol/l.

Figure 4 illustrates the correlations between blood lactate levels and performance measured for RT, SCWT, and TMT-B at the two different exercise intensities (60% on the left and 80% on the right).

First, it is possible to detect that during the exercise performed at 60% of VO_{2max} no correlation was found between the blood lactate levels and the measured values for RT, SCWT and TMT-B. On the other hand, it is possible to detect in **Figure 4** that, during the exercise performed at 80% of VO_{2max}, there is a significant positive correlation of blood lactate levels with RT and a significant negative correlation of lactate with both SCWT and TMT-B performance.

DISCUSSION

The present study has shown that, during aerobic exercise for 30 min, a significant worsening of the executive functions can be detected only if the intensity of the exercise is more than 80% of VO_{2max}. In these conditions it was possible to detect that blood lactate levels were above the OBLA, i.e., 4 mmol/l, for the entire duration of the exercise. The present observation is consistent with what was previously reported, namely, that only aerobic activities exceeding 80% of VO_{2max} are associated with increases in blood lactate above OBLA (e.g., Chicharro et al., 1999).

The result is also in agreement with the observation that only aerobic exercise performed at an intensity that exceeds OBLA is associated with a worsening of attentive processes (Perciavalle et al., 2014). Finally, during exhaustive exercise, a worsening of working memory (Perciavalle et al., 2015) and of some executive functions (Coco et al., 2020) has been observed. Therefore, the deterioration of executive functions, observed throughout submaximal aerobic exercise carried out at 80% of VO_{2max} can be likely related to increased blood lactate levels.

It has been previously reported (Coco et al., 2009) that, after exhaustive exercise, the significant increase in blood lactate levels is associated with a worsening of attention processes. In the same study, it was also found that a lactate infusion in subjects who did not perform any physical activity is associated with a significant worsening of attentive capabilities.

It is interesting to note that it has recently been found that an acute sprint interval exercise is able to improve cognitive functions 20 min following exercise (Kujach et al., 2020). Because it is well-known that blood lactate levels return to pre-exercise levels within 15 min after the end of the performance (cfr. Coco et al., 2009), the positive effects on cognition can hardly be attributed to lactate.

This has allowed the authors to conclude that high levels of blood lactate are capable *per se* of determining a negative effect on the attentive abilities. The present study reinforces the idea that the increase in blood lactate is linearly correlated with a worsening in the efficiency of cognitive processes. The circulating lactate seems to be able to determine these negative effects both when it increases after exhaustive exercise but also when it increases during aerobic activity.

The possibility that the effects of high intensity exercise on cognitive processes may also depend on other factors (metabolic, vascular, or thermic, etc.) cannot be excluded. However, since lactate receptors have been found in the brain (Morland et al., 2015), a role for lactate as a neural regulator could be proposed (see Proia et al., 2016; Coco et al., 2019a).

One limitation of the present study is that it was conducted on young athletes, so it is our intention in the future to test the behavior of a group of sedentary subjects. Another potential limitation is the fact that the study was conducted on only 20 subjects who, although fairly homogeneous in age, gender, and degree of training, constitute a rather limited sample.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of the University of Milan (number 15/16). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MC, ViP, AB, DD, MT, AZ, and VaP contributed to the conception and design of the study. MC, AB, DD, and ViP were responsible for data collection and statistical analysis. MC, AB, AZ, and ViP were responsible for the drafting and finalization of the manuscript. All authors contributed to manuscript revision and approved the submitted version.

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