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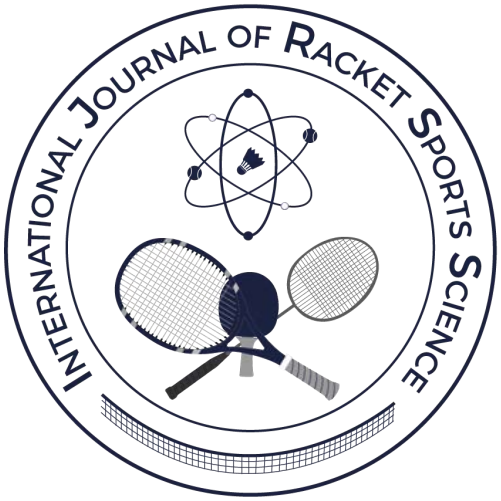

June, 2020

It is a privilege to be given the opportunity to introduce the first issue of Volume 2. A second volume of the Journal necessarily implies some success, as it represents a continuation of academic endeavour associated with racket sports. It is therefore also an opportunity to reflect on the progress of the Journal so far.

The first volume contained papers that covered a range of sports science topics applied to racket sports. This, combined with the high academic standard of these papers is evidence that the Journal is meeting its ultimate goal which is

> … to create a platform for collaboration and cooperation among researchers, where sport scientist can come together and join forces to come up with new perspectives from where to keep expanding the knowledge involving all areas within the field of racket sports. (Cabello, M. D., 2019, Editorial)

It has done this by adopting a rigorous editorial and review process. The high standard of submissions has been achieved by a process which involves initial screening, blind review by two or more experts in the field, amendment of the manuscript by the authors as guided by an associate editor, and finally editorial corrections to ensure consistency in production and use of language. The Editorial Board are proud that they are also able to provide guidance and support to papers that have an important message to convey, but lack some aspect of presentation that would hinder their progress through this demanding process.

Of course, the editorial process could not have been developed without the commitment and support of a number of people and grateful thanks are given to all associated with it. From the guiding influence of the Editor in Chief, through the expertise of the Associate Editors, to the responsiveness and professionalism of those asked to review papers. The final publication would not have been possible without the dedication of the publishing team, guided with tremendous energy, enthusiasm and skill by David Gutierrez Parejo at Granada University, Spain.

It would be remiss not to mention that this issue of Volume 2 is published during a global pandemic. The health issues that have resulted are, of course, regretted, but it is the effect of the related 'lockdown' that has, and will, influence the work of scientists in racket sports. The well-developed electronic communications researchers use nowadays and that the Journal is published online, has meant at this stage there has been little interference in progress. However, we know that the inability to hold tournaments and to meet and interact with players and coaches (both a rich source of data), will have some impact on the nature of research that can be conducted presently, and reported subsequently. We do not know how this might unfold but we are confident that researchers' interest for communicating their findings in a high quality forum will continue and so, we are sure, will the Journal.

Adrian Lees
Associate Editor
International Journal of Racket Sports Science

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Serve analyses of elite European table tennis matches

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Abstract

The purpose of this study was to analyze the serve activities of elite European table tennis players. Twenty matches (78 games, 1466 points) of semifinal and final German League and Europe TOP 16 in men's (in the top 30 of ETTU Rank list) were analyzed. Differences in serving activities (type, stroke type, outcome and placement) were analyzed according results outcome of match, game, point, phase of the game and type of games.

Results showed that forehand short serve prevailed (76.9%) instead other types of serve, mostly placed in the middle of the table on the opponent's backhand side. Percentage of point won directly with serve was 11.6%, points won with 3rd stroke - 22.4% and points won with 5th stroke after serve (10.9%). Lost points after serve mostly were after 3rd stroke (25.0%) and after 5th stroke (22.4%) and serve errors were noted in 1.5% of all analyzed points. In the 3rd phase of the game serve points were won mostly with 3rd and 5th stroke instead previous phases of the game.

Results of Pearson's chi-squared test showed an association between match outcomes and serve type and outcome, serve type and outcome considering phase of the game and different type of games with serve type, outcome and placing zones.

Keywords: *Activity Analyses, Notational Analyses, Player Performance*

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Introduction

Table tennis is a complex sport with a large number of different types of strokes, which become even more specialized or individualized by the type of execution, the intensity, and the tactical goal (Tepper, 2003), However, the serve in table tennis affects the whole rally. The serve in table tennis is the strokes that puts the ball in play and is often referred to as one of the most important strokes in the game, influencing one's scoring or losing tendency. In general, players should take maximum advantage of a service in order to score and this is regarded as the most important challenge for them (Molodzoff, 2008; Geske & Muller, 2010).

High performance table tennis requires observation and measurement to improve knowledge of performance, application of new knowledge to enhance performance (Hughes, Cooper, & Nevill, 2004), so collecting data of strategy and tactics is important, and can help coaches and players to better understand and prepare a strategy for the match (O'Donoghue, 2004; Padulo et al., 2016).

Serve activities already were reported as important indicators of performance in high-ranking table tennis players (Djokic, 2002a, 2002b, 2003; Katsikadelis, Pilianidis, & Mantzouranis, 2013; Zhang, Liu, Hu, & Liu, 2013; Malagoli Lanzoni, Di Michele, & Merni, 2014; Tamaki, Yoshida, & Yamada, 2017; Fuchs et al., 2018; Zhang, Zhou, & Yang, 2018).

Previous research has shown that 80% of rallies in the table tennis matches ends at the fifth stroke, and even if the rally continues, one player is usually in a winning position at that same stroke (McAfee, 2009). Besides, a more recent study confirmed that rallies become shorter (Leite et al., 2017; Djokic, Munivrana, & Levajac, 2016a, 2016b). The application of the most recent service rules as well as the use of new rubbers and plastic balls seem to decrease the efficacy of serve resulting in the shortening of the match (Djokic et al., 2019).

Considering all this as well as the serve impact on the game, there is strong need for permanent analyses and monitoring.

The aim of this study was to analyze the serve activities of elite European table tennis players.

Material and methods

Data sample

Twenty matches (78 games, 1435 points) of semifinal and final German League (season 2018/19 and Europe TOP 16 (2018) in men's competition were analyzed. All players were in the top 30 of ETTU Rank list.

Variables

Performance indicators measured to provide information about the serve activities were:

Serve type:

1) FSHOSE - Forehand short serve (serve that, if allowed, ball would bounce twice on the far side of the table).
2) FLONSE - Forehand long serve (serve, with the second bounce off the table)
3) BSHOSE - Backhand short serve
4) BLONSE - Backhand long serve

Serve outcome:

5) SERDIR - Serve direct point
6) SER3WN - Serve point won after 3rd stroke
7) SER5WN - Serve point won after 5th stroke
8) SER7WN - Serve point won after 7th stroke
9) SER3LS - Serve lost point after 3rd stroke
10) SER5LS - Serve lost point after 5th stroke
11) SERROR - Serve error

Serve placement (Djokic, 2002b):

12) SOUTFH - Outside forehand zone
13) SMIDFH - Middle forehand zone
14) SMIDBH - Middle backhand zone
15) SOUTBH - Outside backhand zone

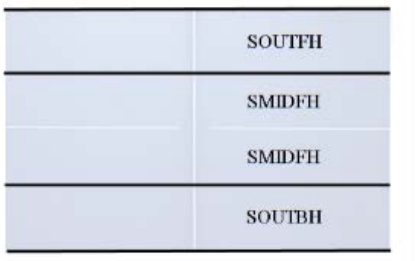

Figure 1. Serve placement zones

Differences in serving activities (type, outcome and placement) were analyzed according to the final results outcome of match, game and point. Also, we considered 3 score periods (phases) in game: from 0 to 4 points as the first phase (e.g. till 4:3), from 5 to 8 the second phase (e.g. from 5:4) and 8 to 11 the third phase (e.g. from 8:5) of the game with the aim to see does the serve activities differ in different part of the game. At the end, according to the game result we analyzed serve activities in three type of games: balanced (2 difference points (e.g. 11:9, 12:10), N = 464), unbalanced (3-5 difference points (e.g. 11:6-11:8), N = 826) and very unbalanced (6 and more difference points (e.g. 11:0-11:5), N = 174).

Procedure

Data were collected by videos of matches available on the official DTTB and ITTF website. The video material allowed the observers during the video analysis to clearly see the players, the table, and the playing area, which allowed a reliable verification of all events during the match. The observer analysed video of the matches in real speed, but in case of certain inconsistencies, they were re-wound and seen in slow motion (0.2 X). Kinovea, a free 2D motion analysis software (player) under GPLv2 license was used. All the data were registered in the specially prepared templates for the analysis of every match (by hand on paper), in which all the analysed variables were coded and after that, the data were input to a Microsoft Excel spreadsheet.

Reliability

In order to ensure a quality of reliability (O'Donoghue & Mayes, 2013), the matches were evaluated by means of intra- and inter-observers. For this research, two expert table tennis coaches were engaged for the role of observers. The intra- and inter-observer reliability is based on the analysis and re-analysis of 20 games randomly selected. Krippendorff's Alpha was calculated to assess data collection reliability (Krippendorff, 2004). The intra-observer reliability analysis showed an Alpha value of 0.995. Inter-observer reliability was assessed reanalysing all the matches by the second analyst.

Statistical analyses

Descriptive statistical parameters (frequencies and percentages) were calculated for all analyzed samples with a consideration of result outcome (winners/losers). A Pearsoń s chi-square test of independence was performed to examine the relation between serve activities and winning matches, with a level of significance of ($\alpha = 0.05$). All the data were analyzed using SPSS 20.0 (IBM Corporation, USA).

Results

Results showed that short forehand serve is the most used kind of service. Complete results of analyses of serve type are shown in Table 1.

Table 1.

Results of analysis of serve type of all sample and according result outcome (winners/losers)

	ALL SAMPLE		WINNERS		LOSERS	
	Frequency	%	Frequency	%	Frequency	%
FSHOSE	1126	76.9	584	80.3	542	74.8
FLONSE	254	17.3	102	14.4	152	20.3
BSHOSE	62	4.2	32	4.6	30	4.5
BLONSE	4	0.3	2	0.7	2	0.4

Based on the results of chi-square test we can state that there was a significant association between winning the match and serve type X2 (2, N=1466) = 11.685, p < 0.20).

The serve outcome in analyzed matches showed that most points were won with the 3rd ball after serving and directly with serve, while most often points were lost after 3rd and 5th stroke. Results of analyses of serve outcome are shown in Table 2.

Table 2.

Results of analysis of serve outcome of all sample and according result outcome (winners/losers)

		ALL SAMPLE		WINNERS		LOSERS	
		Frequency	%	Frequency	%	Frequency	%
Won points	SERDIR	170	11.6	94	12.9	76	10.3
	SER3WN	328	22.4	170	23.3	158	21.5
	SER5WN	160	10.9	92	12.6	68	9.2
	SER7WN	90	6.1	60	8.2	30	4.1
	Total	748	51.1	416	57.1	332	45.1
Lost points	SER3LS	366	25.0	176	24.1	190	25.8
	SER5LS	328	22.4	126	17.3	202	27.4
	SERROR	22	1.5	10	1.4	12	1.6
	Total	716	48.9	312	42.9	404	54.9

Table 3.

Results of analysis of serve placement of all sample and according result outcome (winners/losers)

	ALL SAMPLE		WINNERS		LOSERS	
	Frequency	%	Frequency	%	Frequency	%
SOUTFH	186	12.8	104	14.4	82	11.3
SMIDFH	306	21.1	140	19.4	166	22.9
SMIDBH	730	50.4	354	49.3	376	51.8
SOUTBH	224	15.5	122	16.9	102	14.0

Based on the results of chi-square test we can state the that there was a significant association between winning the match and serve outcome, X2(2, N=1466) = 34.229, p < .000).

Most of the points after serve were finished after 3-5 stroke, and winners has a better percentage of winning points on serve directly and after 3rd and 5th stroke.

The most used zone on the opponent's side of the table where serve were placed was middle, more in backhand side. Results of analyses of serve placement are shown in Table 3.

There was no significant association between winning the match and serve placement.

Analyzing serve activities and outcome instead of the phase of the game, it is noted that in last phase most points were won with 3rd and 5th stroke. Besides, involving the backhand serve was noted in 2nd and 3rd phase (Table 4).

Table 4.

Results of analysis of serve type and outcome in different phases of the match of all sample

		1st PHASE	2nd PHASE	3rd PHASE
Serve type	FSHOSE	79.9	73.9	77.5
	FLONSE	17.6	19.9	16.3
	BSHOSE	2.5	5.8	5.7
	BLONSE	0.0	0.4	0.5
	Total	100.0	100.0	100.0
Won points %	SERDIR	10.5	13.5	10.6
	SER3WN	21.0	21.0	25.8
	SER5WN	10.5	9.0	13.8
	SER7WN	4.4	7.0	6.9
Lost points %	SER3LS	27.0	24.0	24.0
	SER5LS	25.0	24.0	17.5
	SERROR	1.6	1.5	1.4
	Total	100.0	100.0	100.0

Table 5.

Results of analysis of serve activities for won/lost points

		WON POINTS		LOST POINTS	
		Frequency	%	Frequency	%
Serve type	FSHOSE	584	78.1	542	77.8
	FLONSE	130	17.3	124	17.3
	BSHOSE	32	4.3	30	4.2
	BLONSE	2	0.3	2	0.7
	Total	748	100.0	698	100.0
Won points	SERDIR	170	22.8		
	SER3WN	328	44.0		
	SER5WN	158	21.2		
	SER7WN	90	12.0		
Lost points	SER3LS			366	51.1
	SER5LS			328	45.7
	SERROR			22	3.2
	Total	746	100.0	716	100.0
Serve placement	SOUTFH	90	12.0	96	13.7
	SMIDFH	148	19.8	158	22.7
	SMIDBH	396	52.9	334	47.7
	SOUTBH	114	15.3	110	15.9
	Total	1494	100.0	1414	100.0

There was a significant association between phase of the game and serve type, $X2(2, N=1464) = 16.669$, $p < .034$) and serve outcome $X2(2, N=1464) = 22.591$, $p < .031$)

The analyses of all won and lost points were done from the aspects of serve type, outcome, placement and type. Results of analyses are shown in Table 5.

Won points are mostly in the 3rd rally (44.0%) and 5th rally (21.2%), while lost in the 3rd (51.0%) and 5th (45.7%).

Considering type of game, we analyzed differences in serve activities between balanced and unbalanced games (very unbalanced were excluded because they didn't represent real game situation considering result. There was noted a significant association between serve type, X2(2, N=1290) = 12,588, p < .013), serve outcome, X2(2, N=1290) = 14,794, p < .022) and serve placement, X2(2, N=1290) = 81,362, p < .000). In balanced games players used more backhand serves, more points were won in 3rd stroke, fewer lost after 3rd stroke and serves were placed more in middle zones (especially forehand) compared to unbalanced games. All results are shown in Table 6.

Table 6.

Results of analysis of serve activities for different type of game

		Balanced		Unbalanced		Very unbalanced	
		Frequency	%	Frequency	%	Frequency	%
Serve type	FSHOSE	346	74.4	634	76.9	146	83.9
	FLONSE	80	18.7	154	18.9	20	11.5
	BSHOSE	32	6.9	24	2.9	6	3.4
	BLONSE			2	1.3	2	1.1
	Total	458	100.0	814	100.0	174	100.0
Won points	SERDIR	62	13.3	96	11.6	12	6.9
	SER3WN	112	24.0	158	19.1	58	33.3
	SER5WN	56	12.1	78	9.4	26	14.9
	SER7WN	28	6.1	54	6.5	8	4.6
Lost points	SER3LS	96	20.6	236	28.6	34	19.5
	SER5LS	100	21.5	192	23.2	36	20.7
	SERROR	10	2.4	12	1.5		
	Total	464	100.0	826	100.0	174	100.0
Serve placement	SOUTFH	54	11.9	112	13.7	20	11.5
	SMIDFH	162	34.8	118	15.6	26	14.9
	SMIDBH	194	41.9	434	52.5	102	58.6
	SOUTBH	48	11.4	150	18.2	26	14.9
	Total	458	100.0	814	100.0	174	100.0

Discussion

The objective of the research was to analyze serve activities in elite European players. .

Regarding the serve type, the forehand short serve was dominant (around 80%) and as in some previous research there was a significant difference in the use of the forehand short serve in favour of the winners (Djokic, 2003).

Winners are better at performing short serves than losers. Most points were won (and finished) in the 3rd ball and the rate of points won directly with serves is high – 11.6%, but still lower than before changes of the serve rules were applied – 14.3% (Djokic, 2003). The same results were found also in a recent study of Djokic et al. (2019).

There was a significant association between winning the match and serve outcome with point directly won with the serve and the winning point – after 5th and 7th ball. Zhang et al. (2013) indicated a

correlation between technique effectiveness and competition performance based exactly on these activities, which illustrates a difference between winners and losers.

In this study, percentage of won serve for the winners was 57.1%, and is in relation with previous researches of the best European players (53.1 – 61.6%) and best world players (59.3%) (Djokic, Munivrana, & Levajac, 2016a, 2016b, 2017).

The most used zone on the opponent's side of the table where the serve were placed was middle, but more towards the backhand side, so players' placement decisions are more or less the same as before (Djokic, 2003).

Analyzing serve type and outcome instead of the phase of the game, we found that as the game goes on in the second and third phases players start performing backhand serves as an alternative serve (because neither player hadn't use a backhand serve in first phase of game). In the third phase, points were more often won with 3rd or 5th stroke, so, in this phase the server must have a high level of concentration on quality realization in short rallies.

A significant association between phase of the match and serve type was noticed, in fact, that the backhand, serve was in use in the 2nd and 3rd phase (not in 1st phase), probably as a choice by players to change something in the game. In addition, in the last phase, all players were trying to play a short serve in which game points usually were decided after 5th stroke.

Most of the points after the serve were won on the 3rd and 5th stroke (65.2%), which is higher than that reported in some previous research reported in European Championships (46.5%) and World Championships final (50%) (Djokic, Munivrana, & Levajac, 2016a, 2016b).

In balanced games, the backhand short serve was more frequently used, probably as a player's attempt to change something and disturb the receiving opponent. Furthermore, in such matches there were more points won directly with the serve, and points won with 3rd stroke rather than in unbalanced ones. Accordingly, even if several table tennis rules intentionally reduced the advantage of the server (Djokic et al., 2019), the players do have the ability to make multiple types of services with identical motions, and so the service still has an important impact on a rally.

Conclusions

The results of the present study indicate that the quality of serve activities is an important differentiator between winners and losers in table tennis. The results of this research can be useful for coaches and players with regard to the identification of important aspects of serve activities, in order to design better training sessions. In addition, the findings can be seen as an advertisement for a particular model of performance analysis indicating a need for continuous systematic match observation in this sport.

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A Literature Review on Coach-Athlete Relationship in Table Tennis

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Abstract

Coach-athlete relationship is a salient factor in table-tennis as it impacts players' performance and well-being. The structure and set up in table tennis is often designed so the players and coaches are working together through many stages in the players' career. For instance, it is not uncommon for coaches of young table tennis players to accompany their respective players to the senior international elite level. Indeed, the access to the knowledge base regarding coach-athlete relationship represents a major issue for the different stakeholders involved in table-tennis (coaches, athletes, parents, sport psychologists, researchers). To that end, we firstly overviewed and discussed the different theoretical models exploring the concept of coach-athlete relationship to clarify the core dimensions of this construct. Secondly, we provided a rationale behind the salient role of coach-athlete relationship in table tennis by detailing its consequences in order to better understand the mechanisms underlying coach-athlete relationship. Thirdly, we addressed how table tennis coaches can develop and/or maintain an adaptive coach-athlete relationship, especially in reference to specific situations in table tennis. In conclusion, the coach-athlete relationship is a particularly important parameter in the daily life of the table tennis players due to its influence on their performance and well-being. Thus, it is essential that the coaches establish relationship promoting athletes' development throughout their career.

Keywords: *Attachment Style, Autonomy Supportive Coaching Style, Coach Behaviour, Communication, Performance*

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Introduction

Literature in sport and organizational psychology suggests that the quality of leadership has a great impact on the performance of individuals (Jowett & Poczwardowski, 2007; Mageau & Vallerand, 2003; Schmink & Wells, 1999). For instance, Schmink and Wells (1999) provided evidence that the behaviours of the leader (coach) relate to the performance of the team, and that 45-65% of an organization's success is determined by the team leader. Indeed, a growing amount of research has studied coach-athlete relationship in sport settings (Jowett & Poczwardowski, 2007; Mageau & Vallerand, 2003). As a whole, this literature showed that the type of leadership endorsed by the coach and its behaviours strongly impact athletes' behaviours, cognitions, motivation and emotions (Jowett & Poczwardowski, 2007; Mageau & Vallerand, 2003). Nevertheless, the win-at-all-cost atmosphere that can reign in sport setting (Cece, Guillet-Descas, Nicaise, Lienhart, & Martinent, 2019) could potentially create an environment likely to impact coach-athlete relationship. In table tennis, coaches and their players share many experiences across sport career and it is not uncommon for coaches of young table tennis players to accompany their respective players to the senior elite level (Kajtna & Kondric, 2009). Thus, as coaches and players spend a long career together, it makes stronger ties and boosts the influence of leadership (González-García & Martinent, in press). Indeed, the access to the knowledge base regarding coach-athlete relationship represents a major issue for the different stakeholders involved in table-tennis (coaches, athletes, parents, sport psychologists, researchers). Therefore, in light of the importance of coach-athlete relationship in the field of table-tennis (González-García & Martinent, in press; Kajtna & Kondric, 2009; Li-Hua, Cheng-Hua, & Chung-Hsiung, 2012), the present narrative review addressed literature examining this topic in sport and especially in table tennis. To facilitate understanding, our paper was organized into three main sections. The first section provided an overview and a discussion of the different theoretical models exploring the concept of coach-athlete relationship in order to clarify the core dimensions of this construct. The second section provided a rationale behind the salient role of coach-athlete relationship in table tennis detailing its consequences in order to better understand the underlying mechanisms involved in coach-athlete relationship. The third section addressed how table-tennis coaches can develop (and/or maintain) an adaptive coach-athlete relationship, especially in reference to situations related to table tennis.

What does coach-athlete relationship actually mean?

This section provides a theoretical overview of the concept of coach-athlete relationship. This concept can be broadly defined as a situation in which a coach's and an athlete's cognitions, feelings and behaviours are mutually and causally interrelated (Jowett & Poczwardowski, 2007). It is noteworthy that the coach-athlete relationship is expected to change over time due to the interaction between the coach and athlete (Jowett & Poczwardowski, 2007). Beside the issue of the definition of the construct, several conceptual models of the coach-athlete relationship have been proposed within the sport literature (Jowett & Poczwardowski, 2007; LaVoi, 2004; Mageau & Vallerand, 2003; Wyllemann, 2000). Overviewing and discussing these theoretical models would allow depicting the core dimensions of the coach-athlete relationship construct in sport settings and thus in table tennis.

Whereas Poczwardowski's (1997) conceptual model suggested that coach-athlete relationship is a recurring pattern of mutual care, and both are influenced in the relationship, LaVoi's conceptual model (LaVoi, 2004) took a relational-emotional approach. In particular, he suggested that athletes would achieve higher level of satisfaction and growth when feeling optimally close and interdependent with the coach and teammates. Four qualities were conceptualized as being at the heart of the coach-athlete relationship: Authenticity, engagement, empowerment, and the ability to deal with difference.

Wyllemann's conceptual model (Wyllemann, 2000) emphasized that the relationship between the coach and athlete should be analysed according to the behaviours of both stakeholders during training sessions and competitions. In particular, three dimensions were conceptualised within this theoretical framework: Acceptance-rejection (the positive or negative attitude towards the relations), dominance-submission (there is a strong and a weak individual in the relationship) and social-emotional (taking a social or personal role in the relationship). Whereas this conceptual framework suggests that the athlete`s and coach`s reciprocation and correspondence of behaviour is likely to occur on the field of play, it does not yet consider the reasons why, or the timing of the behaviours.

Based on the self-determination theory (Deci & Ryan, 2000), Mageau and Vallerand (2003) proposed that coaches' personal orientation towards coaching, context, and perceptions of the athlete's behaviours and motivation influence coaching behaviours (autonomy-supportive behaviours, provision of structure and involvement) and in turn athletes' well-being (Mageau & Vallerand, 2003). Although focusing and detailing an adaptive form of coach behaviour (autonomy-supportive behaviours) is particularly useful, this model doesn't encompass the wide variety of coach-athlete relationships encountered on the sporting ground. Finally, Jowett's conceptual model suggested that the athlete's and coach's behaviours, emotions and thoughts are mutually and causally interdependent according to the rule of the 3+1 Cs: Closeness (trust and respect), commitment (intention to maintain the relationship), complementary (behaviours of dominance and submission), and co-orientation (establishment of a common ground in their relationship) (Jowett & Pozcwardowski, 2007).

As a whole, compassion emerged as a vital part of the coach-athlete relationship in all the models. Most of the theoretical models also highlighted the causal reciprocity in the coach-athlete relationship. However, Mageau and Vallerand (2003) were the only ones to describe in a particularly comprehensive way the context surrounding an autonomy-supportive coaching style (a particularly adaptive coaching style).

Why paying attention to coach-athlete relationship in table tennis?

The coaching role is demanding and requires a variety of skills to be successful in any sport. There are a lot of issues to consider for optimizing coach-athlete relationship such as the type of sports, the level of coaching or age of the athletes as well as surrounding factors like media, financial issues, pressure from the board and parent's involvement. Adjustments of the coach-athlete relationship need to be made by coaches to lead in the most suitable way in the actual context. In sport settings, the coach-athlete relationship is recognized as a salient factor promoting the development of athletes' physical and psychosocial skills (Dominteanu, 2011; González-García, Martinent, & Trinidad Morales, 2019). Within the first section of this literature review, we provided evidence that the coach and athlete are mutually influenced by each other. So why is it so important to develop an adaptive coach-athlete relationship in sport settings? Jowett and Poczwardowski (2007) argued that the ideal coach-athlete relationship could lead to the two interrelated benefits of: (a) effectiveness that promotes personal growth for both the athlete and the coach; and (b) performance success (i.e., to achieve athletic excellence on the part of the athlete and professional excellence on the part of the coach).

To comprehensively represent research investigating coach-athlete relationship in table-tennis, we undertook an exhaustive search of the literature to locate published work relevant to this concept in table tennis using databases including PsycINFO, PsycARTICLES, Psychology and Behavioral Sciences Collection, and SPORTDiscus. As a first step, to locate published papers, we used the keyword table tennis, crossed with the keywords coach-athlete relationship, coach behaviours, coaching style or coach leadership. In a second step, we combined the keyword table-tennis with that of sport psychology. It is also noteworthy that the

reference lists of all obtained articles were also examined for other relevant studies. Although it is generally recognized that narrative reviews commonly do not list the types of databases and the inclusion criteria (Cipriani and Geddes, 2003), providing some key elements about the search strategy allows the readers to better judge the transparency of the work (Campo, Mackie, & Sanchez, 2019). Literature in sport settings and especially among table-tennis players detailed the consequences of coach-athlete relationship on a wide variety of athletes' outcomes (e.g., motivation, emotions, or well-being) (González-García & Martinent, in press; Jowett & Poczwardowski, 2007; Li-Hua et al., 2012; Mageau & Vallerand, 2003).

Motivation is one of the most fundamental psychological attributes to achieve high performance in sport (Cece, Lienhart, Nicaise, Guillet-Descas, & Martinent, 2018) and in particular in table tennis (Martinent & Decret, 2015a). Several studies conducting among table tennis players showed that autonomous forms of motivation (behaviours performed by choice) are important determinants of optimal functioning, sport persistence and performance whereas the opposite pattern of results was observed for controlled forms of motivation (players feel pressured to practice table tennis) (Chu, Zhang, & Hung, 2008; Martinent, Cece, Elferink-Gemser, Faber, & Decret, 2018; Martinent & Decret, 2015a). Coach-athlete relationship plays a key role in the type of motivation endorsed by players (Mageau & Vallerand, 2003). Coaches' autonomy support helps nurturing athletes' basic psychological needs and in turn fostering autonomous motivation (Mageau & Vallerand, 2003). In particular, being autonomy-supportive means that a coach takes the athlete's perspective and acknowledges the other's feelings (Deci & Ryan, 2000; Mageau & Vallerand, 2003). Autonomy-supportive coaching style is consistent with the tenets of the Jowett's 3+1 Cs theoretical framework (Jowett & Poczwardowski, 2007) in which the coach's and the athlete's emotions and thoughts depend on the perception of closeness, commitment, complementary and co-orientation. In this perspective, coach has to see the athlete as a whole and work comprehensively the relationship with the player to maximize the chance of fulfilling his or her potential. The style of coaching strongly impacts the quality of the coach-athlete relationship (Jowett & Poczwardowski, 2007; Mageau & Vallerand, 2003). As such, it is necessary for coaches to pay attention to the dynamics of the relationship. In the establishment of an effective and successful relationship the responsibility lays mostly with the coach as he or she is the grown-up person, and because of the power that follows with the role.

A coach-athlete relationship is developing as the athlete grows during the career. The athlete's awareness of the responsibility in the relationship should develop as well. In this way the coach and athlete can nurture and maintain the relationship (Jowett & Poczwardowski, 2007). Indeed, it could be particularly useful to examine the topic of the coaching behaviour from the athlete's point of view. In this perspective, 447 competitive table tennis players in a University table tennis tournament attended in a study regarding their perception on coach's leadership behaviour (Li-Hua et al., 2012). Li-Hua et al. (2012) showed that awarding behaviours and training and guiding behaviours were the most experienced behaviours by players. These results suggest that University coaches' positive feedbacks and their effort in guiding players' skills and tactics during training were well recognized by their players. In contrast, autocratic behaviours received the lowest scores suggesting that coaches should minimize the use of such approach to avoid negative effects which may affect players' performance (Li-Hua et al., 2012). The ambiguous results regarding the effects of demographic variables on players' perceptions of coaches' leadership behaviours underlined the importance of adjusting coach behaviours according to the individual preferences of the players in order to optimize coach-athlete relationship and in turn fulfil players' potential (Chelladurai & Saleh, 1980; Li-Hua et al., 2012).

Coach-athlete relationship also plays a key role in the emotional experience of table tennis players through its impact on coping strategies (González-

García & Martinent, in press). This is particularly relevant as the abilities to manage emotions and to cope with stressful situations are considered by several sport psychologists and table tennis coaches as among the most powerful qualities that table tennis players must develop in their career (Kurimay, Pope-Rhodius, & Kondric, 2017; Martinent & Decret, 2015b; Martinent, Ledos, Ferrand, Campo, & Nicolas, 2015). Because high psychological demands are placed on table tennis players, they have to struggle for controlling their emotions and it could impact their performance levels (Chen, Chang, Hung, Chen, & Hung, 2010; Martinen, Campo, & Ferrand, 2012). In particular, table tennis players use a wide variety of coping strategies to manage the demands exceeding their perceived resources (Kurimay et al., 2017) which can be regrouped into several coping dimensions including task-oriented coping (dealing directly with stressful situation and the resulting thoughts and affects), a coping dimension related to optimal functioning and performance (Gaudreau & Blondin, 2002). Of particular importance in the context of the present study, democratic coaching behaviours (perceived from their players) significantly predicted players' task-oriented coping which in turn predicted positive emotions experienced by players during competition (González-García & Martinent, in press). These results obtained in the field of table tennis were consistent with those observed among athletes practicing a wide range of other individual sports (Nicolas, Gaudreau, & Franche, 2011).

In sum, a bulk of studies conducted among table tennis players provided evidence of the main role played by psychological factors (motivation, emotions, coping strategies) in both performance variability and players' well-being (Chu et al., 2018; Kurimay et al., 2017; Martinent & Decret, 2015a, 2015b; Martinent et al., 2015, 2018). In line with this literature, a few studies provided evidence for the main role of coach-athlete relationship in table tennis (Kajtna & Kondric, 2009; Li-Hua et al., 2012) and for the impact of coaches' behaviours on table tennis players' emotional outcomes (González-García & Martinent, in press). Indeed, developing and maintaining an effective coach-athlete relationship should be of high interest for the coaches, the players and the sport psychologists in the field of table tennis.

How coaches can develop and/or maintain a coach-athlete relationship fostering table-tennis players' well-being and performance

Attachment styles and establishment of the relationship between coach and athlete

The attachment styles developed by children as they get older during their infants impact their relationships with adults such as coaches (Bowlby, 1982). Three attachment styles are postulated within this theoretical framework: (a) *A secure attachment* involves the confidence in availability of their close other to provide them with comfort and support and reduced distress upon proximity to the caregiver following separation; (b) *An anxious (insecure) attachment* refers to a strong desire for proximity with caregiver (even in non-distressing situations) and to the experience of upset (with the caregiver) following separation; and (c) *An avoidant (insecure) attachment* is characterized by very few (or almost no) attempts at maintaining contact with caregiver and thus little (or no) distress following separation (Davis & Jowett, 2014; Drake, 2009; Felton & Jowett, 2015; Harmon, Siegien, Watt, Rebers & Pennington, 2015). Individuals with an anxious attachment can develop negative views of themselves because they have the perception they are not worthy of support or attention whereas individuals with avoidant attachment can develop negative connotations with others due to not receiving support in the past (Harmon et al., 2015).

New children coming to the table tennis hall are usually excited and probably a bit nervous as well. Because positive first impression and experience can lead them to come back to future training sessions, coaches should pay particular attention towards establishing of the relationship. Based on the attachment theory (Bowlby, 1982), coaches need to

earn the child's trust and establish a secure base for the child.

A crucial factor for coaches to be aware of and consider is the child's attachment style. Understanding the psychological needs related to each attachment style might help coaches to adjust their behaviour and build that secure base (Harmon et al., 2015). In the initial interactions and conversations with the child and parents, it would usually be beneficial to establish a conversation directly with the child as well. Not only with the parents. Learning and remembering the child`s name is necessary as well in order to make the child feel that the coach cares about him or her as a person. In this initial interaction, coaches could notice clues about the child's attachment style and how protective the parents behave. For instance, children differ in how relaxed they are leaving their parents for taking part in the training and this situation could provide information about the attachment style of the child. Then, based on this information, coaches can decide how to take the next step establishing the relationship with the child.

As securely attached athletes typically have an easier time developing and maintaining relationships with parents and coaches, establishing a relationship with children with this attachment style will be easier for coaches (Harmon et al., 2015). Both anxious and avoidant patterns of attachment can be difficult for coaches, because individuals with insecure attachment are not as trusting of adults due to the lack of support they received when they were younger (Harmon et al., 2015). Nevertheless, knowledge and awareness about attachment styles may help coaches to develop a positive relationship with different individuals and act appropriately in each situation.

Social environment, motivational climate and coach-athlete relationship

The social environment in which the players are immersed is a fundamental base for developing and maintaining a positive (secure) relationship (Harmon et al., 2015). Coaching behaviours that show openness, positivity, and autonomy allow athletes to feel they are supported and given attention, which would help increase the security in coach-athlete relationships (Harmon et al., 2015). For instance, during training sessions, a coach can provide instructions and organization, provide rationale for tasks/requests/constraints, encourages initiative taking or provide opportunity for player input (Smith et al., 2015). During competition, a coach can acknowledge feelings and perspective, engage in non-instructional conversation with athletes, recognize effort, or emphasizes task-focused competence feedback. This kind of environment during training and competition would increase the probability of youth and adolescent table-tennis players experiencing security. When players "who pose insecure attachment characteristics begin to feel that their environment is safe to explore, their security in the coach-athlete relationship will increase because they trust the environment the coach has constructed" (Harmon et al., 2015, pp.16).

As a whole, research provided strong evidence that coaches who employ autonomy-supportive behaviours can create an environment in which athletes feel their psychological needs are satisfied, thus allowing greater well-being (Felton & Jowett, 2015; Harmon et al., 2015; Mageau & Vallerand, 2003). As an illustration of this literature, a bulk of studies in several contexts (e.g., sport, school) showed that individuals immersed in training sessions favouring a choice condition (e.g., the player choose between several exercises, the player offers an exercise consistent with his game system) demonstrated higher intrinsically motivated behaviours than those involved in a no choice condition (Black & Deci, 2000; Deci & Ryan, 2000; Mageau & Vallerand, 2003; Zuckermann, Porac, Lathin, Smith, & Deci, 1978). Nevertheless, an autonomy-supportive coaching behaviour must not be confused with providing total freedom as highlighted by Mageau and Vallerand (2003) who emphasized the importance of providing choices within rules and limits in coaching. In particular, to support athletes' autonomy, coaches need to provide a rationale for requested tasks as well as for limits and rules in order to facilitate the internalization of the underlying reasons for activity engagement

(Mageau & Vallerand, 2003). As such, table tennis coaches need to set rules and limits for players and training groups to be able to work effectively. However, clear instructions may be perceived as controlling by players. As such, it is particularly important allowing table tennis players opportunities for initiative taking within a supportive relationship (Mageau & Vallerand, 2003). When table tennis players are given the opportunity to take initiatives themselves their intrinsic motivation are strengthened. For instance, the problem-solving method is well suited in regards of taking initiatives. Thus, as a table tennis coach, finding the balance between instructive behaviour and giving freedom to choose and take initiatives, is an important issue to consider in the daily training sessions.

Moreover, autonomy-supportive coaches also inquire about and acknowledge athletes' feelings about the tasks and rules (Mageau & Vallerand, 2003). This acknowledgement requires perspective taking on the coach's part. In this way the table tennis players most likely would feel recognized as persons as well, not only athletes. This would strengthen their self and their confidence, and they would be more likely to engage in the table tennis coach`s tasks and rules (Mageau & Vallerand, 2003). For instance, it is important that during training sessions, coaches show care and concern for their table-tennis players, adopt a warm communication style, and show unconditional regard. In a similar vein, positive competence feedback is also acknowledged as a fundamental part of an autonomy-supportive coaching style (Mageau & Vallerand, 2003). It has been argued that positive feedbacks have two functional aspects: An informational and a controlling aspect (Ryan, 1982). When the informational aspect is salient and the controlling aspect is relatively non-salient positive feedback enhances people's perceptions of competence and thus fosters intrinsic motivation (Ryan, 1982). As such, giving positive feedback is not as straight forward as it may seem. If the feedback is provided with a clear and unambiguous message the impact on the intrinsic motivation is positive (e.g., "good placement on that forehand-topspin"). On the other hand, the same feedback with an inadequate formulation is not as effective: "good placement on that forehand-topspin. Do that more often!" The last part of this feedback possesses a controlling aspect and thus undermines the message and the athlete's intrinsic motivation.

Much feedback and behaviour can be controlling (e.g., overt control, controlling statements, guilt-inducing criticisms, tangible rewards and encouragement of athletes' ego-involvement) and could restrain athletes' autonomy (Mageau & Vallerand, 2003). Table tennis coaches can faulty believe that power comes with controlling behaviours such as using controlling language, relying on intimidation, demonstrating negative conditional regard, punishing mistakes, or restricting opportunities for interactions and conversation. However, feedback that appeals to the table tennis player's guilt, or just is excessively controlling, is disrupting to their intrinsic motivation. This kind of communication is also an abuse of power and would decrease the players trust in the coach. Coaches' awareness of their own way of communicating, and the effect of their feedback, is essential for promoting autonomy-supportive coaching behaviours.

Communication skills at the service of the coach-athlete relationship

When table tennis coaches communicate with their players, increasing the chance that players have received, accepted and understood the message according to the coach's wishes is a particularly salient issue. In this way, Dominteanu (2014) elaborated on the questions that can guide coaches before communicating with their players: "Why they want to communicate? Who they want to communicate with? Where and when the message could best be delivered? What do they want to communicate? How are they going to communicate?" (pp. 512). He also explained that effective communication is characterized by six elements: Be clear, concise, correct, complete, courteous and constructive.

Sport settings and its inherent pressure might consistently influence the communication between

coaches and players. Difficulties in the communication can come from several clues including interfering emotions, the coach's and athlete's different perceptions or communication technical obstacles (Dominteanu, 2014). Because coach athlete relationship is dynamic, the way coaches communicate is an important factor causing the players' responsiveness to feedback (Ihlen, Ihlen, & Koss, 2011). The amount of instruction the players can receive and accept is affected by the total amount of feedback, and the amount of instructional feedback/corrections versus positive feedback provided by the coach. Instructions and feedbacks are a natural part of the coaching role, but coaches should count themselves responsible for how their feedbacks are received by players. Over communicating can make players get bored or even irritated when receiving instructions. Too much instructions or corrections can thus make players less responsive (Ihlen et al., 2011). Positive feedbacks should be the largest part of the total amount of feedbacks in order to build the players' confidence and autonomous motivation and to increase the players' responsiveness to further instructions or corrections (Mageau & Vallerand, 2003).

Otherwise, table tennis coaches should be aware of the central role of non-verbal behaviours in the communication (Ledos, Martinent, Decret, & Nicolas, 2013; Martinent, Ledos, & Nicolas, 2016). In order to be clear when communicating, the body-language of the coaches should conform to the verbal message (Dominteanu, 2014). Alternatively, coaches should also be aware of the non-verbal behaviours expressed by the athlete's body language (e.g., facial expressions, body posture). These signs provide rich information about the mental state of players or the group of players (Dominteanu, 2014).

In sum, the complexity of communication with its verbal and non-verbal components shows how demanding coaching is. To communicate effectively with different players requires a lot, and effective communication skills are vital (Dominteanu, 2014). Thus, awareness and knowledge about communication would help table tennis coaches to communicate appropriately with their players. Whereas good communication skills are necessary for allowing coaches to develop and maintain the relationship with their players, a positive coach athlete relationship is necessary to understand the athlete, and thus to minimize the risks of interference in the communication. As such, the coach-athlete relationship and the quality of the communication are strongly influenced by each other (Dominteanu, 2014).

Maintenance of the coach-athlete relationship: The role of openness and conflict management

Openness and conflict management play significant roles in maintaining a positive coach-athlete relationship (Rhind & Jowett, 2010). Openness refers to the three inter-related dimensions of non-sport communication, talking about anything, and other awareness (making an attempt to understand how the player is feeling) (Rhind & Jowett, 2010). Openness is an important contributor to the table tennis player's experience of being seen and heard as a person, not only as an athlete. If the athlete feels secure about bringing up any issue with the coach, it strengthens the athlete`s trust in the coach and thereby the relationship between the two stakeholders. Nevertheless, some disagreements or conflicts are unavoidable between table tennis players and coaches within the daily training sessions. How disagreements or conflicts are handled strongly influence the relationship (Rhind & Jowett, 2010). It is noteworthy that conflict management not only considers co-operative acts during disagreements but also pre-emptive strategies (e.g., clarifying the expectations and the consequences when these are not met) (Rhind & Jowett, 2010). For instance, performing autonomy-supportive coaching behaviours can be considered as a preventative action itself (Mageau & Vallerand, 2003). Indeed, giving athletes the opportunity to take part in decisions (and/or make choices) in training and during competition certainly reduces the occurrence of conflicts. Clarification of expectations from both parties is another important preventive action that can create fundament of further

cooperation, and hopefully keep the prevalence of conflicts rather low (Rhind & Jowett, 2010).

When conflicts occur, the aforementioned preventative measures could serve as primary buffering (Rhind & Jowett, 2010). For instance, with clarifying expectations through dialog with the players, table tennis coaches would: (a) allow athletes to influence the terms themselves, and (b) be able to explain in a good way how they want to cooperate with their players. Aforementioned communication issues are also particularly salient for conflict management (Dominteanu, 2014). For instance, clear and concise communications is vital in conflict management (Dominteanu, 2014). Nevertheless, knowing exactly how to solve a given conflict is probably illusory because it can be affected by the context, the persons involved or the interaction between the context and the individuals. In any case, addressing the actions causing the conflict, not the person, is especially wise (Dominteanu, 2014). With the common expectations as a fundament, the chance of solving the problem and be able to move forward without impairing the relationship is substantial (Rhind & Jowett, 2010).

Coaching behaviours during table tennis competitions

Coping is inherent to the lives of table tennis players participating in competition given the high psychological demands placed on them (Chen et al., 2010; Martinent, Campo, & Ferrand, 2012). Indeed, there is a general agreement among table tennis players, table tennis coaches and sport psychologists that achievement of performance goals depends partly on players' capacity to cope with the various demands encountered in these competitions and to manage emotions experienced during competition (Chen et al., 2010; Kurimay et al., 2017; Martinent & Ferrand, 2009, 2015a; Martinent et al., 2015). A player`s possession of effective coping strategies during competition is important to be able to enjoy the competition and to reach its full potential in the competition (Martinent et al., 2015). Although everybody wants to win, the focus during table tennis competition should be directed towards relevant tasks such as strategic thinking and tactical tasks in order to perform well (and thus increase the chance of winning) (Kurimay et al., 2017). The players' perception of the importance of the event can easily cause them being too caught up in the occasion (Martinent & Ferrand, 2015b). And this issue doesn`t only apply for players, but coaches as well. Coaches who are aware of their own mindset and behaviours during competitions are more likely to control how they influence their player's coping strategies, which in turn could influence their players' emotions during competition (González-García & Martinent, in press). Especially, Nicolas et al. (2011) highlighted that supportive coach behaviour (the feeling that your coach encourages you) was positively linked with the use of functional coping strategies meanwhile unsupportive coach behaviour (the feeling of discouragement from coach) was positively related to the use of dysfunctional coping strategies.

As leading by example is a positive attribute of leadership (Chelladurai, 1990; Jowett & Poczwardowski, 2007), perceived stability and support from coaches is important for table tennis players during matches. Table tennis players experience a wide variety of emotions during matches (Martinent & Ferrand, 2009; Martinent et al., 2012; Sève, Ria, Poizat, Saury, & Durand, 2007). Different opponents, outcome of matches, satisfaction with their own actual playing level, perceived pressure from parents or significant others are factors that can influence their emotions (Martinent & Ferrand, 2015b; Sève et al., 2007). Players don`t need any more pressure than they already are dealing with and they are in no need of handling inexpedient emotions and behaviours of their coach (Martinent et al., 2015). If table tennis coaches want their players to handle their emotions and perform well, coaches should handle their own emotions and be aware of their effect on the players. Indeed, to distinguish between his/her own needs and what the players need is highly relevant in this matter. If coaches stay positive and focused towards relevant tasks, the players are more likely to do the

same (González-García & Martinent, in press). Leading by example is therefore essential.

Conlusion

The present narrative review highlighted the importance of initiating and maintaining a harmonious relationship between coaches and athletes. The reasoning behind is comprehensive and complex. On one hand, a bulk of studies conducted among table tennis players provided evidence of the main role played by psychological factors (motivation, emotions, coping strategies) in players' performance and well-being (Chu et al., 2018; González-García & Martinent, 2019; Kurimay et al., 2017; Martinent & Decret, 2015a; Martinent et al., 2015, 2018). On the other hand, a growing number of studies conducted in table-tennis provided evidence of the impact of coaches' behaviours on table tennis players' psychological outcomes (González-García & Martinent, in press; Kajtna & Kondric, 2009; Li-Hua et al., 2012). Indeed, developing and maintaining a harmonious coach-athlete relationship is of prime importance for the different stakeholders involved in table tennis (coaches, players, organizations).

In this way, establishing an autonomy supportive coaching style (providing choices within rules and limits, acknowledge athletes' emotions, using positive feedbacks) is particularly useful for creating an environment likely to engender a harmonious coach-athlete relationship in the interest of both parties (Mageau & Vallerand, 2003). Attachment styles, communication skills, openness, and conflict management are also main elements to consider for optimizing coach-athlete relationship (Dominteanu, 2014; Harmon et al., 2015; Rhind & Jowett, 2010). Multiple beneficial effects of an autonomy supportive coaching style have been detailed in this study. Nevertheless, the use of an autonomy-supportive coaching style is not without negative effects. Especially a strong coach-athlete relationship could potentially become too prominent and excessive. Jowett and Poczwardowski (2007) emphasized that closeness must be satisfied in a well-functioning coach-athlete relationship. Keeping the right balance in this matter in the relationship is important. For many table tennis players, the coach plays a key role in their everyday life, and bands between coaches and athletes can become tight. The coach should keep in mind that the closeness in the relationship doesn't blurry his/her overview and his ability to provide clear and concise feedback and set limits when necessary.

According to Jowett and Pochwardowski (2007) relationships are expected to change over time. The coach's awareness about the evolvement of the relationship in line with the players' level and growth is an important issue. Throughout a long career a lot of adjustments need to be made. The stage when young table tennis players are entering teenager is one to pay attention to. Younger players possess lower knowledge and are therefore often more likely to just follow instructions. As time goes, and the player develops, the coach should be able to adjust the communication to be most suitable according to the stage of the players' career. Even though the coach performs an autonomy-supportive coaching style, the risk of giving too much instruction is often something to be aware of. When young players become teenagers, their need of making their own choices is usually increased. The balance between instructions, giving opportunities of making choices and taking initiatives is thus in constant adjustment. Without losing track of the athletic development, dialog becomes even more important. Letting table tennis players making choices and taking more initiatives should be a more prominent part of the communication with aging. It can be challenging for a coach to give more responsibility to the players worrying that the athletes will make too many bad decisions. Nevertheless, in order to let the players learn and grow, they need to get the chance to make those decisions. Even if they make some bad ones, it contributes to their motivation. In the long run hopefully, this will increase the chance of fulfilling their potential.

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Performance analysis in wheelchair para-badminton matches

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Abstract

Para-badminton has performance classes which consider the impairment degree of each athlete; two of them use a wheelchair and are identified as Wheelchair 1 (WH1) and Wheelchair 2 (WH2). Due to the difference in functionality of players between the classes, the match characteristics of WH1 and WH2 games are expected to be different. Therefore, the objective of our study was to describe and compare the temporal and technical characteristics of classes WH1 and WH2. Twenty-three matches covering both WH1 and WH2 classes for men's singles performed during the first phase of Brazil Para-badminton Championship 2018 were filmed and assessed. There were differences between all temporal characteristics, except in relation to the rally time and frequency of strokes, which suggested that the WH2 matches were more intense and more prolonged. Both clear and net-lift strokes were the techniques most used by the two classes. The WH2 class showed a higher frequency of total strokes, net-shot, smash, block and non-forced errors ($p<0.05$) than the WH21 class. Regarding the winning of points, the net-lift and service led to higher wins in WH1. Drop-shot and clear (WH1), and net-shot and drop-shot (WH2) were the highest occurring shots leading to winning points.

Keywords: *Paralympic Sport, Para-badminton, Performance, Match Analysis*

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Introduction

The Tokyo Summer Paralympics (scheduled for 2020, but now expected to take place in 2021) marks the official debut of Para-badminton. Para-badminton events encompass performance classes aiming at assuring a fair competition based on impairment degree of each athlete (BWF, 2017). There are six sport classes according to each kind and/or level of impairment, including two that use wheelchairs - Wheelchair 1 (WH1) and Wheelchair 2 (WH2). The former group of athletes presents a higher degree of functional impairment (BWF, 2017; Strapasson Duarte, & Pereira, 2015).

Elaboration of practice planning must take into account the typical demands of the modality (Abian-Vicen, Castanedo, Abian, & Sampedro, 2013; Álvarez, 2001). Therefore, in order to properly determine these demands, coaching staff should perform match analysis. Scouting and match statistics are the most common strategies for analyzing team performance in competitions (Rodrigues, Eduardo, Gois, & Almeida, 2016). However, the notational analysis by video recording can provide more accurate and practical information of each event, player and competition, due to the possibility of reviewing the plays that occurred during the match (Abian-Vicen et al., 2013).

In racket sports, performance analysis usually records number and type of strokes performed through each point, game or match. Afterwards, these data provide indicators for training prescription (Fernandez, Sanz, & Mendez-Vill, 2009). In this regard, some analyses on badminton matches have been carried out (Abian-Vicen et al., 2013; Cabello & Padial, 2002; Cabello, Prada, Sanchez, Sicilia, & Corral, 2004; Cabello-Manrique & Gonzalez-Badillo, 2003), however, considering the recent para-badminton history, studies on match analysis are still scarce (Strapasson et al., 2014, 2018; Straparsson, Baessa, Borin, & Duarte, 2017).

In this regard, it is worth mentioning that these studies narrowed the analysis to a few matches of each para-badminton class, which reduces the generalization of the results. Thus, studies with a broader range of matches are necessary to reinforce data about match characteristics in each class. It is expected that, due to the functionality between the classes, the game characteristics between WH1 and WH2 will be different. Therefore, the objective of our study was to describe and compare the temporal and technical characteristics of classes WH1 and WH2.

Method

Experimental Problem Approach

This is a descriptive and inferential study with two independent groups. All games of the single men's WH1 and WH2 categories held during the Brazilian Para-badminton 2018 Championship were filmed. Subsequently, a notational analysis was performed to compare the two classes in relation to temporal and technical characteristics.

Ethical aspects

The Brazilian Badminton Confederation authorized the researchers to record the matches. This project was approved by the Institutional Research Ethics Committee of the Federal University of Sergipe (protocol nº 2573727).

Sample

All 25 matches of men's singles event performed during the 2018 Brazilian Para-badminton Championship were filmed (WH1: n = 10; WH2: n = 15). Matches would be excluded from analysis if any unexpected event that could affect natural time course of match occurred, or if athletes needed medical care during the game (which did not happen). Besides, matches that lasted more than 2 games were excluded in order to keep similarity with other studies (two matches out) (Abian-Vicen et al., 2013; Fernandez-Fernandez, Tellez, Moya-Ramon, Cabello-Manrique, & Villanueva, 2013). Therefore, the sample comprised 23 matches (10 WH1, and 13 WH2). All participants represented the best players in the country and had already participated in at least one international tournament.

Data Collection and Research Instrument

All matches were recorded by a GoPro Hero 4 Silver camera (GoPro, USA), 4k resolution, and 12 megapixels. The camera was placed baseline, 3 m apart and 1.60 m height, in order to monitor the entire playing area, thus, enabling to identify which strokes were being executed. Further reproduction was performed by using the Windows Media Player software (Microsoft, USA), and the time structure was measured with a digital timer (Casio, Japan). It is worth mentioning that all measurements and observations were carried out by the same researcher who had had extensive training on the methods and procedures of the present study.

Reliability Study

Data collection was performed by a badminton trainer with experience in performance analysis. However, a subsample of 3 matches was randomly selected to analyze intra-rater reliability using the Fleiss Kappa test. The results showed a kappa value of 0.91, considered almost perfect agreement.

Temporal Characteristics

The temporal variables assessed were based on research related to conventional badminton (Abian-Vicen et al., 2013; Chen & Chen, 2008; Faude et al., 2007; Laffaye, Phomsoupha, & Dor, 2015; Cabello-Manrique & Gonzalez-Badillo, 2003) and defined in Table 1.

Table 1.
Operational definition of the variables related to the time characteristics of the para-badminton performance analysis

Variables	Definition
Total playing Time (TT)	Time between the first game service to the last point of the game, recorded in minutes
Rally Time (TR)	Time between contact with shuttle during service and end of point, recorded in seconds
Effective Time (ET)	Time accounted for the sum of rallies, recorded in minutes
Rest time (RT)	It is the sum of the intervals between rallies and the official intervals, recorded in seconds
Frequency of Strokes (FS)	Corresponds to the ratio between the total number of strokes and the actual playing time (TS / ET), strokes per second
Working Density (WD)	Ratio between the effective time and the rest time (ET / RT)
Work load (WL)	Ratio between the total playing time and the effective time (TT / ET) and displays the working relationship during the game. The lower the value, the greater the intensity of the game.

Technical characteristics

The technical characteristics assessed were based on research related to conventional badminton (Abian-Vicen et al., 2013; Cabello-Manrique & Gonzalez-Badillo, 2003) were Rally, Stroke, Total Strokes (TS), Unforced Error (nFE), Winning Points (WP), Block (BL), *Clear* (CL), *Drop* (DS), *Drop* (DS), *Net-Lift ou Lob* (NL), Services (Sv), Short Backhand Service (SBS), Forehand Short Service (SFS), Long Backhand Service (LBS), and Long Service Forehand (LFS) and are defined in appendix 1.

Data Analysis and Interpretation

Means and standard deviation of all the temporal and technical variables were calculated, in addition to the percentages of strokes, services and types of scoring. Normality of the continuous variables was assessed by using Shapiro-Wilk test, which is indicated for samples from 4 to 30 units, in order to reduce the chances of type I error (Miot, 2017). Classes were compared by using the t-test for independent samples (normal distribution) or Mann-Whitney U-test (non-normal distribution). The analysis considered a 95% confidence interval (95% CI), a significance level of 5%, in addition to calculating the effect size (ES) based on Pearson's r. The reference values of the effect size were <0.30 (small effect), 0.30-0.49 (moderate effect) and ≥0.50 (large effect). All calculations were performed by using the SPSS statistical analysis software version 22 (IBM, USA), except for the effect size (Excel, Microsoft, USA).

Results

Temporal Characteristics

There were differences in all temporal characteristics, except for RT and FS. In this sense, WH2 matches were more intense (ES: large for WL, and moderate for WD), and more prolonged (ES: large for ET, and moderate for TT) (Table 2).

Table 2.
Time characteristics of the games of classes WH1 and WH2. Data are presented as mean and standard deviation

Variables	WH1	WH2	*p*	95% CI	ES
WL	3.9 ± 0.7	3.3 ± 0.4 [a]	0.030	-	0.56
TT (min)	21.6 ± 3.5	24.6 ± 3.0*	0.037	-5.82 a -0.20	0.44
ET (min)	5.7 ± 1.6	7.7 ± 1.7*	0.009	-3.49 a -0.55	0.53
TR (s)	5.7 ± 1.3	6.7 ± 1.3	0.073	-2.21 a 0.10	0.38
RT (s)	15.6 ± 1.9[a]	15.0 ± 0.8	0.026	-	0.23
FS (strokes/s)	0.72 ± 0.05	0.72 ± 0.03	0.705	-0.27 a 0.04	0.08
WD	0.36 ± 0.08	0.45 ± 0.09*	0.009	-0.17 a -0.02	0.48

WL: work load; TT: total playing Time; ET: effective time; TR: rally time; RT: rest time; FS: frequency of strokes; WD: work density; ES: *effect size*. *$p < 0.05$ (t test); [a]$p < 0.05$ (Mann-Whitney test).

Technical Characteristics

Regarding the several types of strokes executed, WH2 demonstrated a higher usage of net-shot, smash, and block, besides a higher number of TS (ES: large for all). Moreover, clear and net-lift were the type of stroke most used on both classes (no statistical difference between classes), whereas drive and block were the least used (Table 3).

Players in the WH2 class performed more services during the matches (ES: large), although no differences concerning the specific types of services were found. In that matter, the short backhand service was the most used service, while long backhand service was the least used service (Table 4).

Table 3.

Number of strokes carried out in the classes WH1 and WH2. Data are presented as mean and standard deviation, and as a total number (n) per class with percentage (%).

	WH1		WH2		*p*	95% CI	ES
	Mean ± SD	n (%)	Mean ± SD	n (%)			
TS	189.0 ± 60.8	1890 (100)	266.0 ± 68.2*	3459 (100)	0.007	-146.5 a -25.7	0.54
NL	42.0 ± 12.7	420 (22.2)	52.9 ±14.8	688 (19.9)	0.077	-23.1 a 1.3	0.38
DR	0.8 ± 1.1	8 (0.4)	2.1 ± 1.6	27 (0.8)	0.053[a]	-	0.40
DS	31.2 ± 16.9	312 (16.5)	39.5 ± 9.7	513 (14.8)	0.155	-19.9 a 3.4	0.30
NS	16.4 ± 6.6	164 (8.7)	33.1 ± 11.0*	431 (12.5)	<0.001	-25.0 a -8.5	0.68
CL	91.6 ± 32.3	916 (48.5)	119.9 ± 45.7	1559 (45.1)	0.112	-63.8 a 7.1	0.34
SM	5.2 ± 1.4	52 (2.7)	13.0 ± 4.2*	169 (4.9)	<0.001	-10.7 a -4.9	0.77
BL	1.8 ± 1.9	18 (0.9)	5.5 ± 2.3*	72 (2.1)	<0.001	-5.6 a -1.9	0.67

TS: total strokes; NL: *net lift;* DR: *drive;* DS: *drop shot;* NS: *net shot*; CL: *clear*; SM: *smash;* BL: block. *$p < 0.05$ (t test); [a] Mann-Whitney test.

Table 4.

Number for each types of service performed in games of classes WH1 and WH2. Data are presented as mean and standard deviation, and as a total number (n) per class with percentage (%).

	WH1		WH2		*p*	95% CI	ES
	Mean ± SD	n (%)	Mean ± SD	n (%)			
Sv	58.3 ± 8.7	583 (100)	67.3 ± 6.4*	875 (100)	0.009	-15.60 a -2.45	0.53
SFS	13.1 ± 10.7	131 (22.5)	12.8 ± 11.9	167 (19.1)	0.958	-9.71 a 10.22	0.01
SBS	25.5 ± 20.2	255 (43.7)	26.7 ± 16.1	347 (39.7)	0.876	-16.90 a 14.51	0.03
LFS	13.2 ± 10.5	132 (22.6)	17.5 ± 4.3	227 (25.9)	0.388	-14.32 a 5.80	0.20
LBS	6.5 ± 4.3	65 (11.1)	10.3 ± 11.9	134 (15.3)	0.141	-9.00 a 1.40	0.32

Sv: services, SFS: Forehand Short Service, SBS: Short Backhand Service, LFS: Long Service Forehand, LBS: Long Backhand Service *p < 0.05 (t test).

Table 5.

Number for several performance characteristics in the games of classes WH1 and WH2. Data are presented as mean and standard deviation, and as a total number (n) per class with percentage (%).

	WH1		WH2		*p*	95% CI	ES
	Mean ± SD	n (%)	Mean ± SD	n (%)			
NL	4 ± 2.0*	40 (12.9)	2.3 ±1.6	30 (8.9)	0.04	0.09 a 3.30	0.43
DR	0.1 ± 0.3	01 (0.3)	0.1 ± 0.4	2 (0.6)	0.710[a]	-	0.08
DS	8.6 ± 4.7	86 (27.7)	5.9 ± 3.5	77 (23)	0.135	-0.90 a 6.25	0.32
NS	3.8 ± 2.4	38 (12.2)	6.1 ± 4.4	79 (23.6)	0.153	-5.50 a 0.92	0.30
CL	5.8 ± 2.8	58 (18.7)	3.6 ± 2.6	47 (14)	0.068	-0.20 a 4.54	0.39
SM	2.3 ± 2.1	23 (7.4)	4.4 ± 3.6	57 (17)	0.119	-4.75 a 0.60	0.33
BL	0.6 ± 0.7	06 (1.9)	1.1 ± 0.9	14 (4.2)	0.220[a]	-	0.25
Sv	5.8 ± 2.7*	58 (18.7)	2.2 ± 1.8	29 (8.6)	0.01	1.60 a 5.55	0.63
WP	31.1 ± 3.5	310(53)	30.9 ± 5.7	335(43)	0.933	- 4.12 a 4.48	0.02
nFE	27.6 ± 7	276(47)	37.2 ± 4.9*	444(57)	<0.001	-14.80 a -4.46	0.64

NL: *net lift;* DR: *drive;* DS: *drop shot;* NS: *net shot*; CL: clear; SM: smash; BL: block; Sv: services; WP: Winning Points; nFE: Unforced Error. *$p < 0,05$ (t test); [a] Mann-Whitney test.

Discussion

The present study aimed at identifying and comparing technical and time characteristics of 23 para-badminton matches of WH1 and WH2 classes. It was previously clear that effective time (ET), frequency of strokes (FS) and work load (WL) are extremely important variables to qualify intensity of the match in conventional badminton (Phomsoupha & Laffaye, 2015). Thus, in the present study we used them in a similar way for para-badminton analysis. The main reason for this study was to create a body of knowledge for the competition characteristics that helps to improve training methods and provides information on the total amount of work, rest periods, series or repetitions required with training, especially in sports for people with disabilities (Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2015).

Temporal characteristics

When comparing the temporal characteristics between the classes, some statistical differences were found, mainly considering the variables that determine match intensity, that is, WL and WD, which indicates that the WH2 class match is more intense than WH1. In addition, WH2 class matches were longer when compared to WH1 class, according to TT and ET mean values.

These characteristics provide coaches with important information when working with both classes, since it is necessary to differentiate the exercises based on time characteristics according to the intensity of each class. Exercises, such as multi-shuttle, in which the coach launches several shuttles in sequence to the athlete to simulate a rally, should be performed with greater times and greater speed for class WH2, including with less rest time for the same.

The mean TT of WH1 class match lasted 21 min, and the WH2 one was 24 min long. Similar results were found in worldwide elite athletes, in which the TT in WH2 class (30 min) was longer than WH1 class (21 min), and even longer than in WH2 matches on the present study. However, it is worth mentioning that the study with athletes of the Para-badminton World Championship was carried out based on only one match of each class (Strapasson et al., 2017).

Mean ET found in the present study was 6 min in the WH1 class and 7 min in WH2 class, which shows a longer shuttle playing time in WH2 class, which correspond approximately to 28% and 30% of TT, respectively. These results are in agreement with what was observed previously on conventional badminton matches, ranging between 27% (Abian-Vicen et al., 2013) and 32% (Phomsoupha & Laffaye, 2015). Sánchez-Pay et al. (2015) denoted lower values than these with wheelchair tennis athletes, with an average of 20%. This difference in tennis could be explained by a larger court size, faster strokes, and the use of a ball instead of a shuttle. These three factors favor a less dynamic style of playing, since the distance covered by player/ball is larger. At the end of a play, the shuttle hardly falls down more than one meter apart from the wheelchair, which makes the resting interval shorter.

The ET/RT ratio is used in tennis (ITF, 2012) and badminton to characterize the WD, and has an important role for determining the intensity of the match, that is, the higher the value, the higher the intensity (Cabello-Manrique & Gonzalez-Badillo, 2003; Phomsoupha & Laffaye, 2015). In the present study, RT showed a higher value for WH2 class. WD values below 1.0 corroborate with a modality of an intermittent nature, similar to conventional badminton, whose RT values are higher than ET, which enables enough time for players to be prepared for the next point.

The FS can be used in both, conventional badminton and para-badminton, to provide useful information related to the match speed. Notwithstanding, to the best of our knowledge, this is the first study to analyze this performance indicator. Values slightly above 0.72 were found for both classes, which are lower than those found in conventional badminton athletes, whose means ranged from 0.92 to 1.09 (Abián, Castanedo, Feng, Sampedro, & Abian-Vicen, 2014; Faude et al., 2007). The lower FS for these para-badminton classes when compared to conventional badminton is explained by the most commonly used types of strokes, such as clear and net-lift, which are characteristically slower, and the lower incidence of faster strokes, such as drive and smash. This is due to the net height in

relation to the height of the athletes when seated, which limits the performance of these strokes. Another preponderant factor for a higher FS in conventional badminton is the lower displacement speed of WH1 and WH2 athletes when compared to the badminton ones.

WL is an important tool to quantify the external load of the para-badminton match, i.e., the rate between total and effective match time (TT/ET), which represents the working rate during the game. The lower the WL value, the higher the workload and intensity of the match. Considering this variable, WH2 class showed a higher match intensity, which corroborates with the other temporal characteristics already addressed.

Technical Characteristics

Among the technical characteristics, strokes present the most common techniques used by the athletes and can provide support for training program elaboration, aiming at maximizing the specific skills demands of each class. The clear was the most used stroke, and along with net-lift respond for 70% of the strokes in WH1 class and 65% in WH2 class (Table 4). These strokes reveal the intention to make the opponent go to the back of the court, in addition to allow more time for the attacking player to move and prepare himself for the next stroke. Another relevant tactical aspect associated with the high prevalence of these actions is that the opponent's response also tends to be a stroke to the back of the court in order to protect himself from SM or DS counter-strokes.

Another relevant tactical aspect associated with the high prevalence of these actions is that the opponent's response also tends to be a stroke on the back of the court to protect against smash or drop-shot counterattacks. This tactical intension to conquer points can be justified by the difficulty that athletes of both classes have in their antero-posterior displacement.

Athletes of both classes predominantly performed SBS. In this kind of service, athletes try to throw the shuttle in the frontcourt of the opposing player, as close as possible to the service line. That is the most elemental service technique in para-badminton, due to its teaching-learning ease (Table 5) (Strapasson, 2016). The service importance in WH1 class is decisive, since it is the second technical characteristic that scores the most during the match (Table 6).

The WH2 class showed statistically higher values for the net-shot, smash and block strokes (Table 4). The block in para-badminton is closely associated with an opposing smash, which makes smash a determining factor when considering the possibility of increasing or not block execution. Therefore, it was expected that the class that obtained the highest amount of smash could produce a greater number of block, which happened. It is worth mentioning that, although there is a statistical difference associated with the strokes between these classes, the rational value between smash and block, which is of approximately 2.8 smash/block, shows that there is no significant practical difference between the use of these actions, thus, a differentiate work is not necessary when training these strokes in both classes.

The two scoring forms (nFE and WP) are widely used in conventional badminton and can indicate the quality of the strokes (Blomqvist, Luhtanen, & Laakso, 1998). Regarding the comparative analysis on the types of scoring during the matches, the nFE were more frequent in WH2 class (Table 6). This is due to the greater body control capacity of WH2 class athletes to perform a more intense and aggressive match.

As shown by the time characteristics, the athletes executed riskier plays to score the points; consequently they made more errors in the strokes. This does not mean that the classes had differences in technical quality, but rather a greater risk requirement for scoring the points. This information focuses on the performance of the athletes and the final results of the match (Chiminazzo, Ferreira, Castanho, Barreira, & Fernandes, 2017).

The WPs that occurred most in WH1 and WH2 classes were drop-shot and net-shot, respectively (Table 6). Both strokes throw the shuttle at the opposing frontcourt, the area where most points occur (Strapasson et al., 2017). This factor and the greater occurrence of the clear and net-lift (Table 4) strokes in both classes characterize a type of match, in which the tactical purpose is inducing the opponent to move to the backcourt, thus, creating space for finishing the plays in the frontcourt. This strategy is justified by the difficulty of

anteroposterior displacement of the athletes of these classes.

This study has some limitations. We were not able to identify the detailing of each athlete's training program, such as weekly attendance and training load monitoring. So, It is not possible to know whether athletes with different training regimens can show different game characteristics. However, all the athletes in the sample had already participated in, at least, one international tournament, in addition to being considered the best athletes of this sport in the country. Therefore, it is believed that there might be some similarity among each other as regards to prepare for competitions.

Conclusions

Considering the temporal characteristics of the variables referred to as work load, work density, total playing time, rally time, the WH2 class showed a more intense match-play than WH1. The net-shot was the only stroke that showed a practical difference between classes, with a higher number for WH2 class. The clear and net-lift were the strokes most used by both classes, accounting for 70% (WH1) and 65% (WH2) of the actions. Regarding the scoring types, the nFE were more frequent in WH2 class. The highest winning points occurrences were the strokes executed at the opposing frontcourt, such as drop-shot (WH1) and net-shot (WH2).

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Appendix 1.

Operational definition of the variables related to the technical characteristics of the para-badminton performance analysis.

Variables	Definition
Rally	Set of actions performed between the beginning of a service and the completion of the point
Stroke	Technical gestures used to launch the shuttle by impact with the racket, to the opposing side during the rally
Total Strokes (TS)	Sum of the strokes of a game
Unforced Error (nFE)	The athlete has the control of the play and ends up losing the point by mistake, striking a shuttle or off the net, consequently the opponent's point
Winning Points (WP)	Points earned directly by the action of the scorer, hitting the opponent's body or ground of the court
Block (BL)	Basically defensive stroke, as it is the answer to a fast attack of the adversary, where the objective is to block the trajectory of attack only by positioning the racket to cushion the impact
Clear (CL)	A stroke executed above the head, the shuttle makes a parabolic trajectory from the bottom of the court (or middle) of who strikes to the bottom of the opposing court
Drop (DS)	Strike executed above the head, the shuttle is struck from the bottom (or middle) of the striker's court with downward trajectory near the service line of the opposing court
Smash (SM)	Strike executed from the bottom or middle of the court, the shuttle performs a descending and faster trajectory, so that it falls in the middle or the bottom of the opposing court
Drive (DR)	Strike executed at head or shoulder height, with trajectory parallel to the ground and accelerated to the opposing court
Net-Shot (NS)	Strike performed in the front zone of the court, the athlete strikes the shuttle so that it falls in the front zone of the opponent's court, passing as close to the net as possible
Net-Lift ou Lob (NL)	Strike performed in the front zone of the court, below the upper edge of the net, with a parabolic trajectory to the bottom of the opposing court
Services (Sv)	Technical actions to start a rally, the server must touch the shuttle with the racket passing the same to the opposing side
Short Backhand Service (SBS)	Service executed with the palm of the hand holding the racket backwards, aiming to strike the shuttle to the front of the opponent's court
Forehand Short Service (SFS)	Service executed with the palm of the hand holding the racket facing forward, aiming to strike the shuttle to the front of the opponent's court
Long Backhand Service (LBS)	Service performed with the palm of the hand holding the racket facing back, aiming to strike the shuttle to the bottom of the opponent's court
Long Service Forehand (LFS)	Service executed with the palm of the hand holding the racket facing forward, aiming to strike the shuttle to the bottom of the opponent's court

Influence of playing style on the occurrence of missed shots in table tennis

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Abstract

Although the defensive style is competitive in modern table tennis, statistical analyses of it have been limited. The purpose of this study was to clarify the influence of playing style on the occurrence of missed shots, i.e. shots that resulted in a score for the opponent in table tennis. This study found that the defensive style decreases the incidence of missed shots, particularly after the fourth shot, although those of the second and the following shots also decrease. In matches played by a defensive player, missed shots were 6 to 8% less likely to occur than in matches between two offensive players. In addition, the defensive style reduces the likelihood of missed shots in a rally served by an offensive player, and the amount of reduction is about the same as in a rally served by a defensive player. By gender, male defensive players were less defensive than female. We also found it difficult to identify defensive players by the occurrence of missed shots because there might be players not categorised as having defensive style who were as defensive as defensive players.

Keywords: *Table Tennis, Match Analysis, Performance Analysis, Defensive Player*

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Introduction

In table tennis, defensive players, also known as "choppers", are remarkably different from offensive players. Yuza et al. (1992) experimentally investigated the temporal, spatial, and physiological characteristics of playing styles by analysing six matches played by a defensive player and three offensive players. According to their experimental results, the defensive player required double the time and strokes to score a point than the offensive players did. Moreover, they showed that the playing area of the defensive player was more than double that of the offensive players. Although their study might be outdated for modern table tennis, the results still illustrate that the defensive style is markedly different from the offensive style. The uniqueness of defensive players has often led them to be excluded from research samples (Djokic et al., 2019; Loh and Krasilshchiko, 2015; Malagoli Lanzoni, Di Michele, Baertolomei, & Semprini, 2019a; Malagoli, katsikadelis, Straub, & Djokić, 2019b) or analysed separately (Yoshida, Tamaki, & Yamada, 2019).

Defensive players have been decreasing and offensive styles have become dominant in modern table tennis; however, defensive players remain competitive in world-class table tennis. Defensive players, specifically players who primarily hit a backspin ball by chopping from far from the table, emerged in the late 1930s and dominated until the beginning of 1950 (Straub, 2012). However, defensive players have not won first place in any world championships since 1951. At the beginning of the 1950s, the topspin stroke began to prevail with the evolution of equipment and changes in rules (Straub, 2013). In modern table tennis, the offensive playing style is increasing and currently dominates in both genders, 93.4% among males and 88.9% among females (Malagoli Lanzoni et al., 2017). Whereas defensive players have decreased, the defensive style was confirmed to be as competitive as offensive style through an analysis of the number of medals at world championships and world rankings (Straub, 2012). The effectiveness or impact of defensive style should not be underestimated just because it is decreasing.

The purpose of this study was to compare defensive players and offensive players based on the occurrence of missed shots, i.e. shots that scored the opponent, to clarify the influence of playing styles on table tennis matches. While the defensive style is still competitive in modern table tennis, statistical analyses of the defensive style have been limited. Even in a literature review of match analyses in table tennis, no analytical methods or case studies have been described (Fuchs et al., 2018). This study aimed to statistically determine basic differences in the occurrence of missed shots and the number of shots per rally between defensive and offensive styles.

Method

Match samples

In the current study, 106 men's singles matches (9029 rallies) and 100 women's singles matches (8268 rallies) were selected from the matches played at the 2012 London Olympic games and the 2016 Rio Olympic games. Table 1 shows the profile of players in the selected matches. Selected matches were categorised as the follows: AA, played by two offensive players, and AD, played by an offensive player and a defensive player. Matches played by two defensive players were excluded from this study because of too small a sample size. Of the selected matches, 94 men's singles matches and 60 women's singles matches were categorised as AA, and 12 men's singles matches and 40 women's singles matches were categorised as AD. In the selected matches, defensive players won in three men's matches and 17 women's matches and lost in 9 men's singles matches and 23 women's matches. The world rankings of the players in the selected matches were from 1 to 131 based on the ranking immediately before each Olympic game. Written informed consent from the subjects was unnecessary as the matches were played in public.

Table 1.
The profile of players in the selected matches

Gender	Playing hand		Playing style		Grip	
	L	R	Defensive	Offensive	Penhold	Shakehand
Male	63	16	5	74	6	73
Female	58	20	17	61	5	73

Data collection

The server, winner, and scoring shot number were recorded per rally by observing video recordings broadcast on television or on the Internet. Data were recorded by two operators. If different data were found between the two data collected by the two operators, they reviewed the recordings together, making necessary corrections. Defensive players were identified by their primary use of chop. The agreement rate for the classification was 100%.

Number of shots and missed shots

The number of shots for each shot number was computed by the method proposed by Tamaki, Yoshida and Yamada (2017). In table tennis, players alternate shots. Thus, we can determine which shot a player hit, if we know the server of the rally and the scoring shot number. Let us assume that player A serves to player B, and that the seventh shot scores. We can determine that player A performed the first, third, fifth, and seventh shot; player B thus performed the other shots in the rally, including the eighth shot. In this study, the number of shots is defined as the number of shot opportunities. Therefore, the next from the scoring shot is always counted as the missed shot, regardless of whether it was performed. In the aforementioned example, the eighth shot is the missed shot. The number of missed shots was counted for each shot number.

Occurrence of missed shots and number of shots per rally

The occurrence of missed shots was calculated as a measure of defensiveness. Moreover, the number of shots per rally was calculated as a measure of rally length. In fact, the occurrence of missed shots and the number of shots per rally are reciprocals of each other and provide identical information. However, the number of shots per rally was calculated to easily see the rally length. The occurrence of missed shots and the number of shots per rally were calculated for each player in each match.

Occurrence of missed shots at each shot number

The occurrence of missed shots was calculated for each shot number. Let m_i be the number of missed shots at the *i*-th shot and s_i the number of *i*-th shots. The occurrence of missed shots at the *i*-th shot was calculated as m_i/s_i . The fifth and the subsequent shots were combined as one group, and the occurrence of missed shots was calculated by the following equation.

$$\%Miss_{5+} = \sum_{i=5}^{n} m_i \Big/ \sum_{i=5}^{n} s_i \quad (1)$$

The occurrence of missed shots of each shot number was calculated for each player in each match.

Precision and recall of automatic classification

Precision and recall of automatic clustering were calculated to measure how defensive players differed from offensive players. A Gaussian mixture model was used to statistically model the distribution. Two-group clustering was performed with the occurrence of missed shots at third shot and at the fifth shot using the expectation-maximisation algorithm (Bishop, 2006). Let TP be the number of true positives, FP the number of false positives, and FN the number of false negatives. Precision and recall of automatic classification were calculated using the following equations.

$$Precision = TP/(TP + FP) \quad (2)$$

$$Recall = TP/(TP + FN) \quad (3)$$

Statistical analysis

The occurrence of missed shots was compared between AA and AD using the Mann-Whitney U test. In addition, a Kruskal-Wallis test was performed to compare the occurrence of missed shots among the following combinations of server and receiver playing styles: A-A, an offensive player served and an offensive player returned it; A-D, an offensive player served and a defensive player returned it; and D-A, a defensive player served and an offensive player returned it. Wherever significant differences were observed, a Dunn test with Bonferroni adjustment was used to compare the categories of the rally. All statistical tests were performed for gender at a 95% confidence level. In addition, every statistic was also compared with effect size, Pearson r, and 95% confidential interval. We analysed the magnitude of r with reference to the general frame proposed by Cohen (1988) as follows:

Small: r=0.1
Medium: r=0.3
Large: r=0.5.

Results

Occurrence of missed shots and number of shots per rally

Figure 1 shows the occurrence of missed shots and the number of shots per rally by match category. The occurrence of missed shots in AD was significantly lower than in AA (male: $p<0.01$,$r=0.36$; female: $p<0.01$,$r=0.72$). Hence, as a matter of course, AD's number of shots per rally, namely the reciprocal of the occurrence of missed shots, was larger than that of AA.

Occurrence of missed shots at each shot number

Figure 2 shows the occurrence of missed shots at each shot number. The occurrence of missed shots for AD was lower than for AA at the 2nd shot (male: $p<0.01$,$r=0.22$; female: $p<0.01$,$r=0.51$), 3rd shot (male: $p<0.01$,$r=0.37$; female: $p<0.01$,$r=0.58$), 4th shot (male: $p<0.01$,$r=0.27$; female: $p<0.01$,$r=0.71$), and after the 4th shot (male: $p<0.01$,$r=0.37$; female: $p<0.01$,$r=0.71$). The occurrence of missed shots at the 1st shot for AD was not significantly different from that of AA (male: $p=0.15$,$r=0.10$; female: $p=0.26$,$r=0.08$). Figure 3 shows the cumulative occurrence of shots per shot number. AD's cumulative occurrence of shots surpassed 0.75 at the 8th shot in male matches and at the 11th shot in female matches, while that of AA surpassed 0.75 at the 5th shot in both male and female matches.

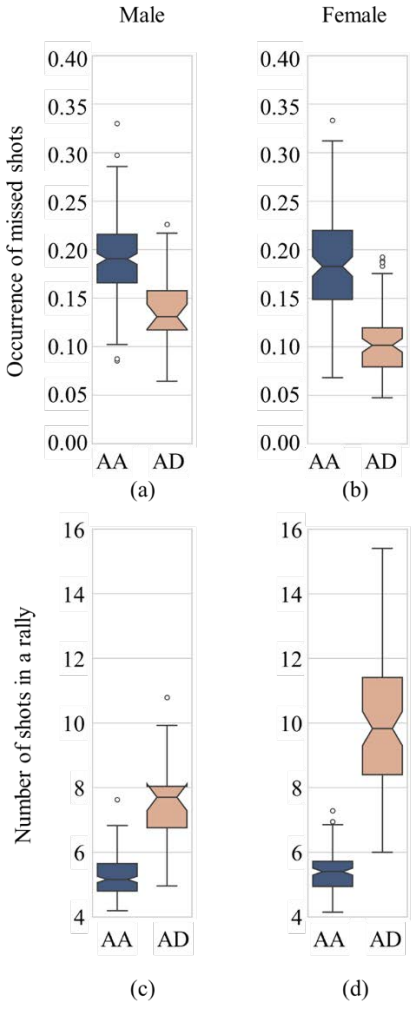

Figure 1. Occurrence of missed shots and number of shots per rally by match category, "AA," played by two offensive players, and "AD," played by an offensive player and a defensive player. The box and

whiskers denote the maximum, minimum, median, first quartile and third quartile. The notches denote the 95% confidence interval. The circle markers denote outliers whose distance from the box is at least 1.5 times the inter quartile range.

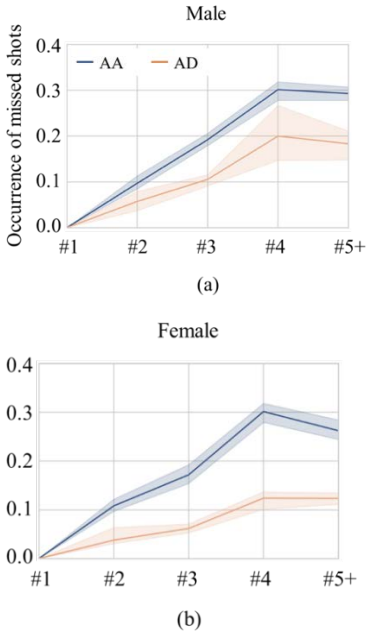

Figure 2. Occurrence of missed shots at each shot number. "*#i*" denotes the *i*-th shot. The median was calculated for each gender. The shaded area denotes the 95% confidence interval.

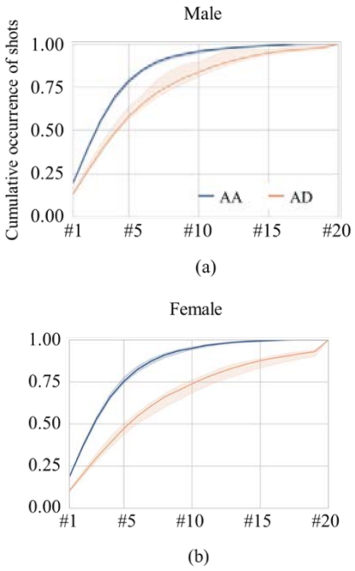

Figure 3. Cumulative occurrence of shots per shot number. "*#i*" denotes the *i*-th shot. The median was calculated for each gender. The shaded area denotes the 95% confidence interval.

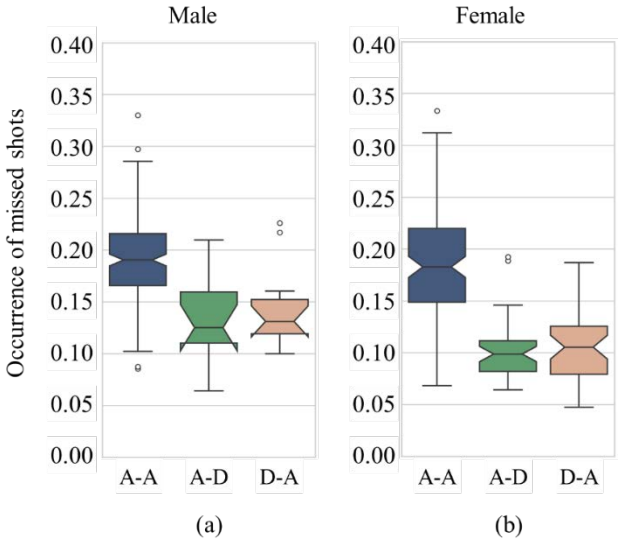

Figure 4. Occurrence of missed shots for each combination of the server's and receiver's playing style: "A-A," an offensive player served and an offensive player returned it; "A-D," an offensive player served and a defensive player returned it; and "D-A," a defensive player served and an offensive player returned it. The box and whiskers denote the maximum, minimum, median, first quartile and third quartile. The notches denote the 95% confidence intervals. The circle markers denote outliers, whose distance from the box is at least 1.5 times the inter quartile range.

Occurrence of missed shots for each combination of server and receiver playing styles

Figure 4 shows the occurrence of missed shots of each combination of server and receiver playing styles. The occurrence of missed shots for A-A was significantly higher than that for A-D (male: $p = 0.00, r = 0.29$; female: $p = 0.00, r = 0.66$) and D-A (male: $p = 0.00, r = 0.25$; female: $p = 0.00, r = 0.61$). A-D's occurrence of missed shots was not significantly different from that of D-A (male: $p = 1.00, r = 0.08$; female: $p = 1.00, r = 0.06$).

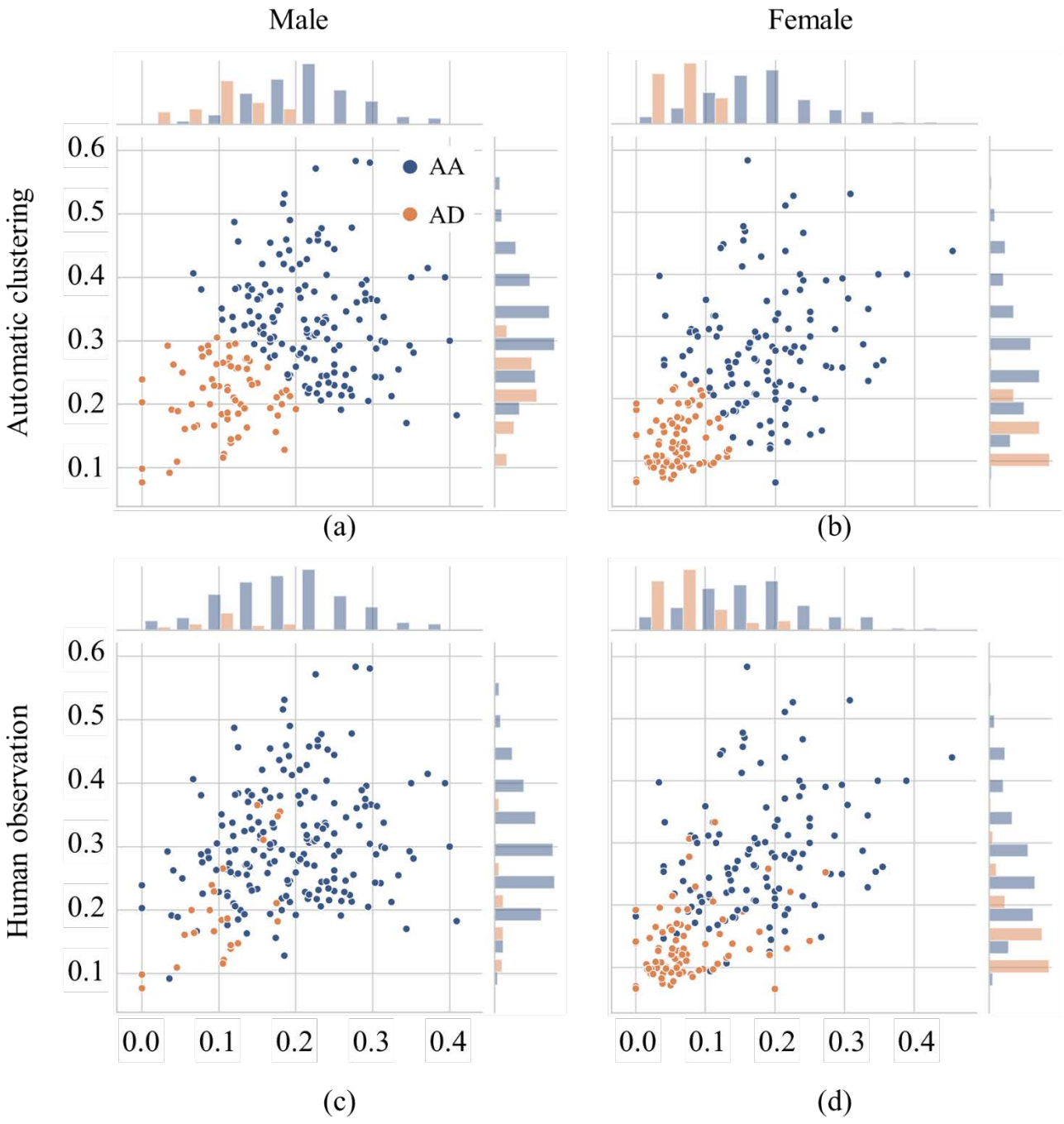

Figure 5. The results of clustering based on the occurrence of missed shots at the third shot (horizontal axis) and the fifth shot (vertical axis). Automatic clustering denotes the results of Gaussian Mixture Model (GMM)-based clustering, and Human observation denotes the data labelled through human observation.

Precision and recall of automatic classification

Table 2 shows the precision and recall of the automatic classification. Figure 5 shows the distribution of the occurrence of missed shots at the 3rd shot and the 5th shot with the category of match automatically labelled and labelled through human observation. The precision and recall were 0.29 (20 / 70) and 0.83 (20 / 24) in male players' matches and 0.80 (63 / 79) and 0.79 (63 / 80) in female players' matches.

Table 2.

Precision and recall of automatic clustering. TP denotes the number of true positives, TF denotes the number of true negatives, FP denotes the number of false positives, and FN denotes the number of false negatives.

Gender	Precision	Recall	TP	TF	FP	FN
Male	0.29	0.83	20	138	50	4
Female	0.80	0.79	63	104	16	17

Discussion

Influence of playing style on the occurrence of missed shots

The defensive style was less likely to lead to missed shots in both male and female players' matches. A rough calculation shows that the difference in the occurrence of missed shots between AA and AD was about 6% in male matches, and 8% in female matches. The difference in the occurrence of missed shots increased by 2.5 shots in male matches, and by 4.4 shots in female matches. This indicates the influence of playing style on the occurrence of missed shots. These results can be naturally described by defensive players' tactics, namely winning a point by lowering one's losing rate more than one's opponent's. Although these results were not surprising, specific differences between the two categories of match were novel in research on table tennis because researchers commonly exclude defensive players in their research sample (Djokic et al., 2019; Loh and Krasilshchiko, 2015; Malagoli Lanzoni et al., 2019a; Malagoli et al., 2019b). These results are therefore meaningful for understanding the influence of playing style on table tennis rally in a quantitative way.

Even if a rally was initiated by an offensive player's service, the occurrence of missed shots would be as low as in the rallies begun by a defensive player's service. The effect size between A-D and D-A was 0.08 in male matches, and 0.06 in female matches, which can be interpreted as small or less than small according to Cohen's guidelines. If offensive players take advantage of service in their tactics, which is more likely than with defensive players, high missed shots ratio at A-D and low missed shots ratio at D-A could co-occur because A-D and D-A are independent. Although the specific reasons cannot be clarified in the current study, these results indicate that the defensive style also reduces missed shots in a rally served by an offensive player, and the amount of reduction is about the same as in a rally served by a defensive player.

Changes in the influence of playing style on the occurrence of missed shots

The defensive style lowers the occurrence of missed shots, especially after the fourth shot, but also at the second and following shots. According to previous studies (Tamaki et al., 2017; Yoshida et al., 2014; Zhang et al., 2014), servers are considered to have the potential advantage of scoring bias toward themselves using service in table tennis. Therefore, if defensive players use services in the same manner as offensive players, it can be naturally inferred that similar amounts of missed shots occurred immediately after the service, such as at the second and third shots. However, the differences in effect size between AD and AA at the second and third shots revealed that missed shots were less likely to occur in AD than in AA, even at the second and third shots. On the other hand, the degree of influence of defensive style was notably different between the second shot and shots after the fourth shot. Missed shots were more likely to occur after the fourth shot than the second shot. Consequently, we can understand that defensive style decreases the

incidence of missed shots particularly after the fourth shot, although the incidences at the second and the following shots are also decreased.

Gender comparison

The occurrence of missed shots at each shot number suggest that the tactics of male defensive players is less defensive than those of female defensive players. According to the effect size, the difference between AA and AD was medium in male matches and large in female matches. Since the 95% confidence intervals of AA in female and male matches overlapped (Figure 1), we can reject the hypothesis that missed shots are less likely to occur in matches played by female offensive players. Hence, we can hypothesise that missed shots are more likely to occur in male players' AD than female players' AD. The occurrence of missed shots at each shot number provides detailed insight of this hypothesis. In male players' matches, the occurrences of missed shots in AD and AA were relatively similar at the fourth shot according to the effect size, 0.37 at the third shot, 0.27 at the fourth shot, and 0.36 at the shots after the fourth shot. This suggests that male defensive players also use service to score a point at the third shot and the ratio of missed shots at the fourth shot was close to that of the matches played by offensive players. On the other hand, such results were not observed in female players' matches; the effect size was 0.58 at the third shot, 0.71 at the fourth shot, and 0.71 at the fifth shot. This suggests that female offensive players are less likely to make a missed shot at the third shot in AD. The specific factors of the difference cannot be mentioned in this study because information about the technique (e.g. kind of shot, ball placement) were not collected. However, the results suggest a gender difference in which the tactics of male defensive players are less defensive than those of female defensive players.

Can we distinguish between defensive and offensive players?

It was found that we could not precisely identify defensive and offensive players by the occurrence of missed shots. According to precision and recall of automatic clustering, if we try to detect defensive players by automatic clustering, we will have a 20% chance of accidentally finding matches played by offensive players in the female cases and a 70% chance of finding matches played by offensive players in the male case. The difficulty of clustering can be understood from Figure 5; there is no division in the distribution of the occurrence of missed shots. The results suggested the necessity of reconsidering the definition of "defensive player" in table tennis. In this study and other studies (Djokic et al., 2019; Malagoli Lanzoni et al., 2019a; Malagoli Lanzoni et al., 2019b; Straub, 2012), the definition of a defensive player is the same as that of choppers. According to the results of this study, we may say that defensiveness or returning stability are not just determined by how often players perform a chop. In the distribution of missed shots, there seem to be a remarkable number of players whose defensiveness was equal to or higher than that of choppers. However, such players cannot be defensive under the current definition because the definition requires the frequent use of chopping. While acknowledging that choppers are relatively defensive, we need to reconsider the definition of "defensive player" based on the fact that there are other types of defensive players than choppers.

Suggestions for athletes and coaches

This study presents useful information for planning technical or tactical practice and physical training. From the cumulative occurrence of shots per shot number, more than 50% of rallies last more than five shots in female players' matches. Female defensive players and their coaches can understand the importance of the tactics and techniques to score a point at shots after the fifth shot from this result. In addition, as the number of shots per rally is almost twice as many, athletes and coaches can understand

the reasonable amount of physical training required. Furthermore, defensiveness is not determined by frequency of chopping. The occurrence of missed shots, or number of shots per rally, should be utilized to understand defensiveness of opponent players to formulate effective tactics to score a point. Thus, athletes and coaches can gain useful information from this study.

Limitation of this study

Our findings have some limitations. As this study focused on the occurrence of missed shots in table tennis, the information about techniques, such as kind of shot or ball placement, were not collected. Therefore, no specific techniques in the analysis were mentioned. For example, the difference in the occurrence of missed shots between A-D and D-A was found to be small in this study. Possible reasons for this result: offensive players might change their tactics when they play with defensive players, defensive players might sufficiently reduce server advantage with their defensive techniques, and so on. However, specific reasons were not determined as no information about playing techniques was included.

Conclusion

The purpose of this study was to clarify the influence of playing style on the occurrence of missed shots in table tennis. We found that matches played by a defensive player had a 6-8% lower chance of making missed shots. Further investigation revealed that defensive style decreases the occurrence of missed shots particularly after the fourth shot, although also at the second and following shots. In addition, the defensive style also reduces missed shots in a rally served by an offensive player, and the amount of reduction is about the same as for a rally served by a defensive player. The occurrence of missed shots was compared between genders, showing that male defensive players were less defensive than female defensive players. It was also found that we cannot precisely identify defensive players based only on the occurrence of missed shots because there may be players who were not categorised as defensive players but who were as defensive as defensive players.

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The relationship between sport-specific training and a perceptuo-motor skills assessment as part of talent identification in young table tennis players (8-10 years)

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Abstract

A perceptuo-motor skills assessment was developed to better estimate the potential of youth table tennis players (8-10 years). Sport-specific training experience might influence the outcomes of this assessment and hinder a fair interpretation. Consequently, the aim of this study was to evaluate the relationship between the training experience (i.e. quantity and quality) and the perceptuo-motor skills assessment outcomes in youth table tennis players. For this purpose, data were collected during the national association's talent days in the Netherlands (2010-2015). In total, 372 young table tennis players (8-10 years) were assessed by a perceptuo-motor skills questionnaire covering current training (hours/week), total training volume (hours) and quality of the trainer (high versus low). Non-parametric partial correlation analyses showed that training quantity outcomes (i.e. current training and training volume) are significantly associated with the test items of speed while dribbling, aiming at target and eye-hand coordination in both sexes with small to medium effect sizes. The multivariate GLM analyses revealed no significant differences between players receiving high versus low quality training regarding the perceptuo-motor skills assessment. The results indicated only a small transfer of skill and a substantial amount of task specificity; as such it seems legitimate to use the perceptuo-motor skills assessment as part of a talent identification programme. However, it seems sensible to take the training volume into account for a fair interpretation of the estimation of potential, especially when large differences exist between players regarding the training experience. Future studies using a longitudinal design could reveal more about the effect of training.

Keywords: *Task/Learning Specificity, Skill Transfer, Talent Identification, Aptitude, Child, Racket Sports*

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Introduction

Talent identification and development are important pillars of success of national sports associations nowadays (de Bosscher, Bingham, Shibli, Bottenburg, & Knop, 2007). Consequently, talent programs have gained priority in many sports during the last decades, including large investments regarding the search and guidance of young talented players who strive to reach world's highest level (e.g. Elferink-Gemser, 2005; Huijgen, 2013; Pion, 2015; Kramer, 2019; Stoter, 2020). This is also the case in the table tennis sport (Faber, 2016). It appears that national table tennis associations have put special efforts specifically into talent identification as part of the talent programs to increase their success-rate. This is likely due to the facts that table tennis is generally considered as an early starting sport and players have a relatively high age of peak performance especially in West-Europe (Faber, Damsma, Pion, in press). Early recognition of talented players at a young age (7-12 years) is anticipated to increase efficiency and effectiveness of the intensive training programs by including only youth players with the highest potential. Therefore, accurate talent identification is expected to be a part of a cost-effective solution to keep up with the global medal race, particularly for relatively small countries with scarce (financial) resources (de Bosscher et al., 2007; Faber, 2016; Pion, Hohmann, Liu, Lenoir, & Segers, 2017).

One initiative following this strategy was conducted by the Netherlands Table Tennis Association (NTTA). From 1998 to 2016, the NTTA developed and evaluated a perceptuo-motor skills assessment in cooperation with a team of sports scientists in order to better estimate the potential of young players (<11 years) regarding the perceptuo-motor domain. The current NTTA's perceptuo-motor skills assessment consists of eight test items (Table 1). These items are intentionally combined together to measure foundational abilities for table tennis (e.g. coordination, dynamic balance, accuracy, agility, ball control), which are crucial for developing excellent technical features (Faber, Elferink-Gemser, Oosterveld, Twisk, J. W. & Nijhuis-Van der Sanden, 2016). Evaluative studies show that the inter-rater reproducibility per test items is good (Intraclass Correlation Coefficient .73–.91 ($p < .01$), Coefficient of Variation 1–15%) (Faber, Elferink-Gemser, Oosterveld, & Nijhuis-Van Der Sanden, 2014a; Faber, Nijhuis-Van Der Sanden, Elferink-Gemser, & Oosterveld, 2015) and the test items are able to discriminate between performance levels (Faber et al., 2014a; Faber, Oosterveld, & Nijhuis-Van der Sanden, 2014b; Faber, Pion, Munivrana, Faber, & Nijhuis-Van der Sanden, 2018; Platvoet et al., 2018). Furthermore, an observational study shows promising results regarding the predictive value in a small sample over a period of 2.5 years. The assessment's test items significantly add to the prediction of future performance and explained 51% of the variance within the best-fitting model (Faber et al., 2016). As such, the NTTA has included this assessment as an instrument to support the identification of talented players in their talent pool at the annual national talent day beginning in 2010.

As an extension to the aforementioned studies, it is important to address the association between the table tennis training and the assessment's outcomes in the current study. This relationship has not been taken into account so far, although the exposure to training is suggested as a possible confounder when interpreting test results for the estimation of potential (Elferink-Gemser, Jordet, Coelho E Silva, & Visscher, 2011; Faber et al., 2015; Faber et al., 2016). If youth table tennis players would benefit from their sport-specific training experience (i.e. youth players with more and/or higher quality table tennis training experience gain better results on the assessment), this might prevent a fair estimation of potential. For that reason, authentic table tennis tasks were deliberately avoided to minimize or even eliminate the effect of training during the developing of the test items. The idea was that skills, which are not trained, are more appropriate to measure future potential than specific sport skills themselves (Faber et al., 2015; Gagné, 2004; Morrow, Jackson, Disch, & Mood, 2011; Vaeyens, Lenoir, Williams, & Philippaerts, 2008; Vandorpe et al., 2012). Indeed,

task/learning specificity theories imply that motor abilities are specific to a particular task and that transfer among skills is quite low (de Camargo Barros, Tani, & Corrêa, 2017; Ellison, Kearney, Sparks, Murphy, & Marchant, 2018; Schmidt & Lee, 2011; Sigmundsson, Trana, Polman, & Haga, 2017).

On the other hand, previous studies on skill transfer show that a transfer is possible based on an underlying general motor ability and training can have an effect on trained and untrained skills (Behringer, vom Heede, Matthews, & Mester, 2011; Farhat et al., 2016; Rylander, Karlsteen, Kougioumtzis, & Gustafsson, 2019). In sports, this perhaps becomes most obvious when taking into account the evidence of successful transfers between sports on the elite level (Collins, Collins, MacNamara, & Jones, 2014). Athletes seem to build upon previous skills and need considerably less hours to get to the elite level in their second target sport (Rea & Lavallee 2015). For example, Rebecca Romero gained a silver medal in rowing in the quadruple sculls at the Olympics of 2004, transferred to cycling and won a gold medal in the individual pursuit at the Olympics of 2008. Based on Thorndike's theory (1914), it is proposed that 'identical elements' between tasks or the 'underlying processes' are transferable (Côté, Baker, & Abernethy, 2007; Schmidt & Lee, 2011). As a nuance to this, Issurin (2013) stated that specificity of motor learning or the degree of transfer are affected by many variables. The amount of practice is considered to be the most important one, followed by structure of the practice and then specificity of learning (Ericsson, Krampe, & Tesch-Romer, 1993; Schmidt & Lee, 2011). Moreover, one especially needs to take training experience into account given the fact that less experienced athletes show greater sensitivity to any kind of training transfer than the more experienced ones (Gamble, 2006; Issurin, 2013).

Thus it appears that the current scientific evidence is ambiguous and prohibits a clear conclusion from studies with regard to, on the one hand 'task/learning specificity' and on the other hand 'transfer of skill', which seem contradictory. Consequently, it is proposed that empirical evidence of the relationship between the table tennis training and the assessment's outcomes is needed to have a better insight in the possible confounding effect of training on the estimation of table tennis potential. Accordingly, this study focuses on the following research question: Are the perceptuo-motor skills assessment outcomes related to the quantity and/or quality of the sport-specific training in youth table tennis players (8-10 years)?

Table 1.
Current test items of the motor skills assessment of the Netherlands Table Tennis Association (Faber et al., 2016)

Test item	Assessing:	Task:
Sprint (s)	The ability for quick accelerations and turns in combination with a manual task while picking up balls in a pyramid shaped circuit.	Gather and return five table tennis balls one by one in a pyramid-shape circuit as fast as possible. Time is measured in seconds.
Agility (s)	The ability to quickly coordinate gross arm and leg movements simultaneously while getting over a gymnastic cabinet and under hurdles several times.	Get through a circuit as fast as possible including climbing over a gymnastics' cabinet (five times) and under and over a low hurdle (four times). Time is measured in seconds.
Vertical jump (cm)	The ability to jump as high as possible.	Stand next to a wall and jump and touch the wall with your fingertips as high as possible. The difference between the jumping height and standing height with one arm up along the wall is measured in centimetres.
Speed while dribbling (s)	The ability to control a basketball during a dynamic task: sideward zigzagging.	Move sideways through a zig-zag circuit as fast as possible while dribbling with a basketball using one hand. Time is measured in seconds.
Aiming at target (points)	The ability to hit a target at 2.5 m distance precisely with a ball using a bat while alternately using a forehand and backhand stroke.	Hit a round target (Ø 60 cm) on the floor at 2.5-meter distance with a table tennis ball using a standard bat. Forehand and backhand need to be used alternately during the attempts. A hit in the target' centre (Ø 0.20 m) or the outer ring yielded 6 and 4 points, respectively. The total score of ten attempts is registered as the final score.
Ball skills (points)	The ability to hit a target precisely by throwing a table tennis ball via the vertical positioned table tennis table alternately from two distances.	Hit a round target on the floor (Ø 75 cm) by throwing a table tennis ball via a vertical table tennis table from two different positions (1- and 2-meter distance away from the target). A hit in the centre (Ø 0.335 m) or the outer ring of the target yielded 2 and 1 points, respectively. The total score of the twenty attempts is registered as the final score.
Throwing a ball (m)	The ability to combine the coordination of an arm movement with high arm velocity by throwing a table tennis ball as far as possible.	Throw a table tennis ball as far away as possible with the preferred hand. The distance from the starting point at the marked line to the point of the ball's first bounce is measured in meters with one decimal.
Eye-hand coordination (points)	The ability to make accurate and cooperative hand and arm movements at a high rate by throwing a table tennis ball towards a vertically positioned table tennis table with one hand and catching is with the other hand and repeating this alternately.	Throw a ball at a vertical table tennis table at 1-meter distance with one hand and to catch the ball correctly with the other hand as frequently as possible in 30 seconds. The number of correct catches is scored.

Materials and methods

Study design and ethical statement

This study used a cross-sectional design including a data-collection carried out at the National Training Center Papendal in the Netherlands during six annual NTTA's national talent days (2010-2015). This study and its informed consent procedure were approved by the ethical committee of the Medical Spectrum Twente (Medical School Twente, Institute for Applied Sciences, Enschede, the Netherlands; MTC/11069.oos 18-2-2011) in full compliance with the declaration of Helsinki. At least 1 month prior to the measurements, players and their parents were informed in writing by the NTTA that data, sampled during the NTTA's national talent day, would be anonymously collected for this study. There was full opportunity for players and their parents to ask for more information concerning this study and/or refuse provision of the anonymous results. All data were recorded in an anonymous data set by the NTTA; the ethical committee consulted waived the need of a written parental and player's informed consent.

Participants

Young table tennis players were recruited during the annual national talent days of 2010 to 2015. Regional technical staff from each department (n=8; Holland-Noord, Zuid-West, West, Noord, Limburg, Gelre, Midden and Oost) were instructed to select youth members of their department with the highest potential for national elite table tennis regarding both physical and mental aspects. A maximum of 8 boys and 8 girls were selected per department. Inclusion criteria were: an age between 8 and 10 years and being a member of a table tennis club associated with the NTTA. Players with injuries were excluded from the study.

Data collection

Perceptuo-motor skills assessment

The perceptuo-motor skills assessment of the young players consists of eight test items (Table 1). The standardization of all test items is captured in protocols, which includes a detailed description of materials, set-up, assignment, demonstration, training and testing phase, as well as registering test scores. The complete test protocol of the assessment is available online (Faber et al., 2016; https://doi.org/10.1371/journal.pone.0149037.s001). All children were tested under similar conditions as part of the event after they did a warm-up. Total testing time for each child was approximately 20 min for the perceptuo-motor tests spread over three sessions. Test leaders were physical therapy students or table tennis trainers who were familiarized with the use of the test protocol. Moreover, instruction and feedback were given during a practical training by an expert trainer of the NTTA.

Questionnaire

All participants were asked to fill in a questionnaire to obtain information about personal characteristics (sex (boy/girl), age (year), height (cm), body mass (kg), playing hand (left/ right)) and the foregoing sport-specific training. The quantity of their table tennis training was mapped by 1.) the current training (hours per week) and 2.) the total training volume (hours) based on average training hours per week of the seasons played. For the quality of the table tennis training, the qualification level of player's trainer was questioned. In the Netherlands there are five levels of trainer's qualifications: TT1 (youth guidance), TT2 (youth/assistant club trainer), TT3 (club trainer), TT4 (trainer of a regional training centre) and TT5 (national trainer). TT1 to TT3 are organized by the NTTA and the highest levels, TT4 and TT5, are offered by the Netherlands Olympic Committee*Netherlands Sports Federation (NOC*NSF) (www.nttb.nl). Additionally, a lack of coaching qualifications was taken into account. In consultation with the Dutch table tennis trainers association it was decided to use a binary outcome

for the quality of training: high (i.e. TT4 and TT5) and low (i.e. no qualification, TT1, TT2 and TT3). High qualified trainers are professional part-time or full-time trainers at clubs or regional/national training centres. In general, these trainers are more experienced and obligated to participate in additional courses to keep their trainer's license. Low qualified trainers are mostly volunteers at clubs and often unpaid. The commitment to additional (refresher) courses are frequently waived by the clubs.

Statistical analysis

IBM SPSS Statistics 26 (IBM Corp., Armonk, New York, United States of America) was used for the statistical analyses. The normality of data was evaluated by comparing (1) means and medians of the test items and (2) standard deviation with minimal and maximal values. Sample characteristics and descriptive statistic were presented per sex. First, to determine the degree of association between the perceptuo-motor skills assessment outcomes and the quantity of the training non-parametric partial correlations were calculated per test item. Second, multivariate General Linear Model (GLM) analysis was used to test for differences regarding the test scores between youth players experiencing a high versus a low quality of training. Age was included as covariate as previous analyses showed that older youth players outperform younger players on the test items (Faber et al., 2014; Faber et al., 2016). Moreover, as boys tend to outscore girls and sex might have a modifying effect on the results, both the partial correlations and multivariate GLM analysis were conducted separately for boys and girls (Faber et al., 2014). Third, an additional multivariate GLM analysis was conducted and followed up with a discriminant analysis, both using age and sex normalised z-scores, to evaluate the relationship between both the quantity and quality of training experience and the perceptuo-motor skills assessment outcomes at once. For this purpose, four groups of youth players were defined based on their total training volume, and the trainer's qualification level; 1.) low volume and low quality, 2.) low volume and high quality, 3.) high volume and low quality and 4.) high volume and high quality. A low training volume was assigned when a player belonged to the 40% of the players with the lowest total training volume of his/her age group. A high training volume was assigned when the player belonged to the 40% players with the highest total training volume of his/her age group. The multivariate GLM analysis was used to test for differences between the four groups. The discriminant analysis, including the case wise results and "leave-one-out method" for cross-validation, evaluated the perceptuo-motor assessment's capacity to classify the young table tennis players in the four groups. Cohen's rules of thumb are used for the interpretation of the effect sizes; partial correlation .10 small, .30 medium and .50 large and GLM's partial eta-squared .01 small, .06 medium and .14 large (Cohen, 1988). Alpha was set at .05 for significance for all analyses.

Results

In total, 372 young table tennis players (age 8-10 years) were assessed during the NTTA's national talent days (2010-2015). Table 2 presents the characteristics of the participants. The characteristics in girls and boys were similar, however more boys were tested compared to girls.

Table 3 shows the descriptive outcomes of the perceptuo-motor skills assessment and the questionnaire (i.e. sport-specific training information). All data collected with the perceptuo-motor skills assessment were evaluated as normally distributed for both boys and girls; mean and medians were similar and the range around the mean followed a normal distribution. This was also the case for the subsamples used within further analyses. The training quantity outcomes (i.e. current training and training volume) on the other hand presented a right-skewed distribution of the data.

Table 2.
Characteristics of participants

		Total	Boys	Girls
Total number	2010-2015	372 (100%)	241 (65%)	131 (35%)
	2010	68 (18%)	42	26
	2011	72 (19%)	41	31
	2012	92 (25%)	57	35
	2013	50 (13%)	38	12
	2014	36 (10%)	27	9
	2015	54 (15%)	37	17
Age group	8 years	48 (13%)	29	19
	9 years	122 (33%)	82	40
	10 years	202 (54%)	131	71
Handedness (n=327)	left	35 (11%)	26	9
	right	292 (89%)	187	105
Standing height (cm)	(n=323; ♂ 211, ♀ 112)	142 ± 8.1	142 ± 8.1	142 ± 8.2
Body mass(kg)	(n=321; ♂ 209, ♀ 112)	34 ± 6.9	34 ± 6.5	36 ± 7.5
BMI (kg/m²)	(n=319; ♂ 207, ♀ 112)	16.9 ± 2.4	16.7 ± 2.4	17.4 ± 2.5
Departments	Holland-Noord	37 (10%)	26	11
	Zuid-West	37 (10%)	23	14
	West	65 (17%)	46	19
	Noord	28 (8%)	16	12
	Limburg	55 (15%)	35	20
	Gelre	40 (11%)	26	14
	Midden	53 (14%)	35	18
	Oost	57 (15%)	34	23

Data are frequencies (and percentage of the total sample (%)) except for standing height, weight and BMI. These latter variables are presented in means ± standard deviations.

Table 3.
Outcomes perceptuo-motor skills assessment and training questionnaire

	Total		Boys		Girls	
Perceptuomotor skills assessment	n	M ± SD	n	M ± SD	n	M ± SD
Sprint (s)	369	34 ± 4	240	34 ± 4	129	35 ± 3
Agility (s)	367	30 ± 8	238	28 ± 7	129	33 ± 9
Vertical jump (cm)	368	29 ± 6	239	29 ± 6	129	28 ± 5
Speed while dribbling (s)	371	23 ± 6	241	22 ± 5	130	25 ± 6
Aiming at target (points)	371	24 ± 10	241	25 ±10	130	22 ± 10
Ball skills (points)	368	17 ± 6	238	18 ± 6	130	15 ± 6
Throwing a ball (m)	369	10 ± 2	239	10 ± 2	130	9 ± 2
Eye -hand coordination (points)	369	15 ± 7	239	16 ± 7	130	13 ± 7

Table 3 (continued)	Total		Boys		Girls	
Training quantity	n	Md (range)	n	Md (range)	n	Md (range)
Current training (hours/week)	257	3 (1-10)	168	3 (1-10)	89	2.5 (1-8.5)
8-year olds	28	1.5 (1-10)	18	1.88 (1-10)	10	1 (1-8)
9-year olds	93	2.75 (1-9.5)	62	3 (1-9.5)	31	2.5 (1-8.5)
10-year olds	136	3 (1-8)	88	3 (1-8)	48	2.75 (1-7)
Training volume (hours)	257	140 (4-1000)	168	144 (4-808)	89	120 (15-1000)
8-year olds	28	70 (25-408)	18	72 (25-408)	10	64 (28-408)
9-year olds	93	120 (15-808)	62	137 (24-808)	31	110 (15-548)
10-year olds	136	148 (4-1000)	88	164 (4-704)	48	142 (28-1000)
Training quality	n	percentage	n	percentage	n	percentage
High	71	27%	43	26%	28	31%
Low	188	73%	125	74%	63	69%

M = mean; SD = standard deviation; Md = median.

Table 4.
Relationship between training and perceptuo-motor skills outcomes

	Current training (hours/week)		Training volume (hours)		Training quality (high versus low)[1]		
Boys (df=163)	*r*	*p*	*r*	*p*	F^2	*p*	partial η^2
Sprint (s)	-.022	.778	-.007	.933	.006	.941	<.001
Agility (s)	-.028	.719	.012	.879	.026	.872	<.001
Vertical jump (cm)	.025	.746	.142	.070	.744	.390	.005
Speed while dribbling (s)	-.189*	.015	-.230*	.003	4.271*	.040	.026
Aiming at target (points)	.345*	<.001	.379*	<.001	.422	.517	.003
Ball skills (points)	-.003	0.967	-.041	.602	.056	.814	<.001
Throwing a ball (m)	.126	.108	.063	.421	.027	.869	<.001
Eye-hand coordination (points)	.214*	.006	.250*	.001	1.404	.238	.009
Girls (df=84)	*r*	*p*	*r*	*p*	F^2	*p*	partial η^2
Sprint (s)	-.134	.220	.043	.695	1.971	.164	.022
Agility (s)	-.125	.250	-.118	.278	.135	.714	.002
Vertical jump (cm)	.058	.595	.058	.595	.357	.552	.004
Speed while dribbling (s)	-.405*	<.001	-.365*	.001	.554	.459	.006
Aiming at target (points)	.352*	.001	.396*	<.001	2.045	.156	.023
Ball skills (points)	.063	.561	.149	.172	.001	.974	<.001
Throwing a ball (m)	.148	.174	.137	.208	.027	.870	<.001
Eye -hand coordination (points)	.264*	.014	.224*	.039	.119	.731	.001

r = non-parametric partial correlation coefficient with test age as covariate; $p < 0.05$; significant partial correlation; df = degrees of freedom. [1]Multivariate GLM results: boys $\Lambda = 0.965$, $F(8,156) = .707$, $p = 0.685$; girls $\Lambda = 0.928$, $F(8,79) = .771$, $p = 0.629$. [2]Univariate GLM results.

The non-parametric partial correlation analyses showed that the current training (hours per week) and three perceptuo-motor test items were significantly associated with small to medium effect sizes in both boys and girls (Table 4); speed while dribbling (♂: r = -.189, p = .015; ♀: r = -.405, p < .001), aiming at target (♂: r = .345, p < .001; ♀: r = .352, p = .001), eye-hand coordination (♂: r = .214, p = .006; ♀: r = .264, p = .014). A similar tendency was seen for the association between the training volume (hours) and the perceptuo-motor test items in both sexes; speed while dribbling speed while dribbling (♂: r = -.230, p = .003; ♀: r = -.365, p = .001), aiming at target (♂: r = .379, p < .001; ♀: r = .396, p < .001), eye-hand coordination (♂: r = .250, p = .001; ♀: r = .224, p = .039). No other significant associations were found.

The multivariate GLM analysis revealed no significant differences between players that received training from a high quality trainers versus players that received training from a low quality trainer in boys (Λ = .965, F(8,156) = .707, p = .685) and also in girls (Λ = .928, F(8,79) = .771, p = .629). The univariate GLM results are summarized in Table 4, revealing one significant difference for speed while dribbling in which the male youth players receiving high quality training outscored their peers receiving a low-quality training (F = 4.271, p = .040). Nevertheless, the effect size was small (partial η^2 = .026).

The multivariate GLM analysis testing difference between the four groups based on training volume and trainer's qualification level showed significant effect regarding the perceptuo-motor assessment outcomes (Λ = .728, F(24,549) = 2.647, p < .001). Significant difference with medium to large effect sizes between the groups were present at the test items: speed while dribbling (F(3) = 7.331, p < .001, partial η^2 = .101), aiming at target (F(3) = 13.150, p < .001, partial η^2 = .168), throwing a ball (F(3) = 3.744, p = .012, partial η^2 = .054), and eye hand coordination (F(3) = 5.422, p < .001, partial η^2 = .077). The consecutive discriminant analysis indicated three discriminant functions F1 (r_{can} = .481; Wilks λ = .728; p < .001), F2 (r_{can} = .205; Wilks λ = .947; p = .721) and F3 (r_{can} = .108; Wilks λ = .988; p = .892) accounting for 84%, 13% and 6% of the variance, respectively. On the whole, 51% of the cross-validated grouped cases were correctly classified into the four groups defined by training volume and trainer's quality based on the assessment outcomes (Table 5). The correct classifications were only noticeable in group 1 (low volume and low quality) and group 3 (high volume and low quality). None of the youth players from the groups with a high-qualified trainer (i.e. group 2 and 4) were qualified correctly.

Table 5.
Discriminant analysis cross-validated classification results

		Predicted group membership				
		1. LL	2. LH	3. HL	4. HH	Total
Cross-validated grouped cases	1. LL	62 (75.6%)	0 (0%)	20 (24.4%)	0 (0%)	82
	2. LH	10 (62.5%)	0 (0%)	6 (37.5%)	0 (0%)	16
	3. HL	23 (35.4%)	0 (0%)	39 (60%)	3 (4.6%)	65
	4. HH	15 (40.5%)	0 (0%)	22 (59.5%)	0 (0%)	37

Data are number and percentages. Groups: 1.) low volume and low quality, 2.) low volume and high quality, 3.) high volume and low quality and 4.) high volume and high quality. The analysis indicated three discriminant functions F1 (r_{can} = .481; Wilks λ = .728; p < .001), F2 (r_{can} = 0.205; Wilks λ = .947; p = .721) and F3 (r_{can} = .108; Wilks λ = .988; p = .892) accounting for 84%, 13% and 6% of the variance, respectively.

Discussion

This study focused on the relationship between the sport-specific training and the outcomes of the perceptuo-motor skills assessment in youth table tennis players (8-12 years) used as a part of talent identification. The results of this study show significant relationships with small to medium effect sizes between three of the included test items (i.e. speed while dribbling, aiming at target and eye hand coordination) and the training quantity outcomes. This means that a part of the test outcomes is indeed associated to a certain extent with the sport-specific training. This might imply that training quantity should be taken into account when interpreting the test outcomes of these test items for the estimation of potential. Furthermore, the relation between the quality of training and the test outcomes seems to be less important or even negligible based on the results of the multivariate GLM analyses and the consecutive discriminant analysis.

The significant relationship between the quantity of the table tennis training and the three test items on the one hand and the lack of association between training quantity and the other test items on the other hand, might be best explained by the differentiation in task characteristics. Speed while dribbling, aiming at target and eye hand coordination all belong to the construct 'ball control' (Faber et al., 2015). These items cover object manipulation while controlling a ball, probably by deploying the visuo-motor system for visual acuity and eye–hand coordination in different circumstances. These characteristics are more similar to the exercises conducted during the sport-specific table tennis training and the actual table tennis play compared to the task characteristics of the other test items. Speed while dribbling and eye hand coordination mimic the rhythm and the back and forth going of the ball and the aiming tasks includes the use of a table tennis bat in a hitting task. As such, transfer of skill is more likely to occur in these tasks compared to the others (Côté et al., 2007; Schmidt & Lee, 2011). Although , the test items 'ball skills' and 'throwing a ball' also belong to the construct 'ball control', these items' characteristics seem less specific, since youth players are requested to throw a ball. The other test items (i.e. sprint, agility and vertical jump) form the construct 'gross motor function' combining strength, speed agility, which are also less specific tasks. Hence, the characteristics of speed while dribbling, aiming at target and eye hand coordination appear to be more near transfer tasks in comparison with the other test items. Near and far transfer are considered according to the degree of similarity between two tasks, assuming that near transfer tasks exist when the task constraints and performance information are quite similar to the initial settings (Issurin, 2013). Nevertheless, the effect sizes are low to moderate, which indicates a low degree of skill transfer and certain degree of task specificity (de Camargo Barros et al., 2017; Ellison et al., 2018).

It is important to acknowledge some limitations of this study. First, it must be mentioned that this study used a cross-sectional design, which prohibits any conclusions about causality. A study with a longitudinal experimental design is needed to provide a fair conclusion about the effect of sport specific table tennis training on the outcomes of the perceptuo-motor skills assessment. Second, this study learned that it was challenging to estimate the quality of the sport specific training based on the questionnaire used. Two reasons for this seem to be most legitimate. To start with, it can be argued whether the qualification of the trainer alone reflects the trainer's competencies in the best way. For example, no attention was paid to the years of experience, the experience with youth athletes, the successes achieved and the participation in refreshing course. Moreover, many players appeared to have more trainers. The highest qualified trainer was taken into account for study, which might not be the 'leading' trainer or the trainer that the youth players mainly receive their training from. These two factors might have influenced the results. However, it is unclear in what direction. Third, no information about the type of training, the variability within the training, training experience in other sports, physical education programs or other physical activity (structured or unstructured) have been taken into

account in this study. This might have influenced the study results (Seifert, Papet, Strafford, Gogliani, & Davids, 2019), but it is unknown to what extent it should be taken into account or be corrected for when estimating the potential of young table tennis players. Finally, it must be mentioned that we missed results on training experience from approximately 30% of the included sample, since not all participants handed in the questionnaire. Only the available data was taken into account for the analysis. Although a substantial part of the sample could be included, there may a response-bias.

Conclusions

In conclusion, there appears to be a significant relationship between the sport specific training and three test items of the perceptuo-motor skills assessment in youth table tennis players (8-10 years) participating at the national talent day. The relationship is determined by the training quantity. The quality of the training seems of less influence. The test items showing a significant association with the assessment test outcomes are considered to be more similar to the table tennis training exercises when compared to the other test items. Still, the effect sizes of the association are small to moderate, which suggests only a small transfer and still a substantial amount of task specificity (de Camargo Barros et al., 2017; Issurin, 2013). For that reason, it seems legitimate to continue to use the perceptuo-motor skills assessment as part of the talent identification in youth table tennis. However, for a fair interpretation of the estimation of potential, it seems sensible to take the training volume into account, especially when large differences exist between players regarding the training experience. Future studies should reveal more about the effect of training in a longitudinal design while improving the determination of the training quality.

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Mental training program in racket sports: A systematic review

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Abstract

The mental aspect is largely acknowledged by athletes and coaches as a salient factor explaining performance variability. The mental component of performance holds a special place in racket sports considering the inherent demands in such intense and emotional activities. The importance of mental skills in racket sports has been examined within the literature through a bulk of studies highlighting associations between mental skills and a wide range of positive outcomes. Access to the programs which aim to improve the mental skills of the athletes represents a major issue for researchers and the different stakeholders (coaches, athletes, parents). The main objectives of this study were to (a) Collect the studies that incorporate mental training programs used in racket sports, (b) Organize the current knowledge on mental training programs and provide a synthesis of the characteristics of these studies, and (c) Identify the gaps in the literature on this topic and propose potential further investigations and practical implications. The present systematic review included 27 studies which involved 715 participants. Most of the studies used a quantitative approach and were conducted on tennis. The mental skills developed varied across the studies with domination of imagery and relaxation techniques. Overall, the programs led to positive outcomes on performance indicators (e.g. improvement of service efficacy and stroke quality) and permitted the development of the targeted mental skills (e.g. concentration, motivation). This review highlighted the weak representation of females and novice players within the studies' participants. Moreover, the unequal representation of the techniques and outcomes in the examined studies encourages the development of further mental programs specifically applied to the demands of racket sports and a focus on different mental skills (e.g. emotional intelligence, coach education).

Keywords: *Mental Skills, Mental Training Program, Racket Sports, Performance, Systematic Review*

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Mental training program in racket sports: A systematic review

Racket sports refer to the physical activities involving rackets to strike a ball or a shuttlecock (Lees, 2003). These activities include some popular sports such as tennis, table-tennis, badminton, and squash but also new activities such as paddle tennis or racketlon. Previous studies have highlighted the complexity of these sports due to the role of a wide variety of factors involved in performance variability (Lees, 2003). To perform in a racket sport, an athlete has to develop technical, physiological, tactical, and mental skills. Athletes and coaches largely acknowledge that the mental aspect is a salient factor and should be trained in the same way as physical or technical components (Jones, 1995). The development of sports sciences and the growing number of studies focused on elite performance led to the implementation of training programs oriented on specific components of sport performance (Kondric, Matković, Furjan-Mandić, Hadzić, & Dervisević, 2011). In this way, mental training refers to the training dedicated to mental skills which refer to internal competences that help the athletes in their goals by learning to manage their psychological states in keeping with their objectives. Mental training mainly aims to improve the well-being and performance level of athletes (Behncke, 2004; Morais & Rui Gomes, 2019). Mental training in sport settings consists of several stage (Terry, Coakley, & Karageorghis, 1995). First, the mental trainer (coach, sport psychologist) should assess the initial skills of the athlete. Second, a mental training program is usually proposed in order to develop targeted mental skills. The programs are composed of intervention sessions including one or many techniques such as relaxation, imagery practice, or cognitive behavioural therapies (Jones, 1995). Third, partial and complete evaluations inform the development and use of mental skills. In the same way as for physical training, the preparation should be suitable for the demands of the activity (Mamassis & Doganis, 2004). Consequently, in order to implement mental training, an investigation of the specific skills inherent to the demands of racket sports has to be realized.

Racket sports demands

Racket sports are associated with specific constrains which differ from other individual sports and involve particular training demands (Dohme, Bloom, Piggott, & Backhouse, 2019; Kondric et al., 2011). An analysis of the sport characteristics could identify the main mental demands and lead to identify the key skills to develop among racket sport athletes. First, a crucial characteristic of racket sports is the speed of the ball/shuttlecock and, in turn the associated required accuracy of all strokes played (Akpinar, Devrilmez, & Kirazci, 2012). These parameters limit the margin of error for each stroke and impose composure in stressful situations to prevent the errors (Ducrocq, Wilson, Smith, & Derakshan, 2017). These sports also require the learning of motor skills (e.g., accurate and powerful strokes) and are characterised by an important volume of training (important number of repetitions) (Doherty, Martinent, Martindale, & Faber, 2018). Consequently, an athlete practicing racket sport should have to be prepared to invest resources (sport motivation) despite the physical, psychological, and social constraints inherent to the practice of racket sports (Martinent, Decret, Guillet, & Isoard-Gautheur, 2014; Martinent & Decret, 2015). During competitive matches, racket sport players perform a series of repeated short and intense efforts (Kondric et al., 2011). Moreover, a competitive game is composed of successive matches across several competitive days. The players should continually project into future points or future games and should thus avoid ruminating about previous situations, behaviours and/or results (emotional regulation). Another major issue of racket sports is the presence of an opponent (Bebetsos & Antoniou, 2003; Caserta, Young, & Janelle, 2007; Poizat, Bourbousson, Saury, & Sève, 2009). The duel is thus central in the performance variability and every player has to focus on the reactions, choices, and behaviours of the other competitor.

Mental skills

In line with the exploration of the main characteristics of racket sports, a variety of key skills were revealed within a large body of literature (Crespo & Reid, 2007; Gould, Lauer, Rolo, Jannes, & Pennisi, 2008; Lees, 2003; Martinent, Cece, Elferink-Gemser, Faber, & Decret, 2018; Riemer & Chelladurai, 1998). This knowledgebase provides the basis for developing mental training programs. A review has highlighted the role of the mental toughness in major racket sports (Lees, 2003) involving targeted skills (e.g. motivation, emotional control, self-confidence). In particular, considering the daily training demands of these activities, motivation has been identified as an essential factor of the long-term performance and continued participation in tennis (Crespo & Reid, 2007) and table tennis (Martinent, Cece, Elferink-Gemser, Faber, & Decret, 2018). During the career, determination and enthusiasm have been identified as factors of performance (Lees, 2003). The environment has also been identified as a determinant of well-being and performance in racket sports especially considering the impact of parents (Gould et al., 2008; Harwood & Knight, 2009) and coaching leadership (González-García, Martinent, & Trinidad, 2019; Kwon, Pyun, & Kim, 2010; Riemer & Chelladurai, 1998; Sharma, 2015) on the athletes' outcomes, behaviours, and performance. Due to the competitive format and the necessity to repeat efforts despite the errors or under-performance, self-confidence has been identified as a salient factor in racket sports studies such as tennis (Covassin & Pero, 2004) and badminton (Bebetsos & Antoniou, 2003). Moreover, the stressful nature of matches in racket sports leads to special attention to the athletes' emotional skills. In particular, emotional control (emotional regulation) has been revealed as a central skill in racket sports such as table tennis (Martinent & Ferrand, 2009; Martinent, Ledos, Ferrand, Campo, & Nicolas, 2015; Sève, Ria, Poizat, Saury, & Durand, 2007) and tennis (Bolgar, Janelle, & Giacobbi, 2008; Laborde, Lautenbach, Allen, Herbert, & Achtzehn, 2014). Similarly, the racket sports literature has also mentioned anxiety control and use of coping strategies as predictors of various outcomes such as well-being and competitive performance in badminton (Bebetsos & Antoniou, 2003), tennis (Bolgar et al., 2008), squash (Mace & Carroll, 1986) and table tennis (Laborde et al., 2014; Martinent & Decret, 2015). Other skills consistent with the high requirements of accuracy and velocity of the racket sports strokes have been highlighted. The literature has provided evidence of the importance of attention control skills in badminton (Bastug, Ağilönü, & Balkan, 2017) and table tennis (Caliari, 2008). In the same way, flow and awareness skills have been related to racket sports performance (Koehn, Morris, & Watt, 2013; Wolf et al., 2015). Finally, based on the rationale that racket sports can be categorised as open skills activities, previous studies have revealed the main role of decision making (del Villar, González, Iglesias, Moreno, & Cervelló, 2007; Hastie, Sinelnikov, & Guarino, 2009) and mental quickness (Williams, Ward, Smeeton, & Allen, 2004) in performance variability.

The present study

Racket sports characteristics lead to specific training requests for these activities (Lees, 2003; Mamassis & Doganis, 2004). Simultaneously, the mental aspect of performance has become a central preoccupation for athletes and coaches (Jones, 1995; Lees, 2003). The relevance of the mental skills in racket sports has been proved through a vast body of literature highlighting associations between mental skills and positive outcomes such as performance and well-being (Jones, 1995; Lees, 2003). For both researchers and practitioners, it seems important to disseminate the studies implementing mental training programs designed to improve athletes' mental skills. However, to the best of our knowledge, no study has summarized the research dealing with mental training programs in racket sports. As such, the main aims of this study were to (a) collect the studies that incorporate mental training programs used in racket sports, (b) organize the current knowledge on mental training programs and provide a synthesis of the characteristics of these studies, and

(c) identify gaps in the literature on this topic, and propose potential further investigations and practical implications.

Methods

Procedure

The electronic search was performed via EbscoHost. Three databases were used including PsyARTICLES; PsyINFO; SPORTDiscuss and the following keywords were researched (within the title and abstract): Mental, psychological, racket, tennis, table-tennis, badminton or squash. The reference lists of all articles obtained were also examined for other relevant studies.

The studies should respect the following inclusion criteria to be included in the study: (1) electronically-accessible in the english language; (2) publication in a scientific peer-reviewed journal; (3) original studies with a specific mental training program presented and tested in the study; and (4) applied exclusively on one or many racket sports. The inclusion/exclusion procedure of the present study respected the systematic review process and is summarised in Figure 1. The first search revealed 565 references. We choose to not include timeframe selection criteria because of the limited number of studies on the thematic of mental training programs in racket sports. Then, 492 references remained with the removal of duplicates. We assessed the electronic abstract of the references and 357 were removed due to non-compliance of inclusion criteria. This level of loss could be explained by the importance of studies exploring the associations between mental skills and performance without a mental training program. Then, the electronic full-text articles were assessed, and 27 references remained after the final assessment for eligibility.

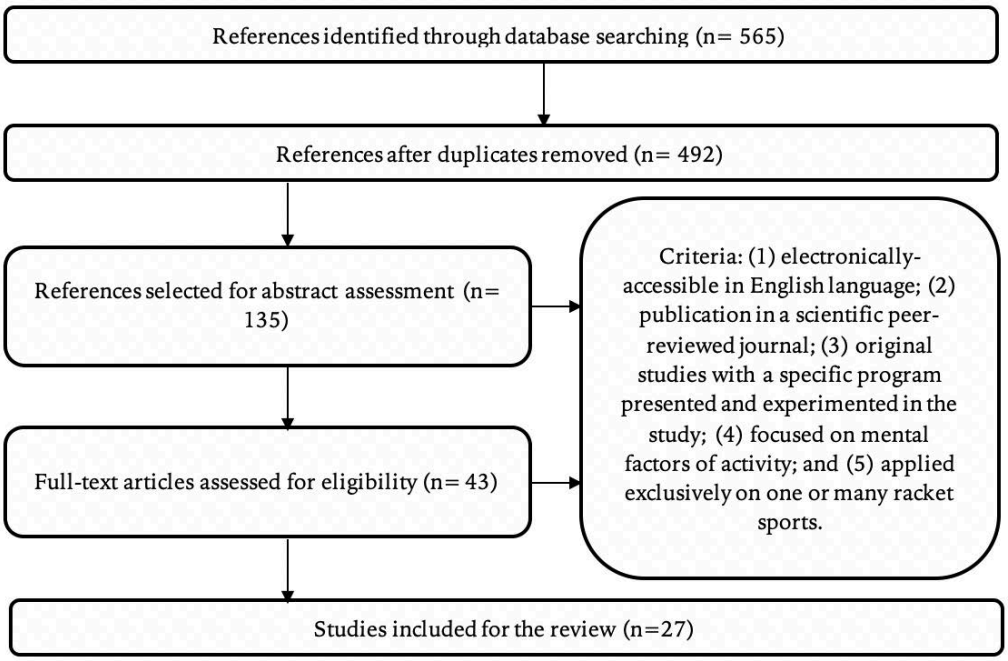

Figure 1. Procedure of inclusion and exclusion of studies

Data extraction

The selected studies were classified according to date of publication, sample characteristics (sample size, gender, competitive level), sport studied, mental training techniques, the goal of the program, and outcomes of the program. The results were analysed using descriptive statistics including distribution with the software Statistica (Hilbe, 2007). The characteristics of the studies were summarised in Table 1.

Table 1.
Characteristics of the studies

Author	Date	Journal	Title	Sport	Sample size	Gender	Age	Level	Intervention time	Method	Aim(s)	Results
Atienza et al.	1998	Perceptual and Motor Skills	Video Modelling and Imaging Training on Performance of Tennis Service of 9- to 12-Year-Old Children	Tennis	12	Females	9-12 years	Intermediate	24 weeks (15min/week)	Video modelling + Imagery	Technique of service	Improvement of service score (speed, accuracy and technique)
Caliari	2008	Journal of Applied Sport Psychology	Enhancing Forehand Acquisition in Table Tennis: The role of Mental Practice	Table tennis	112	-	14-15 years	Novice	A physical education cycle	Imagery	Forehand performance	Improvement of forehand performance (accuracy)
Caserta et al.	2007	Journal of Sport & Exercise Psychology	Old Dogs, New Tricks: Training the Perceptual Skills of Senior Tennis Players	Tennis	27	10 Males / 17 Females	62,50 years / 59,59 years	Intermediate	50 days (40min)	Perceptual-cognitive skills training (situational awareness) + Anticipation + Decision making	Perceptual skills during competition	Improvement of response speed, accurate responses, performance decision making
Coelho et al.	2007	Perceptual and Motor Skills	Imagery Intervention in Open and Closed Tennis Motor Skill Performance	Tennis	48	Males	17-18 years (av. = 17,2)	National	Three times a week (15min), two consecutive months	Imagery (self-confidence + positive feedback) + Technical practice	Service and receiving services	Improvement of service skill and not receiving services
Dana & Gozalzadeh	2017	Perceptual and Motor Skills	Internal and External Imagery Effects on Tennis Skills Among Novices.	Tennis	36	Males	15-18 years	Novice	Six weeks (three times/week - 30 minutes)	Mental imagery (internal or external) + Physical practice	Performance accuracy on serve, forehand, backhand strokes	Increasing performance accuracy for service, forehand and backhand Internal imagery: Greater improvement of serve and backhand accuracy
Daw & Burton	1994	The Sport Psychologist	Evaluation of a Comprehensive Psychological Skills Training Program for Collegiate Tennis Players.	Tennis	26	13 Males / 13 Females	18-23 years	Intermediate	three sessions (20min-1h)	Goal setting + Imagery + Arousal regulation	Quality of shots + Self-confidence	Higher self-confidence and fewer double fault

Table 1 (continued)

Author	Date	Journal	Title	Sport	Sample size	Gender	Age	Level	Intervention time	Method	Aim(s)	Results
Dohme et al	2019	Journal of Applied Sport Psychology	Development, implementation, and evaluation of anathlete-informed mental skills training program for elite youth tennis players.	Tennis	11	Males	8-15 years	Elite	15 months (2 months of intervention)	Targeted cognitive behavioural program (e.g. pre-performance routines, positive self-talk, imagery)	Development of mental skills	Improvement of athletes' regulation and emotional control + Use of psychological skills
Ducrocq et al.	2017	Journal of Sport and Exercise Psychology	Adaptive Working Memory Training Reduces the Negative Impact of Anxiety on Competitive Motor Performance.	Tennis	30	25 Males / 5 Females	17-50 years (av. = 33)	Novice	10 days of training	Memory working tasks on laboratory	Working memory and performance under pressure	Increasing on working memory capacity, quiet eye offset and tennis performance in high-pressure condition
Garcia-Gonzales et al.	2014	Journal of Applied Sport Psychology	Effects of Decision Training on Decision Making and Performance in Young Tennis Players: An Applied Research.	Tennis	11	Males	12-14 years	Intermediate	10 weeks (one session/week)	Video-feedback + Questioning	Decision making and performance during match	Improvement of decision-making and performance
Guillot et al	2015	PLOS One	Implementation of Motor Imagery during Specific Aerobic Training Session in Young Tennis Players	Tennis	10	6 Males / 4 Females	av. = 13,5 years	Elite	One session	Motor imagery	Stroke accuracy and ball velocity of backhand and forehand drives after high intensity intermittent training	Similar cardiac demand Maintaining of accuracy during physical training Development of physical fitness and preservation of stroke performance
Guillot et al.	2013	Journal of Sports Science and Medicine	Motor Imagery and Tennis Serve Performance: The External Focus Efficacy.	Tennis	12	7 Males / 5 Females	av. = 11 years	Elite	12 sessions (8 weeks)	Mental imagery with external focus	Service performance in match	Increase in accuracy, velocity of serve + successful first serves, won points (in match)

Table 1 (continued)

Author	Date	Journal	Title	Sport	Sample size	Gender	Age	Level	Intervention time	Method	Aim(s)	Results
Jeon et al.	2014	Perceptual and Motor Skills	Noise Distraction and Mental Practice in Closed and Open Motor Skills	Badminton	36	Males	Exp 1: 19-27 years (av. = 23,3) Exp 2: 18-22 years (av. = 21,1)	Novice	One session	Relaxation + Video watching + Mental practice (8 minutes)	Performance of close (exp 1) and open (exp 2) skills	Close skill: greater accuracy of service Open skill: less error only in the acquisition trials
Lejeune et al.	1994	Perceptual and Motor Skills	Mental Rehearsal in Table Tennis Performance	Table tennis	40	-	19-27 year (av. = 22)	Novice	Six sessions	Relaxation + Mental imagery + Observational and physical techniques	Technic strokes + Accuracy	Performance index score improvement
Li-Wei et al.	1992	The Sport Psychologist	The Effect of Mental-Imagery Training on Performance Enhancement With 7-10-Year-Old Children	Table tennis	40	21 Males / 19 Females	7-10 years (av. = 8,3)	Elite	22 weeks (30min/week)	Mental imagery + Relaxation + Video observation	Quality of shots	Improvement in the accuracy and technical quality of their shots
Mamassis & Doganis	2004	Journal of Applied Sport Psychology	The Effects of a Mental Training Program on Juniors Pre-Competitive Anxiety, Self-Confidence, and Tennis Performance	Tennis	9	-	av. = 14,1 years	Elite	25 weeks (60min/week)	Goal setting + Positive thinking/self-talk + Concentration & routines + Arousal regulation + Imagery	Performance and psychological factors	Increase in the direction dimension of anxiety and self-confidence + intensity of self-confidence + overall tennis performance
Mathers	2017	The Sport Psychologist	Professional Tennis on the ATP Tour: A Case Study of Mental Skills Support	Tennis	1	Males	av. = 27	Elite	3 years	Education + Assessment + Mental skill learning (goal setting + Imagery + Positive self-statements + Pre-point routine) + Application	Performance and development of mental skills	Improvements in self-reported performance and outcomes (key mental skills)

Table 1 (continued)

Author	Date	Journal	Title	Sport	Sample size	Gender	Age	Level	Intervention time	Method	Aim(s)	Results
Morais	2019	International Journal of Sport Psychology	Pre-service routines, mental toughness and performance enhancement of young tennis athletes	Tennis	11	10 Males / 1 Female	11-14 years (av. = 12,09)	Intermediate	10 sessions (1-2 hours)	Mental and behavioural routine before service	Performance and mental toughness during match	Improvement of mental toughness + Positive impact on performance efficacy (service games won)
Noel	1980	Journal of Sport Psychology	The Effect of Visuo-motor Behavior Rehearsal on Tennis Performance	Tennis	14	Males	17-45 years (av. = 28,57)	low abilities - high abilities	Three sessions (30min) 10 days before the competition	Relaxation + Visualisation	Quality of shots	Improvement of first service and ratio winners to efforts for experts
O et al.	2014	Journal of Applied Sport Psychology	Using Motivational General-Mastery Imagery to Improve the Self-efficacy of Youth Squash Players	Squash	5	2 Males / 3 Females	7-14 years (av. = 10,71)	Intermediate	6 weeks (3 practices/day + meeting with researcher twice a week)	Imagery practice (focused on confidence, control, mental toughness and performance)	Self-efficacy	Improvements in self-efficacy scores (for 3/5)
Ramirez et al.	2010	Polish Journal of Sport & Tourism	Pettlep imagery and video-observation: a motivation case study for four badminton players	Badminton	4	2 Males / 2 Females	24-57 years	Novice	Six weeks (two/week)	PETTLEP Imagery (physical, environment, task, timing, learning, emotion, perspective) + Video observation	Situational motivation	Increasing of self-determined forms of motivation and decreases in less self-determined types of motivation
Robin et al.	2011	International Journal of Sport Psychology	Effects of motor imagery training on service return accuracy in tennis: The role of imagery ability	Tennis	80	-	-	Elite	15 sessions	Imagery training	Service returns performance	Improvement of service returns
Singer et al.	1994	The Sport Psychologist	Training Mental Quickness in Beginning/Intermediate Tennis Players	Tennis	34	16 Males / 18 Females	Undergraduate students	Novice	3 weeks (20min/week)	Mental quickness training (videotape situations)	Quickness	Faster decisions in reaction to serves; faster anticipation times, improved accuracy in predicting serve type and location

Table 1 (continued)

Author	Date	Journal	Title	Sport	Sample size	Gender	Age	Level	Intervention time	Method	Aim(s)	Results
Smeeton et al.	2005	Journal of Experimental Psychology	The Relative Effectiveness of Various Instructional Approaches in Developing Anticipation Skill.	Tennis	33	27 Males / 6 Females	av. = 10,6 years	Intermediate	4 weeks (20min/week)	Perceptual-cognitive training in laboratory	Anticipation skills on laboratory and field	Improvement of the anticipation skills
Steffgen	2017	Journal of Human Kinetics	Anger Management - Evaluation of a Cognitive-Behavioral Training Program for Table Tennis Players.	Table tennis	18	-	16-22 years (av. = 16,6)	Elite	2 months (6 sessions of 120min)	Cognitive relaxation coping training (relaxation) + Social problem-solving training (communication)	Anger management	Reduction in negative anger expression, anger reactions (one-year follow-up)
Tzetzis et al.	2008	Journal of Sports Science and Medicine	The effect of different corrective feedback methods on the outcome and self-confidence of young athletes.	Badminton	48	Males	10-14 years (av. = 12,6)	Intermediate	Two times/week	Correction cues + Positive feedbacks (+ error cues)	Performance (forehand and backhand) and self-confidence	Improvement of self-confidence scores Improvement of easy and difficult skill
Vidic & Burton	2010	The Sport Psychologist	The Roadmap: Examining the Impact of a Systematic Goal-Setting Program for Collegiate Women's Tennis Players.	Tennis	6	Females	17-22 year (av. = 19)	Elite	8 weeks (20-45min/week)	Goal-setting program	Performance, motivation, confidence	Improvements in motivation, confidence and performance scores
Yoo	2018	International Journal of Coaching Science	Using Counselling to Improve the Self-confidence of a Young Competitive Female Tennis Player: A Case Study.	Tennis	1	Female	12 years	Elite	8 counselling sessions	Self-confidence: journal writing technique (goal setting)	Self-confidence and performance	Improvement in self-confidence and tennis performance

Results

General characteristics

Twenty of the 27 studies (74.1%) examined were published between 2005 and 2019. Seven studies were published before 2005 (25.9%) and only three before 2000 (11.1%). The journals the most frequent were Perceptual and Motor Skills, The Sport Psychologist, and Journal of Applied Sport Psychology.

A total of 715 participants (344 males and 112 females) were included in the 27 studies with an average of 23.19 participants per study. Only two studies presented a sample size superior to 50 subjects (Caliari, 2008; Robin et al., 2007) and the majority had a sample size between 10 and 50 participants (n = 19). The gender distribution revealed eight studies with males, three with females, and eleven with both genders (participants' gender was not mentioned in five studies). The age of the participants ranged between 6 and 63 years old. Most of the studies comprised children between 7 and 13 years old (n = 8) or adolescents and young adults between 14 and 22 years old (n = 8) (age of the participants was not mentioned in two studies; Caliari, 2008; Robin et al., 2007). Eleven of the 27 studies concerned elite, expert, or international athletes. In contrast, seven studies mentioned beginner, novice, or recreational players. Finally, nine studies contained participants with an intermediate practice level whereas one study mixed novice, intermediate, and elite levels in the same study.

Nineteen of the 27 studies (73%) exclusively focused on tennis. Four of the programs (14%) were conducted on table tennis players (Caliari, 2008; Lejeune, Decker, & Sanchez, 1994; Li-Wei, Qi-Wei, Orlick, & Zitzelsberger, 1992; Steffgen, 2017) and three (11%) on badminton players (Jeon, Kim, Ali, & Choi, 2014; Ramirez, Smith, & Holmes, 2010; Tzetzis, Votsis, & Kourtessis, 2008). One study was conducted on squash players (O, Munroe-Chandler, Hall, & Hall, 2014). No study combined two or more racket sports.

Mental training programs

Mental training techniques

A wide variety of techniques were used in the mental training programs of the studies reviewed including relaxation, imagery, observation (i.e. video observation of athletes), goal setting, arousal regulation, mental quickness training, self-talk, competitive and pre-competitive routines, perceptual-cognitive training (i.e. which aim to perceive and understand moving patterns), feedback (i.e. targeted feedbacks from the coach), or communication. The mental training programs were always directly applied to the athletes. The most used techniques were imagery (41% of the studies), relaxation (15%), goal setting (15%), competitive and pre-competitive routines (12%).

Design of the intervention

Most of the studies used a pre-test-post-test design with an intervention and measures of the variables before and after the sessions. Three studies have used a qualitative approach with case studies (Mathers, 2017; Ramirez et al., 2010; Seang-Leol & Calderon, 2018) whereas the other research studies have based their protocol on quantitative statistical analyses. The duration of the interventions of the reviewed studies ranged between one short session and three years. Two studies used a short program including only one session, five studies used between two and five sessions, and five studies used between six and ten sessions. In contrast, one study proposed more than 50 training sessions (Mathers, 2017), nine studies mentioned between 11 and 20 sessions, and five studies between 21 and 50 sessions. The timing of the intervention was very fluctuant and ranged between 15 and 90 minutes per session and between one and three sessions for a week.

Aims and outcomes

All of the reviewed studies revealed positive outcomes of the mental training programs with complete or partial validation of the goals. The most common goal of the studies consisted of an improvement of sport performance. The performance was analysed during isolated tests (n = 12, 44.7% of

the studies), practice matches (n = 5, 18.5%) or in competitive matches (n = 4, 14.8%). Specifically, the service was the stroke the most explored (Atienza, Balaguer, & García-Merita, 1998; Coelho, De Campos, Silva, Okazaki, & Keller, 2007; Guillot, Desliens, Rouyer, & Rogowski, 2013; Jeon et al., 2014; Noel, 1980). Several studies also analysed the returning service (Coelho et al., 2007; Robin et al., 2007), the forehand or backhand strokes (Caliari, 2008; Daw & Burton, 1994; Guillot et al., 2015; Li-Wei et al., 1992; Tzetzis et al., 2008) or global performance scores (Gonzalez-Garcia, Pelegrin, & Luis Carballo, 2017; Mamassis & Doganis, 2004; Mathers, 2017; Seang-Leol & Calderon, 2018; Vidic & Burton, 2010) based on the criterion of technique, accuracy, velocity, or effectiveness of the strokes. Positive consequences on the performance were developed such as improvement of the technique, speed, accuracy and efficacy of the strokes, global improvement of the training, and competitive performance.

Other mental training program aimed to improve the mental competitive skills (n = 14) such as mental toughness (Mathers, 2017; Morais & Rui Gomes, 2019), self-confidence (Daw & Burton, 1994; Mamassis & Doganis, 2004; O et al., 2014; Seang-Leol & Calderon, 2018) or motivation (Ramirez et al., 2010; Vidic & Burton, 2010). The mental skills were measured using psychometric self-report questionnaires, interviews, or observations of the athletes during training or competition. Results revealed an improvement of mental skills. The improvement of mental skills was sometimes combined (n = 10) and sometimes not combined (n = 4) with a performance measure. Finally, specific studies aimed to improve the working memory, perceptual skills, and anticipation skills.

Discussion

To the best of our knowledge, there is no review investigating the studies testing the effects of a mental training program in racket sports. Considering the relevance of the mental aspect of the performance in racket sports, the main objectives of this study were: (a) to collect the studies that incorporate mental training programs used in racket sports, (b) to organize the current knowledge on mental training programs and provide a synthesis of the characteristics of these studies, and (c) to identify gaps in the literature on this topic and propose potential further investigations and practical implications.

General findings

Twenty-seven studies since 1980 were selected for the present review. In an applied perspective, we can regret a limited involvement regarding the mental training programs. In contrast, a considerable amount of literature regarding the mental skills required in competitive racket sports have been developed in the scientific literature (e.g. Bastug et al., 2017; Kwon et al., 2010; Sharma, 2015). The lack of studies with mental training programs could be a consequence of the persistent weak interest of several sport stakeholders for the mental practice (Connaughton, Wadey, Hanton, & Jones, 2008). Moreover, the reduced number of scientific studies reviewed in this study could highlight an image of mental training as a less rigorous process than others such as physical training (Jones, 1995).

Inspection of the level of participants revealed 11 studies with elite athletes, nine with an intermediate level, and seven with a novice population. This distribution provides evidence of the elite aspect of mental training for a majority of the sports protagonists (Jones, 1995). This point of view is consistent with the high physical, psychological, and social demands of elite sport and fits with the research of detail of the training for elite athletes in racket sports (Doherty et al., 2018). However, every level of sport experience and practice level could benefit from the effects of mental training programs. The improvement of performance and mental skills among novice participants has provided evidence for the possibility and the interest to include low competitive levels in mental training programs (e.g. Dana & Gozalzadeh, 2017; Ducrocq et al., 2017). The gender distribution showed a total of 344 males and 112 females mentioned in the reviewed studies. This result highlights a gender imbalance and a male

predominance in the mental training programs and very few of the studies reviewed have explored the gender effect on the consequences of the mental training programs (Caserta et al., 2007; Singer et al., 1994).

The studies reviewed were exclusively conducted on the four major racket sports (tennis, table-tennis, badminton, and squash) with a large majority on tennis (n = 19). Badminton and table-tennis were moderately represented, and squash was weakly represented. This distribution is in line with the respective popularity of racket sports considering the mediatise and economic importance of tennis in comparison with other racket sports (Lees, 2003). No study focused on two or more racket sports simultaneously. This kind of study with a comparison between two activities could provide knowledge about the similarities and differences across the racket sports. Moreover, the lack of investigation of some racket sports could restrain the appropriation of mental training programs in such activities.

Design of the studies

A majority of studies used a quantitative approach and adopted the traditional pre-test-post-test paradigm with a control group. The quantitative methods facilitated the statistical analyses and allowed to provide a rigorous examination of the effects of mental training programs (Biddle, Markland, Gilbourne, Chatzisarantis, & Sparkes, 2001). Thus, the bulk of quantitative studies focusing on the interventions consolidated the scientific legitimacy of the tested mental training programs by providing evidence of their significant effects on performance scores and/or on psychological outcomes (e.g., anxiety scores). In addition, few case studies were also reviewed (Mathers, 2017; Ramirez et al., 2010; Seang-Leol & Calderon, 2018). These case studies have furthered knowledge base regarding the mental processes of athletes during training and competitions (Biddle et al., 2001). For instance, Mathers (2017) has recently proposed an individualised program in which athletes were subject to successive mental interventions during a three-year period.

The mental training programs were heterogeneous as indicated by the large variety of the number of training sessions and/or the duration of the mental training programs. Indeed, several studies have proposed duration of intervention ranging from 30 minutes to three years with a majority of programs comprising between 2 and 20 sessions. A lot of studies used repeated measures before and after the interventions but very few have adopted a longitudinal approach to assess the ongoing variability of relevant psychological outcomes during the mental training programs. As such, the use of longitudinal studies continuously tracking the ongoing psychological processes involved in mental training programs could further knowledge about the overtime effects of mental training programs.

Outcomes

All of the mental training programs reviewed have reported positive outcomes. These positive results should encourage the coaches, athletes, and sports psychologists to intervene in racket sports to set up mental training programs suitable for the targeted outcomes. The main objective of the studies was the improvement of the players' performance (Gonzalez-Garcia et al., 2017; Mamassis & Doganis, 2004; Mathers, 2017; Morais & Rui Gomes, 2019; Seang-Leol & Calderon, 2018; Vidic & Burton, 2010) or the quality of their strokes. Various studies have revealed a significant improvement of the velocity, the accuracy, the efficiency, and the regularity of service (Atienza et al., 1998; Coelho et al., 2007; Guillot et al., 2013; Jeon et al., 2014; Noel, 1980), service returning (Coelho et al., 2007; Robin et al., 2007), backhand and forehand strokes (Caliari, 2008; Daw & Burton, 1994; Guillot et al., 2015; Li-Wei et al., 1992; Tzetzis et al., 2008). The open skills (e.g. service returning, decision making) have been less investigated than the closed skills (e.g., service) probably because of the difficulties to assess these factors of performance (Currell & Jeukendrup, 2008). However, open skills represent a crucial aspect of racket sports and could be a potential extension for

further mental training programs (Coelho et al., 2007).

The programs focused on mental skills also reported positive outcomes. These programs increased the levels of mental toughness (Mathers, 2017; Morais & Rui Gomes, 2019), self-determined motivation (Ramirez et al., 2010; Vidic & Burton, 2010), emotional control (Dohme et al., 2019) and self-confidence (Daw & Burton, 1994; Mamassis & Doganis, 2004; O et al., 2014; Seang-Leol & Calderon, 2018) and decreased the athletes' anxiety and anger scores (Mamassis & Doganis, 2004; Steffgen, 2017). The present results suggest the potential benefits of mental training on various key mental skills for racket sports (Jones, 1995; Lees, 2003). The well-being indicators were less explored in the studies with only a few studies including some well-being indicators (e.g. pleasant and unpleasant emotion). This lower preoccupation could be explained by the general focus on performance in competitive sport. However, the association between performance and well-being has been highlighted in previous racket sports studies (Martinent et al., 2018) and could be an area of improvement for sport stakeholders.

Moreover, several specificities of racket sports such as awareness or emotional control have not been explored. For example, despite the identification of keys mental skills in racket sport (Jones, 1995; Lees, 2003; Mamassis & Doganis, 2004), no study proposes a training program explicitly focused on the emotional demands of racket sports. For example, the development of emotional intelligence seems suitable for racket sports. Indeed, the ability to identify, understand, regulate, and use one's and others' emotions could represent an essential skill for coping with the emotional demands of racket sports (Laborde et al., 2014; Martinent et al., 2015).

Techniques

The distribution of the techniques indicated a wide variety of mental training methods used in the explored studies. It is also noteworthy that a particular technique could be used exclusively or combined with other techniques. Among the variety of detailed techniques within the examined studies, imagery emerged as the most used. The results provided evidence of the positive effect of imagery on sport performance indicators related to the strokes realised in racket sports. Imagery programs have permitted to improve the velocity, accuracy, efficiency, and the regularity of serves, returns, backhands, and forehands (Atienza et al., 1998; Caliari, 2008; Dana & Gozalzadeh, 2017; Guillot et al., 2015). Consequently, the imagery programs appeared suitable for the development of racket sports motor skills. Additionally, relaxation techniques were used in five studies, regularly in combination with other techniques such as imagery (Lejeune et al., 1994; Li-Wei et al., 1992; Mamassis & Doganis, 2004). Overall, relaxation techniques have also led to an improvement in players' strokes and performance. Goal-setting learning was proposed in five studies especially within targeted interventions grounded within cognitive behaviour therapies (Daw & Burton, 1994; Mamassis & Doganis, 2004; Mathers, 2017; Seang-Leol & Calderon, 2018; Vidic & Burton, 2010). The goal-setting techniques have permitted improving salient mental skills in racket sport such as self-confidence (Daw & Burton, 1994; Mamassis & Doganis, 2004) or self-determined motivation (Vidic & Burton, 2010). Similarly, the studies that have included competitive and pre-competitive routines techniques have led to an increase of self-confidence scores (Mamassis & Doganis, 2004) and mental toughness (Dohme et al., 2019; Morais & Rui Gomes, 2019), and a decrease of anxiety scores (Dohme et al., 2019). In sum, imagery, relaxation, goal setting, and routines seem fitting with racket sports demands and facilitate performance and the fostering of salient mental skills (self-determined motivation, emotional regulation). Moreover, the results highlighted an association between the technique used during mental training and the mental skills targeted to be improved. In an applied perspective, the present results suggested adapting the techniques of mental programs to the specific objectives and issues encountered by the athletes.

Several techniques were less or even almost not used in the studies reviewed. For instance, arousal regulation or self-talk techniques have been proposed in a very limited number of researches (Daw & Burton, 1994; Dohme et al., 2019; Mamassis & Doganis, 2004). Otherwise, all the techniques used in the reviewed studies have been almost exclusively implemented on the athletes. Very few studies focused on the salient stakeholders grounded with the athletes' environment (e.g., parents, coaches). However, previous studies have highlighted the importance of the athletes' environment in racket sports and have suggested potential techniques to help parents and coaches (Gould et al., 2008; Harwood & Knight, 2009; Kwon et al., 2010; Riemer & Chelladurai, 1998; Sharma, 2015).

Conclusions

The present review aimed to explore the studies which include a mental training program in racket sports. The 27 studies selected in the present review comprised various samples from different racket sports and were characterized by distinct study designs, mental training techniques, and outcomes. The various techniques used in the programs led to positive outcomes such as improvement of performance and mental skills. However, the results of the review highlighted the unequal distribution of the population (e.g. male and expert domination) and the sport (tennis attracting the focus of attention) in the studies. Moreover, the present results suggested several lacks in the targeted outcomes (e.g. lack of focus on well-being indices), and/or in the techniques (e.g. self-talk or relaxation, absence of programs applied on coaches or parents) given the specific constraints of racket sports. In summary, this review suggested potential implications for both researchers and practitioners. The results encouraged further investigations of mental training programs to address the aforementioned unexplored issues. Finally, we hope that this review will promote the development of mental training programs in racket sports and will help several sport stakeholders (coaches, sport psychologists, athletes) to adapt the mental training to the practice constraints and the objectives.

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