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Edited by
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Performance optimization in racket sports: The influence of psychological techniques, factors, and strategies, 2nd Edition

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Editorial: Performance optimization in racket sports: The influence of psychological techniques, factors, and strategies

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Editorial on the Research Topic
Performance optimization in racket sports: The influence of psychological techniques, factors, and strategies

Research and empirical work have revealed the importance of psychological or mental skills factors and strategies in improving athletic performance, especially in racket sports (Cece et al., 2020). The aim of this Research Topic was to bring together articles in which psychological techniques, factors, or strategies are discussed, used or tested in order to improve the performance in racket sport such as tennis, table tennis, badminton and padel.

Performing sport competitions usually generates psychological effects that can affect the psycho-emotional resources of athletes (Di Corrado et al., 2021). For example, Rodríguez-Cayetano et al. showed how precompetitive anxiety is one of the most important psychological factors in relation to padel performance and how it can vary according to competitive level and gender. According to Weinberg and Gould (1996), anxiety could be defined as a negative psycho-emotional mental state characterized by the manifestation of nervousness and worry, in which there is both somatic and cognitive components. Studies showed that anxiety can affect information processing and attentional control (e.g., Cocks et al., 2016), but more ecological validation in sport context, particularly in racket sports, is needed. That's why Ren et al. realized a study in which expert and non-expert table tennis players had to anticipate the serves of opponents under dynamic task constraints using a temporal occlusion paradigm. There findings showed that anxiety negatively influence attention and performance in athletes.

Other emotional response, such as the stress caused by physical or social daily stressors and psychological constraints (Martinent et al., 2020) can negatively influence performance in competitive sports (Lazarus, 2000) and may lead to athlete burnout (Martinent et al., 2014). Martinent et al. investigated the role of stress, recovery and coping on elite table-tennis players' burnout symptoms in considering the roles of contextual and individual factors. Athlete burnout can be defined as a chronic psychological syndrome, manifesting as an emotional and a physical exhaustion, a reduced sense of accomplishment and a devaluation of sport (Raedeke and Smith, 2001). Li et al. (2018) evoked that burnout may be a risk factor of sleep problems among athletes. However, sleep duration and quality can also influence athletic performance (e.g., Kirschen et al., 2020). Indeed, Han et al. evaluated the relationships of sleep inconsistency and duration with tennis competitive performance in soft tennis players and recommended to maintain regular sleep in daily life.

The analyzes made from the observation of competitions, generally with international level players, are also very useful to better understand factors that can influence performance in racket sports. For example, Wang explored the relationship between the scoring structure and the win or loss of a match to better understand what keeps international badminton players competitive. In addition, Sheng et al. investigated the effects of the context-related (e.g., importance of set or rally, game status or result against serve) and technical (e.g., defensive action, forehand or overhead strokes) variables of last strokes in rallies in elite matches. Finally, Kuroda et al. realized a study to better understand the association among time-course changes in the ratings for perceived exertion, the executive functions and the percentage of points won when playing tennis by including the second serve accuracy.

The results of these researches make it possible to improve training intervention or match tactics and implement performance optimization strategies. For example, integrating into research showing beneficial effects of using motor imagery strategy in tennis to improve performance (see Robin and Dominique, 2022 for a review), Robin et al. investigated the combination of this mental strategy with self-talk, in the first serve of skilled tennis players. The authors particularly recommend that tennis players, before performing a particular type of service, imagine seeing the trajectory of the ball and the area they would like to reach in the service box. Koya et al. also suggested the use of physical measurements to improve service performance. In addition to physical strength training, the authors suggested paying particular attention to the depth of the impact point to improve the speed of first serve balls.

The studies previously evoked and which you will find in this Research Topics entitled: "*Performance optimization in racket sports: The influence of psychological techniques, factors, and strategies*," in addition to providing new knowledge in the fields of table tennis, padel, badminton and tennis, offer applied recommendations and suggestions to coaches and players as well as new research perspectives.

Author contributions

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

Conflict of interest

MC was employed by International Tennis Federation.

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

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ORIGINAL RESEARCH
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The Influence of Technical and Contextual Variables of the Last Stroke on Point Outcome in Men's and Women's Singles Badminton

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The purpose of this study was to identify the effects of the technical and context-related variables of last strokes in rallies on the point outcomes of both men's and women's players in elite singles badminton matches. A total of 100 matches during the 2018 and 2019 seasons were analyzed, and the data of 4,080 men's rallies and 4,339 women's rallies were collected. The technical variables including strokes per rally, forehand strokes, overhead strokes, and defensive action, and the context-related variables including game status, result against serve, importance of rally, and importance of set, were modeled with Probit regression modeling as the predictor variables. The binary variables of "winner or not" and "error or not" were considered the response variables. The results showed that defensive actions had the greatest impacts on the winners and errors of both the men's and women's singles players, and the forehand and overhead strokes were negatively associated with the winners and errors of the women's singles players and the winners of the men's singles players. No significant effects were found for the strokes per rally on the winners and errors of the men's singles players, while significant effects were found for the women's singles players. The context-related variables appeared to have positive effects on the winners and negative effects on the errors of both sexes. These findings can provide important insights for coaches and players to evaluate their performances of last strokes in rallies and to improve training interventions and match tactics and strategies.

Keywords: badminton, racket, match analysis, notational analysis, scoring pattern

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INTRODUCTION

Badminton matches are characterized by high intensity and intermittent efforts involving numerous repetitive actions and consecutive movements during rallies (Manrique and Gonzalez-Badillo, 2003; Abdullahi and Coetzee, 2017). Technical, physical, and temporal variables have been widely used in previous studies to interpret and quantify the match characteristics of badminton players, and the technical aspect has gained the most interest of the academic community, especially the singles modality (Phomsoupha and Laffaye, 2015; Chiminazzo et al., 2018; Gómez-Ruano et al., 2020a). Notational methodologies have previously been used to depict and assess the technical characteristics (serving patterns, stroke effectiveness, the effects of context-related variables, and the dynamics of scoring performance) (Phomsoupha and Laffaye, 2015; Barreira et al., 2016; Chiminazzo et al., 2018; Gómez-Ruano et al., 2020a). However, most of the studies were focused on observational analysis by comparing the technical variables of different groups (Abian-Vicen et al., 2013; Torres-Luque et al., 2019; Pérez-Turpin et al., 2020), which provided limited realistic information for coaches and players to prepare for competitions and training sessions. To date, little explorative analysis has been conducted that attempts to investigate the influencing factors of players' scoring performance (Gómez-Ruano et al., 2021).

Due to technological advances, the improved match performance tracking system can provide multidimensional and detailed match performance data for performance analysts to conduct more elaborate analyses, allowing them to explore the keys to succeeding in a match (Hughes et al., 2007; Yi et al., 2020b). Given the focus on the investigation of key factors for the match outcome in badminton, it is of great importance to evaluate the players' performances of the last stroke in the rallies. The authors of the available literature have paid more attention to collecting and analyzing the frequency data of different stroke types based on the whole match scale (clear, smash, lob, cut, drive, etc.) (Chiminazzo et al., 2018), while only a few studies have examined the distribution of last strokes per rally, identifying the unforced error, smash, net, and drop as the most decisive actions to end rallies (Abian-Vicen et al., 2013; Abián et al., 2014). However, investigations into the influencing factors of point outcome (winner, unforced error, and forced error) are still scarce. Evolutionary trends of match characteristics have been previously reported; rally times, the frequency of strokes per second, and the number of shots per rally increase in singles matches over time (Abián et al., 2014; Laffaye et al., 2015). In light of the changes in the playing structure, it is necessary to analyze the relationships between the performance of the last strokes and the point outcome in modern badminton matches, which may provide important information for understanding the scoring patterns.

The significant impact of match context-related variables on the players' match behaviors has been highlighted in the literature (Gómez-Ruano et al., 2013; Yi et al., 2019), and this research topic has been discussed in depth in other sports, including football, basketball, handball, and more (Liu et al., 2015; Prieto et al., 2016; Zhang et al., 2019; Yi et al., 2020a). However, it has only been very recently that the effects of context-related variables on badminton players have been emphasized by researchers (Gómez-Ruano et al., 2020a, 2021). It is obvious that players' performances during rallies may vary dramatically in dynamic situations, for example, the score line, the set number, game points, and the right of service, and these specific situations may place great physiological, psychological, and cognitive loads on players (Ghosh, 2008; Alcock and Cable, 2009; Alder et al., 2019). Players need to adopt different effective technical and tactical actions that make it possible to defeat their opponents during rallies (Hastie et al., 2009; Seth, 2016). Therefore, the effects of context-related variables should not be ignored when analyzing the performance of strokes that players use per rally during the ending rallies. Moreover, the differences between the sexes regarding the temporal, physiological, and notational characteristics have been well-explored in the literature (Cabello et al., 2004; Abian-Vicen et al., 2013; Valldecabres et al., 2017). Abian-Vicen et al. (2013) reported that the smash and drive were used more frequently by men's players and the drop was used more frequently by women's players in singles badminton matches. Presumably, the differences may also exist in the influencing factors of point outcome between both sides.

Therefore, in the current study, we aimed to quantify the influences of the technical variables of the last strokes in each rally and the context-related variables on the point outcome for both men's and women's players in elite singles badminton matches. It was hypothesized that the players' performances during the last strokes are affected by stroke techniques and the match situations in men's and women's singles badminton.

MATERIALS AND METHODS

Sample

The sample was composed of 100 matches for men's and women's singles players (n = 50 matches, n = 4,080 rallies and n = 50 matches, n = 4,339 rallies, respectively), which were randomly selected from matches played in professional badminton competitions from 2018 to 2019 (2018 Japan Open, 2018 China Open, 2018 Uber Cup, 2019 Sudirman Cup, 2018 Denmark Open, 2019 All England Open, 2019 Singapore Open, 2019 Malaysia Open, 2019 China Open, 2019 Indonesia Open, 2019 Asia Championships, and 2019 BWF World Championships). All the matches were publicly available on TV[1] and included all the rallies played within each full match. The data were collected based on videos, and the collecting process was a non-invasive method; only the variables that related to the performance of the last stroke per rally were included in the sample. The ethics committee approval was not required by the university when analyzing the videos available in the public domain.

Procedure

The observational methodology was non-participant and direct with an observational design: nomothetic, multidimensional and follow-up of multiple players (Anguera et al., 2011). The badminton match actions and events and the match contexts of last stroke per rally were considered as independent observations, and were coded from the footage by four well-trained operators with more than 2 years of experience in performance analysis, using a computerized tracking system jointly developed by Danzle Co., Ltd., and Shanghai University of Sport. The inter- and intra-observer reliabilities of the collected data were tested with good to very good levels (Kappa $\geq$ 0.83; correlation coefficient $r \geq 0.86$, intra-class correlation coefficient $\geq$ 0.87; and typical error of measurement $\leq$ 0.48) (Altman, 1990; Hopkins, 2000). The point outcome of each rally for each player was identified as one of three types—winner, forced error, and unforced error according to previous studies of single badminton (Laffaye et al., 2015; Gómez-Ruano et al., 2017). The selected

[1] http://tv.cctv.com/cctv5

technical and context-related variables were defined before the data collection (**Table 1**). The technical variables included the strokes per rally, the stroking position of the last stroke per rally, and the stroking type of the last stroke per rally. All the stroking types (smash, clear, drive, drop, net, and lob) were defined and classified into two groups, offensive actions and defensive actions (active intention to score a point and no intention to score a point). The classification of strokes was based on the tactical aim of a stroke performed and the shuttlecock trajectory (Laffaye et al., 2015), as some strokes (e.g., lob and clear) can be considered either defensive actions or defensive actions in different situations. Four context-related variables were selected—game status, result against serve, the importance of the rally, and the importance of the set.

Statistical Analysis

A data normality test (Shapiro–Wilk) was performed for the continuous variables ($P < 0.05$). Then, Probit regression was used to quantify the effects of technical and context-related variables on the point outcome for both the men's and women's singles players. Forced error and unforced error were merged into a new variable, named error, and then the binary variables of "winner or not" and "error or not" were selected as the response variables, respectively, for the modeling. As the predictor variables included both continuous variables and categorical variables, two polytomous variables (the stroking position of the last stroke per rally and the stroking type of the last stroke per rally) were transformed into dummy predictor variables in order to examine the specific effects of different positions and types of strokes on the point outcome. The results of the Probit regression were easier to interpret when the dummy variables were limited to two values (0 or 1), with 0 representing the absence of a qualitative attribute and 1 representing its presence. The number of dummy variables could be defined as K−1 when the number of values of the polytomous variable was assumed to be K (Hardy, 1993). Therefore, the stroking position of the last stroke per rally (forehand, backhand, and overhead strokes) was transformed into two dummy predictor variables (forehand and overhead strokes), and the stroking type of the last stroke per rally was transformed into one dummy predictor variable (defensive action). The removed dummy became the base category that the other categories could be compared with. Ultimately, there were four technical variables—strokes per rally, forehand stroke, overhead stroke, and defensive action, and four context-related variables (binary situation)—game status (winning or not before this rally), result against serve (points scored against serve or not), importance of rally (key rally or not), and importance of set (key set or not)—were observed as the predictor variables for the Probit regression models. After the estimations, the command mfx was used to calculate the marginal effects. The marginal effect indicates the effect of a one-unit change in the predictor variable on the change (%) in the probability of the response variables (winner or not and error or not) (Mullahy, 2017). The statistical analyses were performed using the statistical software STATA/SE 16.0 (StataCorp., United States). The level of significance was set at 0.05.

TABLE 1 | Definitions of selected technical and context-related variables.

Type of variable	Variables	Definitions
Technical variables	Strokes per rally	The number of strokes achieved during a rally.
	Stroking position	The position that the shuttlecock was hit in the last stroke per rally, including forehand stroke, backhand stroke, and overhead stroke.
	Stroking type	Technical skills that were used for hitting the shuttlecock in the last stroke per rally, including smash, clear, net, lob, cut, drive, flick, etc.
Context-related variables	Game status	Winning or not before the rally.
	Result against serve	Points scored against the serve or not. The right of service is considered an advantage for the server; a point scored against a serve was recorded if players scored a point when the opponent was the server.
	Importance of rally	Key rally/non-key set. The game point was considered a key rally.
	Importance of set	Key set or non-key set. The "second set is the key set if the opponent won the first set; the third set is the key set if both sides won a set.

RESULTS

The parameter estimates of the Probit regression models are presented in **Tables 2, 3**, and the results are summarized and visualized in **Figure 1**. The technical variables of forehand stroke, overhead stroke, and defensive action (marginal effect: ME = −0.58 to −0.10, $P < 0.05$) and the context-related variable of result against serve (ME = 0.085 to 0.176, $P < 0.05$) showed positive and negative relationships, respectively, with the winners of both the men's and women's singles players. In addition, positive effects of the number of strokes per rally and the importance of set on the winners were also identified for women's singles players (ME = 0.085 to 0.176, $P < 0.05$). Only the defensive action (ME = 1.327, $P < 0.01$) from men's singles players showed a positive relationship with the errors, while all the technical and context-related variables (ME = −0.151 to 1.001, $P < 0.05$) showed significant effects on the errors of women's singles players, with the exception of the importance of rally.

The number of variables that showed significant relationships with the winners of women's singles players was higher than the number of variables that showed significant relationships with the errors of men's singles players, and the effects of the selected variables on the winners and errors of women's players were very similar; the only difference was in the context-related variable of game status. The defensive actions showed negative relationships with the winners of both the men's and women's singles players (ME = −0.58 to −0.322, $P < 0.01$), and also

TABLE 2 | Parameter estimates for the relationships between winners and the technical and context-related variables for men's and women's singles players.

Variables	Winner					
	Men (n = 4,080)			Women (n = 4,339)		
	Z-score	Coef.	ME	*Z*-score	Coef.	ME
Technical variables						
Strokes per rally	1.610	0.004	0.002	6.630	0.020**	0.008
Forehand stroke	−2.030	−0.100*	−0.040	−3.750	−0.176**	−0.070
Overhead stroke	−3.390	−0.210**	−0.084	−5.210	−0.305**	−0.121
Defensive action	−12.870	−0.580**	−0.228	−7.820	−0.322**	−0.128
Situational variables						
Game status	−0.290	−0.012	−0.005	1.390	0.056	0.022
Result against serve	2.050	0.085*	0.034	4.420	0.176**	0.070
Importance of rally	1.740	0.164	0.064	−0.230	−0.020	0.042
Importance of set	−0.960	−0.054	−0.021	2.000	0.107*	0.042
Constant	5.910	0.380**		1.080	0.068	
Pseudo R-squared		0.033			0.024	

*$P < 0.05$, **$P < 0.01$.
Coef., Probit regression coefficient; ME, marginal effect.

TABLE 3 | Parameter estimates for the relationships between the errors and the technical and context-related variables for men's and women's singles players.

Variables	Error					
	Men (n = 4,080)			Women (n = 4,339)		
	Z-score	Coef.	ME	*Z*-score	Coef.	ME
Technical variables						
Strokes per rally	0.600	0.002	0.001	−3.170	−0.010**	−0.004
Forehand stroke	−0.860	−0.047	−0.018	−2.750	−0.141**	−0.052
Overhead stroke	−0.480	−0.031	−0.012	−2.400	−0.148*	−0.056
Defensive action	26.510	1.327**	0.462	22.370	1.001**	0.351
Situational variables						
Game status	−0.760	−0.034	−0.013	−2.770	−0.118**	−0.044
Result against serve	−0.890	−0.039	−0.015	−3.560	−0.151**	−0.056
Importance of rally	−0.880	−0.088	−0.034	0.870	0.080	0.029
Importance of set	1.260	0.076	0.029	−2.440	−0.137*	−0.052
Constant	−3.430	−0.237**		4.180	0.280**	
Pseudo R-squared		0.172			0.117	

*$P < 0.05$, **$P < 0.01$.
Coef., Probit regression coefficient; ME, marginal effect.

showed positive relationships with the errors of both the men's and women's singles players (ME = 1.001 to 1.327, $P < 0.01$). No significant relationships were found for the importance of rally with the winners and errors for both the men's and women's singles players. The significant effects of the number of strokes per rally (ME = −0.01 to 0.02, $P < 0.01$) and the importance of set (ME = −0.137 to 0.107, $P < 0.05$) on the winners and errors were only found for women's singles players.

DISCUSSION

In the current study, we aimed to model the relationships between the technical and context-related variables of the last stroke per rally and the point outcome (winner and error) for the elite men's and women's singles badminton players. The current findings revealed the significant effects of technical and context-related variables on the performance of both men's and women's singles players during the last strokes, and it was found that the women's singles players were more susceptible to the technical and context-related factors than the men's singles players.

For the men's singles players, stroking position, stroking type, and result against serve had significant effects on the point outcome of the winner. The positive relationship between the result against serve and the winners indicated that the players were more likely to finish the rally using a winner when the opponent was the server. Serving may potentially help the server to gain some spatial and temporal advantage

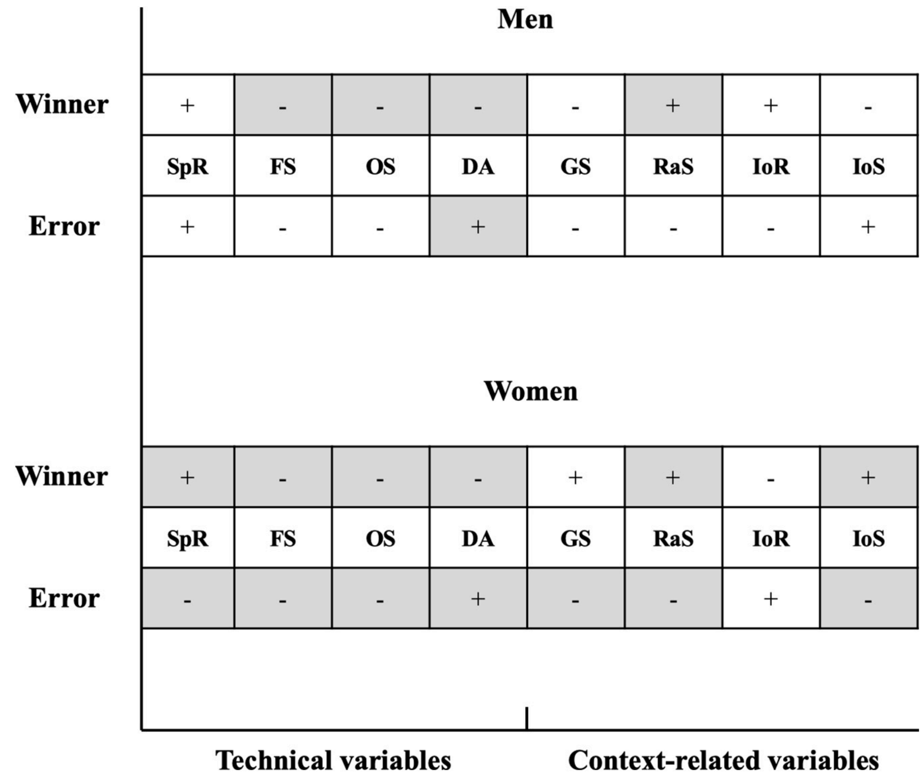

FIGURE 1 | Comparison of identified significant variables between the winner and error for men's and women's singles players. + indicates the positive regression coefficient, – indicates the negative regression coefficient. The gray shaded squares indicate the significant relationships between the corresponding variables and the point outcomes. SpR, strokes per rally; FS, forehand stroke; OS, overhead stroke; DA, defensive action; GS, game status; RaS, result against serve; IoR, importance of rally; IoS, importance of set.

during rallies (Gómez-Ruano et al., 2020a), but players may perform more aggressively as receivers in order to regain the right of serve. It is worth noting that the forehand and overhead strokes were negatively associated with the winners, which means that men's singles players finishing the rally using forehand and overhead strokes may decrease the probability of performing winners compared to using backhand strokes. These results are contradictory to the previous researcher's findings that the overhead stroke was the most popular stroke in singles badminton matches, with more than half of the strokes performed using an overhead (Ghosh et al., 2002). It is easy to understand that the probability of obtaining a winner would be decreased when the men's singles players adopted defensive actions, such as lob, for the last stroke of the rallies rather than offensive actions, such as a smash, Conversely, the last stroke with no intention to score a point may more likely lead to an error, and this notion could be supported by another current finding that only the defensive actions had significant positive associations with the errors. Surprisingly, the number of strokes per rally, stroking positions, and all match contexts had no impact on the errors of the men's singles players, especially in the match contexts.

For the women's singles players, the influencing factors of the winners and errors demonstrated very similar trends, in that all the selected technical and context-related variables showed consistent impacts (significant or non-significant) on winners and errors, except for the game status. However, the majority of technical variables displayed negative effects, and the context-related variables displayed positive effects on winners and negative effects on errors. Specifically, the positive relationship between winners and the number of strokes per rally indicated that the longer the rallies, the higher the probability of achieving the winners, which highlights the importance of physical preparation in singles badminton matches. The players with well-prepared physical capacity may be more likely to disrupt the opponents' balance and achieve the winners during long rallies (Gómez-Ruano et al., 2020b). The positive relationships between the winners and the context-related variables of result against serve and the importance of set demonstrated that the players who scored points without serving were more likely to be linked to the point outcome of the winner, and players had a higher probability of achieving the winners during the key set and during the initial moments of the set (Gómez-Ruano et al., 2021). In addition, similar to the men's singles players, the forehand strokes, overhead strokes and defensive actions also had negative effects on the winners of the women's singles players. More attention should be paid to these negative effects when evaluating the stroking performance of both men's and women's singles players, and further research is necessary to explore the potential reasons. The highest number of influencing factors were identified for the errors of women's singles players. The number of strokes per rally, defensive action, result against serve, and the importance of set showed opposite effects on the errors when compared to their effects on the winners, and the effects of the forehand and overhead strokes on the winners and errors were consistent. The significant effect of the game status was only observed for the errors of the women's singles players; the probability of occurring errors was lower when a player was winning during a set. This could be partially explained by the fact that winning may bring a psychological advantage to the players during match play (Gómez-Ruano et al., 2021).

Interestingly, defensive action was the only variable that displayed significant effects on the winners and errors of both the men's and women's singles players, and the negative and positive effects were observed for winners and errors, respectively. These findings reflect the fact that defensive actions may decrease the frequency of the occurrence of winners and increase the frequency of the occurrence of errors. Notational analyses have been conducted in previous studies to describe the distribution of stroking types of the last stroke in the rallies for different genders (Abian-Vicen et al., 2013), competitions (Abián et al., 2014), and match stages (Chiminazzo et al., 2018), concluding that the smash, net, and drop were more frequently performed by singles players in the last stroke of the rallies. However, stroke effectiveness and the effects of stroking actions on the point outcome failed to be quantified. Our findings may provide important insights for coaches to improve singles players' stroking performances in the last stroke of the rallies. Moreover, no significant effects were found for the importance of rally on the winners and errors of both the men's and women's singles players, Gómez-Ruano et al. (2020c) argued that the context-related variables can affect the variability of match performance, and the critical periods (e.g., game point) could be considered a match-context constraint that impact the players' scoring performance. However, this is not the case in the current study; the probabilities of achieving winners and errors did not correspondingly increase and decrease for either the men's or women's singles players during the key rally. In addition, great differences were found in the number of influencing factors between the men's errors and women's errors; only the defensive actions had a significant effect on the errors of the men's singles players, while only the importance of rally showed a non-significant effect on the errors of the women's singles players. The results indicate that the women's singles players' performances in the last strokes were more sensitive than men's singles players to the technical variables and the match contexts. This finding may partly support the conclusion from Abian-Vicen et al. (2013), who found that women's singles players obtained more unforced errors than men's singles players during match play.

This study identified the effects of the technical variables and match contexts of the last stroke in rallies on the point outcome for both men's and women's singles players in elite badminton matches. The findings of the current study may provide some practical applications for coaches and players in the development of specific training interventions and the decision-making process during match play. We recommend that offensive actions, such as smash, can be used more frequently during rallies, and that a conservative playing strategy, especially at the end of the rallies, may not help the players to score points. This is also in line with the trend that badminton matches are more intense and competitiveness is increasing between players (Abián et al., 2014). As longer rallies may help them to achieve a better point outcome, women's singles players could be advised to play the match more patiently. In addition, the women's singles players were more easily affected by the match contexts than the men's singles players. Therefore, they need to prepare specific match strategies for different match situations.

Some limitations of the present research should be noted and addressed in further studies. Firstly, as the performances of the last strokes are affected by previous actions during the rallies, analysis without the consideration of the entire stroking sequences of the rallies would lead to the loss of some key information about the stroking patterns. Secondly, the opponents' match behaviors have impacts on the performance of the last strokes, and the stroking actions of the opponents also need to be recorded in order to analyze the dynamic interactions between players. Thirdly, the temporal variables should be included in future research to describe the temporal structure of the rallies, which may provide important insights for the understanding of the effects of physical and cognitive fatigue on the point outcome.

CONCLUSION

In conclusion, the current study identified the key influencing factors of the point outcome from the perspective of the last stroke of the rallies in the elite badminton championships. In general, the point outcome of women's singles players may more easily be affected by the technical and context-related variables than those of men's singles players, especially the context-related variables. Specifically, the forehand and overhead strokes were negatively associated with the probability of achieving the winners, and defensive actions presented the greatest effects on the winners and errors of both men's and women's singles players. The selected technical and context-related variables had limited impacts on the errors of the men's singles players, while they had great impacts on the errors of the women's singles players. The match contexts had positive effects on the winners and negative effects on the errors of both sexes. These findings may help coaches and players to understand the scoring patterns of men's and women's singles players based on the performance of the last strokes of the rallies, leading to the development of specific training drills and match tactics and strategies.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

YS, QY, and PC: conceptualization. YS and QY: methodology. YS: formal analysis, data collection, and writing—original draft preparation. QY: software and visualization. QY, M-ÁG-R, and PC: writing—review and editing. M-ÁG-R and PC: supervision. YS, M-ÁG-R, and PC: funding acquisition. Project administration: School of Physical Education and Sport Training, Shanghai University of Sport. All authors have read and agreed to the published version of the manuscript.

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The Adverse Effect of Anxiety on Dynamic Anticipation Performance

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Anticipation is a crucial perceptual-cognitive skill in fast-ball sports, and the effect of high anxiety on performance has attracted more attention from sports psychologists. Related studies mainly focus on the effect of anxiety on influencing processing efficiency and attentional control (top-down vs. bottom-up) during information processing in sport. Attentional Control Theory (ACT) has been supported by several studies. However, these studies have been criticized by the low ecological validity of task design, such as neglecting the dynamic process of anticipation, and inadequate performance analysis, such as analyzing response accuracy and time separately. Using temporal occlusion paradigm, we tested ACT in a dynamic anticipation process. Eighteen skilled and eighteen less-skilled table tennis players were required to anticipate the serves of opponents under dynamic task constraints (early vs. late occlusion) and anxiety conditions (high vs. low anxiety). High cognitive state anxiety decreased processing efficiency (response time/response accuracy) for both groups whereas performance effectiveness (response accuracy) did not differ. In addition, it negatively affected processing efficiency in early anticipation compared with late anticipation tasks, suggesting that high cognitive state anxiety may have a greater impact on top-down attentional control. Our findings provide support for ACT and show that anxiety impairs anticipation efficiency and performance, possibly due to an ineffectively attentional shift from external kinematic cues to internal long-term working memory. Findings also have implications for the adaptation of attentional strategies and anxiolytic training.

Keywords: processing efficiency, table tennis, perceptual-cognitive skill, sport expertise, attention control theory

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INTRODUCTION

The influence of anxiety on performance has attracted more attention from sports psychologists. Recently, researchers have tested assumptions on Processing Efficiency Theory (PET, Eysenck and Calvo, 1992) and Attentional Control Theory (ACT, Eysenck et al., 2007) to explore the effects of anxiety on information processing in the competitive sport context.

Anxiety, as one kind of emotion, may arise in response to a competitive situation. Anxiety is a multidimensional concept in two ways. On the one hand, like other emotions, anxiety has both a trait component and a state component. According to Cox (2012), "state anxiety is an immediate emotional state that is characterized by apprehension, fear, tension, and an increase in physiological arousal" (p. 157). Conversely, trait anxiety is a predisposition to perceive certain environmental situations as threatening and to respond to these situations with increased state anxiety (Spielberger, 1971). State anxiety is a situation-specific affective response to the environment and is influenced by trait anxiety (Endler and Kocovski, 2001). An athlete with a high level of trait anxiety is likely to respond to a competitive situation with a high state of anxiety. That is, the effect of anxiety on performance is finally reflected through the influence of state anxiety. In addition, compared to trait anxiety, state anxiety is easily managed and controlled. Exploring the effect of state anxiety on performance can also inspire more evidence-based practice. Accordingly, the present study focuses on state anxiety.

On the other hand, anxiety has both cognitive and somatic components. Cognitive anxiety is the mental component of anxiety caused by things such as fear of negative social evaluation, fear of failure, and loss of self-esteem, while somatic anxiety is the physical component of anxiety and reflects the perception of physiological responses, such as increased heart rate, respiration, and muscular tension (Cox, 2012). These components have different temporal changes as a sport event approaches. Cognitive anxiety fluctuates throughout the contest as the probability of success or failure changes, while somatic anxiety dissipates rapidly after the start of the performance (for details, refer to 7.3, p. 164; Cox, 2012). This means that cognitive anxiety has a long-term effect during sport performance. Moreover, both PET and ACT emphasize the effect of cognitive anxiety on perceptual-cognitive performance in sport. Accordingly, the present study focuses on cognitive state anxiety.

According to PET, anxiety depletes limited working memory resources, which makes it insufficient for coincident tasks. Anxiety can also motivate individuals to recruit additional resources to maintain performance by improving motivation. Processing efficiency, i.e., the ratio of performance effectiveness (response accuracy) to mental effort, decreases as individuals improve mental effort to maintain performance under high-anxiety conditions. Studies have also shown that processing efficiency is more negatively impacted than performance effectiveness under high-anxiety conditions (e.g., Cocks et al., 2016; Vater et al., 2016).

Eysenck et al. (2007) developed ACT to further explain the cognitive mechanism of the adverse influence of anxiety on performance. ACT suggests that anxiety impairs the central executive system of working memory by reducing working memory resources available for coincident tasks. Attention as a cognitive processing refers to the mental activity of humans taking in external information or attending to internal resources. In addition, it plays an important role in the complex cognitive processing and behavior. ACT also proposes that anxiety impairs goal-oriented (top-down) attentional control by impacting inhibition and shifting the function of the central executive system. Inhibition and shifting dysfunction create the processing under the predominance of stimulus-driven (bottom-up) attentional control. This means that anxious individuals draw more attentional resources to the threat-related or salient stimulus (e.g., internal worrisome thoughts or external environment) and disturb themselves to concentrate on the goal or expectation formulated by prior experience and knowledge.

Based on PET and ACT, several studies have tested the effects of anxiety on sports performance. Cocks et al. (2016) examined the impact of anxiety on anticipation using a dynamic and time-constrained tennis task and found that processing efficiency significantly decreased under high compared to low-anxiety conditions. However, performance effectiveness did not differ. Vater et al. (2016) had a similar finding by using football decision-making tasks. They found that mental effort significantly increased under high-anxiety conditions. These findings suggest that anxiety elicits greater decrements in processing efficiency than performance effectiveness and provide solid support for PET.

To test the impact of anxiety on players' attentional processes (high- and low-level cognitive processes), Cocks et al. (2016) elicited high- and low-level cognitive processes by manipulating the availability of postural, shot sequencing, and court position information in a tennis anticipation paradigm. The findings showed that high anxiety was most detrimental to processing contextual information only (top-down cognitive process) compared to performance in processing postural information only (bottom-up cognitive process), suggesting that anxiety may have a greater impact on top-down attentional control. Vater et al. (2016) investigated how anxiety influenced visual search strategies (attentional control) by manipulating far and near soccer decision situations. Their results showed that high anxiety influenced search strategies, with higher-skilled athletes showing a decrease in the number of fixations for far situations under high anxiety compared to low-anxiety conditions when compared with lower-skilled athletes. Both studies provide support for ACT with high anxiety impairing top-down attentional control.

The studies mentioned above provide partial support for PET and ACT. However, there are also significant shortcomings in sports performance analysis and representative task designs.

When rating processing efficiency, current researches generally use the ratio of performance effectiveness, such as anticipation or decision-making accuracy, to mental effort or only to the score of mental effort. However, there is a lack of performance analysis-combined accuracy with response time. In fact, a fast response is a basis for successful performance, especially in fast-ball sports. For example, with a tennis court length of 23.77 m, a tennis serve speed can reach 240 km/h (66.67 m/s) or higher (Gillet et al., 2009). Hence, receiving players need to complete the receiving motion in less than 0.357 s. Therefore, to examine the effect of anxiety on the anticipation of fast-ball receiving and serving, both anticipation accuracy and response time must be considered.

The study on speed-accuracy trade-off has proposed the indicator of inverse efficiency score (IES, the ratio of response time to accuracy; Bruyer and Brysbaert, 2011). The suggestion that higher IES indicates poorer processing efficiency or sports performance has received much attention and recognition from researchers on athletic anticipation (e.g., Abreu et al., 2012; Liu et al., 2017). Consequently, when examining processing efficiency, in addition to choosing mental effort, it is necessary to add IES to more comprehensively and effectively examine the effect of high anxiety on anticipation processing efficiency and evaluate the quality of anticipation performance.

Currently, researchers increasingly highlight the ecological validity of experimental task designs when conducting athletic anticipation studies, i.e., experimental tasks should adequately represent the real performance environments for better generalization and application of the findings (Runswick et al., 2018). For example, Cocks et al. (2016) classified the information of tennis landing anticipation into postural, shot sequencing, and court position information. They found that experimental tasks with only one kind or part of this information are different from the actual motor tasks where all information is combined. Drawing on a badminton serve anticipation task and an auditory selection response task (dual-task paradigm), Alder et al. (2018) explored the effects of high-anxiety on athletic anticipation, attentional resource allocation, and visual search strategy. However, the manipulation of these auditory tasks in laboratory remained significantly different from the actual performance scenarios. Runswick et al. (2018) examined the impact of anxiety on the processing of various information in sports anticipation by manipulating contextual information, such as the ball and the player's field position using an *in situ* task, and the ecological validity of their study was improved to some extent. Currently, researches mostly discuss the effects of anxiety on perceptual-cognitive processing of different kinds of athletic information from a static perspective, ignoring the dynamic perceptual-cognitive process (for details, refer to Müller and Abernethy, 2012), such as anticipation in sports. That is, few studies pay attention to the effects of anxiety on the anticipation performance at different time points in the real scenarios of fast-ball sports.

Anticipating opponent's movements and ball flight trajectories is particularly important for successful performance in fast-ball sports (Williams and Jackson, 2019). In an actual game, due to the high temporal and spatial pressure, the receiver is often unable to wait until the serving player fully completes a serving action to make a prediction, hence, he/she constantly anticipates the shot landing position during the unfolding events of a serve. Since early anticipation is based on incomplete and limited motor cues (Müller and Abernethy, 2012), athletes could draw on their prior motor experience to form expectations about the direction of a serve. A meta-analysis including 42 studies of perceptual-cognitive skill indicated that experts are better than non-experts in picking up perceptual cues, anticipating the landing area of the ball, and making an action decision, characterized by better response accuracy and faster response time (Mann et al., 2007). This means that expert athletes can consistently demonstrate superior perceptual-cognitive skills in athletic performance.

According to the long-term working memory theory (Ericsson and Kintsch, 1995; Williams and Ericsson, 2005), higher-skilled athletes have more motor experience and knowledge. They can turn attention to internal long-term working memory in the early stage of the opponent's serve (incomplete motor cues). According to ACT, prior experience and knowledge help to make a goal-oriented and top-down attentional control. As a serve event unfolds, the motor cues provide increasingly complete and definitive information. Hence, athletes need to shift attention from internal long-term working memory to external action cues, i.e., to form a stimulus-driven and bottom-up attentional control. As these attentional control skills are expertise-dependent, it seems significant to test whether the effects of anxiety interact with skill level.

To summarize, PET suggests that cognitive state anxiety (e.g., worrisome thoughts) occupies and negatively affects working memory, while ACT further investigates how cognitive state anxiety affects working memory. ACT suggests that cognitive state anxiety impairs the central executive system of working memory, especially inhibition and shifting function.

Based on ACT, long-term working memory theory, and the important role of anticipation in fast-ball sports, this study will examine the differences in anticipation performance between skilled and less-skilled athletes under high- and low-anxiety conditions in early and late anticipation tasks, and whether skill level can moderate the relationship between anxiety and anticipation performance. We propose two following hypotheses: (1) With the increase of anxiety level, processing efficiency in anticipation tasks decrease significantly, while performance effectiveness remain; and (2) with the increase of anxiety level, the processing efficiency and anticipation performance of athletes in early anticipation, especially in skilled athletes, will be disrupted to a greater extent compared to in late anticipation.

In the current study, we make a novel attempt to examine the effects of anxiety on attentional control in anticipation by using table tennis serving tasks at different occlusion times. As a fast-ball sport, table tennis provides a good experimental context, requiring athletes to have the ability to anticipate quickly, accurately, and stably. The role of receiving a serve for the technical and tactical initiative is getting more and more attention from athletes and coaches (Cheng and Yang, 2014; Zhou and Zhang, 2019). In addition, ACT has not found support in table tennis anticipation tasks. Exploring the effect of high anxiety on receiving and serving in fast-ball sports could broaden and deepen the understanding of the relationship between the psychological state of athletes and athletic performance, and provide scientific evidence for guiding table tennis training and competition. In addition, exploring the effects of high anxiety on performance by using table tennis anticipation tasks at different occlusion times could test ACT in a more ecological way and provide more empirical evidence.

MATERIALS AND METHODS

Participants

A prior analysis was used and the sample size was calculated by G*Power 3.1 (Faul et al., 2009). Based on the medium effect size (f = 0.25), given an α of 0.05, and a statistical power (1-β) of 0.95, 36 players took part in this study. Eighteen college table tennis players (10 males and 8 females; M_{age} = 22.8 years, SD = 2.58; $M_{\text{experience}}$ = 13.1 years, SD = 5.11) were recruited for the higher-skilled group, with their highest playing level ranging from regional (n = 7) or provincial (n = 8) to national (n = 3) level and 9.83 training hours per week (SD = 3.67). The lower-skilled group consisted of 18 college students who majored in physical education of table tennis (all male; M_{age} = 20.5 years, SD = 1.43; $M_{\text{experience}}$ = 2.1 years, SD = 0.78). They learned to play table tennis for less than 2 years, with 5.4 training hours per week (SD = 2.14), and only participated in campus table tennis games. All participants were right-handed and reported to be in good health, had no mental illness, and had normal or corrected to normal vision. Participants were tested individually. Before testing, all participants provided written informed consent. The study was approved by the university ethics committee.

Design

The study employed a 2 (skill level: skilled/less-skilled) × 2 (anxiety: high/low) × 2 (occlusion time: early/late) mixed-factor design. Anxiety and occlusion time were within-participants factors. Performance effectiveness (response accuracy), processing efficiency (IES: response time/accuracy; and mental effort ratings), and response time were the dependent variables.

Materials

Trait Anxiety

State anxiety is influenced by trait anxiety (Endler and Kocovski, 2001). Previous researchers proposed that individual differences of trait anxiety may cause the differences of state anxiety induced by the same anxiety-inducing procedure (for details, refer to the Discussion, Vater et al., 2016). Moreover, trait anxiety may interfere with the executive function of participants, such as inhibition function (Sun and Zhang, 2015) and shifting function (Wu et al., 2021). To test the effectiveness of the anxiety induction procedure and reduce the adverse effects of individual differences, trait anxiety was set as the control variable.

Trait anxiety was measured using the Trait Anxiety Inventory (TAI) from the State-Trait Anxiety Inventory (Chinese translation edition, Spielberger et al., 1983; Wang et al., 1999). TAI has 20 items, and each requires a response on a 4-point scale from "Almost Never" to "Almost Always." The scores of TAI range from 20 to 80, and higher scores indicate greater trait anxiety. The coefficient of internal consistency reliability (Cronbach's α) in the study is 0.73.

Competitive State Anxiety

Martens et al. (1990) developed competitive state anxiety as multidimensional anxiety theory that included cognitive, somatic anxiety, and self-confidence. Referring to related studies (e.g., Runswick et al., 2018; Broadbent et al., 2019), we used the Mental Readiness Form-Likert (MRF-L; Krane, 1994) to measure competitive state anxiety. MRF-L has three items to assess cognitive anxiety [from "not worried" (1) to "worried" (11)], somatic anxiety [from "not tense" (1) to "tense" (11)], and self-confidence [from "not confident" (1) to "confident" (11)], respectively, with participants responding on an 11-point Likert scale.

Mental Effort

The Rating Scale for Mental Effort (RSMF; Zijlstra, 1993) was used to assess mental effort. RSMF is a sensitive indicator to assess mental effort (Broadbent et al., 2019). It requires participants to provide a number from "0" to "150" to denote their perceived mental effort, with "0" corresponding to not at all effortful, "75" corresponding to moderately effortful, and "150" to very effortful.

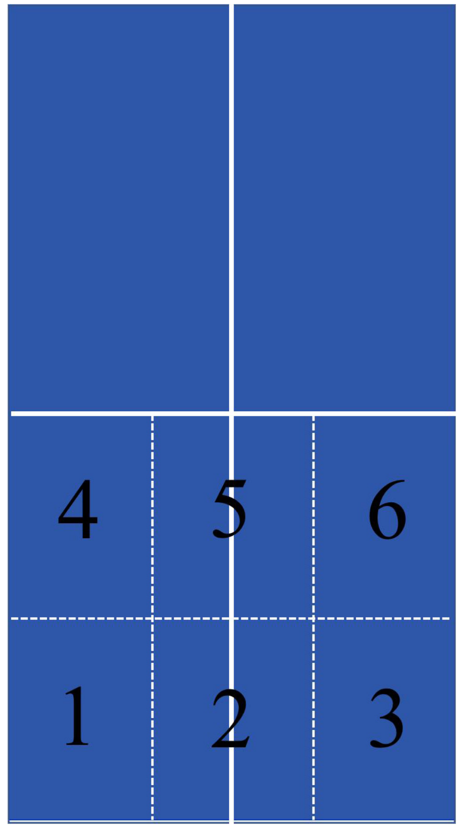

FIGURE 1 | Landing target area division.

Recording, Editing, and Screening of Anticipation Tasks

Four provincial-level table tennis players (4 males; 2 right-handed; M_{age} = 20.3 years, SD = 2.52; $M_{experience}$ = 12.8 years, SD = 3.23) were recruited to record table tennis serves. In accordance to the rules of the International Table Tennis Federation, they used an uncovered serve in the side position. They were required to use forehand backspin or side backspin technique just like in real competition, with six landing zones (left, middle, and right area near and far from the net, as shown in **Figure 1**). Under the requirements of keeping the speed, strength, and flight arc of the serves as stable as possible, each of them completed 10 serves at each landing zone, and a total of 240 serve videos were recorded. To simulate the perspective of real competition, the camera support was placed on the extension line of the centerline on the table, two meters away from the table, and about 4.75 m away from the server. The camera lens was 1.7 m high from the ground. The resolution of the videos was 1,920 × 1,080, with a frame rate of 30 fps.

Four table tennis graduate students (two males and right-handed; provincial-level; M_{age} = 28.2 years, SD = 3.32; $M_{experience}$ = 10.8 years, SD = 2.51) were recruited to screen videos. The quality of the serve was evaluated by four aspects on a 5-point scale, i.e., the server's position, ball throwing, racket leading, and hitting. Finally, the videos with the quality score of each landing zone in the top 1/2 were selected (the average score of each zone is above 4.15), that is, each player had 5 videos at each landing zone, and a total of 120 videos were screened out.

The videos were edited by the software Kinovea 0.9.1 (a free video player for sports analysis created and developed by Joan, 2018) without any sound. An anticipation video clip started at the moment of the ball throw during the serve period, where difficult tasks (early occlusion) ended at the moment when the ping-pong ball touched the home side of the table (lasting about 1,230 ms) and easy tasks (late occlusion) ended at the moment when the ping-pong ball bounced right above the net (lasting about 1,570 ms). Each serve video was edited into an easy task and a difficult one, and a total of 240 videos were generated. Considering the factors of server actors and their handedness, these selected videos evenly distributed in four experimental conditions, namely, early and late occlusion in high-anxiety condition and early and late occlusion in low-anxiety condition. Ultimately, there were 60 videos in each condition.

Apparatus

A Nikon D7100 camera was used for recording. An HP laptop, which was configured with a 15.6-inch screen (resolution of 1,920 × 1,080), 16 g memory, and Intel I5-7300HQ CPU (frequency of 3.25 GHz), was used to edit videos, execute the experimental program, collect data, and do statistical analysis. The experimental data input device was a numeric keypad that only contained numbers 1–6. Four serve actors were provided with uniform sports T-shirts.

E-prime 2.0 (Psychology Software Tools, Inc. [E-Prime 2.0], 2015 Pittsburgh, PA) was used to present the stimuli and record the participants' responses. In addition, a whiteboard (70 cm × 50 cm) was used to record participants' scores in the anticipation tasks and a picture (A4 size) showed a description of the monetary reward.

Using an EPSON projector (CH-TW610) with 1080P resolution and a brightness of 3,000 lumens, video clips were projected onto a 100-in screen, creating an image size of 1.975 m width × 1.48 m height. The lower edge of the screen was 0.85 m from the ground. Participants were asked to stand 1.1 m away from the screen, such that the participant could subtend a similar visual angel as a real game.

Anxiety Induction

Referring to related studies (e.g., Cocks et al., 2016; Vater et al., 2016; Alder et al., 2018; Runswick et al., 2018; Broadbent et al., 2019), we jointly used camera shooting, error feedback, real-time feedback, score ranking, and monetary rewards to induce competitive state anxiety. Under high-state anxiety conditions, the camera recorded the entire experimental process. Participants were informed that their anticipation performance would be shown in the classroom as an instructional video (not actually shown in any occasion). Meanwhile, participants were given five random error feedbacks out of six practice trials. Just when they finished all the tasks in high-anxiety conditions, participants were given their anticipation scores by being shown on the whiteboard and were informed that experimental rewards would be given based on their score ranking.

Response Accuracy and Response Time

After each video was occluded, participants were requested to indicate where on the table they thought the ping-pong ball would land by pressing 1-6 on the keyboard (the arrangement of the number keyboard is the same as shown in **Figure 1**. **Response accuracy** was measured as the percentage of correct responses produced by the participants.

Response time was defined as the time (ms) between the point of video occlusion (the last frame of a video with yellow lines appears as shown in **Figure 2**) and the onset of pressing the number keyboard.

Procedure

The experiment was conducted in a table tennis court. When the participants arrived at the court, they were required to complete an informed consent form, a demographic questionnaire, and a trait anxiety inventory. Then, half of them participate in the low-anxiety conditions before completing the high-anxiety experiment at an interval of 2–3 days. The other half experimented in the opposite order and at the same interval. The order of high- and low-anxiety conditions conducted for participants was at random, according to a random number table with only 0 and 1.

After, the experimental procedure was explained to the participants. They first completed six practice trials and received feedback on correctness and response time. The half of the 240 test stimuli were presented in 12 blocks of 10 trials under the high- or low-anxiety conditions. Participants were given a 10-s break between each block and a 2-min break for every 6 blocks. There were 4 task conditions (right- and left-handed serves in early and late occlusion) in each anxiety condition. The presentation order of early and late occlusion tasks was random among participants, and test stimuli of two handedness conditions in one occlusion condition were also randomly presented. Each anxiety condition took no longer than 30 min to complete. The experimental procedure and formal experimental flow are shown in **Figure 2**.

Data Analysis

Statistical analyses were conducted with (JASP 0.14, Amsterdam, The Netherlands) (Love et al., 2019). A general linear model is used to analyze the data. Before conducting main analyses, an independent sample *t*-test was undertaken to eliminate trait anxiety difference between two groups. In addition, four 2 × 2 repeated measures ANOVA were performed to examine the effects of anxiety induction, with anxiety conditions and skill level as independent variables and cognitive anxiety, somatic anxiety, self-confidence, and mental effort as dependent variables, respectively. Main analyses consisted of three separate 2 × 2 × 2 [anxiety (high/low), skill level (skilled/less-skilled) and occlusion time (early/late)] repeated measures of ANOVA with response accuracy, response time, and inverse efficiency score as dependent variables. Significant interactions were calculated using *post hoc* tests with Bonferroni corrections to avoid the inflation of Type 1 error. Effect sizes were evaluated using partial eta squared values (η_p^2) and Cohen's *d*. The significant level (α) was set at 0.05.

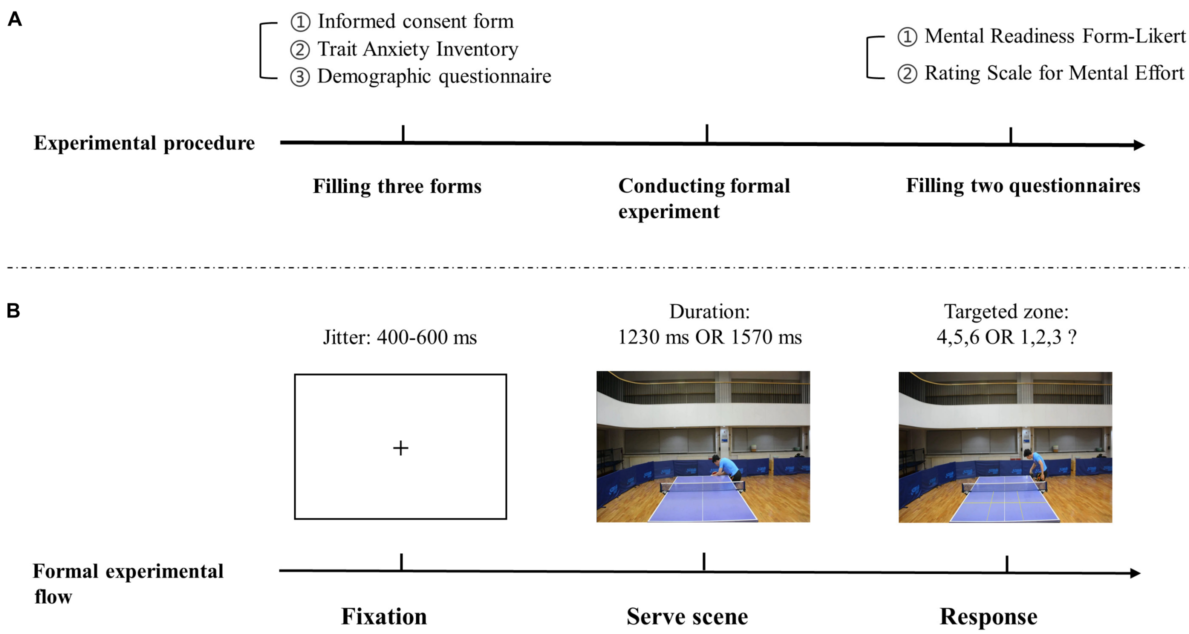

FIGURE 2 | Experimental procedure and formal experimental flow. **(A)** Shows the experimental procedure. Participants first completed three forms before the experimenter explained the experimental procedure to them. Then, participants conducted the formal experiment in low or high-anxiety conditions in one experimental time. Lastly, they filled two questionnaires. **(B)** Shows a formal experimental flow. After low or high anxiety induction procedure, the experiment started from a "+" appearing on the screen as a reminder before the anticipation video played. After the video occlusion, three yellow lines would appear on the last frame of the video to show six targeted zone. Then, participants were asked to press the appropriate key.

RESULTS

Anxiety Manipulation Check

Trait Anxiety

Independent sample *t*-test revealed a non-significant effect of trait anxiety, with the skilled group reporting no significantly different ratings (41.8 ± 6.17; i.e., *M* ± *SD*, the same hereinafter) in comparison to the less-skilled group [(38.6 ± 5.84), $t(34) = 1.64$, $p = 0.11$].

Competitive State Anxiety and Mental Effort

The descriptive statistics of scores on each subscale of MRF-L and RSMF for both groups in high- and low-anxiety conditions are shown in **Table 1**.

TABLE 1 | Mean (SD) scores on each Mental Readiness Form-Likert (MRF-L) subscale and Rating Scale for Mental Effort (RSMF) for both groups in high- and low-anxiety conditions.

Anxiety	Skill level	Cognitive anxiety	Somatic anxiety	Self-confidence	Mental effort
High	Skilled	5.2 (2.66)	4.8 (2.56)	7.0 (2.66)	89.4 (26.78)
	Less-skilled	5.9 (2.37)	5.3 (1.94)	6.7 (2.00)	93.9 (15.96)
Low	Skilled	3.3 (2.11)	3.3 (2.32)	8.1 (2.21)	75.6 (26.62)
	Less-skilled	4.5 (2.18)	4.3 (2.49)	7.4 (2.06)	84.7 (17.86)

Analysis of variances (ANOVAs) revealed significant main effects of anxiety conditions for all the dependent variables. Participants reported significantly higher cognitive anxiety (5.5 ± 2.51) during high-anxiety conditions in comparison to low anxiety [(3.9 ± 2.20), $F_{(1,34)} = 21.62$, $p < 0.001$, $\eta_p^2 = 0.39$]. Similarly, participants reported significantly higher somatic anxiety [(5.1 ± 2.25) vs. (3.8 ± 2.43), $F(1,34) = 10.12$, $p = 0.003$, $\eta_p^2 = 0.23$], greater mental effort [(91. 7 ± 21.84) vs. (80.1 ± 22.82), $F(1,34) = 26.7$, $p < 0.001$, $\eta_p^2 = 0.44$], and less confidence [(6.8 ± 2.32) vs. (7.7 ± 2.13), $F(1,34) = 7.52$, $p = 0.010$, $\eta_p^2 = 0.18$] in high-anxiety conditions compared to low-anxiety conditions. The main effect of skill level and the interaction effect between anxiety and skill level were non- significant.

Response Accuracy

There was a significant main effect of occlusion time [$F_{(1,34)} = 94.1$, $p < 0.001$, $\eta_p^2 = 0.74$]. Participants recorded higher accuracy scores in the late occlusion tasks (0.69 ± 0.11) than in the early occlusion tasks (0.54 ± 0.14). Also, a main effect of skill level was observed [$F_{(1,34)} = 14.8$, $p < 0.001$, $\eta_p^2 = 0.30$]. The skilled group (0.67 ± 0.14) was significantly more accurate than the less-skilled (0.56 ± 0.13). Moreover, a significant anxiety condition × occlusion time interaction was found [$F_{(1,34)} = 5.9$, $p = 0.021$, $\eta_p^2 = 0.15$]. All other effects were non-significant, as shown in **Table 2**.

The two-way interaction shows that there was a downward trend for anticipation accuracy [(0.55 ± 0.15) vs. (0.53 ± 0.13)]. with increasing levels of state anxiety in early occlusion tasks.

TABLE 2 | ANOVA results for response accuracy.

Statistic Effects	*F*	*df*	*p*	η_p^2
Anxiety	< 0.01	(1,34)	0.940	< 0.01
Skill level	14.8	(1,34)	< 0.001***	0.30
Occlusion time	94.1	(1,34)	< 0.001***	0.74
Anxiety × occlusion time	5.9	(1,34)	0.021*	0.15
Anxiety × skill level	0.39	(1,34)	0.538	0.01
Skill level × occlusion time	0.53	(1,34)	0.471	0.01
Anxiety × occlusion time × skill level	0.09	(1,34)	0.766	< 0.01

**p < 0.05, ***p < 0.001. η_p^2 = 0.01, small effect size; η_p^2 = 0.06, medium effect size; η_p^2 = 0.14, large effect size.*

TABLE 3 | ANOVA results for response time.

Statistic effects	*F*	*df*	*p*	η_p^2
Anxiety	21.7	(1,34)	< 0.001***	0.39
Skill level	7.5	(1,34)	0.010*	0.18
Occlusion time	118.0	(1,34)	< 0.001***	0.78
Anxiety × occlusion time	2.9	(1,34)	0.099	0.08
Anxiety × skill level	8.1	(1,34)	0.008**	0.19
Skill level × occlusion time	5.1	(1,34)	0.031*	0.13
Anxiety × occlusion time × skill level	0.1	(1,34)	0.725	< 0.01

**p < 0.05, **p < 0.01, ***p < 0.001. η_p^2 = 0.01, small effect size; η_p^2 = 0.06, medium effect size; η_p^2 = 0.14, large effect size.*

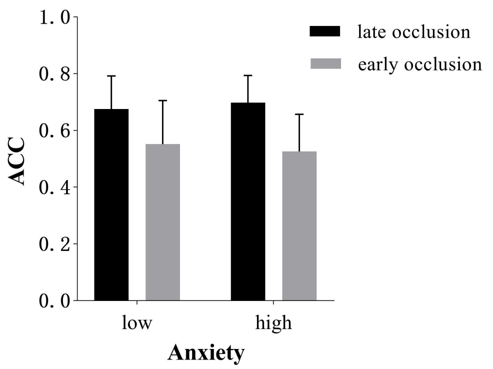

FIGURE 3 | Response accuracy (*M* ± *SD*) of different occlusion time in low and high-anxiety conditions. Error bars are *SD*s.

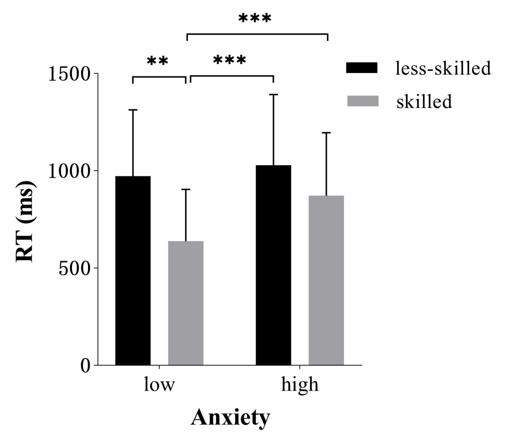

FIGURE 4 | Response time (*M* ± *SD*) for two groups in low and high-anxiety conditions. Error bars are *SD*s. **$p < 0.01$, ***$p < 0.001$.

On the contrary, in late occlusion tasks, there was an upward trend in low anxiety (0.68 ± 0.12) compared to high-anxiety conditions (0.70 ± 0.10). The two comparisons were non-significant, however, as shown in **Figure 3**.

Response Time

There was a significant effect of anxiety [$F_{(1,34)}$ = 21.7, $p < 0.001$, $\eta_p^2 = 0.39$]. Participants responded faster under low anxiety (804.5 ms ± 351.80) compared with high-anxiety conditions (950.1 ms ± 355.47). A significant main effect of occlusion time was observed, with participants responding faster in late (736.4 ms ± 284.52) than in early occlusion tasks [(1018.2 ms ± 373.68), $F_{(1,34)}$ = 118.0, $p < 0.001$, $\eta_p^2 = 0.78$]. Also, there was a significant main effect of skill level [$F_{(1,34)}$ = 7.5, $p = 0.010$, $\eta_p^2 = 0.18$] as shown in **Table 3**. The skilled group (754.7 ms ± 321.35) responded faster than the less-skilled (999.9 ms ± 356.53).

In addition, two significant interactions of anxiety × skill level [$F_{(1,34)}$ = 8.1, $p = 0.008$, $\eta_p^2 = 0.19$] and occlusion time × skill level [$F_{(1,34)}$ = 5.1, $p = 0.031$, $\eta_p^2 = 0.13$] were observed. All other effects were non-significant.

Post hoc analysis of anxiety × skill level interaction revealed that the skilled responded faster in low anxiety (637.6 ms ± 267.26) than high-anxiety conditions [(871.8 ms ± 323.73), $t = 5.3$, $p < 0.001$, $d = 0.79$]. In contrast, the less-skilled did not show significant differences in response time under high anxiety (1028.3 ms ± 363.55) compared to low-anxiety (971.5 ms ± 341.94), as shown in **Figure 4**.

Post hoc analysis of occlusion time × skill level interaction revealed that the skilled (866.4 ms ± 327.24) responded faster in early occlusion tasks than the less-skilled [(1170.0 ms ± 349.58), $t(34) = 6.1$, $p < 0.001$, $d = 0.90$]. However, the skilled did not show significant differences in late occlusion (643.0 ms ± 267.66) compared to the less-skilled group (829.7 ms ± 265. 68), as shown in **Figure 5**.

Inverse Efficiency Score

There was a significant main effect of anxiety [$F_{(1,34)}$ = 6.6, $p = 0.015$, $\eta_p^2 = 0.16$]. Participants were more efficient in low anxiety (1469.3 ± 986.68) compared with high-anxiety conditions (1,705.9 ± 959.89). A significant main effect of occlusion time was observed, with participants more efficient in late (1120.7 ± 578.12) than early occlusion tasks [(2054.5 ± 1070.95), $F_{(1,34)}$ = 74.6, $p < 0.001$, $\eta_p^2 = 0.69$]. Also, there was a significant main effect of skill level [$F_{(1,34)}$ = 16.9, $p < 0.001$, $\eta_p^2 = 0.33$], as shown in **Table 4**. The skilled group (1193.8 ± 621.87) was more efficient than the less-skilled (1981.36 ± 1105.50).

Moreover, there was a significant interaction of occlusion time × skill level [$F_{(1,34)}$ = 7.8, $p = 0.009$, $\eta_p^2 = 0.19$]. Also,

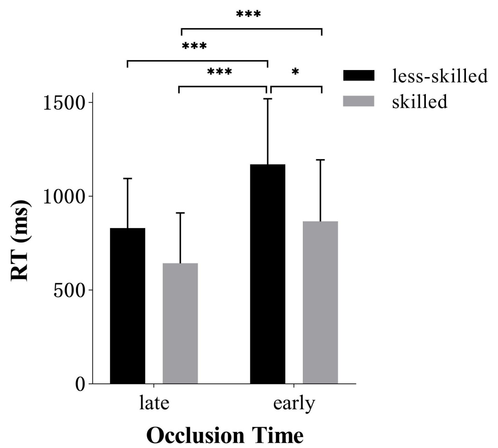

FIGURE 5 | Response time (*M* ± *SD*) for two groups in early and late anticipation. Error bars are *SD*s. $^{*}p < 0.05$, $^{***}p < 0.001$.

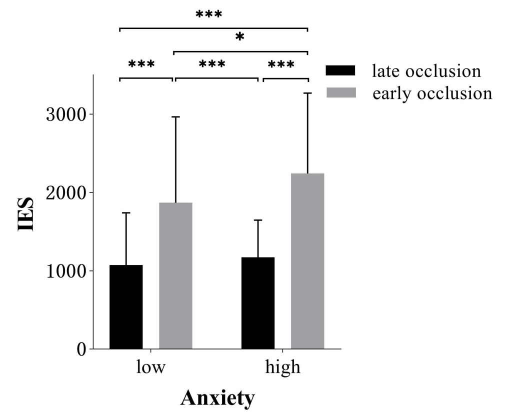

FIGURE 6 | Inverse Efficiency Score (IES; *M* ± *SD*) of different occlusion time in low and high-anxiety conditions. Error bars are *SD*s. $^{*}p < 0.05$, $^{***}p < 0.001$.

TABLE 4 | ANOVA results for inverse efficiency score.

Statistic Effects	F	df	p	η_p^2
Anxiety	6.6	(1,34)	0.015*	0.16
Skill level	16.9	(1,34)	< 0.001***	0.33
Occlusion time	74.6	(1,34)	< 0.001***	0.69
Anxiety × occlusion time	3.83	(1,34)	0.058	0.10
Anxiety × skill level	3.93	(1,34)	0.055	0.10
Skill level × occlusion time	7.8	(1,34)	0.009**	0.19
Anxiety × occlusion time × skill level	< 0.01	(1,34)	0.965	<0.001

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. $\eta_p^2 = 0.01$, small effect size; $\eta_p^2 = 0.06$, medium effect size; $\eta_p^2 = 0.14$, large effect size.

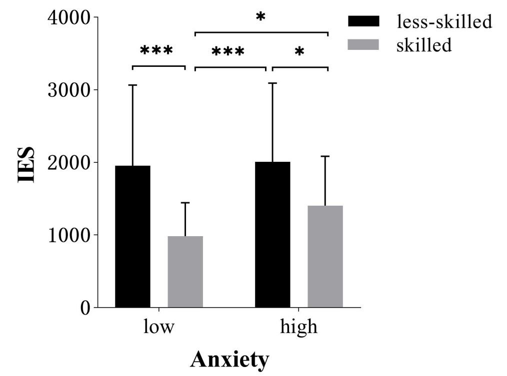

FIGURE 7 | IES (*M* ± *SD*) for two groups in low and high-anxiety conditions. Error bars are *SD*s. $^{*}p < 0.05$, $^{***}p < 0.001$.

two marginally significant interactions of anxiety × skill level [$F_{(1,34)} = 3.93$, $p = 0.055$, $\eta_p^2 = 0.10$] and anxiety × occlusion time [$F_{(1,34)} = 3.83$, $p = 0.058$, $\eta_p^2 = 0.10$] were observed. All other effects were non-significant.

Post hoc test of anxiety × skill level interaction revealed that the skilled responded more efficiently in low anxiety (984.0 ± 460.94) than high-anxiety conditions [(1403.7 ± 679.82), $t(34) = 3.2$, $p = 0.017$, $d = 0.72$]. However, there was no difference for the less-skilled group between two anxiety conditions [(2008.1 ± 1082.77) in high anxiety (1954.63 ± 1,111.97) in low anxiety], as shown in **Figure 6**.

Post hoc test of anxiety × occlusion time interaction showed that participants responded more efficiently with low anxiety (1867.4 ± 1,096.98) than high-anxiety conditions (2241.6 ± 1025.31) in early occlusion tasks [$t(34) = 3.2$, $p < 0.012$, $d = 0.35$]. However, there was no difference for participants in late occlusion between two anxiety conditions [(1170.2 ± 476.91) in high anxiety (1071.2 ± 667.47) in low anxiety], as shown in **Figure 7**.

Post hoc analysis of skill level × occlusion time interaction showed that the skilled (1,510.0 ± 655.95) responded more efficiently than the less-skilled (2599.1 ± 1112.96) in early occlusion tasks [$t(34) = 5.0$, $p < 0.001$, $d = 1.19$]. However, there was no significant difference for participants in late occlusion [(877.7 ± 364.08) for the skilled (1363.7 ± 639.16) for the less-skilled], as shown in **Figure 8**.

DISCUSSION

Attentional control theory was retested using early and late occlusion anticipation tasks of table tennis. As anxiety levels increased, we predicted a more significant decrease in processing efficiency of players' anticipation performance compared to performance effectiveness. In addition, anticipation performance was more disrupted among players in early anticipation tasks, especially in skilled players, compared to late anticipation.

Using a 2 (skill level: skilled/less-skilled) × 2 (anxiety: high/low) × 2 (Occlusion time: early/late) mixed-factor design, we examined the effects of competitive state anxiety on processing efficiency (IES, ratio of reaction time to accuracy) and performance effectiveness (response accuracy) of anticipating landing location of table tennis serves. Results show that high cognitive state anxiety reduces the processing efficiency of

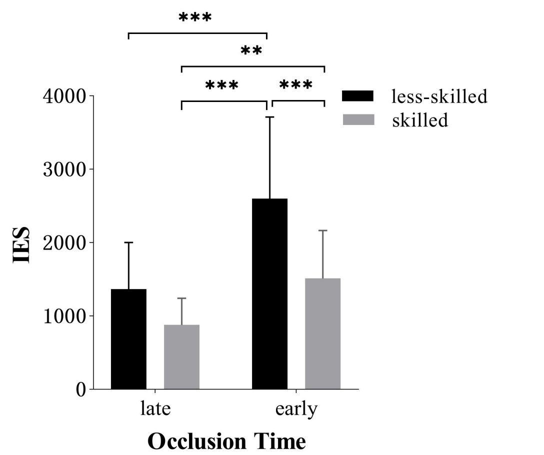

FIGURE 8 | IES (*M* ± *SD*) for two groups in early and late anticipation. Error bars are *SD*s. $^{**}p < 0.01$, $^{***}p < 0.001$.

players in anticipation tasks, but does not disrupt anticipation accuracy. In addition, high cognitive state anxiety disrupts early anticipation performance for both skilled and less-skilled players. By creating a competitive environment and evaluation threat and adding error feedback and money reward, high cognitive state anxiety was successfully induced in athletes after excluding differences of trait anxiety between skilled and less-skilled players. The cognitive anxiety of participants was more pronounced with a large effect size, consistent with PET, which suggests that high anxiety triggers worried thoughts in individuals and increases working memory load (Eysenck and Calvo, 1992). In addition, an anxiety-inducing procedure causes elevated somatic anxiety and a decrease in self-confidence. The effects of induced anxiety in the present studies were better than those of related studies (e.g., Cocks et al., 2016; Vater et al., 2016; Alder et al., 2018; Runswick et al., 2018; Broadbent et al., 2019) in terms of the effect size, most likely due to the combined use of anxiety-inducing methods from the studies mentioned above that induced higher levels of state anxiety.

High cognitive state anxiety reduced the processing efficiency of players in table tennis anticipation tasks but did not reduce their response accuracy. Specifically, the mental effort of athletes in high-anxiety conditions was significantly higher and had large effect size. At the same time, high anxiety did not lead to a significant decrease in anticipation accuracy, i.e., athletes' processing efficiency was significantly affected by high cognitive state anxiety, but performance effectiveness was not significantly affected. Hence, hypothesis (1) was supported. This is consistent with results generally confirmed by related studies (e.g., Cocks et al., 2016; Vater et al., 2016; Broadbent et al., 2019) and can be explained by PET and ACT.

Processing Efficiency Theory (PET) and ACT (Eysenck and Calvo, 1992; Eysenck et al., 2007) suggest that anxiety triggers worried thoughts in individuals and occupies working memory resources, resulting in insufficient working memory resources for the current task. On the other hand, anxiety also improves motivation and drives individuals to exert more effort, i.e., by recruiting more cognitive resources devoted to the current task to maintain performance. As a result, individuals in high anxiety would reduce their processing efficiency.

High cognitive state anxiety reduced the processing efficiency of table tennis players in anticipation tasks, which was also supported by the prolonged response time. Players in high anxiety responded more slowly than those in low anxiety, and the effect size was large. It is speculated that with the improvement of state anxiety, worried thoughts induced by cognitive anxiety occupy some working memory resources. In addition, by prolonging response time to increase the investment of cognitive resources, there was no significant decrease in anticipation accuracy at the cost of reduced processing efficiency in anticipation tasks.

High cognitive state anxiety reduced athletes' performance in early anticipation and was not moderated by skill level. This finding was a moderate effect size and partially supported the hypothesis (2). Athletes in high anxiety had significantly higher inverse efficiency scores in early anticipation than those in low anxiety. High anxiety significantly reduced athletes' performance in early anticipation tasks, while performance in late anticipation was not affected. ACT suggests that high anxiety drives individuals to attend to threat-related stimuli (Eysenck et al., 2007), but the absence of overtly threatening stimuli in the anticipation tasks precludes the influence of threat-related stimuli. The theory also suggests that high anxiety causes individuals to have worried thoughts (Eysenck and Calvo, 1992; Eysenck et al., 2007), which can be verified by the successful induction of high cognitive anxiety. These worrying thoughts occupy the limited working memory resources available for the current anticipation tasks, and the occupation of working memory resources in turn disrupts participants' ability to inhibit irrelevant stimuli (Eysenck et al., 2007). Researchers found that the attentional strategies of athletes were changed in high anxiety compared to low-anxiety conditions. Compared with low-anxiety conditions, athletes employ a strategy of more fixations and shorter fixation duration in high anxiety (Wilson et al., 2009; Runswick et al., 2018), which probably means that athletes attend to more irrelevant stimuli.

On the other hand, the occupation of working memory resources caused by high anxiety also prevented participants from flexibly shifting attention between different stimuli (Eysenck et al., 2007). According to the long-term working memory theory (Williams and Ericsson, 2005) and the conceptual model of motor anticipation (Müller and Abernethy, 2012), the internal and external stimuli in the anticipation process mainly involve the athletes' internal long-term working memory and external action and ball flight cues. That is, high anxiety destroys the inhibition of worried thoughts and shifts functions between internal working memory and external cues.

In contrast to late occlusion tasks, action and ball flight cues are more incomplete in early anticipation, and athletes are more likely to constantly shift attention between expectations of where the ball will land based on their motor experience and external environment (actual action and ball flight trajectory). This view is consistent with recent researchers' argument that the motor anticipation process is consistent with Bayesian theory, which suggests that athletes could combine ongoing expectations and dynamic environmental information to make a decision in sport under time pressure (Yarrow et al., 2009; Gredin et al., 2018). Therefore, we speculate that high anxiety disrupts the reasonable and efficient allocation of attentional resources between internal and external stimuli for athletes. Thus, performance in early anticipation, which is demanding in attentional resource allocation, is adversely affected by high anxiety. It is speculated that high anxiety disrupts the goal-directed, top-down attentional control of athletes in anticipation tasks.

In addition, the effect of sports expertise has also been verified. Compared with less-skilled players, skilled players have better anticipation performance both in high and low anxiety. Skilled players have higher anticipation accuracy (large effect size), shorter response time (large effect size), and lower inverse efficiency score (large effect size), indicating that the skilled can make better use of action posture and ball flight cues in anticipation. These results can be explained by more refined perceptual-cognitive skills of skilled players (Mann et al., 2007; Williams and Jackson, 2019). Experts have domain-specific knowledge structures that result in tasks being completed with fewer demands on working memory (Ericsson and Kintsch, 1995). These lower demands on working memory may allow the skilled to redistribute attentional resources to internal and external stimuli under high anxiety. In contrast, the unskilled players with high demands on working memory are not likely to redistribute attentional resources under high-anxiety conditions.

This study also found the interaction between skill level and state anxiety. High anxiety slowed down the response of skilled players and reduced their processing efficiency. However, the effect was not found in less-skilled players. According to the oral report of athletes, researchers found that the skilled players use more cognitive expressions than the less-skilled players in sports anticipation (Roca et al., 2013). These cognitive expressions based on memory representation help to guide athletes' visual attention. Moreover, systematic differences in visual search behaviors were also observed, with experts using fewer fixations of longer duration, including prolonged quiet eye periods, compared with non-experts or the less-skilled players (Mann et al., 2007). These studies suggest that the skilled players are in a top-down, goal-directed attentional control mode, which can also explain why the skilled perform more efficient anticipation in early occlusion tasks than the unskilled. In contrast, the less-skilled players are likely to rely more on the bottom-up, stimulus-driven attention control mode. Therefore, the skilled are more vulnerable to the adverse effects of high anxiety.

It is worth noting that the effect of high anxiety on attentional control did not differ between the two groups, which is consistent with the findings of Cocks et al. (2016) (based on response accuracy) and inconsistent with the findings of Vater et al. (2016) (based on the eye-movement measure). One possibility is that the skilled and less-skilled players use different attentional strategies (Roca et al., 2013). Particularly, the advantage of the less-skilled being less susceptible to high anxiety is likely offset by the disadvantage of insufficient perceptual-cognitive skills. In addition, the results of Runswick et al. (2018) suggest that the effect of high anxiety on motor performance was limited to the attentional level. However, high anxiety did not affect the cognitive interpretation level and motor behavior level. Therefore, the degree and extent to which high anxiety affects attentional control and multi-level motor performance remain to be further investigated.

Our results re-emphasize the importance to focus on the adverse effects of cognitive state anxiety on athletic performance. Cognitive state anxiety can influence perceptual-cognitive skills, such as anticipation, by disrupting attentional control system. Athletes should balance self-focus (internal long-term working memory) and task-focus (external kinematic cues) under high anxiety, especially for skilled athletes. They should efficiently detach attention from external kinematic cues with the help of the domain-specific knowledge structures. One way is to frequently undergo some training in high anxious or competitive environment in order for athletes to be able to endure high anxiety and have less anxious thoughts (e.g., Pusenjak et al., 2015; Alder et al., 2016). Another method is to develop executive functions, especially shifting and inhibition function (e.g., Ducrocq et al., 2016).

There are some limitations in the current study that should be acknowledged. Although the results show that high state anxiety destroys athletes' goal-oriented and top-down attentional control, these only speculate on the attention mechanism of athletes during anticipation. Further research should be conducted to investigate how high anxiety affects the attention mechanism, such as the allocation of attention to internal and external stimuli and the change of attentional priority, to broaden and deepen ACT.

In addition, although state anxiety was successfully increased with a combination of manipulations (competitive environment, evaluation threat, error feedback, and monetary reward), there is still a large gap between anxiety induced in a laboratory and anxiety experienced by athletes in a real game. In the future, VR and other technologies can be used to improve the ecological validity of anxiety-induced procedure. Then, researchers should think how to implant the paradigm to a real match. In addition, with the help of video, athletes may possibly evaluate the level of anxiety in a retrospective paradigm for researchers to examine the relationship between anxiety and athletic performance. Moreover, the inclusion of beginners may broaden our understanding on the effect of anxiety on different stages of motor learning and control.

Despite the group-based experimental pattern, the individual zones of optimal functioning (IZOF) model in a sport-specific framework provides us with an individual-based pattern to examine the relationship between emotional experiences and athletic performance (Ruiz et al., 2017). This kind of person-centered design gets rid of the single perspective of intensity of anxiety and emphasize individual differences, such as personal motivation (Ruiz et al., 2017) and personal sport identity

(Masten et al., 2006), which would inspire more evidence-based practice that may be especially beneficial for elite athletes.

CONCLUSION

In conclusion, using a temporal occlusion paradigm to test ACT in a dynamic anticipation process, we find that high cognitive state anxiety disrupts the goal-directed, top-down attentional control of athletes and reduces their processing efficiency and anticipation performance. The results have implications for the adaptation of attentional strategies in sports competition and daily anxiolytic training.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Beijing Sport University. The patients/participants provided their written informed consent to participate in this study. The individual(s) provided their written informed consent for the publication of any identifiable images or data presented in this article.

AUTHOR CONTRIBUTIONS

PR: conceptualization, methodology, software, formal analysis, and writing—original draft. TS: investigation, methodology, software, resources, and writing—original draft. LC: supervision, project administration, funding acquisition, and writing—review and editing. XW: visualization and writing—review and editing. XM: data curation and writing—review and editing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.823989/full#supplementary-material

Supplementary Table 1 | The prime data of the anticipation performance and the scale scores.

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A Binary-Entropy Analysis of the Relationship Between Scoring Structure and Match Outcome in Badminton

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This study explores the relationship between the scoring structure and the win or loss of a badminton match, while providing quantitative analytic data using binary entropy to determine the uncertainty of said win or loss. Scoring structure data were collected from the official match records of the top 16 events of the World Badminton Championships from 2006 to 2020 (a total of 10 editions) as collection objects (745 matches and 1,734 sets in all) and were analyzed by means of notational analysis. Our entropy analysis showed that the main factor affecting the certainty of win or loss in men's singles, men's doubles and mixed doubles comes from the number of leading points, and in women's singles and women's doubles from whether the current point is closer to the match point. Our binary-entropy analysis based on scoring structure showed that, to maintain high uncertainty so that players stay competitive, the scoring points of two sides should differ in less than 5; in addition, the decisive factors for victory strongly depend on gender, also justifying research results of previous studies.

Keywords: notational analysis, data analysis, win rate, racket sports, elite player

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INTRODUCTION

Using data analyses of sports competition information, important indicators in athletes' competition performance can be objectively evaluated, and such data can serve as an important reference for movement analysis, evaluation of techniques and tactics, and decision-making of future training plans and pre-match drawing-up of tactics (Hong and Tong, 2000; Hughes and Franks, 2004; Dieu et al., 2020). Moreover, by analyzing and comparing the competition data of athletes with other athletes, athletes can be evaluated, talents selected, and professional knowledge in the field of sports competition effectively constructed, which has an important contribution to improving the performance of athletes and the accumulation of sports science knowledge (McGarry et al., 2002).

New badminton competition rules were introduced in 2006, in which the original 15-points system was changed to the 21-points system, not only significantly impacting athletes' careers, training, and tactics planning, but also reducing the usability and reference value of the competition information and scientific research results analyzed in connection with the old badminton competition system. Therefore, many studies have recently been conducted on match time structure, strokes, footwork, and movement of the new badminton competition system (21-points system) (Laffaye et al., 2015; Abdullahi and Coetzee, 2017; Abián-Vicén et al., 2018; Gómez et al., 2019, 2020; Valldecabres et al., 2020), as well as physiological and psychological characteristic performances (Alcock and Cable, 2009; Phomsoupha and Laffaye, 2015), in order to reconstruct the competition information and data analysis results of the new badminton system.

Nevertheless, different scoring states, in particular, the current score and points being ahead/behind the opponent's, are indisputably essential to players' strategies for winning a match, as well as the excitement of the game. Notably, the relationship between players' scoring coordination and point outcome entropy using the temporal-related variables was investigated in Gómez et al. (2021); also, match outcome prediction using Naive Bayes and Feature Weighting technique has been addressed in Sharma et al. (2021). However, the study of badminton from the perspective of scoring status has not yet been seen in the literature.

The extent to which people get excited about sports is closely related to the uncertainty of who the winner will be. Therefore, probability theory and statistics offer a framework for scientific quantitative studies of sports. In fact, various probabilistic models along with numerical search methods have been developed to investigate the scoring issues of such racket sports as tennis, table tennis, squash, and badminton (Clarke and Norman, 1979; Riddle, 1988; Stewart, 1991; Barnett and Clarke, 2002; Seve and Poizat, 2005; Percy, 2009). For badminton specifically, Percy (2009) utilized tools from combinatorics and probability theory to analyze and compare the likelihood of winning a game in both the old and new game rules. In particular, using a simple conditional probability model and assuming that each team has a constant probability of winning any rally against the other and that the outcomes of all rallies are independent, the authors derived for both sets of rules the corresponding probabilities of winning for all types of matches (men's single/double, women's single/double, mixed double). Their results can be explored to assess the extent of excitement offered by both scoring systems, as well as for predicting the outcome of the game.

Entropy, which dates back to the seminal work of Shannon (1948) regarding the ultimate data rate for reliable communication, is undoubtedly the most commonly used measure of uncertainty in all disciplines of science and engineering research. In sports research, entropy has been adopted by Hobbs et al. (2020) to investigate how spatial uncertainty of the basketball over the field can impact "effectiveness," that is, the likelihood of scoring. By dividing the space into disjointed grids, a Bayesian hierarchical model was then used to establish an explicit connection between spatial entropy and effectiveness, thus justifying that the factor of space plays a potentially important role in studying the basketball scoring system. Entropy was also considered by Baio and Blangiardo (2010) and Taylor et al. (2020) to conduct spatial analysis of football. By dividing the football court into multiple disjointed spatial grids, entropy was used to quantify the uncertainty of plays appearing in each grid, which was then exploited to examine and study the strategies of attack/defense in accordance with the trajectories of players and the football under a probabilistic framework. In the study of badminton, entropy is utilized in Gómez et al. (2021) for dynamic analysis of scoring performance of men's single matches. To the best of our knowledge, the aforementioned works are currently the only entropy-based sports studies. Given that entropy is the core basic element in quantifying uncertainty, much remains to be investigated in the research area of sports.

In this paper, we leveraged entropy to study the impact of scoring states on the likelihood of winning a badminton game. Our study was based on the scoring records of BWF World Championships (top 16 events from 2006 to 2020). We considered five official match types, namely men's single, men's double, women's single, women's double, and mixed double. Conditioned on the event that the current score was k points and was m points ahead of the opponent, the probability of winning is first computed for each such *scoring state* (k, m). The collection of scoring states over certain k's and m's is formally referred to as the *scoring structure*, a list of evolution of scores en route to victory. Since the outcome of the game can be viewed as a (conditional) Bernoulli random variable, the uncertainty of winning associated with the scoring state (k, m) can be naturally assessed using the binary entropy of a Bernoulli random variable. Unlike existing entropy-based studies of sports (Baio and Blangiardo, 2010; Hobbs et al., 2020; Taylor et al., 2020; Galeano et al., 2021) that were developed under specific probabilistic models, our study is model-free, thus eliminating the need to identify model parameters and, more importantly, being immune to potential model uncertainty and inaccuracy. In addition, the computed binary entropy revealed several interesting insights into the match results associated with various scoring states and the potential strategies players should adopt in order to stand an improved chance for winning the match. At the same time, through the relationship between scoring states and the uncertainty of the outcome of the game, it can be used as a reference for future revision of the system.

MATERIALS AND METHODS

Sample and Materials

In this study, we took the top 16 events of the World Badminton Championships from 2006 to 2020 (a total of 10 editions) as collection objects, excluding five matches with incomplete information (such as abandonment due to injury and abstention), so we ultimately obtained information covering 745 matches and 1,734 sets, including 150 matches (341 sets) of men's singles, 149 matches (349 sets) of women's singles, 149 matches (353 sets) of men's doubles, 149 matches (343 sets) of women's doubles, and 148 matches (348 sets) of mixed doubles. The scoring structure data came from the data source of official match records provided on the official website of the BWF (tournament software), and three badminton experts were invited to develop the scoring structure record form for badminton match for this study by referencing the record form designed by Wang (2017).

Parameters

This study primarily explored the impact of the scoring structure (bilateral scoring changes in the badminton match) on the win or loss of the match, that is, the win rate situations with various different points obtained first and leading points. For example, when the score was 15:13, the score obtained first (the current score) was 15 and the leading point was 2, thereby a scoring state (15, 2), and the probability of winning the match for this situation was calculated.

After discussions with experts and scholars, under the current 21-points competition system, when the score obtained first reaches 15, the match enters the important stage plays strive to lead all the way to win the match. That we choose the scoring point 15 as the "crunch moment" is justified by our previous study using the top 16 events of World Badminton Championships, indicating that, before scoring point 15, the scoring pattern is of little relevance to the final match outcome; the impact becomes perceptible once larger than 15 (Wang, 2017). Combined with relevant research results in the past, most victory and defeat difference scores in badminton have fallen between 2 and 7 points, with the biggest lead being between 4 and 7 points (Torres-Luque et al., 2019). Accordingly, under the scoring structure of this study, we started analysis when the score obtained first reached 15 (k = 15), while the leading scores (m) ranges from 2, 3, 4, 5, and 6 points or more.

Procedure

In this study, we used notational analysis (Abdullahi and Coetzee, 2017; Gómez-Ruano et al., 2020) to collect data (focusing on the task of building up the scoring status/structure data sets) and invited four badminton experts (coaches and players) to be observers. Prior to the actual analysis, the items to be analyzed were defined and clarified; then the data of five matches were randomly selected for pre-test. After statistical analysis of the data obtained by the four observers, the inter- and intra-observer reliability analysis was assessed as very good (Kappa: > 0.91; correlation coefficient r > 0.98; ICC: > 0.95) (Hopkins, 2000).

During the formal analysis, the four analysts were arranged in separate spaces for data label, and completed analytic records were directly handed to the researcher. Among them, the first and second analysts (Team A) independently annotated 5-year data (2007, 2009, 2010, 2011, and 2013), and the third and fourth analysts (Team B) also independently annotated 5-year data (2014, 2015, 2017, 2018, and 2019). After completing data notation, Team A checked the data annotated by the two analysts of Team B, and Team B checked the data annotated by the two analysts of Team A. If any difference was found in the annotated data, it was submitted and confirmed for the correctness of the data by the four analysts together.

Why Entropy?

In general, the most intuitive description of a match by the public is usually win or loss, but in this paper, we adopted entropy for analysis. The first reason for doing so was that the win rate diagram could not provide a data display consistent with intuition, usually the higher wonderful degree expressed by larger values was consistent with the intuitive reaction in reading diagrams. However, when discussing the wonderful degree, the most wonderful match is one in which the win rates of the two opponents are about the same, that is, when the win rate is 0.5, the value 0.5 is, however, in the very middle of the win rate diagram, being rather counter-intuitive. Furthermore, when the win rate crosses 0.5 and appears on either side of the straight line (y = 0.5), it is not easy to directly judge the wonderful degree associated with a given win rate based on its distance to 0.5, namely, the absolute value | win rate-0.5|. Using the first scoring of 20 points with a 3-point lead and a 4-point lead of women's singles as an example (**Table 1**), the win rate with a 3-point lead (equal to 1) can be directly seen to be higher than that with a 4-point lead (equal to 0.933); the gap between the two (1−0.933 = 0.067), on one hand, is almost nil when seen from the win rate diagram, and on the other hand hardly indicative of the true difference between their wonderful degree.

In **Table 1**, the win rate is not less than 0.5, because if a player has a leading advantage, naturally he/she has a better chance to ultimately win. When the amount of statistical data is large enough, the probability of the win rate being less than 0.5 becomes lower; the second reason is that the difference in statistical win rate values is not big; in many cases, the difference between two points is only a fraction of zero, and such razor-thin difference might be hardly discernable from the win rate diagram (as demonstrated from **Table 1**). In the win rate diagram, the same absolute values of | win rate-0.5 | correspond to the same wonderful degree (e.g., the wonderful degree is the same at win rate = 1 and win rate = 0); this also implies that the actual usage range in the win rate diagram is only between 0 and 0.5, a bit small.

To eliminate this drawback, in this paper we employed binary entropy, rather than the probability of winning, as a measure of uncertainty (**Figure 1**). More specifically, for a random variable X with n outcomes $\{x_1, x_2, \ldots, x_n\}$, the denotation by $P(x_i)$ is the probability that the outcome x_i occurs. Then the entropy of X can be as defined by Cover and Thomas (2006).

$$H(X) = -\sum_{i=1}^{n} P(x_i)\, log_2 P(x_i) \tag{1}$$

When specialized to the binary case, i.e., X is a binary random variable with outcomes $\{x_1, x_2\}$, if we write $P(x_1) = p = 1 - P(x_2)$, $H(X)$ in (1) is the binary entropy, which as a function of p is reduced to

$$H(X) = -p log_2 p - (1-p) log_2 (1-p) \tag{2}$$

The following figure plots $H(X)$ in (2) as a function of p. We observed from the figure that $H(X)$ reached its maximum for

TABLE 1 | Entropy analysis for women's singles.

	Win rate	Entropy
m = 3 points	1	0
m = 4 points	0.933	0.353

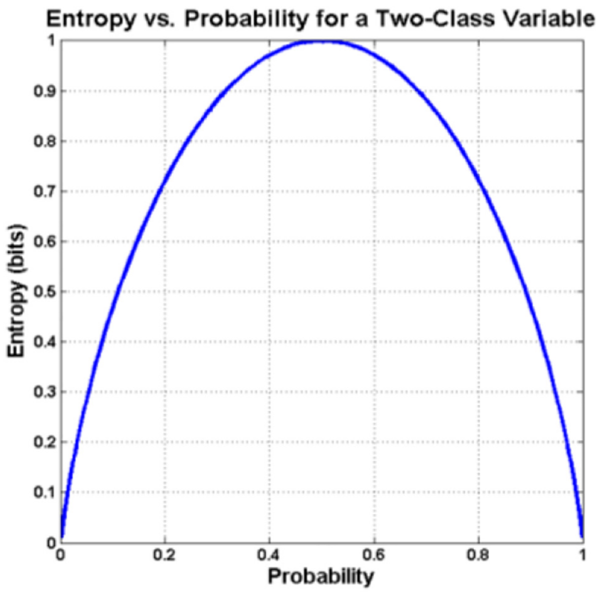

FIGURE 1 | Plot of binary entropy *H(p)* as a function of the parameter *p*.

p = 0.5 (i.e., largest uncertainty occurs when the two events are equally likely) and its minimum when p = 0 or 1 (i.e., there is no uncertainty when one is definitely sure about which outcome will take place).

Clearly, entropy expands the range from 0–0.5 in the win rate diagram to 0–1, leading to better separation of two distinct points. Using the first scoring of 20 points with a 3-point lead and a 4-point lead of women's singles as an example, the numerical difference between the two points using entropy in **Table 1** was converted into increases from 0.067 to 0.353, demonstrating a bigger gap as compared to the decrease of win rate from 1 to 0.933. As further shown in **Figures 2**, **3**, entropy can better highlight the difference between data; confirming with intuition, high entropy directly corresponds to high wonderful degree and uncertainty, free from the need for additional conversion when working on win rate.

This study examined the first scoring (k) and its current different leading point (m); first scored points were divided into 15, 16, 17, 18, 19, and 20 points, while the leading points were divided into 1–6 points. When a certain leading situation is reached, the leading player wins or loses at the end of the match, and the win rate is converted into entropy for analysis and study.

Statistical Analysis

We carried out analyses of the data collected in this study with IBM SPSS Statistics for Macintosh, Version 19.0. (IBM Corp. Armonk, New York, NY, United States) and Microsoft Excel 2010. First, the matches and sets of the five individual events competition of badminton and each match outcome (i.e., win, loss) were calculated with descriptive statistics (i.e., frequency). Then Excel was used to calculate entropy according to the binary entropy formula (2).

RESULTS

Men's Singles

Based on the actual scoring structure of badminton courts, this study used different scoring states (k, m) (wherein the first scoring was k and the leading point was m) to calculate entropy in order to determine the uncertainty of win or loss of a badminton match. Results of men's singles analysis are shown in **Table 2** and **Figure 4**. **Table 2** demonstrates that in a men's singles match, when the first scored points k are from 15 to 20 points, entropy decreases with the leading points m. We should first note that, regardless of whether the first scored point being 15 points or even close to the match point, at 20 points, for leading points within 2 points (including 2 points) entropy remains high and does not have a significant decline trend even though first scored point comes close to the match point. We therefore conclude that the uncertainty of the outcome of men's singles depends mainly on the number of leading points, but less on the first scored point.

It is noteworthy that when the leading point is greater than 3 points (inclusive) in men's singles, entropy has a significant downward trend, and the closer the first scored point is to the match point, the more entropy decreases downwards, indicating a higher certainty of the outcome of the match. In other words, when the leading point reaches 3 points (including 3 points) in men's singles, the closer the point is to match point, and the outcome is almost finalized.

Men's Doubles

The results of men's doubles analysis are shown in **Table 3** and **Figure 5**. **Table 3** demonstrates that in a men's doubles match, when the first scored points are from 15 to 20 points, entropy declines with the increase of leading points, and the leading point is within 3 points (inclusive). This result shows that, similar to the men's single case, the uncertainty of men's doubles match mainly lies in the number of leading points.

When the leading point is greater than 4 points (inclusive) in men's doubles, entropy has a significant downward trend, and the closer the first scored point is to the match point, the smaller the entropy coefficient is, which means that when the leading point is greater than 4 points (inclusive) in men's doubles, the closer the point is to the match point, and the clearer the outcome is.

Women's Singles

The results of women's singles analysis are shown in **Table 4** and **Figure 6**. **Table 4** demonstrates that in a women's singles match, entropy gradually becomes smaller when the first scored point is closer to the match point. When the first scored points are from 15 to 17 points and the leading points are within 5 points (inclusive), the decreasing trend of entropy is not obvious (the outcome is still highly uncertain), and it does not have a decreasing trend even with more leading points. Therefore, we found that, quite different to the men's single case, the uncertainty affecting the outcome of women's singles matches is whether the first scored point is closer to the match point.

It is particularly seen that only after the first scored point is 18 in women's singles does entropy gradually become smaller with

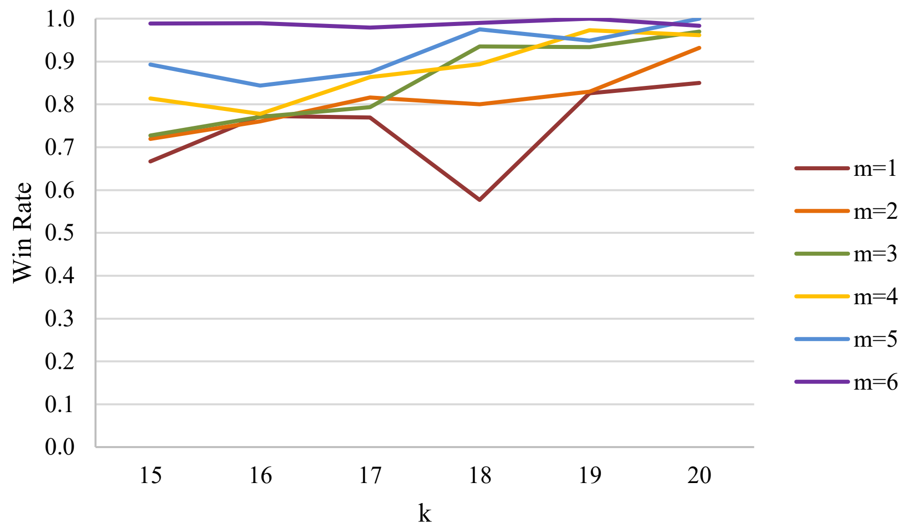

FIGURE 2 | Analysis diagram on win rate of first scoring of 15 points and leading points in women's singles.

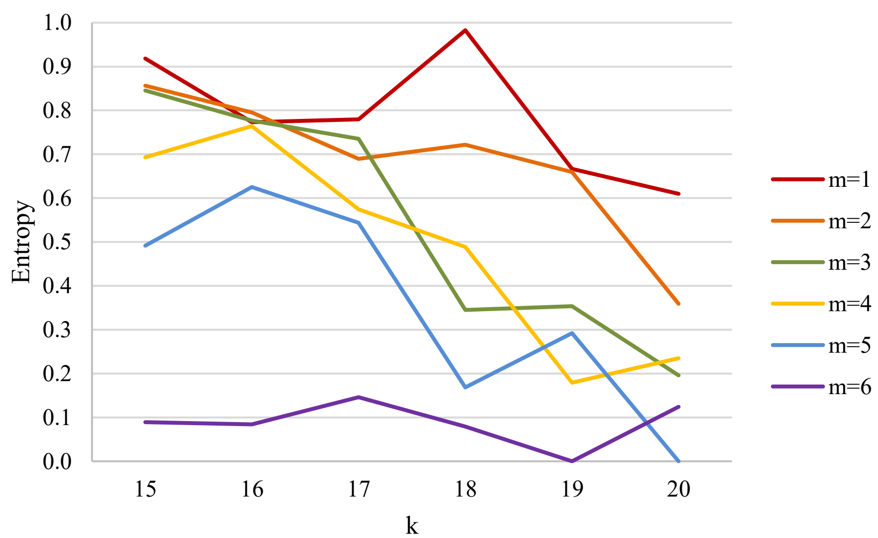

FIGURE 3 | Entropy analysis diagram of first scoring of 15 points and leading points in women's singles.

the increase of the leading point, and entropy has a significant downward trend when the leading point is greater than 3 points (inclusive), indicating that after the first scored point reaches 18 points and when the leading point is greater than 3 points (inclusive), the outcome of the match is almost finalized.

TABLE 2 | Entropy analysis for men's singles.

Men's singles	*k* = 20	*k* = 19	*k* = 18	*k* = 17	*k* = 16	*k* = 15
m = 1	0.799	0.928	0.869	0.964	1.000	0.759
m = 2	0.555	0.784	0.850	0.799	0.494	0.750
m = 3	0	0.211	0.391	0.316	0.562	0.503
m = 4	0	0.187	0	0.183	0.206	0.449
m = 5	0	0.196	0	0	0.292	0
m = 6	0	0	0.065	0.118	0.122	0.077

Women's Doubles

The results of women's doubles analysis are shown in **Table 5** and **Figure 7**. **Table 5** demonstrates that in a women's doubles match, entropy has a sharper downward trend when the first scored point is closer to the match point. When the first scored points are from 15 to 17 points, and the leading points are from 2 to 5 points, entropy does not seem to decline with more leading points; however, after the first scored point is 17 and when the leading point is 2, entropy decreases significantly, and entropy becomes smaller when the first scored point is closer to the match point. In short, after the first scored point reaches 17 points and

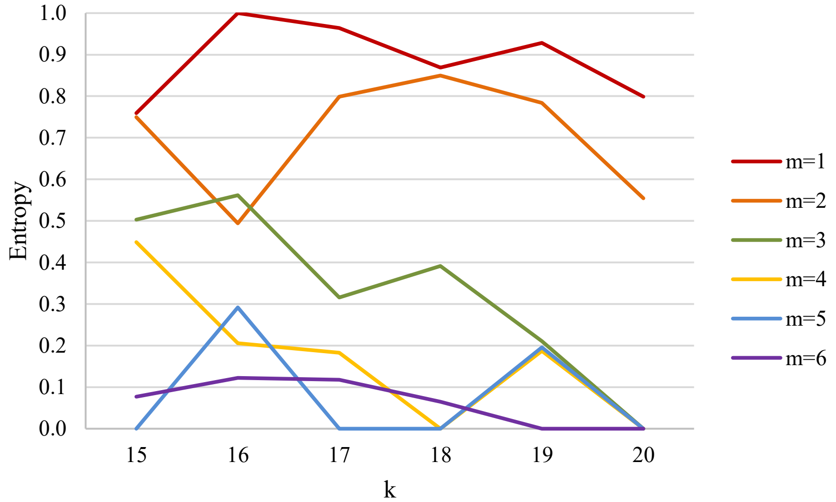

FIGURE 4 | Entropy coefficient line chart for men's singles.

when the leading point is more than 2 points, the uncertainty of the outcome of the match decreases as the score gets closer to the match point.

Of particular note, after the first scored point reaches 17 points, the uncertainty of the match has a close relationship with whether the first scored point is closer to the match point and the number of the leading point. If the uncertainty of the result of the match is to be maintained, the relationship between the first scored point and the leading point should have a negative correlation, namely the closer the first scored point is to the match point, the narrower the leading range should be.

Mixed Doubles

The results of mixed doubles analysis are shown in **Table 6** and **Figure 8**. **Table 6** demonstrates that in a mixed doubles match, when the first scored points are from 15 to 20 points, entropy declines with the increase of leading points, and when the leading point is greater than 4 (inclusive), entropy has a significant

TABLE 3 | Entropy coefficient analysis for men's doubles.

Men's doubles	*k* = 20	*k* = 19	*k* = 18	*k* = 17	*k* = 16	*k* = 15
m = 1	0.977	0.831	0.583	0.925	0.961	0.973
m = 2	0.310	0.696	0.950	0.771	0.731	0.787
m = 3	0.577	0.165	0.511	0.675	0.552	0.461
m = 4	0.183	0.533	0.222	0.303	0.176	0.146
m = 5	0	0	0.169	0.281	0.426	0.384
m = 6	0	0.075	0.129	0.076	0.141	0.209

TABLE 4 | Entropy coefficient analysis for women's singles.

Women's singles	*k* = 20	*k* = 19	*k* = 18	*k* = 17	*k* = 16	*k* = 15
m = 1	0.610	0.667	0.983	0.779	0.773	0.918
m = 2	0.359	0.659	0.722	0.689	0.795	0.856
m = 3	0.196	0.353	0.345	0.736	0.777	0.845
m = 4	0.235	0.179	0.489	0.575	0.764	0.693
m = 5	0	0.292	0.169	0.544	0.625	0.491
m = 6	0.124	0	0.079	0.146	0.084	0.089

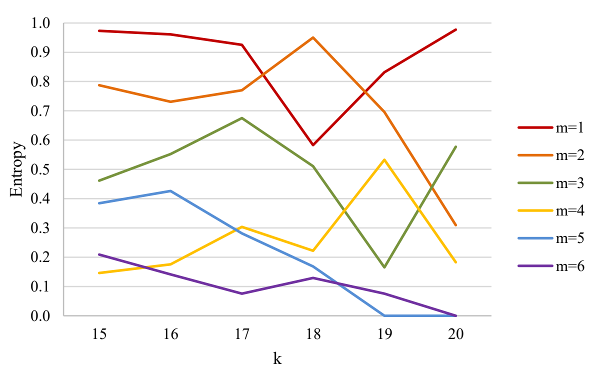

FIGURE 5 | Entropy coefficient line chart for men's doubles.

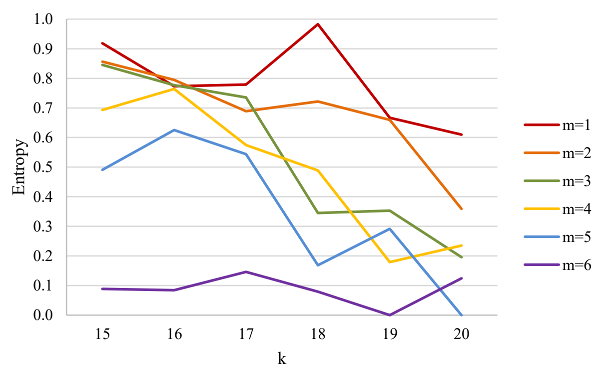

FIGURE 6 | Entropy coefficient line chart for women's singles.

TABLE 5 | Entropy coefficient analysis for women's doubles.

Women's doubles	*k* = 20	*k* = 19	*k* = 18	*k* = 17	*k* = 16	*k* = 15
m = 1	0.602	0.937	0.927	0.893	0.759	0.926
m = 2	0.353	0.581	0.485	0.469	0.700	0.667
m = 3	0.337	0.513	0.624	0.641	0.811	0.624
m = 4	0.176	0.297	0.494	0.562	0.494	0.771
m = 5	0	0	0.235	0.439	0.353	0.592
m = 6	0	0	0	0	0.136	0.194

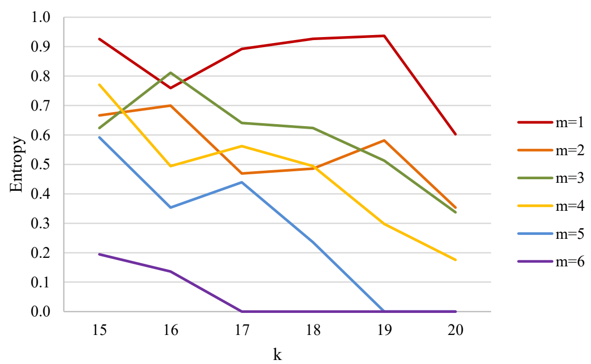

FIGURE 7 | Entropy coefficient line chart for women's doubles.

TABLE 6 | Entropy coefficient analysis for mixed doubles.

Mixed doubles	*k* = 20	*k* = 19	*k* = 18	*k* = 17	*k* = 16	*k* = 15
m = 1	0.878	0.850	0.837	0.990	0.960	0.983
m = 2	0.679	0.700	0.811	0.821	0.868	0.759
m = 3	0.362	0.629	0.729	0.552	0.592	0.672
m = 4	0.323	0.176	0	0.310	0.327	0.584
m = 5	0.156	0.176	0.149	0.276	0.337	0.156
m = 6	0	0	0	0.073	0.083	0.087

downward trend. This indicates that in the mixed doubles match, when the leading point reaches 4 points (inclusive), the certainty of the outcome of the match is higher. Furthermore, when the leading point is within 3 points (inclusive), regardless of whether the first scored point is close to the match point, entropy does not change much, indicating that the uncertainty of the match is high. Therefore, the uncertainty that affects the outcome of mixed doubles matches comes from the score of leading the opponent.

Only when the leading point reaches 4 and 6 points can it show that the first scored point is closer to the match point and that entropy is smaller, further indicating a higher degree of certainty in the outcome of the match.

Analytic Comparison on the Relationship Between the Leading Points in Five Singles and Entropy

Figure 9 is a line chart of different leading points in five match types in badminton and entropy coefficient. It is noteworthy from the figure that in women's events, when the leading points are from 2 to 4 points, the slopes of women's singles and women's

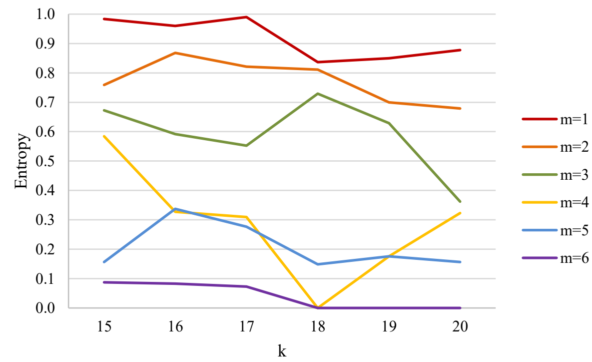

FIGURE 8 | Entropy coefficient line chart for mixed doubles.

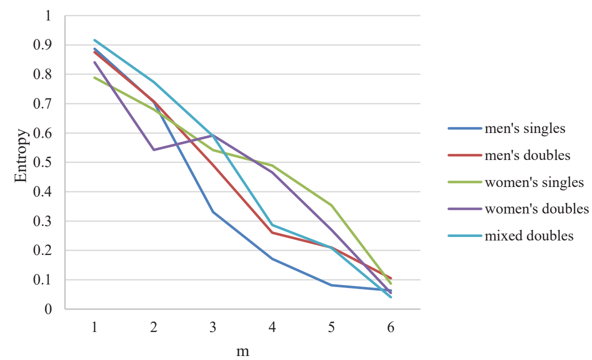

FIGURE 9 | Line chart of different leading points and entropy coefficient.

doubles are −0.095 and −0.012, respectively, while in men's events, the slopes of men's singles and men's doubles are −0.267 and −0.223, respectively, and that of mixed doubles is −0.243, indicating that in comparison with women's events (women's singles and women's doubles), the certainty of the outcome in men's events and mixed doubles is affected more by the difference in leading points.

DISCUSSION

To the best of our knowledge, this study is the first to discuss the winning and losing relationship of the five singles in badminton matches from the perspective of scoring structure. Mathematical quantification (using entropy) was adopted for computational analysis to determine the uncertainty of the win or loss of a badminton match. The research results demonstrated the following:

1. In the scoring system of the new badminton competition system, if the high uncertainty of a match is to be maintained, the relationship between the first scored point and the leading point should have a negative correlation, namely the closer the first scored point is to the match point, the narrower the leading range should be. This result is quite consistent with intuition.

2. In men's singles, men's doubles, and mixed doubles, whether the first scored point is close to match point or not, the more the leading point is, the lower the entropy coefficient is, indicating that a greater leading point dominates the uncertainty of the match's outcome.
3. The situations of women's singles and women's doubles are just the opposite; as long as the first scored point is closer to the match point, regardless of the score difference between each other, the entropy coefficient is relatively low, indicating that the closer it is to match point, the win or loss of the match is roughly determined.

The aforementioned findings of this study are discussed as follows. First of all, we used entropy in this study to pin down the relationship between different first scored points, leading points, and outcome in the scoring system of the new badminton competition system. We found that the closer the first scored point is to the match point or the more the leading point is, the lower the uncertainty of the match is. This means that in badminton matches, when the score is ahead of the opponent, one should strike while the iron is hot to expand the lead, whereas when the opponent is in the lead, one should narrow the gap to maintain competitiveness in the match (Percy, 2009; Wang, 2017). In terms of entropy, this study puts forward quantitative data to provide more specific advice, namely in all the five match types, when the leading point is 1 point, the uncertainty of the outcome of the match is highest, but when the leading point reaches more than 5 points, the outcome of the match is nearly determined. Therefore, to maintain competitiveness in the match, one should strive to maintain a 5-point gap with the opponent. This result echoes the research of Percy (2009), and, more importantly, it confirms that entropy is an effective measure for characterizing the relationship between victory and defeat in a sports competition system, thus providing an important reference for objective and scientific training and competition system planning.

Secondly, important findings of this study include that in men's singles, men's doubles, and mixed doubles, the main factor affecting the certainty of victory or defeat comes from the number of leading points, while in women's singles and women's doubles, whether the first scored point is closer to the match point is most influential. In particular, in men's singles and mixed doubles, when the leading points are more than 3 points (inclusive), and in men's doubles when the leading points are more than 4 points (inclusive), the outcome of the match is almost finalized. Meanwhile, in women's singles, after the first scored points reach 18 points and in women's doubles after the first scored points reach 17 points, the certainty of the outcome of the match is greater. In other words, in women's singles and women's doubles, even if the lead is as many as four points or even five points, as long as the first scored points at that time are not more than 17 points, the one lagging behind still has a chance of winning.

We also found in this study that in men's singles, men's doubles, and mixed doubles, the certainty affecting the outcome of the match comes from the number of the leading point, while in women's singles and women's doubles, the first scored point being closer to the match point has a greater influence. This result echoes previous research results in that different match characteristics will show in the five singles events of badminton, among which the main influencing factors are the different genders of the players and the number of the participants (Abián-Vicén et al., 2013, 2018; Gawin et al., 2015; Valldecabres et al., 2017; Gómez et al., 2019; Torres-Luque et al., 2019). Previous studies have confirmed that male players have higher physiological indicators (such as physical ability and strength) than female players, so male players have higher explosive power and smash frequency and show higher sports intensity performance, of which the proportion of the direct scoring through smash is 29.1% (Abián-Vicén et al., 2013; Gómez et al., 2019; Torres-Luque et al., 2019). Therefore, in men's events, when the leading point difference is small, male players can actively take points by way of continuous attack to narrow the gap in the score and increase the uncertainty of the match's outcome. However, the active attack method to take points easily consumes a lot of energy, and when the score gap is too big, changing the score through this way to improve the win rate of the match is not easy. Relatively speaking, because of the lack of the weapon of a finishing shot, female players often need to strike back and forth to create better timing for key points, or to wait for their opponents to make a mistake to take a point. Work density and percentage of time played, average rally (strokes), and average rally(ies) in women's events are all higher than those of men's events (Gawin et al., 2015; Gómez et al., 2019; Torres-Luque et al., 2019), showing that it is not easy for female players to take points through the active attack way with fewer strikes in the match, so that a large score gap is dominant factor hard to change in a short period of time. Therefore, the closer the first-scored point of women's events is to the match point, the higher the certainty of the outcome of the match is.

Through further exploration, we found in this study that the outcome of the match in men's singles is almost determined when the leading point is more than 3 points (inclusive), but the outcome of the match in men's doubles is clear only when the lead is more than 4 points, indicating that the uncertainty of the outcome of the match in men's doubles is higher than that in men's singles. This result is consistent with previous related research indicating that singles and doubles are mainly affected by the differences in the match court and the number of players, resulting in considerable differences in play and tactics. Men's singles stress efficient movement about the court and varied shot combinations (clear, drop, smash, lift, or net shot), while men's doubles focus more on flat shots and attacks, emphasizing faster and more attacks, so that average rally (strokes) and average rally (ies) in men's doubles are both lower than those in men's singles (Alcock and Cable, 2009; Gawin et al., 2015; Torres-Luque et al., 2019). Therefore, in men's doubles, with its emphasis on fast attacks and fast play, the score can easily change (score or loss of points) in short strokes or time, resulting in higher match uncertainty.

In women's events, we found that the main factor affecting the certainty of outcome in women's singles and women's doubles is whether the lead is closer to the match point. The analysis results show that after the first scored point is 18 in women's singles and when the leading point is greater than 3 points (inclusive), the outcome of the match is almost finalized. Meanwhile, as long as the first scored point is 17 in women's doubles and the leading point is greater than 2 points (inclusive), the outcome of the match becomes clear. This finding shows that the uncertainty of the outcome of women's singles is higher than that of women's doubles; interestingly, this result is the opposite of the men's events described above. The above relevant studies have demonstrated that the main scoring methods of female players are the organization of back and forth of multiple strikes and opponents' mistakes. Coupled with the tactical difference between singles and doubles, forced and unforced errors are prone to occur in the process of being mobilized for movement about the court and varied shot combinations in women's singles. In women's doubles, two players' participation in the match can make a front and rear division of the play and rotation to reduce the movement distance, but they lack powerful fast attacks as in men's doubles, giving priority to taking more shots to organize attacks or defensive attack in women's doubles. That is why in five match types of badminton events, women's doubles tend to have higher total shots per match and longest strike strokes and average strike strokes (Abián-Vicén et al., 2018; Gómez et al., 2019; Torres-Luque et al., 2019).

Finally, in mixed doubles, the position mode of female in front and male in rear is a commonly adopted tactic; the female player blocks the net, and the male player attacks in the backcourt. Therefore, in mixed doubles, the male player plays an important and key role in organizing the shot route and launching strikes to take points, so that the scoring structure and competition characteristics in mixed doubles tend to be the same as in men's doubles rather than in women's doubles (Torres-Luque et al., 2019).

Practical Implications

The analysis results of this study confirm that entropy can be used effectively in the field of sports science. As a new method for exploring the uncertainty of the scoring structure change and the outcome of the match, entropy not only expands knowledge in the field of sports, but also makes practical contributions via quantitative analysis. In particular, Percy (2009) pointed out that the excitement and wonderful degree of the match lie in the uncertainty of the outcome of the match. Therefore, the uncertainty of the outcome of a match calculated through entropy to determine the rationality of the new rules can provide more objective and scientific methods, as well as a reference basis, for formulating sports rules or competition systems in the future. In practice, gender differences of players have been confirmed to produce different competition characteristics, and clarifying these differences will help the technical and tactical application and strategy arrangement in both training and matches, as well as highlight the importance of design and simulation of competition characteristics consistent with different genders (Gómez et al., 2019, 2020).

Limitations and Future Directions

Some factors may limit the scope of this study. First, although this study analyzes and discusses the scoring structure of actual matches, this study makes its exploration only via scoring structure, reasoning of the influencing of the relationship between winning and losing a match therefore being somewhat limited. Notably, reflection of the badminton evolution over years, the variation of players' performances along seasons, and any other situational variables into our research work definitely call for explicit mathematical models to pinpoint the specific factors to be considered. However, since our study is model-free, it is therefore not clear as how such mathematical models (if in existence) can be incorporated into our analysis and discussions. Despite this, we are aware of the facts that the presented scoring status/structure can be regarded as outcomes summarizing of all the related situational variables. Still, we believe such issues are worthy of our efforts once a model-based framework can be further devised, which is definitely one important future work.

Secondly, from the support of these study results and the results of previous studies (Alcock and Cable, 2009; Gawin et al., 2015; Torres-Luque et al., 2019), we inferred that the main factors influencing the uncertainty of the outcome of the five match types are the difference in the genders of the players and the number of participants, but empirical research support is still lacking. Therefore, we suggest that experimental studies be conducted to further explore this issue in order to provide empirical supporting data. Finally, in terms of future study topics, this study proves that entropy calculation and analysis can be effectively used to explore the scoring structure and the certainty of the outcome of the match. Future studies can apply entropy to the field of sports and provide a platform for further applications of this analytical approach to other aspects of sports events (e.g., table tennis, volleyball, tennis, etc.), as well as players' movement path or kick-in possession (Taylor et al., 2020) and space and time variables of the sports field, such as the entropy of badminton player's returning the shot to different positions in the back court (Galeano et al., 2021), from which important match information is obtained to help coaches or players in training and tactical planning during the preparation period and the match period to improve performance in sports matches.

CONCLUSION

This study is the first to explain the decisive factors that affect the uncertainty of the outcome of the match via analysis of the scoring structure in badminton matches. Unlike previous studies that focused on the analysis of techniques and tactics, as well as training methods, the analysis of the scoring structure in this study offers a new aspect for understanding the factors that determine the outcome of badminton matches. Through the introduction of the specific scoring structure, the significant differences in the relationship between score evolution and final outcome derived from different "genders" in the "five individual events" of badminton can be more directly reflected. It is worth mentioning that the analysis framework of the scoring structure is not limited by the type of events (singles or doubles) or gender, so more objective and comprehensive analysis and exploration can be made. The results of the analysis, through the calculation of entropy, provide easily observed and quantitative scientific data and verify that the outcome of a match is almost determined when the leading point reaches more than 5 points. The results also confirm that in the five individual events of badminton, competitive events of different genders may influence the scoring structure and the certainty of the outcome of the match (the main factor determining the outcome of the male event is the number of leading points, while in the female event, whether the first scored point is closer to the match point matters). This finding indicates that the differences in genders and physical development of the players need to be stressed in the training and tactical drafting of the badminton players, that different training plans and tactical arrangements should be developed, and in the process of actual competition, more attention should be paid to the score gap with the opponent in male events and mixed events, while in female events, after the score reaches 15 points, the score lead needs to be maintained, thus increasing the possibility of winning.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

C-CW developed the project, reviewed the literature, registered the data, and wrote the manuscript.

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The Relationships of Sleep Duration and Inconsistency With the Athletic Performance of Collegiate Soft Tennis Players

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We evaluated the relationships of daily sleep duration and inconsistency with soft tennis competitive performance among 15 healthy collegiate soft tennis players (13 male, 2 female, mean age = 19.7 ± 0.8 years, height = 170.8 ± 7.3 cm, weight = 60.3 ± 5.6 kg, soft tennis experience = 8.7 ± 2.0 years). Sleep duration and inconsistency were determined by a 50-day sleep diary, which recorded sleep and wake times of sleep. Soft tennis athletic performance was evaluated by a service and baseline stroke accuracy test and the spider run test. Mean sleep duration was 7.4 ± 1.7 h. No correlation was found between long-term mean sleep duration and athletic performance. But inconsistency in sleep duration (SD of sleep duration) was inversely correlated with service score after controlling for soft tennis experience and sex ($r = -0.56$, $p = 0.046$). There was no significant relationship between sleep inconsistency and other athletic performance. This result indicates that reducing the instability of sleep duration (i.e., sleep regular hours) in the long-term may have a positive effect on soft tennis players' service performance. Although participants' current mean sleep duration (7.4 h) was not as sufficient as the recommendation in sleep extension experiments (9–10 h), it revealed the importance for athletes to maintain regular sleep in daily life.

Keywords: sleep duration, sleep inconsistency, serve, performance, agility

INTRODUCTION

Experimental evidence for sleep extension has accumulated and demonstrated the important role of sleep duration on athletic performance (Watson, 2017). Mah et al. (2011) revealed that basketball performance is improved by prolonged sleep duration. Specifically, 11 players were asked to lie on a bed 10 h every night for 5–7 weeks to evaluate the effect on their daytime performance. Compared to baseline, participants' sprint time was 0.7 s shorter after sleep extension, and their shooting accuracy was improved: successful free throws increased 0.9 times and successful three-point field goals increased 1.4 times. The results also showed a faster timed on-court sprint following sleep extension. A more recent study that involved 12 collegiate tennis players, extending sleeping time up to 9 h for 1 week, improved the service accuracy from 36 to 42% (Schwartz and Simon, 2015).

Three additional experiments that examined sleep restriction revealed a lower service accuracy among collegiate tennis players (Reyner and Horne, 2013). Their first experiment involved 16 collegiate tennis players and compared a 5 h sleep (33% restriction) condition with a normal sleep condition. Researchers found that players' service success (total 30 times) decreased about four times in both male and female players after sleep restriction. Their second experiment involved 12 collegiate tennis players and reduced normal sleeping time by 33% (the same as in the first experiment); however, participants then ingested 80 mg of caffeine before the performance measurement. Results showed that, although players' service success (total 30 times) in the caffeine condition was better than in the restricted no caffeine condition, the success rate was still about three times lower than in the normal condition for both male and female players (Reyner and Horne, 2013). A third study conducted a randomized, counterbalanced, and crossover experiment to evaluate the effect of acute sleep restriction on sport-specific technical and athletic performance in male junior tennis players; compared to the control group, significant decreases were observed in serve accuracy and crosscourt shots after experiencing acute sleep restriction (sleep $\leq$ 5 h) the night before the test session (Vitale et al., 2021). In basketball, Filipas et al. (2021) also observed negative effects on free-throw after participants experienced sleep restriction and mental fatigue.

Clearly, laboratory studies have been demonstrating that sleep extension and restriction affects athletic performance among collegiate players. And systematic review also had determined that the sports requiring speed, tactical strategy, and technical skill were the most sensitive to sleep duration manipulations (Kirschen et al., 2020). Nevertheless, collegiate athletes have been reporting experiencing poor and insufficient sleep in reality (Mah et al., 2018). Further contributing factor presumed to affect athletic performance is sleep inconsistency, sometimes called "social jet lag." This is defined by an inconsistency in sleep schedule and/or duration (Okano et al., 2019). Professional athletes usually experience fatigue and poor sleep and when they travel to countries in different time zones to participate in international competitions, therefore, inconsistency in sleep is considered unfavorable and thought to disrupt the synchrony of circadian rhythms. Not merely one night of impaired sleep but extreme sleep loss or accumulated sleep debt may have negative consequences, and affect subsequent sleep duration/quality, and performance (Knufinke et al., 2018b; Nedelec et al., 2018; Janse Van Rensburg et al., 2021). In Japan, collegiate students join the soft tennis team of university, participate training while studying university courses, and some of them become professional athletes after graduate. To our knowledge, there is a dearth of studies evaluating sleep duration and inconsistency with the athletic performance of collegiate sports players in more naturalistic settings (Irish et al., 2015).

Therefore, the present study examined the relationship between sleep duration, inconsistency and the athletic performance of collegiate players by employing naturalistic observational methods. Clarifying these relationships informs strategies to improve athletic performance. We hypothesized that we would find a negative correlation between sleep indices and athletic performance if participants showed insufficient and large inconsistencies in their sleep.

MATERIALS AND METHODS

Participants

Twenty-seven healthy soft tennis players (23 male, 4 female, mean age = 19.9 ± 1.0 years, mean height: 170.8 ± 6.9 cm, mean weight: 61.1 ± 5.9 kg, experience = 7.5 ± 2.4 years) belonging to the Hokkaido University soft tennis team, who also had experience participating in the Hokkaido Soft Tennis Championship were recruited at the beginning. Players were requested to complete the Morningness-Eveningness Questionnaire (Horne and Ostberg, 1976) at the beginning, which identifies extreme morning or evening chronotypes (Morningness–Eveningness Questionnaire $<$ 30 or $>$ 70), and no players reported sleep problems. There were no extreme morning or evening chronotypes to exclude, but we did exclude potential participants who did not complete the performance test (n = 2) and had incomplete diaries (sleep diary $<$ 50 days, n = 10). Finally, 15 participants both finished the 50-day sleep diary and performance test were included in analyses (13 male, 2 female, mean age ben = 19.7 ± 0.8 years, height = 170.8 ± 7.3 cm, weight = 60.3 ± 5.6 kg, soft tennis experience = 8.7 ± 2.0 years). Soft tennis differs from regular tennis in that it uses soft rubber balls instead of hard yellow balls. It is played primarily in Japan, and it was introduced to Europe in 2004. Participants had the procedures fully explained to them, along with their freedom to withdraw, signed consent forms, and voluntarily participated in the experiment without pay. Moreover, personal information was strictly protected. The experimental protocol was approved by the Hokkaido University Faculty of Education Ethics Committee (No. 17-37-02) and conducted according to the ethical standards described in the Declaration of Helsinki.

Design and Procedures

Sleep Index

In the present study, participants were instructed to use a sleep diary (Yamanaka et al., 2010) to record their sleep duration for 50 days including the times they go to bed, get up, and nap. Sleep duration for 1 day was a sum of naps and night-time sleeping time (Schwartz and Simon, 2015). We used the raw data of mean sleep duration as well as intra-individual variability (i.e., standard deviation) of sleep duration in each participant. The intra-individual variability of sleep duration was used as the measure of sleep inconsistency (Okano et al., 2019).

Evaluation of Athletic Performance

Participants performed three tests: a service test, a baseline stroke test, and a spider run. Participants were instructed to eat and sleep as usual and avoid alcoholic drinks for 1 day before the performance test. To avoid the negative influence of menses, female participants were requested to record menstruation in their sleep diaries to determine a suitable day for their athletic performance test.

The performance test was conducted on the soft tennis team training courts (outdoor, clay) in Hokkaido University, test time was 8:30 a.m.-11:30 a.m. on October 21st, 2017. Participants used their soft tennis rackets and balls as usual (soft tennis ball and racket are different from tennis, but serve method and court are as same as tennis). The test protocol design consists of 10 min warming up, 40 min service test, 60 min baseline stroke test, 5 min rest, 10 min spider run test and 5 min cool down (total 130 min, confirmed by coach and captain of soft tennis team).

Service performance was tested after warming up. Participants were required not to consider their shots as "first or second serves" but to aim all their serves into the two target boxes across the net (center and side), where the area they could maximize the movement of the opponent were clearly marked with red tape (see **Figure 1**, left). Participants were asked to serve as accurately as possible 10 times (20 balls in total). All scores were recorded and calculated as follows: in the target, 2 points; out of target but still in the service area, 1 point; and out of the service area, 0 points. Linesman were set for judge.

For the baseline stroke test, participants were instructed to aim at target area (2 m × 2 m) across the net, which was clearly marked with red tape and strike a ball coming from their opposite side (**Figure 1**, middle). Participants took turns to feed balls to each other, in accurate balls, where those out of the black dotted square were invalid, the participant was fed one more ball instead. Every participant stroked 40 balls (4 conditions: forehand straight = 10, forehand cross = 10, backhand straight = 10, backhand cross = 10). Left and right-handed players both stroked balls under these conditions. Participants' baseline stroke scores were calculated as follows: in the target area, 3 points; out of the target but on the same side between baseline and service line, 2 points; out of 2-point area but in the opposite single court, 1 point; and out of the opposite single court, 0 points.

Spider run is a tennis-specific sprint test (also use in soft tennis), which was developed by the Japan Tennis Association (2005; **Figure 1**, right). It measures the on-court movement of the athlete, including speed, coordination and the ability to accelerate and brake over short distances, in five directions and in three different stances, which is used as an essential agility index of players' on-court performance (Kuroda et al., 2015, 2017; Dobos et al., 2021). Participants were requested to run from the center of the baseline to a marked point and back; then, they would repeat this until five different directions were completed. The total time taken to run to each point and return to the center mark was recorded.

Statistical Analyses

All observed values are displayed as means ± standard deviation values. The Shapiro–Wilk test was used to examine the normal distribution of all indices. All data showed a normal distribution except baseline stroke score. To examine the correlation of sleep and performance over the long term, sleep and athletic performance indices were examined after 50 days, we using Pearson's correlation to analysis data showed normal distribution and Spearman's rank correlation to analysis data showed non-normal distribution. Considering that the athletic performance test is confounded by the soft tennis experience and sex, partial correlation analyses were also performed. All statistical analyses were conducted using R Studio software version 1.3.1056, and significance was set at $p < 0.05$. Since previous studies designed to examine the association of sleep duration with tennis performance had not reported the effect size, we could not calculate the adequate sample size *a priori*. The current sample size was set based on the previous studies ($N \geq 12$; Reyner and Horne, 2013; Schwartz and Simon, 2015). Furthermore, the *post hoc* power analyses were conducted to determine statistical power using G*Power 3.1 (Faul et al., 2007, 2009). The effect size was defined as small, medium, and large when $r = 0.1$, 0.3, and 0.5, respectively (Cohen, 2013).

RESULTS

Characteristics of Sleep Duration, and Inconsistency

Characteristics of sleep duration and soft tennis athletic performance scores are summarized in **Table 1**.

The sleep diary showed varied length during the investigation period of sleep duration (7.4 ± 1.7 h) even in the same person. A typical example of the distribution of sleep duration

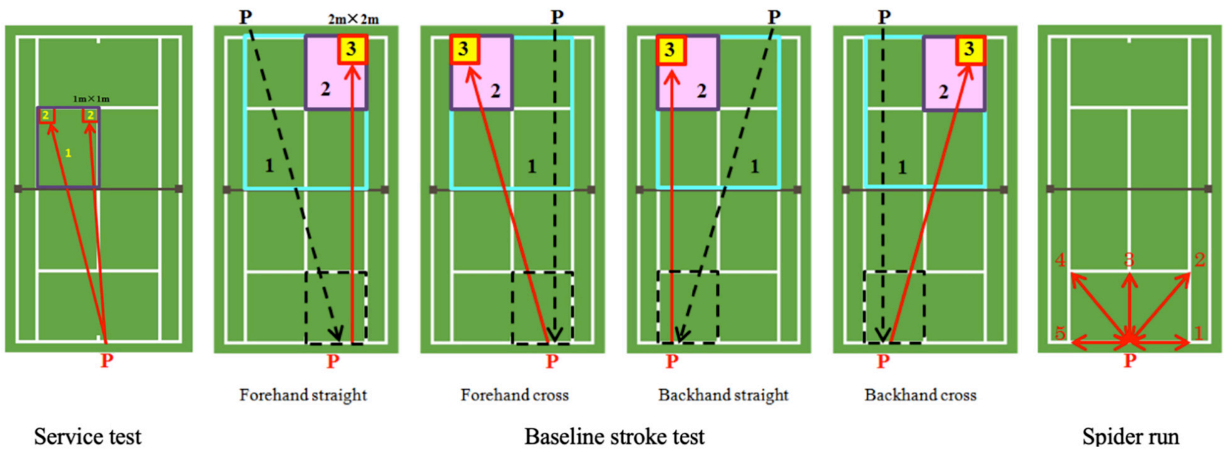

FIGURE 1 | Athletic performance test. Black P is player who strike ball to participant. Red P is participant who strike ball coming from opposite side.

TABLE 1 | Summary of participants' characteristics, sleep duration and athletic performance test score.

No.	50 days Sleep duration (h)			Service score	Baseline stroke score	Spider run time (s)
1	7.6	±	2.8	10	55	18.7
2	6.0	±	1.4	15	42	18.3
3	6.2	±	1.7	14	61	19.1
4	7.6	±	1.2	8	46	19.0
5	7.4	±	1.9	8	54	18.0
6	8.0	±	1.6	16	49	18.1
7	6.7	±	1.2	15	45	18.8
8	7.3	±	1.5	4	58	17.0
9	8.0	±	1.3	12	48	17.8
10	7.1	±	1.9	9	56	18.9
11	7.6	±	0.5	16	55	19.3
12	7.3	±	1.7	3	39	17.9
13	7.8	±	2.0	7	40	18.7
14	9.0	±	2.7	6	46	20.0
15	7.2	±	1.8	5	18	20.4
Average	7.4	±	1.7	9.9 ± 4.5	47.5 ± 10.6	18.7 ± 0.9

Mean (standard deviation).

TABLE 2 | Correlations and partial correlation (after controlled soft tennis experience and sex) of Sleep Index and athletic performance.

Sleep diary	Sleep index	Service score		Baseline stroke score		Spider run time	
		Pearson	*p*	*Spearman*	*p*	*Pearson*	*p*
50 days	Correlation						
	Average sleep duration	−0.317	0.250	−0.038	0.894	0.146	0.604
	SD of sleep duration	−0.452	0.091	0.018	0.950	0.193	0.490
	Partial correlation						
	Average sleep duration	−0.239	0.431	0.116	0.704	0.068	0.825
	SD of sleep duration	−0.562	0.046*	−0.036	0.908	0.266	0.379

$^{*}p < 0.05$.

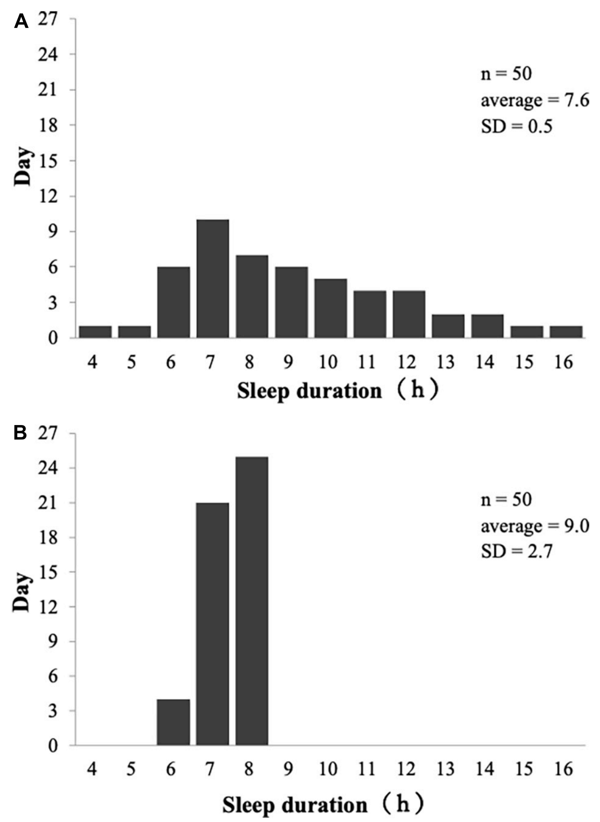

FIGURE 2 | Sleep inconsistency on typical players. **(A)** Example of sleep duration in large variations; **(B)** Example of sleep duration in small variations.

is presented in **Figures 2A,B**. The participant with the largest standard deviation of sleep duration slept for 9 h on average with a wide dispersion (mean sleep time = 9.0 h, range (shortest-longest) = 4–16 h, SD = 2.7 h; **Figure 2A**). In contrast, the participant with small standard deviation of sleep duration slept 7.6 h on average with a narrow dispersion (mean sleep time = 7.6 h, range (shortest-longest) = 6–8 h, SD = 0.5 h; **Figure 2B**).

Main Findings

The correlations between sleep index scores and athletic performance are summarized in **Table 2**.

Relationship Between Sleep Duration and Athletic Performance

There was no significant relationship between mean sleep duration and athletic performance (service score: $r = -0.32$, $p = 0.25$; baseline stroke score: $r_s = -0.04$, $p = 0.89$; Spider run time: $r = 0.15$, $p = 0.60$). These results were unchanged after controlling for tennis experience and sex.

Relationship Between Sleep Inconsistency and Athletic Performance

The inconsistency in sleep duration (SD of sleep duration) was inversely correlated with service score ($r = -0.45$, $p = 0.09$) and this correlation became slightly stronger after controlling for soft tennis experience and sex ($r = -0.56$, $p = 0.046$, $1\text{-}\beta = 0.63$, **Figure 3**). There was no significant relationship between sleep inconsistency and other athletic performance (baseline stroke score: $r_s = 0.02$, $p = 0.95$; Spider run time: $r = 0.19$, $p = 0.49$). These results were unchanged after controlling for tennis experience and sex.

DISCUSSION

Main Analyses and Implications

The purpose of this study was to evaluate the relationship between daily sleep status and athletic performance among 15 healthy collegiate soft tennis players. As we hypothesized, the current results showed a tendency that the greater sleep

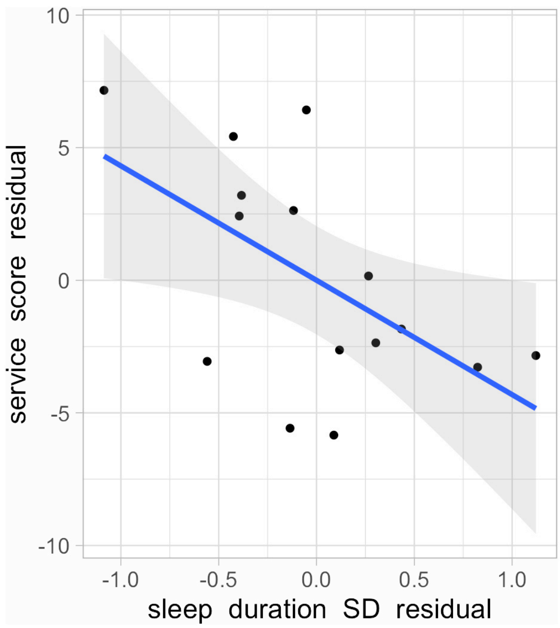

FIGURE 3 | Relationship of sleep duration SD residual and service score residual (*r* = −0.56, *p* = 0.046, 1-β = 0.63).

inconsistency showed lower service performance. Regular sleep duration appears to be a possible contributor to improving soft tennis service performance.

Sleep Duration and Athletic Performance

As compared with sleep extension experiments (Mah et al., 2011; Schwartz and Simon, 2015) which measured the effects among participants who slept 9–10 h every night, the average sleep duration in this study was 7.4 ± 1.7 h. This result is close to collegiate student-athletes at Stanford University: 7.1 ± 1.6 h on campus, 7.6 ± 1.7 h when travelling (Mah et al., 2018), and 7.5 ± 1.1 h of the Italian Tennis Federation control condition group (Vitale et al., 2021), but around 2.8 h less than in the basketball players' sleep extension experiment (Mah et al., 2011) (10.4 ± 1.1 h) and 1.2 h less than in the tennis players' sleep extension experiment (Schwartz and Simon, 2015) (8.8 ± 0.6 h). In contrast, compared to the two sleep restriction experiments of tennis players (Reyner and Horne, 2013; Vitale et al., 2021), the average sleep duration in this study was 2.6 and 2.8 h longer respectively.

Although better sleep may reduce the risk of injury and potentially enhance performance, the above-mentioned research suggests that sleep duration was not commensurate with what players optimally required. In fact, quite a number of collegiate athletes fail to obtain the recommended amount of sleep or ideal sleep habits because of the irregular academic, competition schedules, and mental stress in daily life (Watson, 2017; Mah et al., 2018). Our sleep data was naturalistic (recorded without any external manipulation), record period was long (50 days), sleep duration showed big difference even in the same participant, which may explain why we revealed no relationship between average sleep duration and soft tennis competitive performance.

Inconsistent Sleep Duration and Soft Tennis Athletic Performance

As demonstrated in two previous studies, sleep restriction did lead to a decrease in tennis serve accuracy (Reyner and Horne, 2013; Vitale et al., 2021). In the present study, it is difficult to compare serve accuracy directly because of the different shapes and sizes of the accuracy test area. However, daily sleep inconsistency may lead to a decreased tendency of tennis service accuracy. Despite this, we did not impose any restrictions on sleep duration, and no participants were extreme morning or evening chronotypes as in a previous study (Vitale et al., 2021).

Kirschen et al. (2020) conducted a systematic review on the relationship between sleep duration, sleep quality, and objective athletic performance among competitive athletes across 19 studies, representing 12 sports. They determined that the sports requiring speed, tactical strategy, and technical skill were the most sensitive to sleep duration manipulations. Moreover, another study demonstrated that "social jetlag" may affect athletes' specific brain areas—those involved in posture control, such as the thalamus and the prefrontal cortex as well as the cerebellum, resulting in poorer performance (Umemura et al., 2018).

Homeostatic sleep drive and the circadian system work together to enhance stable patterns of sleep and wakefulness, in normal sleepers; adherence to regular bedtimes and wake times promotes optimal sleep propensity and consolidation, thus, regular sleep-wake patterns may facilitate a sleep upgrading process (Dijk and Czeisler, 1995; Knufinke et al., 2018a). However, inconsistent sleep may disorganize the synchrony between physiological sleep drive, circadian rhythms, and the nocturnal sleep episode (Stepanski and Wyatt, 2003), reduce wakefulness and lead to lower performance in competition.

Knufinke et al. (2018a) analyzed 98 highest (inter-)national level elite athletes' non-manipulated sleep, psychomotor vigilance and performance data on three non-consecutive nights within a 7 day monitoring period. Their results indicated natural variation in sleep quantity impacts psychomotor vigilance to a greater extent than athletic performance and suggested one night minor sleep loss may not immediately have negative impacts, but extreme sleep loss or accumulated sleep debt, may have more severe consequences.

Furthermore, unlike a service, which a player can complete by him/herself after deliberate consideration, an effective baseline stroke tests athletes' ability to estimate the speed and direction of the coming ball, analyze spin level, and then stroke the ball back all in a short time. These variables are further influenced by different opponents, which could be one reason for our finding no relationship between sleep duration, inconsistency and baseline stroke score. Although it is clear that sleep deprivation generates negative effects such as crosscourt stroke accuracy (Vitale et al., 2021), reaction time, and cognitive function (Taheri and Arabameri, 2012), daily sleep inconsistency seems not to have the same effect.

Limitations

First, sleep data in the present study were self-reported; therefore, it is difficult to evaluate participants' sleep condition objectively. Second, due to the different shapes and sizes of the accuracy test area, it was difficult for us to directly compare the accuracy of serves (Reyner and Horne, 2013; Schwartz and Simon, 2015; Vitale et al., 2021). Speed of service and baseline stroke speed was not measured; thus, participants may have focused more on accuracy than on speed or power to improve their test score. Third, only 15 participants persisted complete 50 days sleep diary, only 2 were female and none of them were a top-level soft tennis player. In the future, it is necessary to verify with rigorous, larger samples including more females. Fourth, we found that the greater sleep inconsistency may be associated with impaired serve performance, and the effect size was large ($r = -0.56$). However, the *post hoc* power analysis showed a statistical power of 63%. Fifth, diurnal naps are regarded as an advantageous intervention to enhance the recovery process and mitigate the negative effect of partial sleep deprivation on physical and cognitive performance (Lastella et al., 2021; Souabni et al., 2021). In the present study, although nap records were found in several players' sleep diaries, they were not habitual, so it was difficult for us to make further analyses on naps. Sixth, due to the flexible training schedule and timetable changing in 50-day record time (from summer vacation to autumn semester), it was difficult to assess the weekly training time of every participant. To enhance reliability, a similar experiment with varied athletes, involving different training types, night match and top-level players are recommended. Finally, psychological, training, and living habitual factors like mental health, late-evening consumption of heavy meals, night games, common use of electric devices and amber lenses should be considered in the future (Burkhart and Phelps, 2009; Halson, 2016; Romyn et al., 2016; Knufinke et al., 2018a; Nedelec et al., 2018; Vitale et al., 2019; Bonato et al., 2020).

Conclusion

This study evaluated the relationship between long-term daily sleep duration and competitive performance among 15 healthy collegiate soft tennis players. The results revealed that inconsistency in sleep duration (SD of sleep duration) showed a tendency with service score ($r = -0.45$, $p = 0.09$), and this correlation became slightly stronger after controlling for soft tennis experience and sex ($r = -0.56$, $p = 0.046$). This indicates the key role of regular sleep for athletes' service, despite the under-recommended sleep duration of our participants. In sum, athletes who get regular sleep in the long term may perform better in service than those who get varied amounts of sleep.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Hokkaido University Faculty of Education Ethics Committee (No. 17-37-02). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TH and MM participated in the design of the study and contribute to data collection and data analysis. WW contributed to tennis competitive performance data collection. YK contributed to the tennis competitive performance test design and interpretation of the results. All authors contributed to the article and approved the submitted version.

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BRIEF RESEARCH REPORT
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Beneficial Effects of Motor Imagery and Self-Talk on Service Performance in Skilled Tennis Players

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This research aim to investigate the effects of motor imagery (MI), focused on the trajectory of the ball and the target area, and self-talk (motivational function) before the actual strike on the performance of the service in skilled tennis players. Thirty-three participants (6 females and 27 males, $M_{age} = 15.9$ years), competing in regional to national competitions, were randomly divided into three groups: Control, MI, and MI + self-talk. They performed a pre-test (25 first service), 20 acquisition sessions (physical trial, physical trial + MI and physical trial + MI + self-talk), and a post-test similar to the pre-test, in match situations. The percentage of the first service, their speed, and the efficiency scores, evaluated by experts, were use as dependent variables and indicators of performance. While there was no difference in service speed ($p > 0.05$), this study showed an improvement in the first service percentage and efficiency (all ps < 0.01) in the participants of the MI and MI + self-talk groups. Additionally, analyses revealed greater efficiency when MI was combined with self-talk compared to other conditions. It, therefore, seems advantageous for skilled tennis players to use MI and motivational self-talk before performing the first service balls.

Keywords: motor imagery, self-talk, service, tennis, performance, service speed, efficiency

INTRODUCTION

Coaches and athletes widely recognize the potential effects of using mental strategies to improve performance (Crespo et al., 2006), especially in racket sports (Cece et al., 2020). The latter authors, in their recent systematic review, revealed that Motor Imagery (MI) was the most used technique in tennis. MI can be defined as the brain's ability to recreate motor experiences in the absence of actual execution (Vasilyev et al., 2017). Many researchers have shown that MI and physical practice promotes motor learning and performance in the forehand (Guillot et al., 2015; Dana and Gozalzadeh, 2017); backhand (Hegazy et al., 2015; Turan et al., 2019), volley (Cherappurath and Elayaraja, 2017; Türk et al., 2019), service return (Robin et al., 2007) and service (Desliens et al., 2011; Fekih et al., 2020). For example, Dominique et al. (2021) recently showed that skilled tennis players who used MI intervention focused on the trajectory of the ball and the target, before serving, had higher percentage success and greater first service efficiency than the participants of the control group who only performed physical practice. Other researches also showed the beneficial effects of combining different strategies such as MI and self-talk, in mental training programs, in order to improve overall tennis performance (Mamassis and Doganis, 2004; Dohme et al., 2020). According to Latinjak et al. (2019), self-talk refers to over or covert verbalizations that the individual (e.g., tennis player) addresses himself or herself. A distinction is made between spontaneous (i.e., organic) or uncontrolled self-talk and goal-directed (i.e., strategic) self-talk (Latinjak et al., 2014; Van Raalte et al., 2016). The spontaneous self-talk statements relate to the activity (e.g., tennis match) that come to mind spontaneously and effortlessly. It generally concerns past events (e.g., "that was a bad shot") or future outcomes (e.g., "I will win"). The goal-directed self-talk is a deliberate mental technique or strategies frequently used by athletes to optimize performance utilizing its cognitive function (Boudreault et al., 2016) or regulate emotions by means of its motivational function (Fritsch et al., 2020). Cognitive or instructional self-talk aims to improve performance by means of an attentional focus directed toward technique (e.g., "bending the knees") or necessary motor actions (e.g., "getting back on the court"), whereas motivational self-talk can be employed to proactively and reactively regulate motivation, self-confidence, and emotion (e.g., "enjoy your game") or to sustain effort (e.g., "I will play well in the next set"). Several studies support the effectiveness of self-talk in sports (for a review, see Hardy, 2006), and a few researchers showed comparable effects of the two self-talk functions (e.g., Hatzigeorgiadis and Biddle, 2008; Chang et al., 2014). However, in a precision motor football task, Hardy et al. (2015) showed greater performance, in skilled athletes, who used motivational compared to cognitive self-talk functions. The authors suggested that attention directed toward the execution of a technical gesture (e.g., service in tennis) could adversely affect the performance of a mastered skill (Porter et al., 2010) as proposed by some attentional theories (e.g., Masters and Maxwell, 2008).

Previous studies showed, in tennis, the beneficial effects of using MI (e.g., de Sousa Fortes et al., 2019; Dominique et al., 2021) or self-talk (e.g., Zourbanos et al., 2015) on service performance and successful game outcome; and other studies supported the combination of these two mental techniques, among others, in mental skills training program (e.g., Dohme et al., 2020). That's why, this original study aimed to evaluate, in skilled tennis players, the influence of a combination of MI (based on the trajectory and the target to be reached) and controlled motivational self-talk, performed before the actual strike, on the performance of the first service balls in match play situations, which could be especially beneficial as it is the only shot that is not preceded by another leaving the server enough time to perform it. We hypothesized that this strategy (i.e., MI plus self-talk), should achieve greater performance than MI alone, which in turn should achieve higher performance than the absence of mental practice (i.e., control condition).

MATERIALS AND METHODS

Participants

Thirty-three skilled tennis players (6 females and 27 males, $M_{age} = 15.9 \pm 2.1$ years) volunteered to participate in the study. The participants competed in regional to national competitions (French second series) and played tennis for over 8 years ($M = 9.5 \pm 1.8$ years) at the Team Run Elite Tennis Club Dionysien. The parents of the players signed a consent form to participate in this study, received details of their required involvement, and about their right to withdraw. They were randomly drawn into 3 groups: Control, ($N = 11$, 2 females and 9 males), MI ($N = 11$, 2 females and 9 males) and MI + self-talk ($N = 11$, 2 females and 9 males). This study, approved by the local ethics committee, was carried out per the Helsinki Declaration (ACTES-3596-0422).

Material and Procedure

This study consisted of 3 phases performed in a green set tennis court during good weather. Week 1, participants performed a pre-test: 25 first service, in competitive situations (see Guillot et al., 2013 for a similar procedure). The speed (recorded using a radar Cordless MPH radar Gun Type R1000), the percentage of first services in and the efficiency (evaluated by two tennis qualified tennis coaches external to the research) of the first service served as dependent variables and indicators of performance (see Dominique et al., 2021 and Robin et al., 2021 for similar procedures). The second phase (i.e., acquisition), which consisted of 20 tennis sessions lasting 1.5 h (2 sessions per week), was carried out from week 2 to week 11. During each session, participants performed a standardized 30-min warm-up (i.e., jogging, sprint, controlled pop up rally, and 12 warm-up services) followed by 25 services under match play conditions by switching service box after each point and with 20-s rest between points. Participants in the Control group only performed physical trial and did not receive any special instructions. Before each service, those in the MI group were asked to perform MI using an external visual modality (i.e., seeing each other in third person as if they were being filmed with a camera) of a successful service by visualizing the trajectory of the ball as well as the target area in the appropriate service box (for a similar procedure see Guillot et al., 2013). Participants of the MI + self-talk group had to perform MI combined with motivational self-talk (e.g., "I/you can do it," "come on," "I feel good," and "I will play well on the next point") before serving. At the end of each MI session, participants of the two latter group had to self-assess the perceived vividness of visual images using an MI quality index consisting of a Likert scale ranging from 1 ("Unclear and faint mental representation") to 6 ("Perfectly clear and vivid mental representation"; for a similar procedure, see Dominique et al., 2021). The third phase (i.e., post-test), performed in week 12, was identical to the pre-test. All the participants were filmed (Canon HD, Legria HF G25) during the pre-and post-tests.

Data Analysis

For each test performed during pre- and post-test, the average speed (in km/h), the percentage (successful), and the efficacy scores of the first service were computed. For these dependent variables, ANOVAs were performed: 3 independent groups (Control vs. MI vs. MI + self-talk) × 2 phases (pre-test vs. post-test) with repeated measures on the second factor.

Normality was checked (Kolmogorov–Smirnov test), α was set at 0.05 for all the analyses, effect sizes (ηp2) were indicated, and post-hoc analyzes were performed using Newman–Keuls tests.

RESULTS

Imagery Ability

None of the participants of the MI and MI + self-talk groups reported having difficulty in performing MI (M_{score} = 5.1; SD = 0.9) and none of the participants of the Control group declared using MI during the 3 phases. The participants of the MI + self-talk group reported using self-talk during match circumstances.

Speed

The ANOVA did not reveal a main effect of the group, $F(2, 30) = 0.97$, $p = 0.89$, $\eta_p^2 = 0.01$, and of the phase, $F(1, 30) = 0.43$, $p = 0.39$, $\eta_p^2 = 0.01$; nor significant interaction between the group and the phase, $F(2, 30) = 0.78$, $p = 0.53$; $\eta_p^2 = 0.02$ (**Table 1**).

Percentage of Success

The ANOVA revealed a main effect of the phase, $F(1, 30) = 59.28$, $p < 0.01$, $\eta_p^2 = 0.66$, but an absence of main effect of the group, $F(2, 30) = 0.57$, $p = 0.52$, $\eta_p^2 = 0.02$. The analysis also revealed a significant interaction between the group and the phase, $F(2, 30) = 5.48$, $p < 0.01$, $\eta_p^2 = 0.28$. The post-hoc tests revealed that the participants of the MI and MI + self-talk groups increased their percentage of success of the first service from the pre- to the post-test and had greater performance than the Control group at the post-test (**Figure 1**).

Efficiency

The ANOVA revealed main effects of the phase, $F(1, 30) = 59.05$, $p < 0.01$, $\eta_p^2 = 0.66$ and of the group, $F(2, 30) = 5.45$, $p = 0.01$, $\eta_p^2 = 0.24$. In addition, the analysis revealed an interaction between the group and the phase, $F(2, 30) = 26.44$, $p < 0.01$, $\eta_p^2 = 0.47$. As shown in **Figure 2**, the post-hoc tests revealed that the participants of the MI and MI + self-talk groups increased their first service efficiency scores from the pre- to the post-test and that the participants of the MI + self-talk had greater scores than the MI and Control group participants at the post-test.

TABLE 1 | Mean (standard deviation) first service ball speed (km/h) for the control, MI and MI + self-talk groups during pre- and post-test (all ps > 0.05).

Group	Pre-test	Post-test
	Mean (SD)	Mean (SD)
Control	143.3(4.5)	146.1(5.2)
Imagery	145.7(5.7)	150.2(3.9)
MI + self-talk	146.9(6.1)	148.5(4.8)

MI, Motor imagery; SD, Standard deviation.

DISCUSSION

This study aimed to assess the effects of a MI intervention focused on the trajectory of the ball and the target zone, combined or not with motivational self-talk, on the performance of the first service in skilled tennis players. The results of the study first revealed that using MI before serving improves the percentage of success and efficiency scores of the first service, while the performance of the control group remained stable confirming our hypothesis. These results confirm those of previous researchers that have shown beneficial effects of using MI interventions whatever the level of expertise of the practitioners (Toth et al., 2020). Indeed, while beneficial effects have been observed in children (e.g., Atienza et al., 1998), teens (e.g., Dana and Gozalzadeh, 2017) or adults (Cherappurath and Elayaraja, 2017) playing at a recreational level, others studies showed a positive effect of MI in teen with a regional level (Guillot et al., 2012), in young adults at collegiate level (Daw and Burton, 1994), in youth (Dohme et al., 2020) or young adult (Robin et al., 2007) elite players and even at a professional level (Mathers, 2017). More specifically, our results confirm the beneficial effect of MI on service performance in teen (Guillot et al., 2013; Türk et al., 2019) and young adults (e.g., Fekih et al., 2020; Dominique et al., 2021) skilled (i.e., national and elite) and international (e.g., Mathers, 2017) tennis players. However, the results of the current study did not show any improvement in service speed. Although participants in the MI group increased their service ball speed by just over 4 kilometers per hour, between pre-test and post-test, this difference was not statistically significant. As recently mentioned by Dominique et al. (2021), inconsistent results are reported in the literature. While some authors have observed an absence of change in the speed of service after MI intervention in skilled players (e.g., Guillot et al., 2012; Dominique et al., 2021), others showed an improvement among young tennis players (e.g., Mamassis, 2005; Guillot et al., 2013). This difference in results could on the one hand be explained by a possible weaker margin of progress for skilled players compared to beginners. On the other hand, it is possible that the duration of the acquisition phase, which consisted of 20 sessions over 3 months, should have been increased in order to be able to significantly improve the speed of the services of the participants in the current study.

Finally, the results of this study showed that the participants who performed MI combined with motivational self-talk (i.e., MI + self-talk group), had greater service performances (i.e., efficiency scores) than the participants of the other groups (i.e., Control and MI), supporting our hypothesis. The latter results confirm those of previous studies, which have shown the beneficial effects of combining different mental strategies (e.g., MI and self-talk) on tennis performance (Mamassis and Doganis, 2004; Dohme et al., 2020). In addition, these results seem to show the beneficial benefits of the motivational function of goal-directed self-talk (Hardy et al., 2015; Zourbanos et al., 2015; Boudreault et al., 2016; Fritsch et al., 2020), especially when this technique is combined with MI (Dohme et al., 2020).

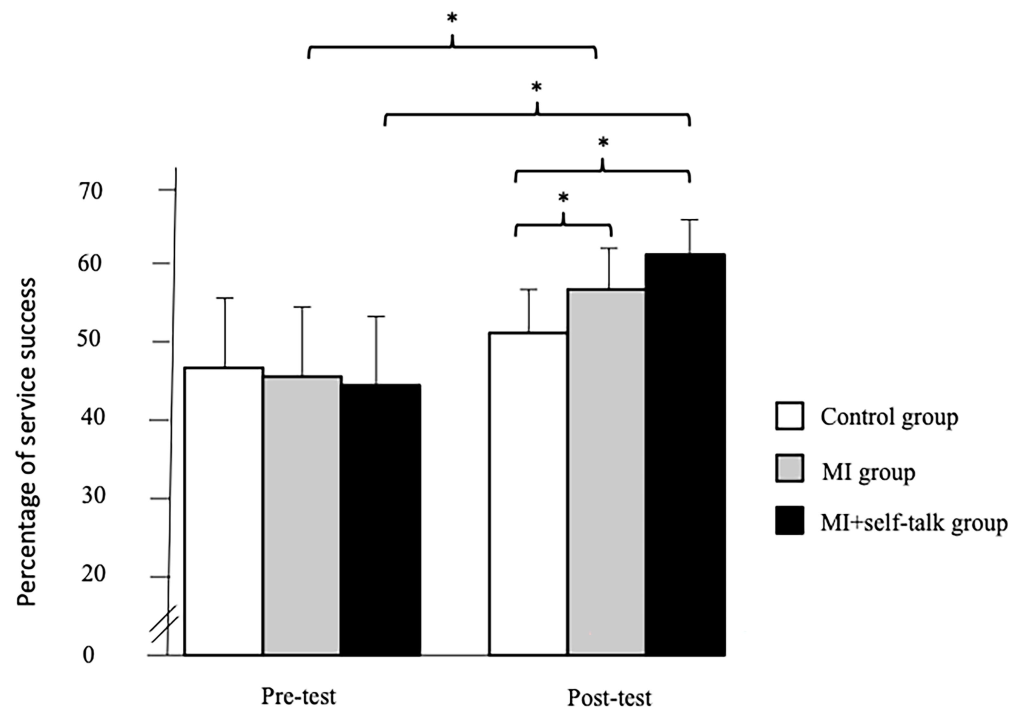

FIGURE 1 | Significant interaction between the group and the phase (*$p < 0.05$) concerning the percentage of service success. Motor imagery (MI).

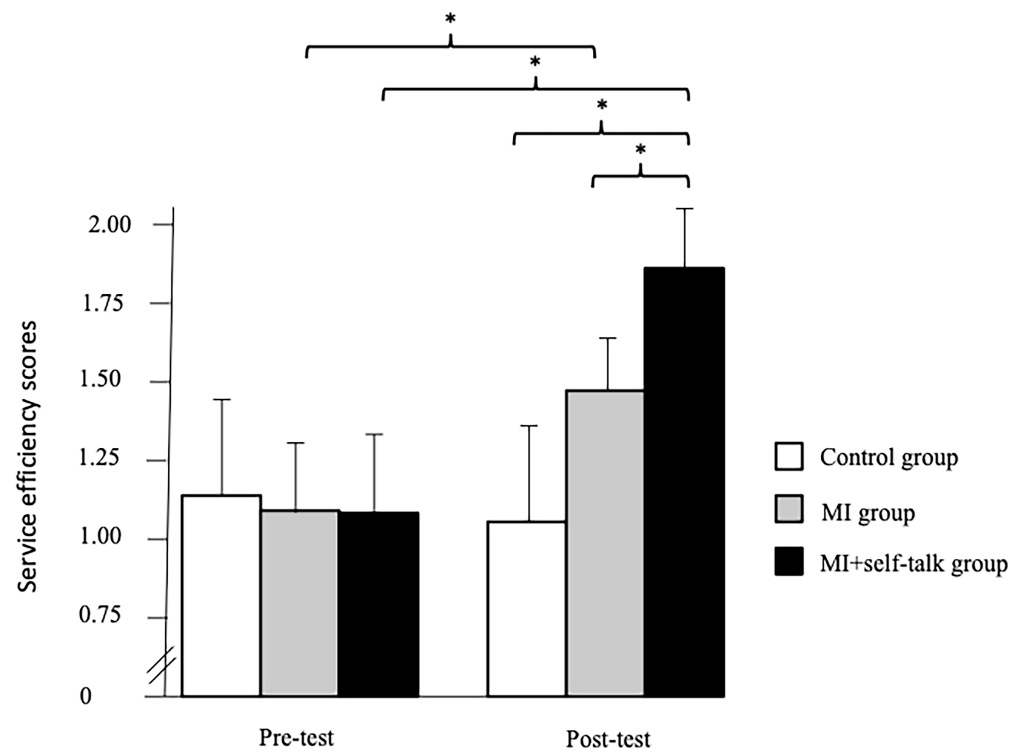

FIGURE 2 | Significant interaction between the group and the phase (*$p < 0.01$) concerning the service efficiency scores. Motor imagery (MI).

As suggested by Landin and Hebert (1999), we may postulate that the use of self-talk could increase the self-confidence of the participants of the MI + self-talk group inducing greater service efficiency and points won than the participants of the other groups. In addition, Hardy (2006) evoked that motivational self-talk can proactively and reactively regulate motivation and emotion and sustain the effort, which can give an advantage to tennis players during competition. Indeed, Van Raalte et al. (1994) showed that the self-talk (e.g., positive verbalizations) was related to successful game outcome for the servers. Finally, the fact that the MI + self-talk group did not improve more than the MI group, in the percentage of service success, could be explained by a plateau effect due to the level of expertise of the participants limiting the margin of progress. More research is needed to better explore the potential differential effect of MI + self-talk on the percentage of success and tennis technical efficiency.

LIMITATION

This study is not without limitations. Firstly, the fact that there was an absence of self-talk only could be considered as a limit to the current study. Indeed, although all participants who beneficiated from MI interventions increased their service performances, with more significant effect for the participants in the MI + self-talk group, it is possible that the use of motivational self-talk alone could be beneficial, even optimal. More research is needed to compare the performance of the participants in all these conditions. In addition, although the video of the participants of the Control and MI groups did not show the use of external observable verbalizations or negative gestures during the post-tests, it is possible that they used internal negative verbalizations that can decrease the probability of increased performance (Van Raalte et al., 2014). In addition, this study was centred on the first service, but due to its natural stress and anxiety, it could be interesting to explore the effect of MI + self-talk on second service performance. Finally, the fact that only skilled players were used in this study can also be seen as a limitation.

CONCLUSION

The current study highlights the beneficial effect of using a combination of MI and self-talk to improve the service performance in skilled players and provides additional arguments in favour of mental imagery in tennis. Although the results obtained in the current must be confirmed, it seems that the combination of motivational self-talk and MI, performed before serving, can be beneficial in tennis players. We suggest expert players to test and choose individual motivational self-talk, in training, and to combine it with MI, for later use in matches. More research is needed to understand better and explore the effect of MI and self-talk, in different tennis task performances, especially with participants of varying skill levels.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by ACTES (EA3596), Université des Antilles. 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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Prediction of Service Performance Based on Physical Strength in Elite Junior Tennis Players

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In tennis, service requires a variety of complicated movements. Given the importance of taking the initiative to obtain points in a tennis match, it is crucial to make full use of speed and spin rate of service. Generally, a service that requires a higher spin rate would slow down, and a service that has increased speed would have a decreased spin rate. For players who are disadvantaged in height, although controlling spin rate is essential, slowing down service speed should be avoided. For these players, the challenge of service is to improve the speed without decreasing the spin rate. Players must also be trained to build physical strength required for this skill. It is not uncommon to work on physical training without a racket; however, few studies have reported on the effects of cultivated physical strength on on-court tennis performance. Therefore, this study aimed to propose physical measurements that could be used as indices to improve service performance in 58 elite Japanese junior male players. To test service performance, we used TrackMan tennis radar device to assess speed, spin rate, impact height, and impact depth. To test physical strength, we measured 5- and 20-m sprint, broad jump, medicine ball throw (forward, backward). We used a significant multiple regression equation to predict the first service speed obtained from the broad jump and the Medicine ball throw (backward). Additionally, a strong correlation was obtained between the predicted and measured values. In addition to physical strength, we suggest that the depth of the impact point (taking the hitting point forward toward the net) is important for improving the first service speed. However, we were not able to identify the physical strength test items that improve service spin rate. Other item should be examined in the future to determine the physical strength associated with spin rate. This result could help connect physical training and service performance.

Keywords: tennis, service speed, physical strength, broad jump, medicine ball throw, multiple regression analysis

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INTRODUCTION

The modern game of tennis has evolved from a primarily technical sport to an explosive sport (Ulbricht et al., 2016). Tennis has increasingly become faster and more dynamic, requiring increased strength, speed, and power to achieve higher stroke and serve velocities. The service game has, therefore, become a key factor in game success (Reid and Schneiker, 2008; Gillet et al., 2009;

Kovacs and Ellenbecker, 2011). In particular, service is the only stroke in tennis that is entirely under the player's control and is the most powerful and important shot. After the toss-up, while moving the power from the lower half of the body to the upper half using the whole-body movement chain, the racket speed is increased toward impact (Kibler, 2009). This racket motion can create a mix of ball speed and spin, and a clear trade-off between these has been reported (Sakurai et al., 2007, 2013). Indeed, serving speed is decreased when spin is applied, and vice versa. A high correlation has been reported between the service speed and percentage of points won. According to Fett et al. (2017) and Kramer et al. (2017), the maximal service speed is the most appropriate on-court predictor of player performance. Service reportedly affects the overall game results for male and female players, and service speed is highly correlated with an athlete's competition level (Whiteside et al., 2013; Ulbricht et al., 2016). This is because an increasing serve speed reduces the time for the receiver to hit the return precisely, and it is possible to take advantage of the following hits and get a direct point (O'Donoghue and Brown, 2008; Vaverka and Cernosek, 2013; Whiteside and Reid, 2017).

To achieve higher speeds during service, the player must account for the net height, position of the service line, and height of the impact point (Koya et al., 2021). Brody (1987) reported that a minimum height of 2.74 m on the baseline is required to eliminate gravity and ball aerodynamics concerns. To get a higher impact point, a player needs to be anthropometrically tall or jump higher, as there is a positive correlation between the impact height and service speed (Girard et al., 2005; Vaverka and Cernosek, 2013; Bonato et al., 2015; Dossena et al., 2018; Hayes et al., 2018). Tall players have the advantage of being able to hit the service at a higher height and in a wider service area (Vaverka and Cernosek, 2013). They are able to serve with an emphasis on ball speed rather than ball spin, without worrying about the net. In addition, taller players have longer upper limbs that enables them to achieve increased speeds with a kinetic chain, using a stronger moment arm (Bahamonde, 2000). However, players with shorter height are required to compensate to impact height by improving their jumping power. Moreover, players are required to improve their spin rate to compensate for insufficient height. Spinning is therefore particularly essential for shorter athletes; however, speed is also required to some extent. As of July 2020, the average height of the top 50 ranking players in the International Tennis Federation was 188.73 cm (International Tennis Federation, 2021), whereas that of the four Japanese players in the top 100 was 176.50 cm (International Tennis Federation, 2021). Japanese players, who are generally shorter, must therefore acquire this technical skill associated with service performance to reach global elite status (Koya et al., 2021). However, it has also been reported that the world's top players can serve at a high speed while maintaining a high spin rate (Muramatsu et al., 2010, 2015). Thus, it is important for Japanese athletes to learn to improve both the spin rate and speed of their service, and it is necessary to train the physical strength systematically of these athletes in order to make this possible.

Technical skills are predominant factors in tennis (Groppel, 1992; Smekal et al., 2001); thus, players spend much time on the court for technical training with a racket; however, it is difficult to devote the same time to on-court technical and physical training without a racket. However, as the level of competition increases, many players realise the importance of physical strength and fitness (Smekal et al., 2001; Reid and Schneiker, 2008; Fernandez-Fernandez et al., 2009, 2018). Functional links observed between muscular strength in the dominant upper and lower limbs and ranking position in competitive tennis players reinforce the notion that physical characteristics have a strong influence on tennis performance and may be important determinants for successful participation in elite tennis (Girard and Millet, 2009; Fernandez-Fernandez et al., 2013; Ulbricht et al., 2016). The overhead medicine ball throw (MBT), for example, which tests upper-body power as a factor that influences service speed, has been widely used (Kramer et al., 2017; Colomar et al., 2020; Fett et al., 2020). MBT is comparable to training in tennis because this movement requires coordination of energy transfer using a kinetic chain. However, since the kinetic chain of the service in tennis is not the same as that in an MBT perfectly, studies have reported different results depending on the age and level of the players. A study that proposed that an original MBT shot put is similar to serving using a kinetic chain, targeting male professional players, reported that 86% of the service speed could be explained by the MBT result (Sánchez-Pay et al., 2021). In the case of male players, there seems to be no doubt about the relationship between MBT and service speed (Kramer et al., 2017; Colomar et al., 2020; Fett et al., 2020). However, it has not been scientifically proven that the service speed could be predicted by the distance at which the medicine ball (MB) is thrown when junior players are undergoing systematic physical training. It is important to obtain an index that connects the technical achievement of players to physical training, which may lead to further improvements in training efficiency.

Therefore, this study aimed to present physical strength items that could be used as an index for predicting service performance in tennis, which affects the competitiveness of top Japanese junior players in each age category. It is important to connect the technical achievements of players with physical training to obtain indicators, and further improvements in training efficiency are expected.

MATERIALS AND METHODS

Participants

Fifty-eight male elite tennis players (mean ± standard deviation age, 14.66 ± 1.98 years; height, 169.94 ± 7.17 cm; weight, 60.37 ± 11.13 kg) participated in this study, including top-level junior Japanese players in each generation category. Players were selected by the National Federation's coaching staff based on their competitive performance, and all players had at least 7 years of tennis training. Under our Institutional Review Board's policies for the use of human participants in research (Approval No. 199) in accordance with the Declaration of Helsinki, the investigator informed all participants about the benefits and possible risks associated with participation in the study. All participants (or guardians) signed a written informed consent document indicating their voluntary participation. Additionally, self-reported medical histories were obtained from all participants. We examined the history of injuries and determined that it had no effect on this study.

Design and Procedures

We aimed to examine whether a relationship between service performance (speed, spin, impact height, and impact depth), anthropometry (participant height and weight), and physical conditions (sprint, jump and medicine ball throw) exists. Variables were categorised as service speed, service spin, impact height, impact depth, and physical strength. Five independent variables for physical strength were converted into a principal component analysis (PCA) score, and the correlation with service performance (speed, spin, impact height and impact depth) was analysed.

Service Performance Test

The service tests were conducted using a TrackMan tennis radar device (TrackMan Inc., Vedbæk, Denmark). This device is an advanced radar that utilises the Doppler effect to capture the behaviour of an object. In this case, the full three-dimensional flight of a tennis ball (speed, spin, spin axis) was recorded. The Doppler effect is an effect in which the relative velocity between a source and an observer results in the shifting of sound or radio wave frequencies (Murata and Takahashi, 2021). If a ball in flight reflects a radio wave, the frequency of the reflected wave shifts, depending on the velocity and spin of the ball, and is calculated using the dedicated software (Martin, 2012). Doppler effect-based measurement devices are superior to other devices in terms of immediacy and user-friendliness and are often used in golf coaching and baseball (Murata and Takahashi, 2021). The accuracy of the TrackMan system is equivalent to that of conventional high-speed cameras or speed radar devices (Martin, 2012; Murakami et al., 2016; Sato et al., 2017; Murata and Takahashi, 2021). This allows for real-time measurements and analysis of parameters, such as spin rate, speed, direction, impact location (height and depth), net clearance, and landing position. In this study, the TrackMan was set at approximately 4 m behind the centre mark, which allowed the radar to visualise the service box (**Figure 1**).

Service impact was defined as the moment when the ball hit the racket, and the height and depth of the impact point at that moment were measured. The impact depth was analysed with the baseline set to 0 with the forward direction closer to the net considered as positive (+) and backward direction away from the net as negative (−) (**Figure 1**). The tests were conducted in an indoor tennis court with no returner in place. After a brief warm-up consisting of serves with increasing velocities, players were instructed to perform the first service as fast as possible and the second service with as much spin as possible. Both were directed at the T of the service box. Participants performed three sets of service tests, hitting the first and second serve from the deuce side and then hitting the third serve from the advantage side. The details of the 12 serves per player were collected. For analysis, the average of the six serves was used for each variable. Serves such as faults and nets were excluded, and only successful serves were used.

Physical Strength Test

Based on the published literature, five variables (5-m sprint, 20-m sprint, broad jump, MBT overhead backward, and MBT overhead forward) related to service performance were measured (Signorile et al., 2005; Kramer et al., 2017; Koya et al., 2018; Delgado-García et al., 2019). In addition to height and weight, the following physical condition variables were measured using the Japan Tennis Association protocols (Koya et al., 2014, 2015):

1. 5- and 20-m sprint: Players were instructed to sprint in a straight line for 20 m; the durations from the starting line to the 5- and 20-m marks were measured using a photocell (Timing Systems by Brower Timing Systems, Draper, UT, United States). In the analysis, the speed was calculated (m/s) based on time. The best values were used.
2. Broad jump: Players performed a jump as far as possible in an open stance with arm action.
3. Medicine ball throw (MBT): Players performed forward and backward (overhead) throws in an open stance with both legs fixed while throwing a 2 kg medicine ball. The best values were obtained.

Test reliability was confirmed by performing a retest (ICC; 5 m sprint:0.75, 20 m sprint:0.91, Broad jump: 0.95, MBT overhead backward: 0.93, MBT overhead forward: 0.97).

Analyses

Pearson product-moment correlations were conducted to assess the association between the service performance variables (speed, spin rate, impact height, and impact depth) and anthropometric variables (physique and physical strength) (**Table 1**). We performed PCA using the physical strength test variables and extracted the first principal component score as a comprehensive index of physical general strength (strength PCA) to comprehensively evaluate each player's physical strength. **Table 2** shows the factor loadings, which are the loads of each variable to the strength PCA (**Table 2**).

Multiple regression analysis with service performance (speed and spin rate) as the dependent variable and each physical strength test item as the independent variable was performed to determine the physical strength items improving service performance. Based on this, a regression formula was derived for predicting the first service speed. Further multiple regression analysis with strength PCA, impact height, and impact depth as independent variables was performed to determine a regression formula developing the first service speed. No multicollinearity problems were confirmed. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, NY, United States). Statistical significance was set at $p < 0.05$.

RESULTS

Table 3 shows the results of the service performance and physical strength tests. Regarding the service speed, a correlation between

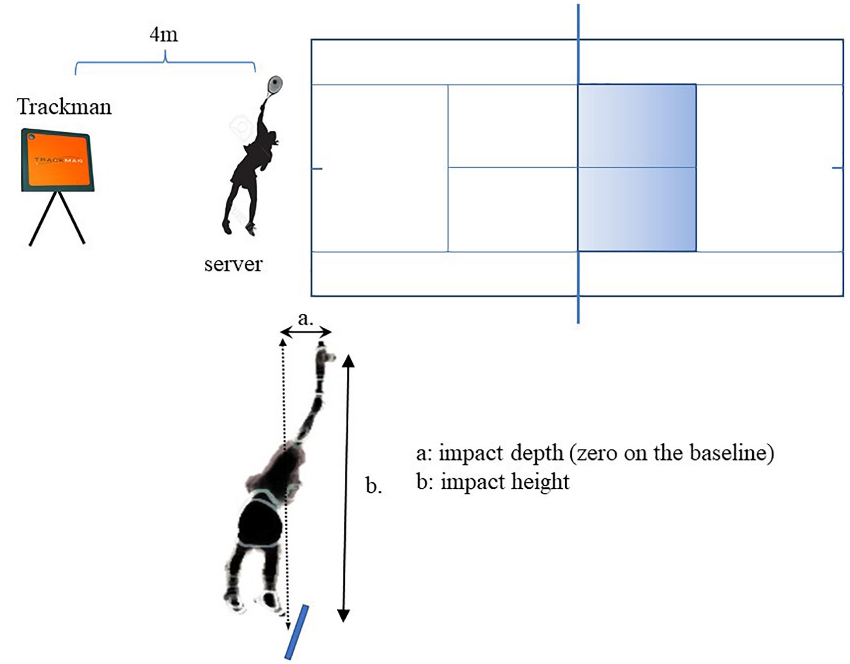

FIGURE 1 | Experimental set up for service performance test and service impact items (Koya et al., 2021).

TABLE 1 | The correlation coefficient of physique and physical strength versus service performance.

		1st service				2st service			
	Measured item	**speed (km/h)**	**spin (rpm)**	**impact H**	**impact D**	**speed (km/h)**	**spin (rpm)**	**impact H**†	**impact D**†
physique	Height (cm)	**0.53****	−0.20	**0.79****	**0.28***	**0.57****	0.13	**0.81****	0.06
	Weight(kg)	**0.67****	−0.06	**0.56****	0.26	**0.45****	**0.50****	**0.52****	0.03
Strength	5 m sprint (m/sec)	**0.47****	0.03	0.22	0.24	**0.44****	0.12	0.21	0.12
	20 m sprint (m/sec)	**0.72****	0.10	**0.37****	**0.44****	**0.64****	0.24	**0.40****	**0.29***
	Broad Jump (cm)	**0.79****	0.05	**0.47****	**0.43****	**0.64****	**0.34****	**0.52****	0.16
	MBT overhead backward (m)	**0.81****	0.04	**0.59****	**0.44****	**0.72****	**0.33***	**0.61****	0.26
	MBT overhead forward (m)	**0.74****	−0.06	**0.52****	**0.35****	**0.59****	**0.36****	**0.51****	0.14

*r, correlation coefficient; bold notation *p < 0.05, **p < 0.01, †MBT, medicine ball throw; H, height; D, depth.*

TABLE 2 | Factor loading in strength PCA.

	Factor loading in strength PCA	
Strength PCA	5 m sprint (m/sec)	0.682
	20 m sprint (m/sec)	0.908
	Broad jump (m)	0.884
	MBT† overhead backward (m)	0.887
	MBT† overhead forward (m)	0.829

†MBT, medicine ball throw.

physique and physical strength in the first and second service was found (**Table 1**). Conversely, the service spin rate in the second service was correlated with physique, jump, and MBT. However, the correlation coefficient was not as high as the speed. No correlation was found between physique and physical strength in the first service spin. Regarding the impact point in the first service, both the impact height and depth were correlated with physique and physical strength; in the second service, only the impact height was correlated with physique and physical strength, whereas the impact depth was only correlated with the 20-m sprint.

Multiple regression analysis was performed to predict the first service speed based on these physical strength test items. Multiple stepwise regression analysis was performed on 58 male tennis players, and multicollinearity was observed. As a result, a significant regression equation [$Y = 64.307 + 3.258x_1 + 30.593x_2$ (x_1: MBT backward, x_2: broad jump), $F = 72.298$, $p = 0.001$] was found using broad jump and MBT (backward) as independent variables, which could predict the first service speed. The contribution rate of this equation was 72.0% ($r = 0.851$); in other words, 72% of the first service speed could be explained by MBT (backward) and broad jump. **Figure 2** shows the estimated value based on this regression equation and the measured value of

TABLE 3 | Physique, strength test and service performance test results of players.

	Physique					Strength		
	Age (years)	Height (cm)	Weight (kg)	5 m sprint (m/sec)	20 m sprint (m/sec)	Broad jump (m)	MBT overhead backward (m)	MBT overhead forward (m)
Male players (58)	14.66 ± 1.98	169.94 ± 7.17	60.37 ± 11.13	4.47 ± 0.26	6.08 ± 0.28	2.23 ± 0.20	11.53 ± 2.36	8.25 ± 1.80

	Service							
	1st service speed (km/h)	1st service spin (rpm)	1st service impact H† (m)	1st service impact D† (m)	2nd service speed (km/h)	2nd service spin (rpm)	2nd service impact H† (m)	2nd service impact D† (m)
Male players (58)	170.22 ± 15.18	1378.89 ± 334.83	2.60 ± 0.12	0.01 ± 0.18	130.32 ± 13.46	3487.58 ± 518.22	2.56 ± 0.14	−0.26 ± 0.20

†*MBT, medicine ball throw; H, height; D, depth.*

the first service speed. A strong correlation was found between the estimated and measured values (r = 0.794, p = 0.001), and the average value of the difference between these two values was 6.38 ± 4.71 km/h.

As a comprehensive physical index from the physical strength test, strength PCA was calculated and used for analysis as an independent variable. Impact height and impact depth were set as independent variables, as indices of service skill. Multiple stepwise regression analysis was performed, and multicollinearity was found. As a result, a significant regression equation [$Y = 170.075 + 11.959x_1 + 10.735x_2$ (x_1: strength PCA, x_2: impact depth), F = 73.703, p = 0.001] was found with strength PCA and impact D as independent variables, which could also predict the first service speed. The contribution rate of this equation was 72.8% (r = 0.853); in other words, 73% of the first service speed could be explained by strength PCA and impact depth. **Figure 3** shows the estimated value based on this regression equation and the measured value of the first service speed. A strong correlation was found between the estimated and measured values (r = 0.851, $p < 0.001$), and the average value of the difference between these two values was 7.72 ± 6.04 km/h.

DISCUSSION

Physical Strength Factors Leading to Service Speed

In this study, a multiple regression formula was obtained for predicting the first service speed using broad jump and MBT (backward) values. Indeed, a strong correlation was shown between the calculated and measured values. Additionally, impact depth (taking the hitting point forward from the baseline) was found to be as important as physical strength to improve the first service speed. Compared to the broad jump and MBT (backward), a similar movement common to service is to use the flexion and extension of the hip joint to exert power. Utilising this flexion and extension of the hip joint, a leg drive is thought to increase the service speed. The tennis service motion has three distinct phases: preparation, acceleration, and follow-through (Kovacs and Ellenbecker, 2011). The acceleration phase, which starts with preparation for power loading to hitting the ball, involves physical factors; this phase marks the beginning of physical strength utilisation for service speed. When the server initiates knee flexion for power loading, a natural stretch-shortening cycle and a combination of eccentric and concentric contractions of the leg muscles help store elastic energy (Girard et al., 2005). This elastic energy can assist the leg drive (Elliott et al., 2009). Indeed, service speed is correlated with a forceful leg drive created by greater muscle forces (Bahamonde, 1997). Elite players can coordinate bilateral extension at the lower limb joints to propel their bodies off the ground during the leg drive (Bahamonde, 2000; Knudson et al., 2004; Girard et al., 2005; Reid and Schneiker, 2008). This lower limb motion contributes significantly to the force required for a tennis serve (Kibler, 2009). The pushing action, which uses a backward-to-forward sequence with higher horizontal forces, as seen in elite-level servers, may be of greatest importance in generating high-speed

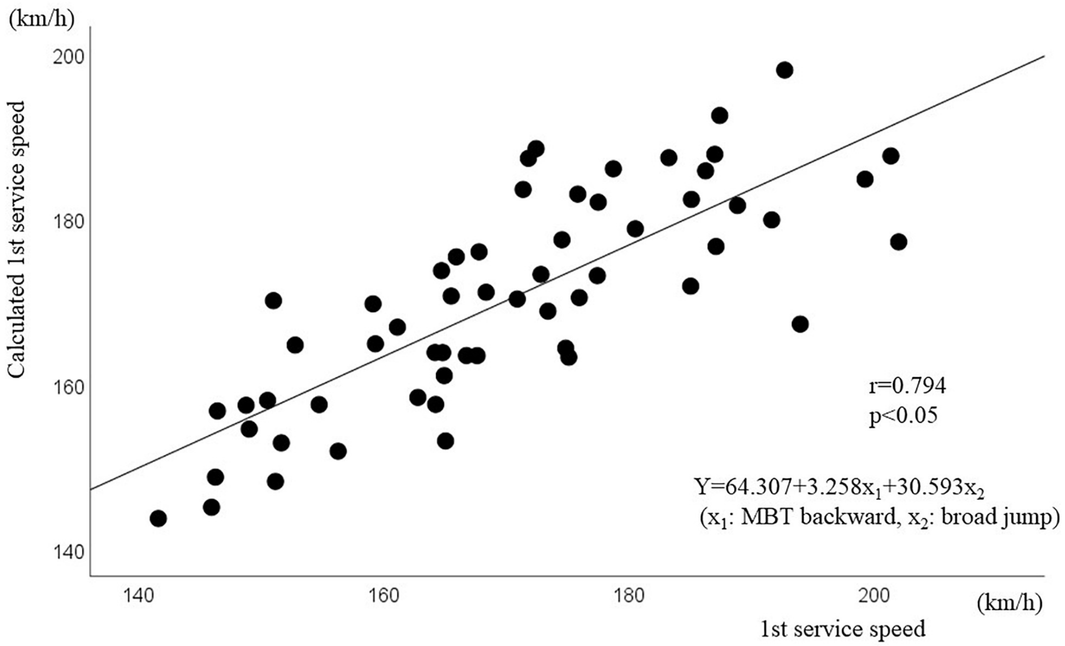

FIGURE 2 | Correlation analysis between the measured first service speed and calculated service speed Estimated formula from MBT backward and broad jump.

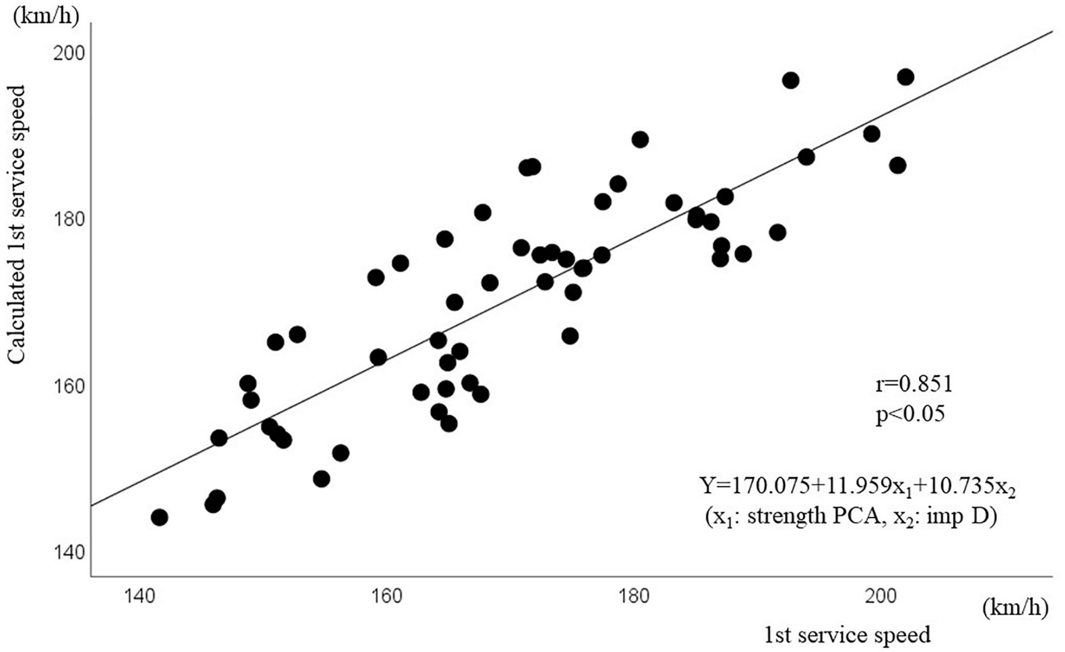

FIGURE 3 | Correlation analysis between the measured first service speed and calculated service speed Estimated formula from strength PCA and impact.

serves (Girard et al., 2005). A server that effectively uses a leg drive could have a maximum swing speed of 7.4 m/s (Elliott et al., 1986). An effective leg drive could not only increase service speed but also make it possible to hit at a higher impact point to pass over the net at higher point (Elliott et al., 2009). Whiteside et al. also reported that the lesser the leg drive that produces angular momentum connecting to the trunk, the lesser power transmitted to the serve is (Whiteside et al., 2015). In this manner, a previous study clarified that leg drive could be highly related to service speed (Elliott et al., 1986, 2009; Girard et al., 2005; Whiteside et al., 2015); the regression formula in this study is in line with these results.

Previous studies have shown diversity results on the contribution of jumps to service speed (Sebolt, 1970; Bahamonde, 2000; Chow et al., 2003; Cardoso Marques, 2005; Girard et al., 2005; Ferrauti and Bastiaens, 2007; Fett et al., 2020); however, unifying the jump directions could lead to similar results. In this study, the jumps were performed horizontally rather than vertically, which might have greatly contributed to service speed owing to their relationship with leg drive. Sánchez-Pay et al. (2021) reported that although there was a correlation between service speed and countermovement jump, there was no correlation between service velocity and jump height when serving. Moreover, flight time is more important than the jump height (Sánchez-Pay et al., 2021), which might be because the jump is not vertical but horizontal (forward to the net) while serving, in which the impact depth is forward. Considering this mechanism, it is expected that the results of this study showed that service speed is highly correlated with broad jump and impact depth.

As conditions for impact related to service speed, as shown in this study, taking the impact point much higher and more forward is required (Girard et al., 2005). Typically, a tall player has longer upper limbs and the length of the moment arm makes it possible to increase the racket swing speed. In addition, it is possible to take the impact point forward to the net. Conversely, players who are shorter must make up for this by physical training to take the impact point much higher and more forward (e.g., improve the strength of jumping higher and forward). The service form must transit power to the ball *via* the lower limbs, trunk, upper limbs, and racket while efficiently using the kinetic chain of the whole body. MBT has been widely used to train this kinetic chain. MBT is a test item for the power of the upper body, and it also uses the kinetic chain from the lower body to transfer energy to the upper limbs, thus training the entire body for the strength required for serving. While there are some studies on the relationship between service speed and MBT (Kramer et al., 2017; Colomar et al., 2020; Fett et al., 2020), the contribution of MBT to service speed is varied. Comparing the body movement during service, the racket operation is performed using one arm at the end, whereas in MBT, the MB is thrown using both arms. In addition, because the players were not accustomed to the weight of a 2 kg MB and MBT movements were complicated, the results were considered to vary depending on the age, competition level, and sex of the participants. In this study, junior players performed two types of MBT, forward and backward, and MBT in the backward direction was found to predict service speed. Abdominal muscle strength is important for overhead forward throwing, while back muscle strength is required for overhead backward throwing. Since impact depth affects the service speed, stabilizing the trunk could play an important role in the service movement to hit the forward impact point. The results of this study suggested that stabilizing the trunk might lead to a successful overhead swing-like service. A similar movement is required for javelin throwers and baseball pitchers and stability training around the scapula is necessary to rotate the shoulder efficiently (Wilk et al., 1993; Ali and El-Ghaffar, 2010; Kim et al., 2014; Hurd et al., 2017). However, even if some muscle strength is gained, it may not immediately be reflected in the service speed, and it is necessary to efficiently train to transmit power while considering the overall movement balance. When training physical strength without a racket, it is difficult to imagine how the target physical factor affects the shot on the court. It is not easy to imagine how far to jump, how far to throw the medicine ball, and the speed with which this corresponds. As movements of broad jump and MBT are different from service, it is necessary for players to be aware of the kinetic chain of the whole body and to acquire efficient power transmission. Considering this, training and measurement items are desirable so that the value reflect correct and efficient use of the body.

The multiple regression formula shown in this study can predict the first service speed by applying the value of their broad jump and MBT (backward). In order to hit the service of 200 km/h, players could have a standard by which they have to jump and throw in order to aim for during physical training without a racket. An index that connects physical training and on-court performance might make it possible to allow for training that is intimately linked to improving competitiveness. In reality, the strong correlation between the first service speed and broad jump and MBT (backward) does not necessarily guarantee an improvement in service speed. However, if physical training aims to refine the movement of tennis and improve the physical strength required for the technique, such a task setting might be useful in the training field. In addition, as a practical use of this regression formula, it will be possible to prioritize the training program order of players. For example, if the player is plotted on the left side of the regression line, it could be determined that the service should be able to hit at a faster speed, considering their physical strength. In this case, technical improvement is a priority task for these players. In this way, it is thought that it will lead to the formulation of an efficient training plan by determining the priority of whether to train physical strength or improve skills in improving the competitiveness of players. In future studies, a regression formula for each age category of players, such as U12, U14, U16, and U18, could be developed by including more participants. Furthermore, even in racket sports, such as paddle-tennis, a connection can be noted between physical training and skill practice by obtaining a regression formula from the physical strength index and performance index.

Reasons a Relationship Between Service Spin Rate and Physical Strength Were Not Found

In this study, it was not possible to extract the physical strength factors affecting the spin rate of the service. According to previous study, no correlation was found between service spin and physical strength in male players, but a correlation was reported in female players (Koya et al., 2021). However, due to the small number of participants, further research was needed (Koya et al., 2021). We examined more than 50 players this time, but the results were the same as that in the previous study. The variables of physical strength dealt with in this study were selected based on running, jumping, and throwing, which are the basic movements of sports.

In racket sports, it is thought that the swing speed affects the spin rate; however, these test variables, using the movement of the shoulder joint on the dominant side that directly affects swing speed, were not adopted in this study. If there was a variable to measure the physical strength related to the speed of the swinging arm, the relationship between spin rate and physical strength may have been found. In a previous study, female players showed a correlation between spin rate and physical strength; in the future, this should be examined using the additional measurement of racket swing speed. Tall players generally have long limbs. Increased forearm angular momentum improves the forward linear speed of the wrist, accelerating the racket speed, which plays an important role in improving the speed of the ball (Bahamonde, 2000). The forearm of a tennis player is interpreted as a moment arm with the axis of rotation at the elbow, and if this moment arm becomes longer, the tangential speed may increase (Elliott, 1988; Cross, 2004). However, in this study, no significant correlation was found between height and the spin rate. In the future, it is necessary to reconsider the measurement items. This is a limitation of this study. Further investigation using additional measurements of the racket swing speed that directly affect spin rate is needed.

CONCLUSION

The present study found that a significant multiple regression equation for predicting the first service speed was obtained from the broad jump and the MBT (backward), and a strong correlation was found between the predicted and measured values. In addition to the physical strength factor, it was suggested that the depth of the impact point (taking the hitting point forward toward the net) is important for improving the first service speed.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because they can only be used with the permission of the Japan Tennis Association National Team. Requests to access the datasets should be directed to NK, n-koya@daido-it.ac.jp.

ETHICS STATEMENT

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

AUTHOR CONTRIBUTIONS

NK: conceptualisation, methodology, data collection, formal analysis, writing – original draft preparation, review, and editing. TK and HT: data collection and advising. All authors contributed to the article and approved the submitted version.

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Tennis vs padel: Precompetitive anxiety as a function of gender and competitive level

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The main objective of this research is to analyze the level of anxiety and precompetitive self-confidence of tennis and padel players and to check the influence of gender and competitive level in each of the sports. Four hundred and twenty-three tennis and padel players, with a mean age of 15.40 (± 3.43) years, participated in the study. Of the total number of players surveyed, 291 were padel players and 132 were tennis players. The Spanish version of the Competitive State Anxiety Inventory-2R (CSAI-2R) in the Spanish version was used to measure the level of cognitive anxiety, somatic anxiety and self-confidence between 30 and 35 min before the start of the match. The general results showed that the level of self-confidence of padel players is higher of tennis players. In relation to gender, female tennis players showed a higher level of precompetitive anxiety than male players, while, in padel, it was the opposite. In terms of competitive level, U14 players had the highest level of self-confidence and the lowest level of precompetitive anxiety. When comparing both sports, female tennis players show a higher level of state-anxiety than female padel players and U14 tennis players are the ones who showed a higher level of self-confidence. This study shows how precompetitive anxiety is one of the most important psychological variables in relation to sport performance and how it can vary according to gender and competitive level.

KEYWORDS
sport, racket sports, sport psychology, gender studies, sport performance

Introduction

"He is anxious about playing" or "he has anxiety problems" are expressions increasingly used by professionals dedicated to the sports field. The influence of precompetitive anxiety on sport performance has focused the attention of many sport psychologists (Gómez-López et al., 2020), being one of the most studied aspects in sport psychology in recent years (Cuesta-Vargas and Vertedor, 2016; Correia and Rosado, 2019; Pineda-Espejel et al., 2021; Ren et al., 2022).

In this way, competition generates psychological effects on athletes that counteract their psychoemotional resources (Flores et al., 2017; Coco et al., 2020; Jaramillo et al., 2020; Di Corrado et al., 2021). Likewise, one of these main effects is anxiety, which is characterized by an increase in physiological activity that manifests itself in contexts of high emotional and physical demand, accompanied by the activation of the autonomic nervous system (Rodríguez et al., 2015; Castro-Sánchez et al., 2018). In this sense, anxiety is understood as a psycho-emotional negative state of mind characterized by the manifestation of worry and nervousness, finding a cognitive and a somatic component (Weinberg and Gould, 1996). It is regularly associated with restlessness, muscular tension, problems with concentration and fatigue (Ayuso-Moreno et al., 2020; Mehrsafar et al., 2021).

Anxiety is a multidimensional construct in two ways: state anxiety and trait anxiety. State anxiety is understood as an immediate emotional state that appears when the athlete responds with anxiety to specific situations that are characterized by fear, tension and increased physiological arousal and an increase in physiological arousal (Cox, 2012). Trait anxiety is a predisposition to perceive certain environmental situations as threatening and to respond to these situations with increased state anxiety (Spielberger, 1971; Dosil, 2004). This present study focuses on state anxiety.

In addition to state-anxiety and trait-anxiety, the concept of anxiety can be discriminated between the cognitive component and the somatic component, cited above (Andrade et al., 2007). On the one hand, cognitive anxiety manifests with negative thoughts, uneasiness and feelings of insecurity caused by fear of negative social evaluation, failure and loss of self-esteem (Cox, 2012; Rodríguez-Cayetano et al., 2017). On the other hand, somatic anxiety is associated with an increased level of activation of physiological functions produced by nervousness, such as increased heart rate, rapid breathing and muscle tension (Grossbard et al., 2009). Although, it was supposed that these types of anxiety are conceptually unrelated, these two factors are related and interdependant in conditions of stress (Masten et al., 2006) and maintain control over them will make the athlete more likely to succeed in competition (Kotnik et al., 2012).

With respect to sport, the previous moment to competition is the most propitious for anxiety to occur (Dosil, 2004). This type of anxiety is known as precompetitive anxiety (Cox, 2012), being one of the psychological factors that most influence competitive sport performance, along with self-confidence (León-Prados et al., 2014; Pineda-Espejel et al., 2019). Research in the sport context shows how athletes with high levels of anxiety achieved worse results than those who showed lower levels of anxiety in competition (León-Prados et al., 2011; López-Torres et al., 2011; Ngo et al., 2017; Sánchez et al., 2017). On the other hand, the athlete's self-confidence, understood as the athlete's belief that he/she can perform successfully in competition (Robazza and Bortoli, 2007), has a positive correlation with sport performance (Santos-Rosa et al., 2007; Díaz et al., 2008; Martínez-Romero et al., 2016; Zurita-Ortega et al., 2017), although an excess of self-confidence can cause a decrease in the optimal level of performance (Weinberg and Gould, 1996). The correlation between self-confidence and competitive performance is one of the most important aspects of competitive performance for athletes (Vodicar et al., 2012).

The dimensions of competitive anxiety tend to be influenced by numerous factors, such as gender or type of sport (Martens et al., 1990). Racquet sports present a series of physical characteristics and physiological demands different from other types of sports due to the nature of their game (Ford et al., 2017), with intermittent sprints and incomplete recoveries between points (Alvero-Cruz et al., 2005; Courel-Ibáñez et al., 2017; Castillo-Rodríguez et al., 2022) and constant decision making in a very short period of time (Castillo-Rodríguez et al., 2014) and, in turn, being accurate to reduce the inaccuracies that arise during the course of the game (Barahona-Fuentes et al., 2019). In this regard, the ability of the players to deal with pressure situations is directly related to their performance (González-Díaz et al., 2012; Knight et al., 2016; Martínez-Gallego et al., 2022).

Most previous studies that have studied the difference in the level of precompetition anxiety between men and women have shown that women show a higher level of somatic and cognitive anxiety and a lower level of self-confidence than men in the moments prior to competition (Dias et al., 2010; Gutiérrez et al., 2013; Ruiz-Juan and Zarauz, 2013; Ramis et al., 2015). However, Zarauz-Sancho et al. (2016) found higher levels of somatic anxiety in male runners than in female runners.

In the sport of tennis, several studies have shown that female tennis players showed a higher level of cognitive and somatic anxiety and a lower level of self-confidence than men before the sport competition (Correia and Rosado, 2019; Khot and Bujurke, 2021; Martínez-Gallego et al., 2022). In addition, other studies have shown that anxiety affects female professional tennis players more at key moments of the match and the tournament prize money (Cohen-Zada et al., 2017). However, Keskin et al. (2021) found no significant differences in the level of cognitive anxiety and somatic anxiety in adult tennis players in the moments before the competition and, even, that women showed a lower level of precompetitive anxiety than men with increasing age (Ebbeck, 1994). With respect to padel, few studies have analyzed the level of precompetitive anxiety in this sport (Almendros-Pacheco et al., 2022; Castillo-Rodríguez et al., 2022). It is worth highlighting the study by Castillo-Rodríguez et al. (2022) in which they showed that the level of self-confidence of the players increased as the player competed in a higher category.

For this reason, the literature shows the need to analyze and work on the psychological aspect in order to reduce the level of anxiety of each athlete and, thus, achieve a better sporting performance. For this reason, the main objective of this research is to analyze the level of anxiety and precompetitive self-confidence of tennis and padel players and to check the influence of gender and competitive level in each of the sports.

With reference to this main objective, it was hypothesized that:

1. Tennis players would have higher values of cognitive and somatic anxiety and lower values of self-confidence than padel players.
2. Female tennis and padel players will have a higher level of cognitive and somatic anxiety and a lower level of self-confidence than male tennis and padel players.
3. U14 players would have a higher level of self-confidence and a lower level of precompetitive anxiety, since, although they are federated and competitive athletes, they are just beginning their competitive stage.
4. Male and female padel players would have a higher level of self-confidence and less precompetitive anxiety than tennis players, as they have the support of a partner in the competition.
5. Padel players would have lower values of precompetitive anxiety and a higher level of self-confidence than tennis players, regardless of their competitive level.
6. Two variables related to anxiety would correlate positively with each other, while both would correlate negatively with self-confidence.

Materials and methods

Research design

The study design is cross-sectional descriptive. The type of sampling was non-probabilistic by convenience, i.e., the selection of participants was based on the presence of characteristics that respond to the needs of the research (Otzen and Manterola, 2017). Players were selected who competed in federated tennis and padel tournaments and who trained a minimum of 3 h per week in the selected categories.

Participants

A sample of 423 tennis and padel players with a mean age of 15.40 (± 3.43) years participated in this study. Of the total number of players surveyed, 291 were padel players and 132 were tennis players. By gender, there were a total of 191 males and 100 female padel players, while, in tennis, there were 85 male and 47 female players. Finally, in terms of competitive level, in padel, there were a total of 93 Under14 (U14) players, 93 Under16 (U16) players and 105 in the senior category, while, in tennis, there were a total of 31 U14 athletes, 34 U16 and 67 players who competed in the senior category.

The sample was obtained from various sports clubs that organized federated tournaments in both sports, requesting the voluntary participation of the athletes. All players were informed about the characteristics and objectives of the study and signed an informed consent form. Finally, the non-repetition of individuals was guaranteed with individualized follow-up during data collection to avoid duplication of data during the selection process.

Instruments

The Spanish version of the Competitive State Anxiety Inventory-2R (CSAI-2R) by Cox et al. (2003) in the Spanish version by Andrade et al. (2007) was used to measure the level of precompetitive anxiety of tennis and padel players.

This instrument is composed of 16 items using a Likert-type response format, with four different alternatives, numbered from 1 (not at all) to 4 (very much). These items make up a total of three subscales: cognitive anxiety, somatic anxiety and self-confidence.

An analysis of the instrument indicated that the reliability measured by Cronbach's alpha was 0.825 for cognitive anxiety, 0.778 for somatic anxiety and 0.771 for self-confidence, which is considered very good internal consistency (Nunnally and Bernstein, 1994; Vaughn et al., 2012).

Procedure

The study was consistent with the Helsinki Declaration of 2013. Participants were treated ethically under the American Psychological Association code of ethics regarding consent, anonymity and responses. Also, the study is covered by the current Spanish legal regulations governing research on human subjects (RD 561/1993), respecting at all times privacy and the law on the protection of personal data (Organic Law 15/1999).

Firstly, the people in charge of organizing the tournaments were contacted to request permission to administer the questionnaires to the players before the start of the competition. In order to respect the principle of voluntariness and confidentiality, each player signed an informed consent form (in the case of minors, their legal representatives did so), in which the objectives of the research and their voluntary participation in it were detailed.

The questionnaire was administered to the players between 30 and 45 min before the start of each of the matches in all cases, following the same criteria as Andrade et al. (2007) in which they administered the questionnaire between 15 and 45 min before the start of the competition. Finally, it is essential to highlight that the questionnaire was administered in tennis in individual matches (1vs1) while padel matches were played in their usual format (2vs2).

Statistical analysis

All data were analyzed using the statistical package SPSS for Windows v.25.0 (*SPSS Inc.,* Chicago, IL, United States). Descriptive analysis was initially conducted. The test is considered a valid statistical procedure when skewness and kurtosis range between

−1 and 1 (Blanca et al., 2017; Fernández-Río et al., 2022) and, in the present study, these were (Sk = 0.357; Ku = −0.730) for cognitive anxiety, (Sk = 0.873; Ku = 0.230) for somatic anxiety and (Sk = −0.627; Ku = 0.403) for self-confidence.

To analyze the differences between the anxiety factors with the independent variables sport (tennis/padel), gender (male/female) and competitive level (U14, 16 and Senior), a one-way ANOVA test was performed for each of them. Significant interactions were calculated using *post hoc* tests with Bonferroni test, using a level of significance of 0.05. The effect size was assessed using Cohen's *d* test (Cohen, 1988). The threshold values for the Cohen effects sizes in the ANOVA test were small: 0.10; moderate, 0.25; and large, 0.40. Finally, Pearson's correlation coefficient was used to analyze the correlations between the psychological variables at a general level and according to the sport practiced.

Results

Firstly, the overall results obtained among tennis and padel players showed a higher level of self-confidence, with significant differences [$f_{(1.00)} = 4.51$; d = 0.223; $p < 0.05$], than cognitive anxiety and somatic anxiety, the latter being the one with the lowest values (Table 1).

Regarding the gender of the players and the sport played, male padel players obtained higher values in the three factors analyzed than female, highlighting significant differences in the somatic anxiety variable ($f_{(1.00)} = 14.49$; d = 0.459; $p < 0.001$). With respect to tennis, female players showed higher values in the variables related to anxiety, with significant differences in cognitive anxiety ($f_{(1.00)} = 8.40$; d = 0.527; $p < 0.001$) and lower self-confidence, without significant differences, in the moments prior to the start of the competition (Table 2).

Referring to the competitive level, senior padel players showed the highest values in cognitive anxiety and somatic anxiety and the lowest level of self-confidence, with significant differences in all factors ($p < 0.001$). On the other hand, in tennis, U16 players showed the highest level in factors related to precompetitive anxiety and the lowest level of self-confidence, with significant differences in all of them ($p < 0.001$) (Table 3).

Figures 1, 2 show the level of precompetitive anxiety of female and male racket sports players as a function of the sport played. Female tennis players showed a significantly higher level of cognitive anxiety [$f_{(1.00)} = 10.34$; d = 0.526; $p < 0.001$] and a significantly lower level of self-confidence [$f_{(1.00)} = 5.05$; d = 0.314; $p < 0.05$] than female padel players. For boys, padel players obtained higher values in all three variables than tennis players, showing significant differences in the somatic anxiety factor [$f_{(1.00)} = 11.30$; d = 0.442; $p < 0.001$; Figures 1, 2].

In addition, Figures 3–5 show the level of precompetitive anxiety of racket sports players as a function of competitive level and sport played. U14 padel players showed higher values of cognitive anxiety [$f_{(1.00)} = 25.80$; d = 1.060; $p < 0.05$] and somatic anxiety [$f_{(1.00)} = 12.67$; d = 0.725; $p < 0.001$] and a lower level of self-confidence than tennis players [$f_{(1.00)} = 5.42$; d = 0.493; $p < 0.05$; Figure 3]. In contrast, U16 tennis players showed a higher level of cognitive anxiety [$f_{(1.00)} = 33.26$; d = 1.153; $p < 0.001$] and somatic anxiety and a lower level of self-confidence [$f_{(1.00)} = 21.75$; d = 0.931; $p < 0.001$; Figure 4]. Finally, for senior players, padel players showed a higher level of somatic anxiety than tennis players [$f_{(1.00)} = 9.84$; d = 0.487; $p < 0.005$; Figure 5].

Finally, bivariate correlations are established between the variables of precompetitive anxiety at a general level and according to the sport practiced. As can be seen, in all cases, there is a significant positive correlation between cognitive anxiety and somatic anxiety and both correlate significantly negatively with self-confidence (Table 4).

TABLE 1 Precompetitive anxiety as a function of the practiced sport modality.

	Padel	Tennis	Value of *p*	*f*	*d* Cohen
CA	2.01 (± 0.679)	2.07 (± 0.781)	0.421	0.65	0.079
SA	1.60 (± 0.557)	1.50 (± 0.467)	0.055	3.71	0.202
SC	3.25 (0.548)	3.13 (0.548)	0.034*	4.51	0.223

*$p < 0.05$.
CA, Cognitive anxiety; SA, Somatic anxiety; SC, Self-confidence.

Discussion

The main objective of this research was to analyze the level of precompetitive anxiety and self-confidence of tennis and padel players and to test the influence of gender and competitive level in each sport. As an initial hypothesis, it was proposed that tennis players would have higher values of cognitive and somatic anxiety and lower values of self-confidence than padel players. This hypothesis was partially accepted, since, as the results indicate, tennis players showed a significantly lower level of self-confidence than padel players. There are no previous studies comparing the level of precompetitive anxiety and self-confidence between tennis and padel players with similar characteristics, but these results can be related to previous studies that showed that team sports players showed a higher level of self-confidence than individual sports players and a higher level of cognitive anxiety (Dias et al., 2010; Correia and Rosado, 2019; Marín-González et al., 2022). However, they do not follow the line of other research in which no differences were found between the type of sport played, individual or team (Hanton et al., 2008; O'Donoghue and Neil, 2015). However, the results obtained may be due to the fact that in tennis, being an individual sport, there is a greater concern about not performing at the highest level, which leads to a decrease in self-confidence, as there is no one who can cooperate with you to achieve the goal of victory.

As a second hypothesis, it was established that female tennis and padel players will have a higher level of cognitive and somatic anxiety and a lower level of self-confidence than male tennis and

TABLE 2 Precompetitive anxiety in racket sport players as a function of gender.

	Padel					Tennis				
	Girls	Boys	Value of *p*	*f*	*d* Cohen	Girls	Boys	Value of *p*	*f*	*d* Cohen
CA	1.96 (0.67)	2.04 (0.68)	0.363	0.83	0.118	2.33 (0.59)	1.93 (0.84)	0.004*	8.40	0.527
SA	1.44 (0.52)	1.69 (0.56)	0.000**	14.49	0.459	1.56 (0.53)	1.46 (0.43)	0.280	1.18	0.214
SC	3.22 (0.56)	3.27 (0.54)	0.497	0.46	0.073	3.00 (0.52)	3.19 (0.65)	0.088	2.95	0.315

*$p < 0.05$; **$p < 0.001$.

TABLE 3 Precompetitive anxiety in racket sport players as a function of competitive level.

	Padel					Tennis				
	U14	U16	Senior	Value of *p*	*f*	U14	U16	Senior	Value of *p*	*f*
CA	1.79 (0.70)[3]	1.96 (0.55)	2.26 (0.69)[1]	0.000**	13.39	1.13 (0.29)[2,3]	2.56 (0.42)[1,3]	2.26 (0.71)[1,2]	0.000**	57.61
SA	1.44 (0.55)[3]	1.52 (0.51)[3]	1.82 (0.54)[1,2]	0.000**	14.31	1.09 (0.15)[2,3]	1.71 (0.54)[1]	1.58 (0.41)[1]	0.000**	21.71
SC	3.44 (0.54)[3]	3.27 (0.49)[3]	3.07 (0.55)[1,2]	0.000**	12.94	3.69 (0.40)[2,3]	2.83 (0.43)[1]	3.01 (0.60)[1]	0.000**	25.30

**$p < 0.001$. Bonferroni *Post-hoc* test are given below.
[1]Differences with U14.
[2]Differences with U16.
[3]Differences with Senior; CA, Cognitive anxiety; SA, Somatic anxiety; SC, Self-confidence.

padel players. This hypothesis was only partially valid, since, in tennis, female tennis players showed lower values in self-confidence and higher values in somatic anxiety and cognitive anxiety, with significant differences in the latter. These results are in line with the study conducted by Martínez-Gallego et al. (2022) with 42 male and female tennis players between 12 and 18 years old, Filaire et al. (2009) and Keskin et al. (2021) with adult tennis players and Wang (2021) with 187 table tennis players in which they showed differences in anxiety-related variables and lower values in self-confidence, although there were no significant differences. Furthermore, they also corroborate the line of Di Corrado et al. (2021) in which they demonstrated that female athletes showed higher levels of tension, stress and anger than male athletes, key psychological aspects for sport performance. This may be due to the fact that, when facing the challenge of competition alone, it causes doubts in the sporting performance of these players. For these reasons, it is coherent to think about the importance of establishing psychological training with special emphasis on female players in order to improve the mental aspect before the start of the competition. It is important to find their own identity which should be independent of stereotypes (Masten et al., 2006). On the contrary, in padel, it is the players who showed the highest values in the three variables analyzed, showing significant differences in somatic anxiety, so the hypothesis initially put forward for this sport is not fulfilled. These results do not follow the line of Rodríguez-Cayetano et al. (2017) who, despite not finding significant differences in any of the three factors, padel players showed a higher level of self-confidence and a lower level of cognitive anxiety. In this sport, it may be advisable to establish guidelines and routines to work on cohesion between the couple to improve the level of self-confidence prior to the competition.

The third hypothesis was related to the competitive level of the players. It was established that U14 players would have a higher level of self-confidence and a lower level of precompetitive anxiety, since, although they are federated and competitive athletes, they are just beginning their competitive stage. In both sports, this hypothesis was completely fulfilled, as it was the U14 players who obtained lower values of precompetitive anxiety and a higher level of self-confidence, with significant differences in all factors. These results are in line with other studies related to racket sports for these ages (Martínez-Gallego et al., 2022). In contrast, in the study conducted by Castillo-Rodríguez et al. (2022) with 100 padel players, the players who competed at a higher competitive level were the ones who obtained a higher level of self-confidence, unlike in this research where the senior players obtained the lowest level of self-confidence and higher values of anxiety. This may be due to the fact that these players are the ones who seek a higher sporting performance and are focused on the pursuit of a result in the competition, which makes them approach the sporting event with a higher level of stress. However, it is important to note that in tennis, it was the U16s who showed the highest levels of anxiety and the lowest levels of self-confidence. This may be explained by the adolescents' desire to achieve victory in competition, compared to children who may still see sport as a game (Crocker and Park, 2004).

In relation to the fourth hypothesis, it was established that male and female padel players would have a higher level of self-confidence and less precompetitive anxiety than tennis players, as they have the support of a partner in the competition. This hypothesis was fulfilled in the female modality, as female tennis players obtained a significantly higher level of cognitive anxiety and a significantly lower level of self-confidence. This fact may be one of the reasons for the high female participation in this sport nowadays, as more than 30% of the existing licenses in Spain, one of the countries with the highest number of professional padel athletes, are girls (Courel-Ibáñez et al., 2017). On the other

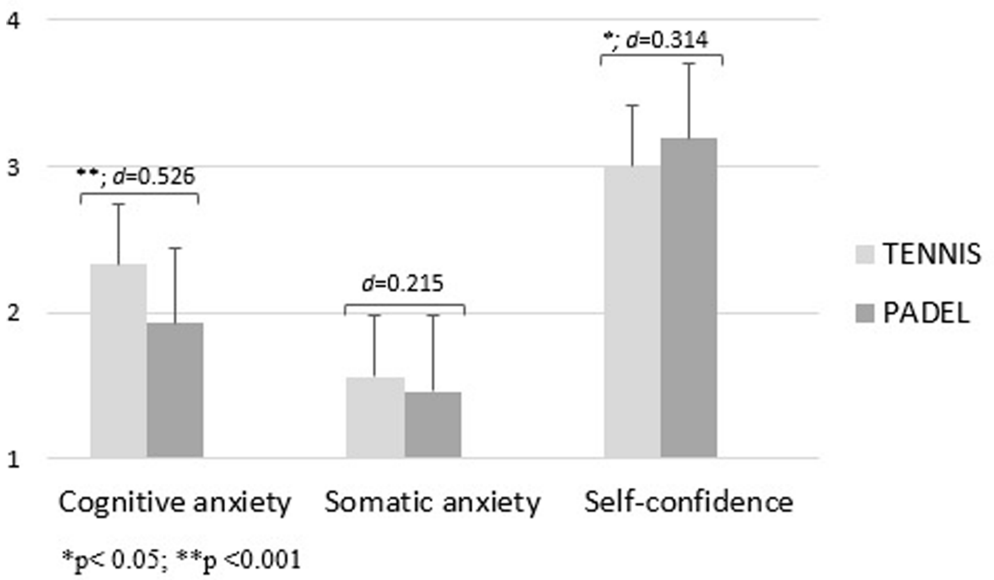

FIGURE 1
Precompetitive anxiety in female racket sports players as a function of the sport played.

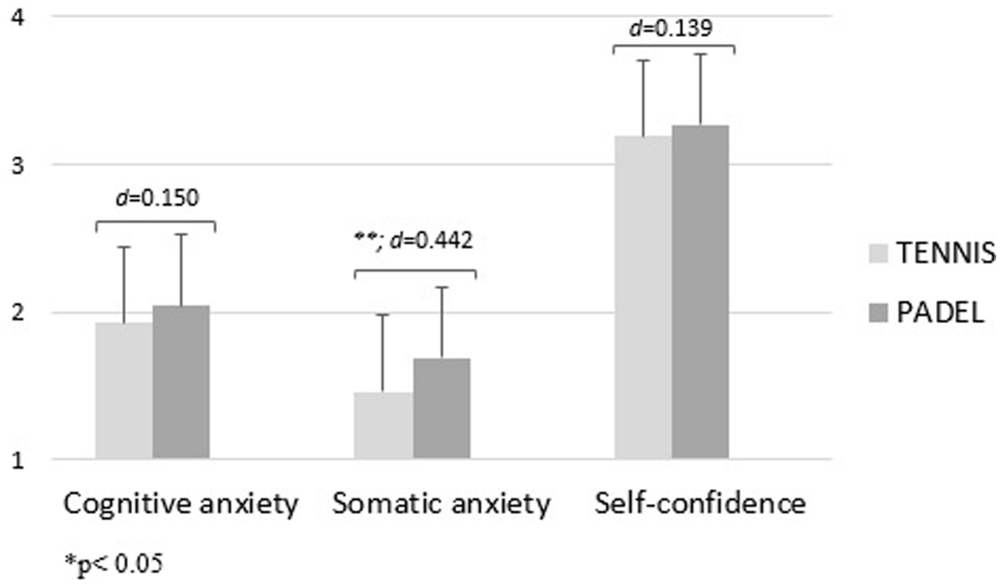

FIGURE 2
Precompetitive anxiety in male racket sports players as a function of the sport played.

hand, in the male modality this is not the case, as the padel players are the ones who have shown the highest values in the three variables, with significant differences in the somatic anxiety variable. It should be noted that the players of both sports have relatively low anxiety values and a high level of self-confidence, which may be due to the fact that, by playing sports in which there is constant decision making and acceptance of making mistakes on a constant basis, they are athletes used to withstanding a high level of mental pressure both in the competition and in the moments prior to it (González-Díaz et al., 2012; Knight et al., 2016).

The fifth hypothesis was that padel players would have lower values of precompetitive anxiety and a higher level of self-confidence than tennis players, regardless of their competitive level. This hypothesis was fulfilled with the U16 players, as the tennis players showed a significantly higher level of cognitive

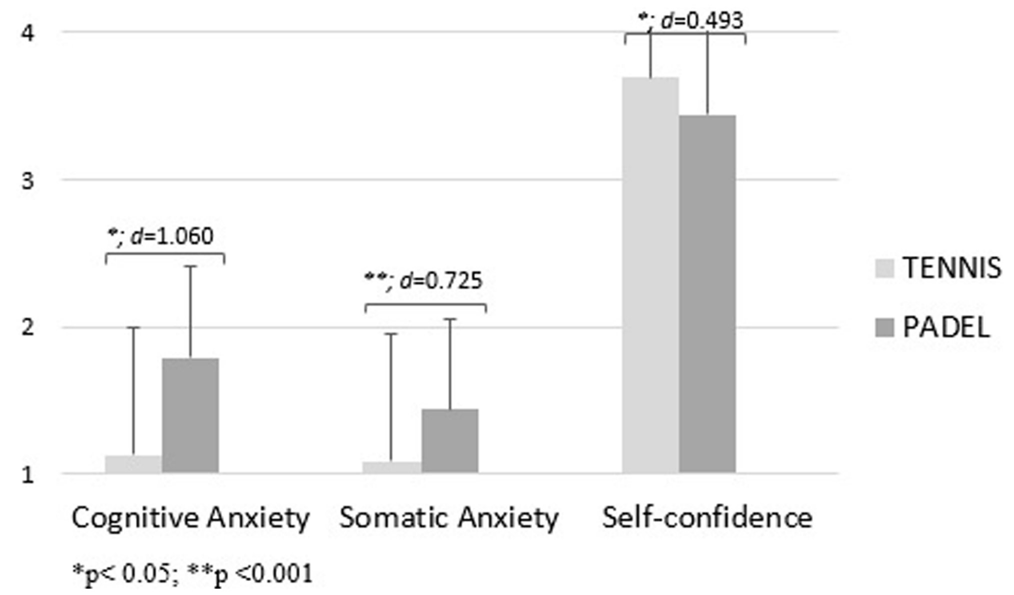

FIGURE 3
Precompetitive anxiety in U14 racket sports players as a function of the sport played.

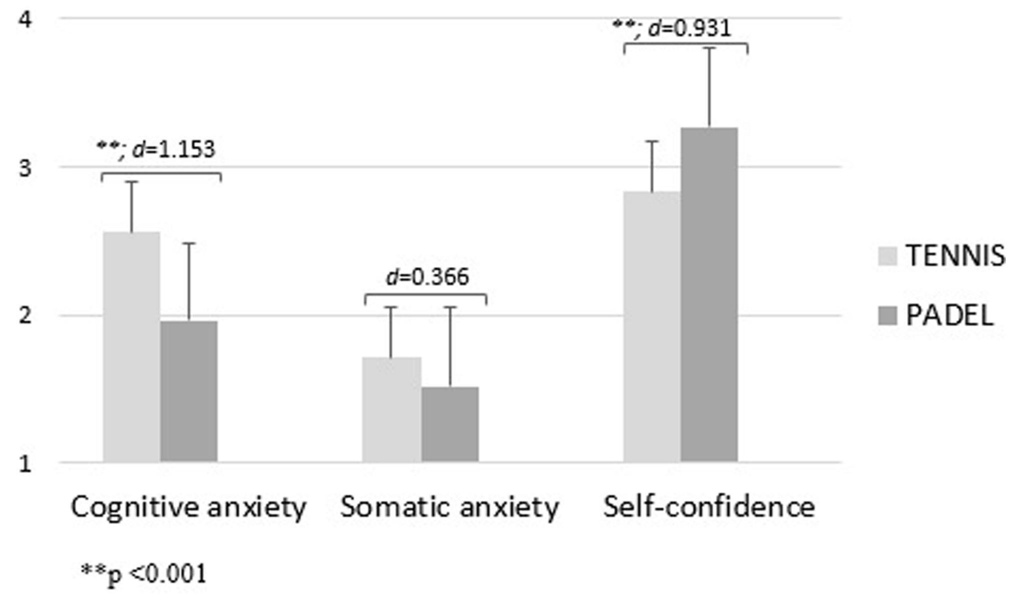

FIGURE 4
Precompetitive anxiety in U16 racket sports players as a function of the sport played.

anxiety and a significantly lower level of self-confidence. On the other hand, with U14 players it was not fulfilled, as U14 tennis players are the ones who showed a lower level of anxiety and a higher level of self-confidence of all the categories analyzed, with significant differences in all three variables. Moreover, this was not true for senior players either, as padel players showed significantly higher values in somatic anxiety. There are no previous studies that have compared the level of precompetitive anxiety between tennis and padel players according to the competitive level, but it can be affirmed that specific training programs should be established at a mental level to maintain over time the levels obtained in these three variables in children's tennis players with the aim of learning skills to improve future sporting performance as the competitive level increases.

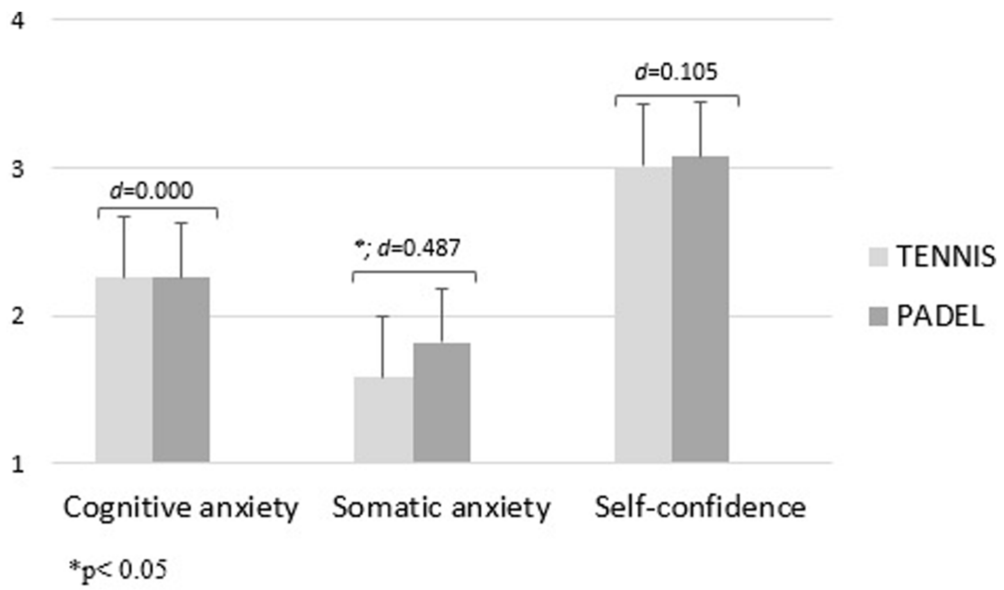

FIGURE 5
Precompetitive anxiety in senior racket sports players as a function of the sport played.

TABLE 4 Correlation coefficient between precompetitive anxiety variables and sport practiced.

	SA	SC
Racket sport players		
CA	0.522**	−0.415**
SA		−0.317**
Tennis players		
CA	0.641**	−0.591**
SA		−0.521**
Padel players		
CA	0.487**	−0.312**
SA		−0.254**

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

Finally, it was hypothesized that the two variables related to anxiety would correlate positively with each other, while both would correlate negatively with self-confidence. The results obtained showed that this hypothesis was completely fulfilled, since, both at a general level and for each of the sport modalities, this statement was fulfilled. These results show the importance of working on players' self-confidence to improve their sporting performance (Martínez-Romero et al., 2016; Zurita-Ortega et al., 2017).

This study has several strengths. Firstly, it is the first research that compares the level of precompetitive anxiety in tennis and padel tennis players, the two most played racket sports in the world today. Secondly, the results obtained have a very important practical character for coaches and sport psychologists, especially taking into account the differences by gender and competitive level. The results should be taken into account in order to implement appropriate training programs for each individual athlete, both on and off the track.

Although this study follows a methodology very similar to other recent research carried out in this field, it is important to highlight some limitations of this research work. To measure anxiety, it would be advisable to be able to use not only questionnaires, but also other types of tools that can help to measure the level of precompetitive anxiety and to relate it to other psychological variables that are essential for sports performance. Future studies should relate the level of precompetition anxiety with the player's performance in the competition and some other post-match psychological characteristics such as, for example, mood, and thus be able to relate these first data obtained by comparing both sports to a greater extent.

Conclusion

In conclusion, the results of the present study show how tennis and padel players have a higher level of self-confidence than pre-competitive anxiety, as well as the influence of several factors such as gender and competitive level on the psychological characteristics of the athletes prior to the start of the match.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

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

Author contributions

AR and SP: conceptualization, methodology, investigation, formal analysis, and writing—original draft. FH and JM: data curation. AR, JM, and SP: performed the statistical analysis. AR: supervision. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

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The impact of stress, recovery and coping on burnout symptoms of young elite table-tennis players: A prospective multilevel study

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Objective: The aim of the present study was to explore the role of stress, recovery, and coping on table-tennis athlete burnout symptoms in considering both the roles of individual and contextual (training center) factors.

Methods: One hundred and fifty-nine youth elite table-tennis players (*Mage*=14.07, *SD*=2.13) involved in 15 intensive training centers completed self-report questionnaires and socio-demographic data.

Results: When time 1 (T1) levels 1 (individual) and 2 (training group, contextual factor) stress, recovery, and coping were simultaneously entered as predictors of each of the three burnout symptoms (physical and emotional exhaustion, sport devaluation, reduced accomplishment) at T2 (controlling for levels 1 and 2 burnout at T1), the results of multilevel analyses revealed that: (a) T1 level 1 recovery significantly negatively predicted T2 reduced accomplishment (β=−0.23, p=0.03); (b) T1 level 2 disengagement-oriented coping significantly negatively predicted T2 reduced accomplishment (β=−0.71, p=0.03); and (c) T1 level 2 task-oriented coping marginally significantly positively predicted T2 physical and emotional exhaustion (β=0.99, p=0.06).

Conclusion: Results of the present study provided evidence for the usefulness to disentangle the variances attributable to the individual (level 1) and contextual (level 2; training group) levels of the predictors (recovery, stress and coping) of athlete burnout. Moreover, rather than examining the antecedent role of stress on athlete burnout, it could be particularly fruitful to explore theoretical constructs able to annihilate the maladaptive effects of chronic stress such as coping and recovery.

KEYWORDS

athlete burnout, coping, multilevel analyses, recovery, stress

Introduction

Young elite athletes in intensive training settings must commit to a significant amount of training to accede to the highest competitive levels. Within intensive training centers, they have to manage a series of physical (e.g., injury risks), psychological (e.g., demonstrating personal competence), and social (e.g., distance from family) daily stressors in a win-at-all-coast atmosphere (Martinent et al., 2020). In particular, table-tennis players are confronted to specific psychological constraints related to the limited margin of error, the important number of required repetitions, and the pressure inherent to the competitive environment (Martinent et al., 2014a). These daily stressors may lead to athlete burnout (Martinent et al., 2014b) which can be defined as a syndrome characterized by reduced sense of accomplishment, sport devaluation, and emotional and physical exhaustion (Raedeke, 1997). Burnout is related to maladaptive outcomes such as illness or dropout (Gustafsson et al., 2011). Although prolonged experience of stress can be conceptualized as an antecedent of athlete burnout (Gustafsson et al., 2011), it is noteworthy that a certain level of stress is an integral part of elite sport settings (Martinent and Decret, 2015a). As such, the objective is no longer to annihilate stress but to attempt to reach a balance between stress state and personal resources (e.g., recovery, coping).

The concept of recovery has received increasing attention in research and practice over the past 20 years based on the rationale that it helps understanding how to cope with stress and how to build enduring resources (Kellmann, 2010). Biopsychological perspective of recovery and stress (Kellmann et al., 2018) "embraces physical and biopsychosocial dimensions of both stress and recovery to indicate the extent to which an athlete is physically and/or mentally stressed, as well as whether this athlete is capable of using individual strategies for recovery and which strategies are used" (Nicolas et al., 2022, pp. 1). For instance, recovery allows athletes supporting high loads of daily training and improving their overall fitness whereas the absence of recovery can lead to overtraining and burnout (Kellmann, 2010). Thus, simultaneously measuring stress and recovery states seems particularly salient to assess individual biopsychosocial balance able to foster high-level performance and prevent the triggering of athlete burnout (Kellmann, 2010; Vacher et al., 2017; Kellmann et al., 2018).

Burnout may also depend on athletes' ability to cope with their daily stressors (Martinent et al., 2014b). Coping can be defined as the set of cognitive strategies and behavioral efforts carried out by athletes to handle the internal and/or external sports requirements that threat to surpass their perceived resources (Nicholls and Polman, 2007). Sport scholars conceptualized coping construct using three core coping dimensions (Gaudreau and Blondin, 2002). Task-oriented coping (TOC) involves strategies that directly face the stressful situation, and the thoughts and affects that appear in the situation (thought control, seeking support, relaxation, logical analysis). Distraction-oriented coping (DsOC) comprises the strategies that focus on other stimuli instead of the stressful one to disconnect from the stressful situation (distancing, mental distraction). Disengagement-oriented coping (DgOC) refers to the strategies allowing to escape from the stressful situation (resignation, venting of unpleasant emotions; Martinent and Nicolas, 2016). Young athletes use fewer coping strategies and are less flexible in their coping range than older athletes (Nicholls and Polman, 2007). Thus, young athletes in intensive training settings could be particularly vulnerable to the stressors encountered in their daily life and in turn to athlete burnout (Martinent and Decret, 2015a). As such, it could be particularly useful to explore the respective impact of stress, recovery and coping strategies on athlete burnout symptoms in including simultaneously these three constructs within the design of the study. Past studies have generally reported positive associations of the use of TOC with adaptive outcomes such as positive affect or sport performance and the use of DgOC with maladaptive outcomes such as negative affect (Gaudreau and Blondin, 2002; Nicholls and Polman, 2007; Doron and Martinent, 2021). Moreover, previous longitudinal studies have highlighted the critical role that coping plays in the development of athlete burnout (Madigan et al., 2020; Pires and Ugrinowitsch, 2021). Results of this literature showed that the use of DgOC was linked to an increase in athlete burnout over time, while TOC was unrelated or negatively associated with changes in burnout over time.

The sport literature also suggested that athlete burnout may result from both personal (stress, recovery, and coping) and contextual factors (Gustafsson et al., 2011). Of particular importance in the context of the present study, the environment in which the young athletes are grounded (intensive training centers) could be conceptualized as a contextual factor likely to impact athlete burnout. Indeed, the atmosphere in the training group could impact recovery, stress and coping factors. For instance, Tamminen and Gaudreau (2014) pointed out an interesting result regarding the social nature of coping processes when athletes deal with shared challenges and demands within a training group characterized by day-to-day influence of teammate interactions on stressors and coping. As such, disentangling the variances attributable to the individual and contextual levels could help clearly depicting the respective roles of individual and contextual factors in the prediction of athlete burnout symptoms. This might provide new insights on the athlete burnout literature likely to bring applied implications related to the prevention of athlete burnout. Distinct strategies aiming at preventing athlete burnout could be implemented if individual or contextual factors predict athlete burnout symptoms.

In sum, the aim of the present study was to explore the role of stress, recovery, and coping on athlete burnout symptoms in considering both the roles of individual and contextual (training center) factors. We hypothesized that: (1) the scores of stress and DgOC would be positively associated with burnout; and (2) the scores of TOC and recovery would be negatively related to burnout symptoms. Moreover, we broadly assumed that the two levels (individual and contextual) would be involved in the prediction of burnout scores.

Materials and methods

Participants

One hundred and fifty-nine youth table-tennis players (50 girls, 109 boys; *Mage* = 14.07, *SD* = 2.13; range = 11–19) involved in 15 intensive training centers (from 8 to 22 athletes per centers) accredited by the French Federation of table-tennis participated in this study. These training centers "focus on helping athletes to reach the highest levels of performance, providing the necessary preparation for a successful transition to professional sporting life, and having good academic results" (Martinent et al., 2018, pp. 2726). Participants trained 15.04 h a week (*SD* = 5.78; from 1 to 2 training sessions per day) and their playing experience was 6.36 years (*SD* = 2.24). They participated in regional (*n* = 32), national (*n* = 82), or international (*n* = 45) table-tennis competitions. The competitive schedule of young athletes is based on the school time (main competitive events planned for the end of the school calendar). This study is part of a broader research project focused on different purposes. Thus, the sample of the present study was also used by Martinent and Decret (2015a,b) and Martinent et al. (2014a,b, 2018, 2020). None of the results pertaining to the data in this study are presented elsewhere.

Measures

The Coping Inventory for Competitive Sport (CICS: Gaudreau and Blondin, 2002) is a French questionnaire of 39 items assessing 10 coping strategies aggregating in the three core dimensions of TOC (thought control, effort expenditure, seeking support, logical analysis, relaxation, mental imagery), DsOC (mental distraction, distancing), and DgOC (venting of unpleasant emotions, disengagement/resignation). Participants rated the use of each coping strategy to cope daily stressors of the past 3 days on a scale of 1 (does not correspond at all) to 5 (corresponds very strongly). Cronbach's alphas were of 0.86, 0.76 and 0.82 for TOC, DsOC and DgOC, respectively.

The French version of the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport: Martinent et al., 2014b) contains 67 items measuring 17 subscales organized in the two macro dimensions of stress (general stress, emotional stress, social stress, conflicts/pressure, fatigue, lack of energy, physical complaints, disturbed breaks, emotional exhaustion, injury) and recovery (physical recovery, general well-being, sleep quality, being in shape, personal accomplishment, self-efficacy, self-regulation; Kellmann, 2010). Participants rated frequency of each item during past 3 days on a scale ranging from 0 (never) to 6 (always). Cronbach's alphas were of 0.94 and 0.90 for stress and recovery, respectively.

The French version of the Athlete Burnout Questionnaire (ABQ: Isoard-Gautheur et al., 2010) comprised three subscales assessing reduced accomplishment, sport devaluation, and emotional/physical exhaustion. Participants responded on a 5-point Likert scale ranging from 1 (almost never) to 5 (most of the time). Cronbach's alphas ranged from 0.66 to 0.89 (for the two measurement times).

Procedure

The research was approved by the National table-tennis federation's ethical committee and followed the principles of the Declaration of Helsinki. Permission to contact participants was obtained from the head coaches of each training center. Prior to data collection, written informed consent was gathered from players and their parents. Firstly, participants completed the ABQ, CICS and RESTQ-Sport on the half of the competitive season (Time 1, T1) during which "athletes must cope with ever-increasing social, psychological and physiological demands" (Martinent et al., 2014b, pp. 1651). Secondly, participants completed the ABQ 3 months later, at the end of the competitive season (Time 2, T2).

Data analyses

A multilevel analysis approach allowed exploring relationships between study variables. Multilevel models extend multiple regressions to nested (hierarchically structured) data (Vacher et al., 2017). Considering hierarchical structure of the data (Level 1: individuals; Level 2: training groups) allowed unbiased estimates of the parameters (Singer and Willett, 2003). All the analyses were computed using the lme4 package of R. Firstly, the intra-class correlations were examined in computing the null models for the three dimensions of athlete burnout at T2 (i.e., dependent variables of the present study). Secondly, we ran a series of multilevel models in which burnout symptoms at T2 were regressed onto levels 1 and 2 coping and recovery-stress states controlling for levels 1 and 2 burnout symptoms at T1. Group mean centering was used for all Level 1 predictors whereas grand mean centring was used for Level 2 predictors based on the rationale no centering may produce biased point estimates (Doron and Martinent, 2016).

Results

Descriptive statistics are presented in Table 1. The systematic within-and between-individual variance in the T2 athlete burnout dimensions were computed using the null models (see Table 2). Results indicated that there was substantial level 1 (individual) and level 2 (training group) variance: σ^2 (i.e., variance in level-1 residual) ranged from 0.49 to 0.87 whereas τ_{00} (i.e., variance in

TABLE 1 Descriptive statistics of the study variables.

	Mean	Standard deviation
Time 1 Stress	1.82	0.80
Time 1 Recovery	3.64	0.74
Time 1 Task-oriented coping	2.85	0.57
Time 1 Distraction-oriented coping	2.00	0.64
Time 1 Disengagement-oriented coping	2.05	0.72
Time 1 Reduced accomplishment	2.45	0.72
Time 1 Emotional/Physical Exhaustion	1.80	0.89
Time 1 Sport devaluation	3.09	0.88
Time 2 Reduced accomplishment	2.40	0.72
Time 2 Emotional/Physical Exhaustion	2.92	0.98
Time 2 Sport devaluation	1.73	0.78

TABLE 2 Results of the null models.

Model equations	Fixed effects	Random effects		−2*log likelihood
	γ_{00} (ES)	σ^2 (SD)	τ_{00} (SD)	
Reduced accomplishment = $\beta_0 + r$	2.40*** (0.07)	0.49 (0.70)	0.02 (0.15)	301.2
Physical and emotional exhaustion = $\beta_0 + r$	2.95*** (0.11)	0.87 (0.93)	0.08 (0.28)	384.3
Sport devaluation = $\beta_0 + r$	1.71*** (0.08)	0.57 (0.76)	0.03 (0.18)	323.7
$\beta_{0j} = \gamma_{00} + U_{0j}$				

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. SE, standard errors; SD, standard deviations; β_{0j} is the average level of burnout symptoms for individuals; γ_{00} = is the group mean of burnout symptoms; σ^2 = var. (r_{ij}) variance in level-1 residual (i.e., variance in r_{ij}); τ_{00} = var. (U_{0j}) variance in level-2 residual (i.e., variance in U_{0j}); ***$p < 0.001$.

level − 2) ranged from 0.02 to 0.08. Thus, the intra-class correlations (ICC = $\tau_{00}/(\tau_{00} + \sigma^2)$) revealed that level 2 variance represented 4–8% to the total variance whereas level 1 variation accounted for 92–96% to the total variance of the athlete burnout symptoms (Table 2).

Not surprisingly, the largest effects of multilevel models were observed for the effects of T1 levels 1 and 2 burnout on the same burnout variable at T2 ($0.42 \geq \beta \geq 1.78$; Table 3). Of greater interest, when T1 levels 1 and 2 stress, recovery, and coping (TOC, DsOC, and DgOC) were simultaneously entered as predictors of each of the three burnout symptoms (physical and emotional exhaustion, sport devaluation, reduced accomplishment) at T2 (controlling for levels 1 and 2 burnout at T1), the results revealed that: (a) T1 level 1 recovery significantly negatively predicted T2 reduced accomplishment ($\beta = -0.23$, $p = 0.03$); (b) T1 level 2 DgOC significantly negatively predicted T2 reduced accomplishment ($\beta = -0.71$, $p = 0.03$); and (c) T1 level 2 TOC marginally significantly positively predicted T2 physical and emotional exhaustion ($\beta = 0.99$, $p = 0.06$; Table 3).

Discussion

The fact that stress did not significantly predicted athlete burnout suggested that rather than annihilating the stress inherent to competitive sport, it seems more useful to help athletes recovering and/or coping with stress to reach an individual biopsychosocial balance able to prevent the fostering of burnout symptoms. In this perspective, it seems particularly useful to examine the role of theoretical constructs able to buffer the maladaptive effects of chronic (prolonged) stress. Indeed, as hypothesized and confirming previous literature (Kellmann et al., 2018), T1 level 1 recovery significantly and negatively predicted T2 reduced accomplishment. Results also provided evidence of the role of coping in the prediction of burnout symptoms. In particular, T1 level 2 DgOC significantly negatively predicted T2 reduced accomplishment whereas T1 level 2 TOC marginally significantly positively predicted T2 physical and emotional exhaustion. These two results are in contrast with cross-sectional (Nicholls and Polman, 2007; Doron and Martinent, 2017) and longitudinal (Madigan et al., 2020; Pires and Ugrinowitsch, 2021) literature showing that DgOC is generally related to dysfunctional athletes' outcomes whereas TOC is associated with functional athletes' outcomes. As such, future research should test again the prospective relationships between coping and athlete burnout to see whether the present results emerge in other samples, or whether there were results specific to the current sample.

Of particular importance in the context of the present study, results of the multilevel analyses provided evidence for the usefulness to disentangle the variances attributable to the individual (level 1) and contextual (level 2; training group) levels of the predictors (recovery, stress and coping) of athlete burnout. From an applied perspective, these results might help psychologists and consultants to prevent detrimental psychological outcomes related to burnout. Based on the rationale that only level 1 recovery (but not level 2) significantly predicted burnout symptoms, coaches of intensive training centers of young elite table tennis players had to prioritize individual recovery strategies to ensure an effective biopsychosocial adjustment leading to athletes' performance, health and well-being (Nicolas et al., 2022). In contrast, results of the present study showed that only level 2 coping (but not level 1) significantly predicted burnout symptoms. As such, sport psychologists should mainly work on collective or shared coping strategies used by table tennis players within the training group in order to optimize the coping process of youth athletes involved in intensive training centers.

Given the specificity of our sample, future research is needed to replicate the present findings with athletes from different ages, sports, levels or other achievement fields (work). Otherwise, only few significant relationships were observed between stress, recovery, coping and athlete burnout. Nevertheless, it is

TABLE 3 Results of the multilevel models.

Model equations	Fixed effects													Random effects		−2*log likelihood
	γ_{00} (SE)	γ_{01} (SE)	γ_{02} (SE)	γ_{03} (SE)	γ_{04} (SE)	γ_{05} (SE)	γ_{06} (SE)	γ_{07} (SE)	γ_{08} (SE)	γ_{09} (SE)	γ_{10} (SE)	γ_{11} (SE)	γ_{12} (SE)	σ^2 (SD)	τ_{00} (SD)	
T2ReducedAccomplishment = $\beta_0 + \beta_1$StressL1 + β_2StressL2,β_3RecoveryL2 + β_4RecoveryL1 +	2.42***	0.19	0.04	0.71	−0.23*	−0.36	−0.00	−0.10	0.07	−0.72*	0.00	1.78***	0.42***		0.00	223.2
β_5TOCL2 + β_6TOCL1 + β_7DsOCL2 + β_8DsOCL1 + β_9DgOCL2 + β_{10}DgOCL1 +	(0.05)	(0.23)	(0.01)	(0.67)	(0.11)	(0.35)	(0.12)	(0.04)	(0.01)	(0.33)	(0.11)	(0.50)	(0.01)	0.30	(0.00)	
β_{11} T1ReducedAccomplishmentL2 + β_{12}T1ReducedAccomplishmentL1 + r														(0.54)		
T2SportDevaluation = β_{0j} + β1StressL1 + β_{2j} StressL2,β_3RecoveryL2 + β_4RecoveryL1+	1.77***	0.23	0.15	0.40	−0.10	−0.86	0.17	0.02	−0.07	0.04	0.02	0.50¥	0.45***	0.35	0.00	248.0
β_5TOCL2 + β_6TOCL1 + β_7DsOCL2 + β_8DsOCL1 + β_9DgOCL2 + β_{10}DgOCL1 + β_{11}T1SportDevaluationL2+	(0.05)	(0.25)	(0.10)	(0.53)	(0.11)	(0.55)	(0.14)	(0.37)	(0.11)	(0.30)	(0.11)	(0.27)	(0.08)	(0.59)	(0.00)	
β_{12}T1SportDevaluationL1 + r																
T2Emotional/PhysicalExhaustion = β_{0j} + β_1StressL1 + β_2StressL2,β3RecoveryL2 + β_4RecoveryL1 + β_5TOCL2 +	2.92***	−0.36	0.03	−0.86	−0.02	0.99¥	0.14	−0.14	−0.09	0.12	0.10	0.82***	0.56***	0.58	0.00	317.1
β_6TOCL1+ β_7DsOCL2 + β_8DsOCL1 + β_9DgOCL2 + β_{10}DgOCL1 + β_{11}T1Emotional/PhysicalExhaustionL2 +	(0.07)	(0.36)	(0.14)	(0.68)	(0.15)	(0.53)	(0.17)	(0.42)	(0.14)	(0.36)	(0.14)	(0.28)	(0.09)	(0.76)	(0.00)	
β_{12}T1Emotional/PhysicalExhaustionL1 + r																
$\beta_{0j} = \gamma_{00} + U_{0j}$; $\beta_{1j} = \gamma_{10} + U_{1j}$; $\beta_{2j} = \gamma_{20} + U_{2j}$; $\beta_{3j} = \gamma_{30} + U_{3j}$; $\beta_{4j} = \gamma_{40} + U_{4j}$; $\beta_{5j} = \gamma_{50} + U_{5j}$; $\beta_{6j} = \gamma_{60} + U_{6j}$; $\beta_{7j} = \gamma_{70} + U_{7j}$; $\beta_{8j} = \gamma_{80} + U_{8j}$; $\beta_{9j} = \gamma_{90} + U_{9j}$; $\beta_{10j} = \gamma_{100} + U_{10j}$; $\beta_{11j} = \gamma_{110} + U_{11j}$; $\beta_{12j} = \gamma_{120} + U_{12j}$																

¥$p < 0.06$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. SE, standard errors; SD, standard deviations; TOC, task-oriented coping; DsOC, distraction-oriented coping; DgOC, disengagement-oriented coping; γ_{00} = intercept of level-2 regression predicting; β_{0j}; γ_{10}, γ_{20}, γ_{30}, γ_{40}, γ_{50}, γ_{60}, γ_{70}, γ_{80}, γ_{90}, γ_{100}, γ_{110}, γ_{120} = intercept of level-2 regression predicting β_{1j}, β_{2j}, β_{3j}, β_{4j}, β_{5j}, β_{6j}, β_{7j}, β_{8j}, β_{9j}, β_{10j}, β_{11j}, β_{12j}. ¥$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

noteworthy that T1 level 1 and 2 athlete burnout were controlled in the prediction of T2 athlete burnout. Another explanation refers to the timing of data gathering of athlete burnout (3 months between the two times). Because athlete burnout is considered to be an enduring phenomenon, substantial time could be needed to note changes (Martinent et al., 2014b). Thus, the present study could be replicated across the entire competitive season. Common method bias might have distorted the findings as all the study variables were measured using a single source of data (self-report questionnaires). Future research should complement self-report questionnaires with objective (e.g., performance data) or physiological indicators of overtraining (e.g., heart rate variability).

In conclusion, our investigation has shed light new insights on the athlete burnout literature in providing evidence for the usefulness to disentangle the variances attributable to the individual (level 1) and contextual (level 2; training group) levels of the predictors (recovery, stress and coping) of athlete burnout. Moreover, results of the present study highlighted that rather than examining the antecedent role of stress on athlete burnout, it could be particularly fruitful to explore theoretical constructs able to annihilate the maladaptive effects of chronic (prolonged) stress such as coping and recovery. Finally, the present study provided further evidence of the usefulness to examine the social nature of coping processes when athletes (individual or team sports) deal with shared challenges and demands within a training group.

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by French table-tennis federation's ethical committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

GM: conceptualization, methodology, investigation, and writing—original draft preparation. VC: formal analysis. GM, VC, EG-D: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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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Association between perceived exertion and executive functions with serve accuracy among male university tennis players: A pilot study

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Serve in tennis is a very important strokes and is positively correlated with the rankings of the Association of Tennis Professionals ranking. This study investigated the associations between time-course changes in the ratings for perceived exertion, executive function, and second serve accuracy during 30-min tennis exercise sessions. Eleven Japanese male tennis players participated in the study, and their executive function and second serve performance were evaluated using the paper version of the Stroop Color and Word Test, followed by a serve performance test. The participants took part in a 30-min tennis exercise program and performed the Stroop Color and Word Test, heart rate (HR) check, and second serve accuracy test before and after the tennis exercise. Pearson correlation was used to determine the relationships between the ratings for perceived exertion, interference scores on Stroop Color and Word Test performance, and second serve performance. Post exercise, the rating of perceived exertion tended to correlate with serve accuracy (r=−0.57, p=0.07) and interference score (r=0.65, p=0.03). The pre-to-post changes in second serve accuracy were negatively associated with the changes in interference score (r=−0.54, p=0.08) and interference score in the posttest (r =−0.73, p=0.01). The results suggest that time-course changes in executive function when playing tennis are positively associated with the accuracy of the second serve. These findings expand the previous knowledge regarding the positive association between time-course changes in executive functions and percentage of points won when playing tennis by including more specific skills (i.e., second serve accuracy).

KEYWORDS

cognitive function, physical exertion, racquet sports, sports performance, second serve

1. Introduction

There is a positive association between sports performance and cognitive function at rest (Vestberg et al., 2012; Alexandru et al., 2014; Sakamoto et al., 2018; Ishihara et al., 2019). This line of literature focused on executive functions, which include goal-directed cognitive processes that coordinate and regulate thought and action. For example, previous findings suggested that greater executive function at rest predicts future success in tennis (Ishihara et al., 2019) and soccer (Vestberg et al., 2012; Sakamoto et al., 2018). However, studies on the association between time-course changes in executive function and performance while playing sports is scarce. Since executive function is altered by acute exercise (Ishihara et al., 2021), evidence of the association between executive function and sports performance during matches will benefit players and their coaches.

Ishihara et al. (2018) investigated the relationship between match statistics variables and executive function in singles tennis matches. The findings showed that executive function evaluated during matches was positively correlated with the percentage of points won. Additionally, executive function during tennis singles matches was inversely correlated with perceived exertion. However, this previous study focused on relationship between tennis match analysis and cognitive function, and the possible association between time-course changes in executive function and more specific skills remains unclear.

A serve refers to one of the strokes the players can hit at their own time, and this behavior is called self-paced. It is classified into categories similar to those of pitching in baseball, bowling, golfing, and running. However, the action affected by the opponent's movement is called externally paced. Soccer, basketball, and volleyball are classified in a similar category (Singer, 2000). Functions that support higher cognitive functions such as decision-making, problem solving, and inhibitory control are called executive functions, and exercise has a particularly strong association with executive functions (Diamond, 2013). Jacobson and Matthaeus (2014) examined the characteristics of executive function (e.g., decision-making, problem solving, and inhibitory control) of an externally paced athlete, a self-paced athlete, and a non-exercising college student. They reported that inhibitory control is more important in a self-paced athlete compared to externally paced athletes and non-exercising college students. Furthermore, among self-paced athletes, those with high athletic performance have high inhibitory control. Inhibitory control is the ability to control attention, behavior, thought, and emotion to suppress unnecessary information inside or outside as well as selectively focus on important information (Diamond, 2013). In tennis competitions, athletes must ensure that the second serve stays within the service box. Therefore, the second serve is a shot focusing on accuracy. When players hit the second serve, it is necessary to suppress the unnecessary attention on audiences and opponents and pay attention to the service box. Therefore, inhibitory function is significant in the accuracy required for the second serve.

In modern tennis, competitive players must maintain their serve quality throughout the game to win a match. Serves account for 45, 60, and 56% of all strokes played during service games in the French Open, Wimbledon, and US Open, respectively (Johnson et al., 2006). Furthermore, the numbers of aces, valid first serves, and second serve points won were associated with winning the match in the Association of Tennis Professionals (ATP) dataset includes 18,288 performances from 9,144 matches involving 845 players held between 1991 and 2008 (Ma et al., 2013). Moreover, the number of double faults in the Grand Slam has been decreasing year by year (Cross and Pollard, 2009). Winning the point on the second serve ($r = -0.64$) is more related to higher ATP rankings than winning the point on the first serve ($r = -0.28$; Reid et al., 2010). Considering the importance of second serve performance in winning tennis matches, examining the contribution of executive function to second serve performance during matches warrants clarification. Hence, this study investigated the associations among time-course changes in the rating of perceived exertion, executive function, and second serve accuracy during 30-min tennis exercise sessions.

Abbreviations: HR, Heart rate; %HRR, Preliminary heart rate; RPE, Rating of perceived exertion; RT, Reaction time; SD, Standard deviation; SCWT, Stroop Color and Word Test.

2. Methods

2.1. Subjects

Eleven men participated in this study, including seven from the All Japan Student Tennis Championship (mean [range]: age: 23.1 years [19–30]; height: 175.5 cm [166.8–183.0]; weight: 65.1 kg [53.8–74.0]). The All Japan Student Tennis Championship is a tournament open only to the top few winners of the regional qualifying rounds in each prefecture. Therefore, the participants are athletes with high skill levels. All of them were right-handed. Participants provided written informed consent in accordance with the requirements of the Hokusho University Research Ethics Committee (HOKUSHO-UNIV:2020-006). This study was approved by Hokusho University Research Ethics Committee. They were instructed to consume their daily intake on the day before and the day of the exercise, avoid alcohol intake the day before the exercise, and avoid caffeine and smoking on the day of the exercise.

2.2. Experimental protocol

Participants were asked to remain quiet upon arriving at the experimental site. They wore a heart rate (HR) monitor. After resting for 5 min, resting heart rate was measured and resting executive function was then measured at pre training exercise. After completing the executive function measurement, participants performed a normal warm-up, subsequently the first second serve accuracy test was performed. Participants undertook 30 min of training exercise (10 min ground strokes vs. ground strokes rally, with 20 min volley vs. strokes rally). Our preliminary experiments have demonstrated that this 30-min exercise, which is a habitual practice in tennis, can be performed with relatively high intensity. This exercise was used in the present study to examine the relationship between service accuracy and executive function under conditions that were less stressful than the actual match (removing the tactical component). They were allowed unlimited water intake every 10 min during the exercise. The rating of perceived exertion (RPE) was measured immediately post the exercise using the Borg scale. After 30 min of training exercise, the executive function and the second serve accuracy test at post training exercise were measured following the same procedure as that at pre training exercise.

2.3. Measurement

2.3.1. Executive function assessment

Participants' basic cognitive processing and inhibitory control were assessed using a modified version of the Stroop Color and Word Test (SCWT; Stroop, 1935), that comprises two trials (congruent and incongruent). The stimuli used in the congruent trials were four colored patches (red, yellow, green, and blue). The incongruent trials used color names as stimuli, where the color of the text did not match the named color (e.g., the word "BLUE" was printed in yellow). The stimuli for each task appeared on a gray background. For the congruent condition, 48 patches (vertical 8 × horizontal 6) were printed in red, green, blue, or yellow at random. All participants read these patches. For the incongruent condition, the words "RED," "GREEN," "BLUE," or "YELLOW" were printed in an incongruent color on 48 patches. The word stimuli were presented in Japanese.

Participants were required to quickly respond to the two conditions. The main variables were the differences in the two conditions (*Interference score* in reaction time [RT] and correct reactions), using the mean RT and correct reactions of each trial, which were calculated as follows (Scarpina and Tagini, 2017):

$$\text{Interference score} = (\text{incongruent} - \text{congruent}) / \text{congruent} \times 100.$$

The interference score is evaluated as the amount of interference increases when the numerical value increases. This amount of interference evaluates the inhibitory control at SCWT, and if the value increases before and after exercise, it can be considered that the inhibitory function has decreased. In this study, we examined time-course change in interference score pre and post exercise.

2.3.2. Rating of perceived exertion

The rating of perceived exertion (RPE) was measured immediately post the exercise using the Borg (1982) scale. After the exercise, participants were asked, "How difficult was the exercise?" The Borg scale assessed their perceived physical exertion on a scale of 6 to 20.

2.3.3. Heart rate

HR was measured using a Heart Trainer (Konami, Japan). Exercise intensity was calculated from the preliminary HR (%HRR) using the HR pre and post the exercise:

$$\text{Maximum HR} = 220 - \text{Age}$$

$$\%\,\text{HRR} = (\text{HR} - \text{resting HR}) / (\text{maximum HR} - \text{resting HR}) \times 100.$$

2.3.4. Serve accuracy performance test

Serve accuracy is determined by counting the number of times the ball landed within the designated target zone —that is, serves that landed in a hitting area located in the back-right region of the service box (1.07 m × 1.07 m, the height of singles sticks; see Figure 1; Kuroda et al., 2016). This test used only the deuce side and required the players to hit 20 trial second serves. The serve accuracy performance test was performed before and after the exercise, and the success of each serve was decided by two referees who were tournament-level tennis players. In this study, we examined time-course change in serve accuracy pre and post exercise.

$$\begin{aligned}&\text{Change in serve accuracy}\\&= \text{serve accuracy performance test at post exercise}\\&- \text{serve accuracy performance test at pre exercise}\end{aligned}$$

2.3.5. Statistical analysis

The results of the normality test were $p < 0.18$ and $p < 0.34$ for the Kolmogorov–Smirnov and Jarque-Bera tests, respectively. The time-dependent change in each measurement item was analyzed using a paired *t*-test. Effect sizes are shown in Cohen's d. Serve accuracy and cognitive functions, as well as their relationship with other measurement items, were evaluated using Pearson's correlation coefficient. The statistical significance was defined as $p < 0.05$. Given the sample size of 11 participants and a power = 0.80, the present study theoretically had sufficient sensitivity to detect an effect size exceeding $r = 0.68$ for the variance explained by each variable in the regression analysis (G*Power 3.1; Faul et al., 2007, 2009).

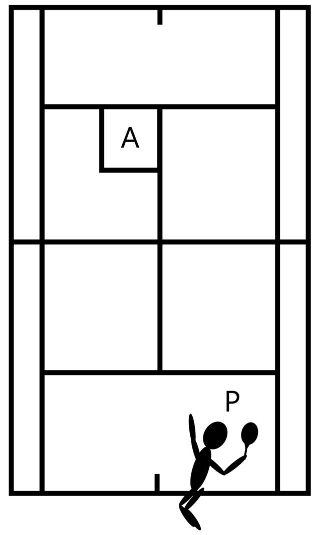

FIGURE 1
Serve accuracy. The subjects served 20 times from point P to the left side of the serve box, aiming at target A. Serve accuracy was determined as the number of serves that successfully hit target A out of 20 serves. The players hit their second serves at match pace [A: target zone [1.07m×1.07m]; P: the player].

3. Result

The intensity of the exercise, result of SCWT, and second serve accuracy are presented in Table 1.

3.1. Rating of perceive exertion and HR

The participants' average rating of perceive exertion was 15.4 immediately post the exercise (standard deviation [SD] = 1.8) as measured on the Borg scale. The mean HR were 68.7 ± 9.9 bpm and 147.1 ± 16.9 bpm at pre and post exercise, respectively. The mean percentage of HRR calculated was 51.7 ± 11.5%.

3.2. Executive function

The mean SCWT RTs in the congruent trials were 22.8 s (SD = 3.4) pre exercise and 21.2 s (SD = 3.3) post exercise, which were significantly different [$t(10) = 2.52$, $p = 0.03$, Cohen's d = 0.50]. The mean SCWT RTs in the incongruent trials were 32.3 s (SD = 5.1) pre exercise and 31.6 s (SD = 6.4) post exercise, which were also not significantly different [$t(10) = 0.57$, $p = 0.57$, Cohen's d = 0.14]. Additionally, interference score at pre and post were 42.2% (SD = 15.0) and 49.0% (SD = 16.0), respectively; which did not change significantly [$t(10) = -1.29$, $p = 0.23$, Cohen's d = −0.44; Table 1].

The rate of correct reactions in the congruent trials pre and post exercise were 96.2 (SD = 3.3) % and 91.5 (SD = 4.7) %, respectively; which did not change significantly [$t(10) = 1.15$, $p = 0.27$, Cohen's d = 0.29]. The rate of correct reactions in the incongruent trials pre and post exercise were 95.1 (SD = 4.3) % and 85.6 (SD = 7.4) %, respectively,

TABLE 1 The intensity of the exercise, result of SCWT, and second serve accuracy.

	Pre		Post	
	Mean±SD	Range	Mean±SD	Range
Stroop color word task				
Congruent condition reaction time (sec)	22.8 ± 3.4	17.8–29.0	21.2 ± 3.3	17.5–29.8
Congruent condition correct reactions (%)	96.2 ± 3.3	89.6–100	95.1 ± 4.3	85.4–100.0
Incongruent condition reaction time (sec)	32.3 ± 5.1	23.3–39.7	31.6 ± 6.4	22.7–45.9
Incongruent condition correct reactions (%)	91.5 ± 4.7	85.4–97.9	85.6 ± 7.4	70.8–93.8
Interference score reaction time (%)	42.2 ± 15.0	18.4–64.7	49.0 ± 16.0	23.8–71.1
Interference score correct reactions (%)	-4.9 ± 4.2	−12.8–0.0	−10.0 ± 6.6	−23.4–2.3
Serve accuracy performance test				
2nd serve accuracy (times)	6.0 ± 1.3	5.0–8.0	5.4 ± 2.1	3.0–10.0

constituting a significant decrease post exercise [$t(10) = 3.76$, $p = 0.004$, Cohen's d = 0.95]. The interference scores at pre and post exercise were-4.9% (SD = 4.2) and-10.0% (SD = 6.6), respectively, constituting a significant change post-exercise [$t(10) = 2.57$, $p = 0.03$, Cohen's d = −0.44; Table 1].

3.3. Serve accuracy

The number of times the ball landed within the designated target pre and post exercise were 6.0 times (SD = 1.3) and 5.4 times (SD = 2.1), respectively. Thus, serve accuracy did not differ significantly pre and post exercise, and seven of the 11 players had decreased accuracy in their serves post the exercise [$t(10) = 0.78$, $p = 0.45$, Cohen's d = 0.37].

3.4. Relationship between RPE, interference score, and serve accuracy

The relationship between RPE, interference score and serve accuracy are presented in Table 2. RPE post exercise tended to negatively correlate with serve accuracy ($r = -0.57$, $p = 0.07$; Figure 2A) and interference score of RT at post exercise ($r = 0.65$, p = 0.03; Figure 2B). The pre-to-post changes in second serve accuracy were negatively associated with the changes in interference score of RT ($r = -0.54$, $p = 0.08$; Figure 3A) and interference score of RT in the post exercise ($r = -0.73$, $p = 0.01$; Figure 3B).

4. Discussion

This study aimed to investigate the relationship between second serve accuracy and executive function in college tennis players. The results showed no significant change in RT in the congruent and incongruent conditions of the SCWT before and after the exercise. The rate of correct reactions did not change significantly in the congruent condition prior to and post the exercise, however they decreased significantly in the incongruent condition. Changes in second serve accuracy were negatively correlated with changes in interference score and interference score post the exercise.

4.1. Exercise intensity during exercise

Tennis players run approximately 8–15 m for one point and 3 m for each shot, on average, equating to a total of 1,300–3,600 m during a 1-h exercise session (Fernandez-Fernandez et al., 2009). Thus, tennis is a high-intensity activity. In this study, exercise intensity during exercise was evaluated using percentage of HRR, while the Borg scale was used to assess subjective exercise intensity. Additionally, rather than increasing the RPE using a match, physical exercise load was manipulated using tennis-specific exercise. The average subjective exercise intensity in previous studies using the Borg scale in actual tournaments and simulated games ranged from 11 ("light") to 15 ("somewhat hard"), with a peak value of 17 ("very hard"; Mendez-Villanueva et al., 2007). The average value for subjective exercise intensity using the Borg scale was 14.4 post 60 min of exercise, with a peak value of 18 and a trough value of 12. Therefore, this study replicated the exercise intensity in a previous study that used tennis matches (Mendez-Villanueva et al., 2007).

4.2. Changes in result of SCWT pre and post exercise

RTs in the congruent and incongruent conditions did not change significantly between pre and post exercise conditions. However, the rate of the correct reactions index was significantly poorer. When completing this task, the participants were instructed to respond as quickly and accurately as possible. If participants had focused on providing all accurate responses, we may have observed no change in the number of wrong answers; however, their RTs may have been delayed. However, in this study, the participants may have focused on quick responses, and therefore, the number of wrong reactions increased as they could not make accurate judgments.

Brown and Bray (2015) reported that an increase in exercise intensity increased the number of false responses on the SCWT. Similarly, the results demonstrated the exercise was likely to have increased the number of false responses. Kamijo et al. (2004) reported an inverse U-shaped relationship between subjective exercise intensity and cognitive function. This previous study, using event-related brain potentials, reported that brain activity decreased during high-intensity exercise, and it may have occurred in the current exercise too.

TABLE 2 Relationship between RPE, interference score, and serve accuracy.

	Interference score RT at pre exercise	Interference score RT at post exercise	Change in interference score RT	Interference score correct reactions at pre exercise	Interference score correct reactions at post exercise	Change in interference score correct reactions	Serve accuracy at pre exercise	Serve accuracy at post exercise	Change in serve accuracy	HR at pre exercise	HR at post exercise	HRR	RPE
Interference score RT at pre exercise	–												
Interference score RT at post exercise	0.37	–											
Change in interference score RT	−0.52^{+}	0.60*	–										
Interference score correct reactions at pre exercise	−0.42	−0.34	0.05	–									
Interference score correct reactions at post exercise	−0.36	−0.44	−0.10	0.33	–								
Change in interference score correct reactions	−0.09	−0.23	−0.13	−0.31	0.80**	–							
Serve accuracy at pre exercise	0.17	0.70*	0.50	−0.10	0.07	0.14	–						
Serve accuracy at post exercise	−0.08	−0.51	−0.40	0.39	0.42	0.18	−0.22	–					
Change in serve accuracy	−0.15	−0.73*	−0.54^{+}	0.35	0.29	0.07	−0.65*	0.89**	–				
HR at pre exercise	−0.30	0.18	0.42	0.39	0.47	0.23	0.48	0.25	−0.03	–			
HR at post exercise	0.58^{+}	0.64*	0.09	−0.38	−0.53^{+}	−0.30	0.36	−0.47	−0.54^{+}	0.12	–		
HRR	0.64*	0.60^{+}	0.00	−0.46	−0.66*	−0.37	0.25	−0.56^{+}	−0.56^{+}	−0.16	0.96**	–	
RPE	0.48	0.65*	0.18	−0.60*	−0.90**	−0.52	0.04	−0.57^{+}	−0.47	−0.41	0.67*	0.77**	–

**$p < 0.01$; *$p < 0.05$; $^{+}p < 0.10$.

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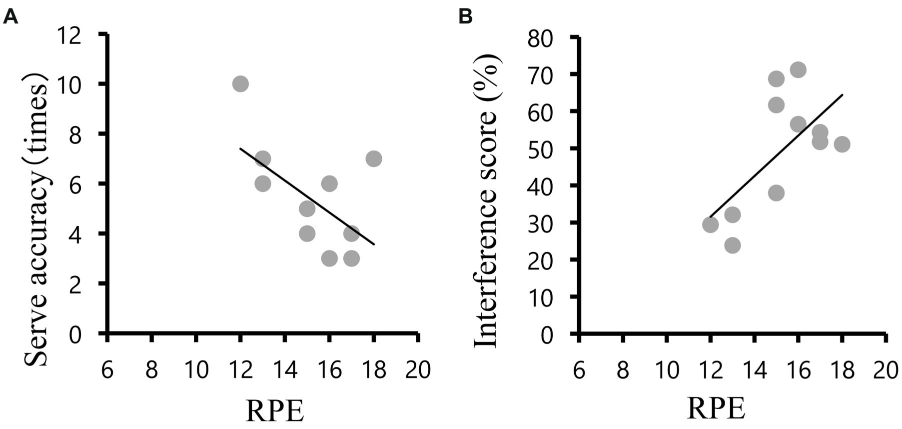

FIGURE 2
(A) An inverse correlation was detected between post-exercise serve accuracy and post-exercise rating of perceived exertion (r=−0.57, p=0.07). **(B)** A correlation was detected between post-exercise reaction time in the Stroop Color and Word Test and post-exercise rating of perceived exertion (r=0.65, p=0.03).

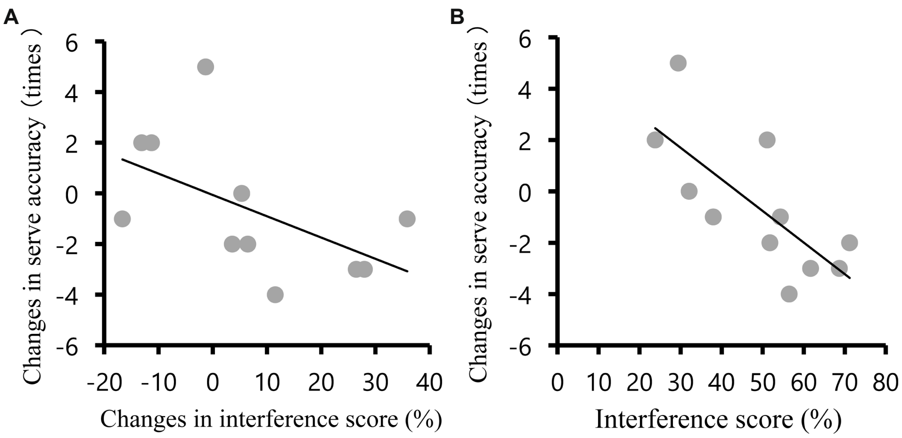

FIGURE 3
(A) The pre-to-post changes in second serve accuracy were negatively associated with the changes in interference score of RT in the posttest (r=−0.54, p=0.08). **(B)** The pre-to-post changes in second serve accuracy were negatively associated with the interference score of RT in the posttest (r=−0.73, p=0.01).

Additionally, the behavioral indices used in our study, such as RT of cognitive function and the number of wrong answers, only infer the information processing in the brain, and it is difficult to clearly separate whether the factor is related to the cognitive processing process or the response processing process. However, Hornery et al. (2007) reported that reproducibility of the serve action (e.g., position of the arm releasing the ball and of the ball) decreased with the passage of time. Similarly, the results demonstrated increased subjective exercise intensity may have affected the cognitive function, which in turn may have affected the response and processing process (e.g., serve movement).

4.3. Relationship between RPE, interference score, and serve accuracy

The change in the second serve accuracy before and after the exercise was negatively correlated with the interference score of RT and its change post-exercise. The results indicate that the change in the second serve accuracy decreased as the RT was delayed in the incongruent condition compared to the congruent condition. Therefore, the execution function may be one of the factors affecting the change in second serve accuracy.

In a previous study, athletes with higher subjective exercise intensity had lower second serve accuracy (Kuroda et al., 2016). Their second serve accuracy may have been influenced by physiological and psychological factors that the athlete experienced during the competition. Kuroda et al. (2016) examined the relationship between second serve accuracy and results of a grip strength test (muscle strength), spider run test (agility), and subjective evaluation (subjective feeling of fatigue and subjective exercise intensity) of university student tennis athletes. They reported that muscle strength and agility had no relationship with second serve accuracy, and they found a negative correlation with subjective exercise intensity. Additionally, Davey et al. (2002) found that the Loughborough test reduced stroke accuracy by 69% at exhaustion. Lyons et al. (2013) found that the Loughborough test (RPE = 18) reduced stroke accuracy by 40% at expert players and reported a 40% decrease in stroke accuracy with the Loughborough test (RPE = 18), and a decrease in athletic performance with increased subjective exercise intensity. Kamijo et al. (2004) reported an inverse U-shaped relationship between subjective exercise intensity and executive function. If the subjective exercise intensity is moderate, the executive function improves, but if subjective exercise intensity is low, the cognitive function may deteriorate. In addition, a recent study reported a relationship between executive function and sports performance (Ishihara et al., 2018). Ishihara et al. (2018) had university student tennis players play a simulated match and examined the relationship between statistics during the match and cognitive function. They showed the relationship between cognitive function and first serve points won as an index in a simulated match. Kuroda et al. (2016) experiment involved exercise in which subjective exercise intensity increased, which may have caused a decline in executive function and affected second serve accuracy. Therefore, it is possible that executive function may be a contributing factor to the poor performance in previous studies (Davey et al., 2002; Lyons et al., 2013).

The greatest strength of this study lies in its design. The present study is one of the few to examine the relationship between cognition and sport performance using a field-based approach. Most research in this area has been conducted in the laboratory. Therefore, this study extends previous findings on the relationship between exercise, cognition, and physical performance found in laboratory settings by suggesting practical applications to sport. Additionally, this study is one of the few to examine the relationship between changes in executive function over time and performance. Evidence indicating an association between executive function during games and sports performance is beneficial for athletes and their instructors.

Future research should examine whether executive function is truly related to athletic performance. Furthermore, we will examine whether improving the resting cognitive function improves tennis performance. It is also necessary to test whether improved resting cognitive function improves tennis performance and whether sustained or facilitative attention contributes to improved tennis performance. The present results provide the following practical implications. Second service accuracy is negatively associated with inhibitory function.

4.4. Limitation

There were only 11 participants. Given the sample size of 11 participants and a power = 0.80, the present study theoretically had sufficient sensitivity to detect an effect size exceeding $r = 0.68$ for the variance explained by each variable in the regression analysis. The main result of this study is the relationship between execution function and serve accuracy. Relevance of pre-to-post changes in second serve accuracy and interference score of RT in the post exercise were robust ($r = -0.73$, $p = 0.01$). However, relevance of the pre-to-post changes in second serve accuracy and the changes in interference score of RT were not robust ($r = -0.54$, $p = 0.08$). Thus, this result may not be applicable depending on the subject's level of tennis competition. Therefore, it may not be possible to obtain robust conclusions from a small sample size. In the future, it is necessary to verify with rigorous, larger samples.

4.5. Conclusion

This study investigated the relationship between second serve accuracy and executive function in college tennis players. The results showed no significant change in RT in the congruent and incongruent conditions of the SCWT pre and post the exercise. The rate of correct reactions did not change significantly in the congruent condition pre and post the exercise, however, they decreased significantly in the incongruent condition. Changes in second serve accuracy were negatively correlated with interference score and its variations post the exercise. Future research should examine the relationship between the execution function and the actions proposed in previous studies that are related to the success of the serve (tossing up the ball) and selection of information (whether the toss position is appropriate for hitting the ball or not). Our results suggest that the time-course changes in executive function when playing tennis are negatively associated with the accuracy of the second serve. Thus, our findings expand previous knowledge regarding the positive association between time-course changes in executive functions and percentages in points won when playing tennis by including more specific skills (i.e., second serve accuracy).

Data availability statement

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

Ethics statement

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

Author contributions

YK, TI, and MM participated in the design of the study and contribute to data collection and data analysis. YK contributed to writing manuscript, contributed to tennis competitive performance data collection, and contributed to the tennis competitive performance test design and interpretation of the results. TI contributed to executive function data collection. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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