Original research

Corresponding Author:

Caroline Martin, M2S Laboratory, University of Rennes 2, ENS de Rennes, Avenue Robert Schuman, 35170 Bruz, France.
Email: caromartin@numericable.fr

Identification of serve pacing strategies during 5-set tennis matches

C. Martin[1], B. Bideau[1], P. Touzard[1], & R. Kulpa[1]

[1] M2S Laboratory, University of Rennes 2, ENS de Rennes, Bruz, France

Abstract

This study investigates the prominence of pacing strategies adopted by tennis players during 5-set matches and their relationship with match outcome, ATP ranking and Grand Slam tournament. Fifty 5-set matches of the 2014 Grand Slam tournaments were analyzed. 1st and 2nd serve velocities, percentages of 1st serve in, and percentages of 1st and 2nd serve points won were collected for each of the 5 sets. According to fluctuations of mean 1st serve velocity for each of the 5 sets, players were classified into five types of pacing strategies: 'variable', 'parabolic', 'constant', 'all-out' and 'negative-split'. Players mostly used 'variable' pacing strategy (45%), followed by 'parabolic' (20%), 'constant' (18%), and 'all-out' (15%) strategies, which are closely distributed. Finally, 'negative-split' strategy (2%) is infrequently used. The pacing strategy used by players tends to exert an influence on match outcome ($P = 0.072$). There is no significant association between players' ranking and type of pacing strategy used ($P = 0.384$). There is no significant association between Grand Slam tournaments and type of pacing strategy used ($P = 0.875$). Serve velocity and serve points won are significantly decreased in losers while they are increased or kept constant in winners during the 5th set of the match. 'Negative split', 'variable' and 'parabolic' strategies seem to be the most effective for winning 5-set match, while 'all-out' strategy appears ineffective since when players used it, they lost the match in 73 % of cases. Players should consider physical conditioning programs to maintain serve velocity and percentage during the 5th set.

Keywords

professional players, performance, fatigue, serve velocity

INTRODUCTION

The activity pattern of tennis match play is intermittent with players switching between short bouts of high intensity effort (< 10 seconds), short recovery (10-20 seconds) and rest periods of longer duration (90 – 120 seconds) [1]. A typical match duration is between 1 and 2 hours but this duration can be prolonged during five set matches (from 3 to 6 hours) [2]. Throughout an extreme 5-set match, players can hit around 500-1000 groundstrokes and 200-400 explosive serves [2]. The margin between winning and losing a 5-set match is small and may be related to serve performance. The ability to produce high ball velocity and to reach high 1st serve percentage is a key element of successful play, because it puts the opponent under stress and may hinder its return [3]. Indeed, the number of good returns decreases and the number of aces and 1st serve points won increase as serve velocity increases over 44 $m \cdot s^{-1}$ [4]. Moreover, the percentages of 1st serves, 1st serve points won and 2nd serve points won impact the final match outcome [5].

Serve velocity and accuracy (measured by a scoring system taking account target areas in the serve box) decline from the beginning to the end of a prolonged match or a strenuous training session on hard courts [6 7]. These decreases are generally attributed to fatigue, since studies have reported muscular force deficits in upper and lower limbs at the end of a prolonged tennis match [8 9 6 7]. Moreover, potential causes of fatigue during tennis match play are multiple: limitations in energy supply (phosphocreatine), intramuscular accumulation of metabolic products (lactate, H^+, inorganic phosphate) [10], muscle damage [11], sweat loss and thermal stress [12], central activation failure and alterations in excitation-contraction coupling [13]. Alternatively, different studies observed no decreases in serve velocity between the beginning and the end of a prolonged match or competition [14 15 16]. Maquirriain et al. (2016) analyzed serve statistics from 15 five-set male professional tennis matches. Their results showed no statistical difference of serve velocity between the first and the fifth set on grass courts. One may hypothesize that the playing surface could influence the evolution of serve velocity during prolonged tennis matches.

During the 5-set Wimbledon semi-final in 2013 between Djokovic and del Potro that lasted 4h43, del Potro's first serve velocity decreased by 2 $m \cdot s^{-1}$ between the first and the fifth set, whereas Djokovic's first serve velocity increased by 1.5 $m \cdot s^{-1}$ during the same time. Consequently, some theories suggest that performance variations could be the result of conscious or unconscious pacing strategies to preserve physical condition, prevent injuries and enable successful completion of the match [2]. Although this is an interesting hypothesis, no data exist in the literature to support or reject such a statement. Yet, fatigue and pacing in scientific literature about intermittent sport have become increasingly popular in recent years [17 18]. Pacing is described as the distribution of energy resources that optimize match performance whereas fatigue is considered as an unidirectional construct that relates to eventual reduction in performance compared with baseline values [18]. Several studies in intermittent team sports quantified the evolution of sport performance during a match to determine if players fatigue or modulate their effort according to a pacing strategy [17 18]. By analyzing athletic performances, researchers have observed “negative-split”, “all-out”, “positive”, “constant”, “parabolic-shaped” and “variable” pacing strategies (defined in the methods section) in different sports such as running, swimming, cycling, soccer, and rugby [19]. However, no similar studies have been applied on tennis serve performance throughout prolonged (e.g. 5 sets) matches. Yet, analysis of pacing strategies employed by successful professional players might lend insight into the most desirable pacing strategy for a 5-set match in Grand Slam tournaments. Indeed, in order to structure efficient and productive training programs, coaches must have a solid knowledge of their players’ physical responses [20]. Serve performance statistics and pacing strategies are thus very useful for coaches because they give information about match period from or during which the player is more or less efficient.

The aim of this study is to investigate the prominence of different pacing strategies adopted by professional tennis players and their relationship with match outcome, ranking and Grand Slam tournament.

METHODS

Experimental approach of the problem

This study analyzed fifty main draw five-set men's singles matches from the 2014 Grand Slam tournaments (12 matches at Australian Open, 12 matches at French Open, 12 matches Wimbledon and 14 matches at US Open) by using the statistics published on official websites of Grand Slam tournaments. Serve performance parameters of professional players (ATP ranking from 1 to 406) were analyzed.

Mean values of 1st and 2nd serve velocities, 1st serve in and 1st and 2nd serve points won were collected for each of 5 sets by an IBM radar gun.

Abbiss and Laursen (2008) defined main pacing strategies for athletic events. The authors of the current study have adapted them for tennis competition (Table 1). According to fluctuations of mean 1st serve velocity for each of the 5 sets, players were classified into five types of pacing strategies: “variable”, “parabolic”, “constant”, “all-out” and “negative-split” [19] (Table 1).

Pacing strategy	Athletic competition[19]	Tennis competition
Variable strategy	Variable pacing strategy is a term that has been used to define the fluctuations exercise intensity or work rate (i.e. power output) observed during exercise	Mean serve velocity highly fluctuates from one set to another
All-out strategy	After an athlete has reached peak velocity, speed gradually	After a player has reached peak of mean first serve velocity during one of the sets, his

	decreases	performance gradually decreases until the end of the match, set after set.
Constant strategy	The athlete maintains constant pace during an event	Mean first serve velocity is constant set after set. Difference of mean first serve velocity between sets is less than 0.8 $m \cdot s^{-1}$
Parabolic strategy	Athletes may progressively reduce speed during an endurance trial but tend to increase speed during the latter portion of the distances.	This strategy concerns a player who temporarily reduces its first serve velocity during a match's period (1, 2 or 3 sets) but increases it during the latter part of match. This tactic ultimately results in U, J or reverse J-shaped behavior
Negative-split strategy	An event is considered to have been performed with a negative-split, or through use of a negative pacing strategy, when there is an increase in speed observed over the duration of the event.	There is a gradual increase in 1st serve velocity observed set after set

Table 1. Definition of the pacing strategies in athletic events according to Abbiss and Laursen (2008) and their adaptation for tennis competition

Separately for pacing strategies, players were sorted into the following groups for comparison: (a) "winners" versus "losers" according to match's outcome, (b) "< Top 20" versus "> Top 20" according to player's Association of Tennis Professionals (ATP) ranking at the beginning of tournament. "<Top 20" means players that have a ranking number lower than 20, indicating a better player than the 20th ranked player. Similarly, ">Top 20" means players who have a ranking number greater than 20, indicating a worse player than the 20th ranked player.

Statistical analysis

An analysis of variance with repeated measures and a Student-Newman-Keuls post hoc test were used to determine significant differences in serve performance between sets for all 5-set tennis matches. To investigate data differences between winners and losers, two-way mixed analyses of variance with repeated measures (match outcome x set) and Student-Newman-Keuls post hoc tests were used. A two-way mixed analyses of variance with repeated measures (tournaments x set) was used to investigate data differences between tournaments (Australian Open, French Open, Wimbledon, US Open).

Fisher exact tests were used to analyze:

- effect of pacing strategies on match outcome
- effect of players' ATP ranking on pacing strategies
- effect of Grand Slam tournament on pacing strategies

Statistical significance was accepted as $P < 0.05$. Effect size (ES) (Cohen's d) was calculated to document the size of statistical effects observed and defined as small for ES

>0.1, medium for ES >0.3, and large for ES >0.5 [21]. Cramer's V was computed to complement the Fisher's exact test results.

RESULTS

Mean 1^{st} serve velocity was significantly higher for the 1^{st} set of match than for the 3^{rd}, the 4^{th} and the 5^{th} sets (main effect: P =0.020, 1^{st} and 3^{rd} sets comparison: P= 0.006, ES =0.27; 1^{st} and 4^{th} sets comparison: P =0.008, ES =0.26; 1^{st} and 5^{th} sets comparison: P=0.032, ES=0.21) (Table 2). On average, players lost 0.6 $m \cdot s^{-1}$ between the 1^{st} and the 5^{th} set. Conversely, set duration (main effect: P =0.449), 2^{nd} serve velocity (main effect: P =0.083), 1^{st} serve in (main effect: P =0.365), 1^{st} serve points won (main effect: P =0.533) and 2^{nd} serve points won (main effect: P =0.758) were not significantly different from one set to another.

	Whole match	**1^{st} set**	**2^{nd} set**	**3^{rd} set**	**4^{th} set**	**5^{th} set**
			Duration (min)			
Whole players	212 ± 27	39 ± 12	43 ± 10	43 ± 11	40 ± 11	47 ± 22
			1^{st} serve velocity ($m \cdot s^{-1}$)			
Whole players	50.5 ± 2.7	51.1 ± 3.0	50.7 ± 3.0	50.5 ± 2.7**	50.4 ± 2.7**	50.5 ± 3.0*
			2^{nd} serve velocity ($m \cdot s^{-1}$)			
Whole players	41.2 ± 2.5	41.4 ± 2.6	41.4 ± 2.5	41.3 ± 2.9	41.3 ± 2.9	40.9 ± 2.8
			1st serve in (%)			
Whole players	62 ± 7	62 ± 11	62 ± 10	63 ± 10	61 ± 11	64 ± 11
Winners		62 ± 12	62 ± 9	63 ± 9	61 ± 9	65 ± 11
Losers		62 ± 10	61 ± 10	62 ± 11	61 ± 13	63 ± 10
			1^{st} serve points won (%)			

Whole players	71 ± 8	71 ± 12	74 ± 13	72 ± 11	71 ± 16	72 ± 14
Winners		71 ± 11 [$$]	74 ± 12	72 ± 10 [$$]	73 ± 15	78 ± 12£££
Losers		71 ± 13 [$]	75 ± 13 [$$$]	72 ± 12 [$$]	69 ± 16	65 ± 14
			2nd serve points won (%)			
Whole players	51 ± 9	51 ± 16	53 ± 16	51 ± 18	49 ± 17	53 ± 21
Winners		50 ± 14 [$$$]	52 ± 17 [$$$]	54 ± 17 [$$]	49 ± 17 [$$$]	66 ± 15£££
Losers		52 ± 18 [$]	54 ± 15 [$$$]	48 ± 19 [$]	49 ± 16 [$$]	39 ± 18

Table 2. Duration and serve performance parameters for all 5-set matches analyzed (n=50). Data are presented as means and standard deviation of the mean. Significantly different from 1st set (**P* <0.05; ***P* <0.01). Significantly different from 5th set ($ *P* <0.05; $$$ *P* <0.001), £££: significantly different from losers (*P* <0.001)

"Variable" pacing strategy was incorporated the most (45%), followed by "parabolic" (20%), "constant" (18%), and "all-out" (15%) strategies, which were closely distributed (Figure 1). Finally, "negative-split" strategy was infrequently used among the 64 players observed (2%).

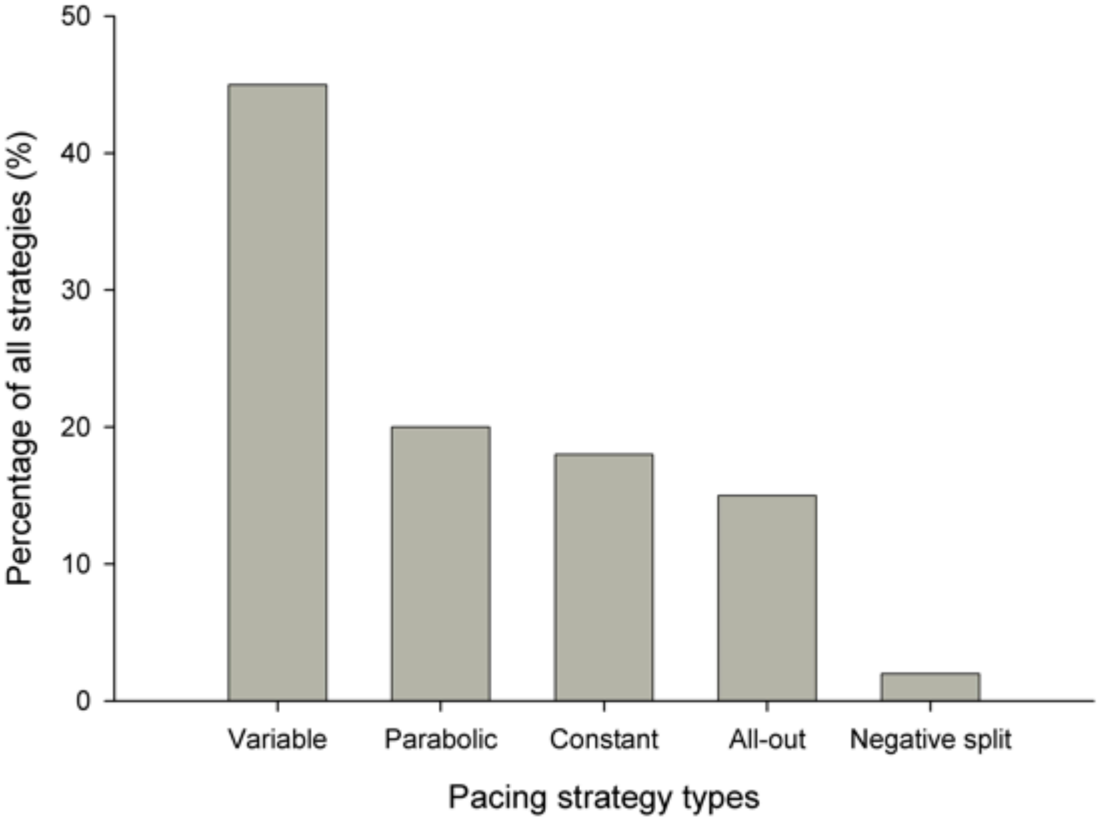

Figure 1. Proportion of pacing strategies about 1st serve velocity for all players

Differences between serve performance of winners and losers during 5-set matches

Winners' 1st serve velocity did not significantly differ across the five sets (main effect: P =0.355) while losers' 1st serve velocity changed significantly between sets (main effect: P =0.023). 1st serve velocity significantly decreased for losers between 1st and 3rd sets (P =0.002, ES =0.15), a further decrease at the 4th (P =0.002, ES =0.24) and 5th sets (P =0.002, ES =0.28), and between 2nd and 5th sets (P =0.013, ES =0.14) (Figure 2(a)). On average, losers lost 1.2 $m \cdot s^{-1}$ between 1st and 5th sets. Moreover, for the 5th set, mean 1st serve velocity was significantly higher (+ 1.4 $m \cdot s^{-1}$) for winners than for losers (P =0.021, ES =0.22).

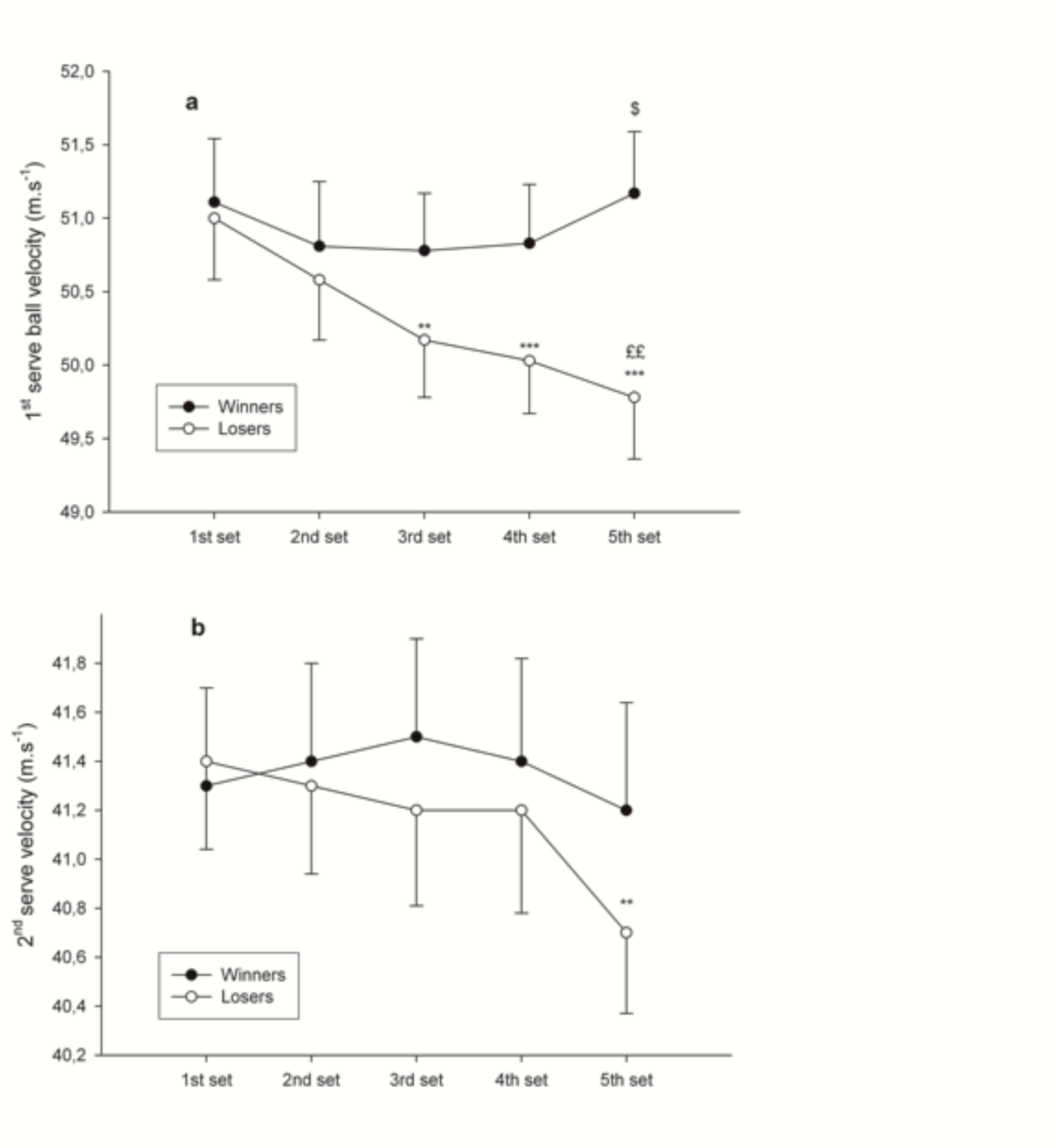

Figure 2. Evolution of 1st serve (a) and 2nd serve (b) velocities in winners and losers throughout the 5-set matches. Significantly different from 1st set (** P<0.01; *** P<0.001). Significantly different from 2nd set (£ P<0.05). Significantly different from losers ($ P<0.05). Data are presented as means and standard error of the mean.

Winners' 2nd serve velocity did not significantly differ across the five sets (main effect: P =0.943), while 2nd serve velocity significantly decreased during match for losers (main effect: P =0.023, comparison of 1st and 5th sets: P =0.003, ES =0.41) (Figure 2(b)). Concerning percentage of 1st serve points won, results significantly decreased for losers during the match (main effect: P =0.013, comparison of 1st and 5th sets: P =0.013, ES =0.32, comparison of 2nd and 5th sets: P <0.001, ES =0.53, comparison of 3rd and 5th sets:

P =0.007, ES =0.37), while results significantly increased for winners during the match (main effect: *P* =0.016, comparison of 1st and 5th sets: *P* =0.002, ES =0.39, comparison of 3rd and 5th sets: *P* =0.002, ES =0.42). Furthermore, percentage of 1st serve points won was significantly higher for winners (+13%) than for losers for the 5th set (*P* <0.001, ES =0.35). In the 5th set, winners were able to significantly increase their percentage of 2nd serve points won in comparison with all of other sets (main effect: *P* <0.001, 1st and 5th sets comparison: *P* <0.001, ES =0.62; 2nd and 5th sets comparison: *P* <0.001, ES =0.52; 3rd and 5th sets comparison: *P* =0.001, ES =0.44; 4th and 5th sets comparison: *P* <0.001, ES =0.63). For losers, the percentage of 2nd serve points won in the 5th set was significantly lower than in all other sets (main effect: *P* =0.006, 1st and 5th sets comparison: *P* <0.06, ES =0.48; 2nd and 5th sets comparison: *P* <0.001, ES =0.51; 3rd and 5th sets comparison: *P* =0.019, ES =0.33; 4th and 5th sets comparison: *P* =0.004, ES =0.39). During the 5th set, winners won significantly more points (+ 27%) on their 2nd serve than losers (*P* <0.001, ES =0.55).

Comparison of pacing strategies used by winners and losers during 5-set matches

Fisher exact test (pacing strategy x match outcome) demonstrates a trend towards an association between pacing strategy and match outcome (Fisher exact test =7.99, *P* =0.074, ES =0.29). Winners and losers use “variable” (50 vs. 40%), “parabolic” (22 vs. 18%) and “constant” (16 vs. 20%) in similar proportions. “All-out” strategy was twice as common for losers (22%) than for winners (8%). “Negative-split” was only observed in winners (4%). When players used “variable” or “parabolic” strategies, they won match in 55 and 56% of the cases. But, when they used “all-out” strategies, they lost match in 73% of the cases (Figure 3a).

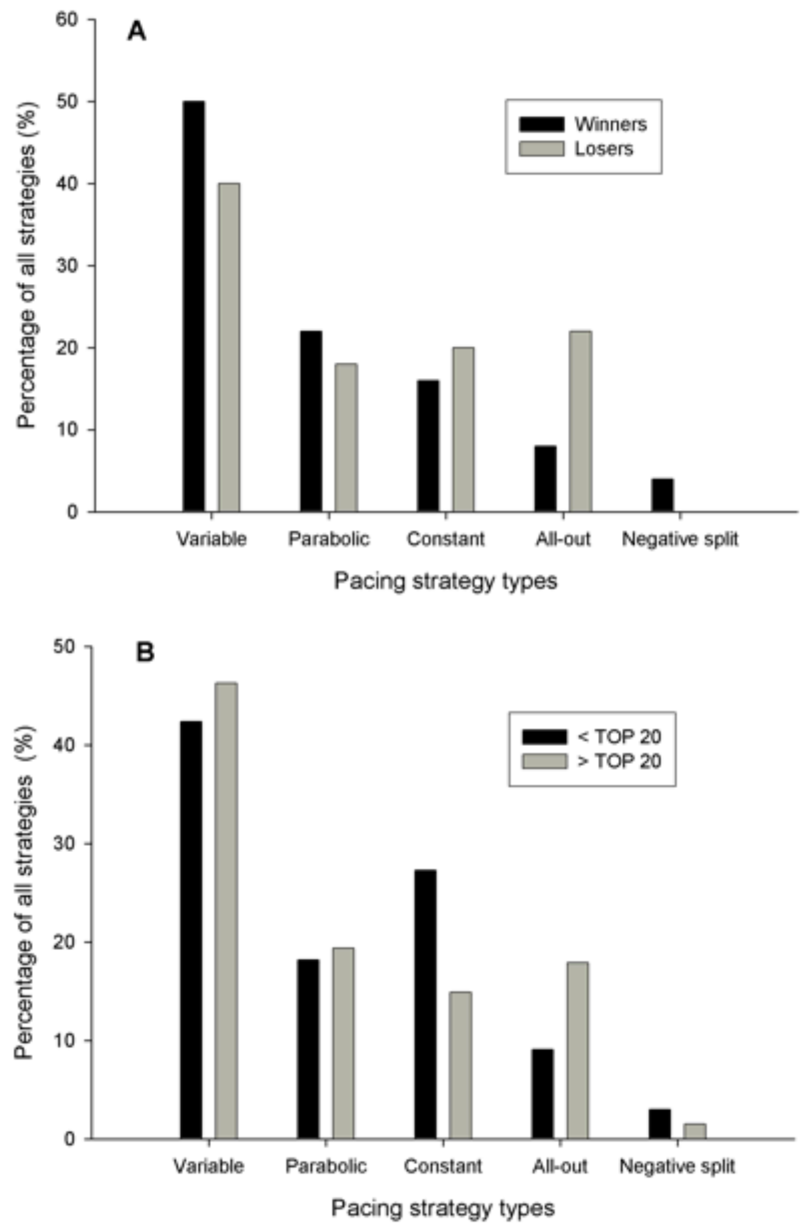

Figure 3. Proportions of pacing strategies about 1st serve velocity used according to the match outcome (a) and the ATP ranking of the players (b)

Comparison of pacing strategies according to players' ATP ranking

There was no significant association between players' ATP ranking and type of pacing strategy used (Fisher exact test =4.15, *P* =0.384, ES =0.04). "Variable" (42 vs. 46%), "parabolic" (18 vs. 19%), and "negative split" (3 vs. 1.5%) pacing strategies were used in similar proportions in < Top 20 and > Top 20 players (Figure 3b). "All-out" strategy was used 2 times more by > Top 20 (18%) than by < Top 20 players (9%). "Constant" strategy was more frequently observed in < Top 20 (27%) than in > Top 20 players (15%).

Differences of serve performance between Grand Slam tournaments during 5-set matches

There was a statistically significant interaction between tournaments and sets concerning 1st serve velocity (main effect: *P* =0.008) (Table 3). Results show no significant differences for 2nd serve velocities and for 2nd serve points won between tournaments (main effect: *P* =0.262 for 2nd serve velocity and *P* =0.261 for 2nd serve points won). Conversely, 1st serve in and 1st serve points won were significantly different between tournaments (main effect: *P* <0.001). There was not significant interaction between tournaments and sets for 1st serve in (*P* =0.160) and 1st serve points won (*P* =0.388). In Wimbledon, 1st serve in was significantly higher in comparison with all other Grand Slam tournaments (Australian Open *P* =0.031, Roland Garros *P* =0.006, and US Open *P* <0.001). In Roland Garros, 1st serve points won was significantly lower in comparison with all other Grand Slam tournaments (Australian Open *P* =0.017, Wimbledon *P* =0.029, and US Open *P* <0.001).

	Whole match	**1st set**	**2nd set**	**3rd set**	**4th set**	**5th set**
			1st serve velocity ($m \cdot s^{-1}$)			
Australian Open	50.5 ± 2.5	50.6 ± 2.6	50.8 ± 2.7	50.0 ± 2.3	50.5 ± 2.5	50.6 ± 2.4
Roland Garros	49.8 ± 3.2	50.0 ± 3.2**	49.4 ± 3.4**	49.9 ± 2.8	49.7 ± 3.0	49.8 ± 3.6
Wimbledon	50.7 ± 2.8	50.9 ± 2.9	50.6 ± 2.7	50.5 ± 2.9	50.7 ± 2.7	50.8 ± 2.8
US Open	51.4 ± 2.9	52.5 ± 2.8	51.8 ± 2.9	51.4 ± 2.7$$	50.8 ± 2.6$$$€€	50.6 ± 3.3$$$€€
			2nd serve velocity ($m \cdot s^{-1}$)			
Australian Open	41.0 ± 2.8	41.1 ± 2.6	41.2 ± 2.9	41.3 ± 3.0	40.8 ± 2.7	40.8 ± 2.7
Roland Garros	40.6 ± 3.2	40.7 ± 2.4	40.5 ± 2.2	40.5 ± 2.3	40.6 ± 2.7	40.5 ± 2.6
Wimbledon	41.7 ± 3.0	41.8 ± 2.6	42.0 ± 2.3	41.5 ± 3.2	41.9 ± 3.2	41.3 ± 3.6
US Open	41.7 ± 2.6	42.1 ± 2.5	41.7 ± 2.6	41.9 ± 3.0	41.8 ± 2.8	41.2 ± 2.3
			1st serve in (%)			

Australian Open	62.4 ± 7.5 $^{@}$	66.6 ± 10.7	61.0 ± 8.7	61.0 ± 10.4	61.8 ± 11.0	62.2 ± 8.8
Roland Garros	61.4 ± 6.7 $^{@@}$	59.0 ± 10.6	60.5 ± 9.9	61.5 ± 10.1	55.8 ± 13.7	61.6 ± 11.4
Wimbledon	65.7 ± 4.8	66.2 ± 10.4	67.4 ± 9.0	66.3 ± 8.6	65.2 ± 8.9	67.2 ± 10.3
US Open	59.7 ± 5.7 $^{@@@}$	55.7 ± 11.1	57.0 ± 9.0	60.3 ± 9.1	59.8 ± 10.5	62.9 ± 10.7
1st serve points won (%)						
Australian Open	72.7 ± 8.6 $^{\#}$	73.8 ± 10.0	77.4 ± 11.7	73.6 ± 11.0	68.7 ± 16.6	70.9 ± 10.7
Roland Garros	66.4 ± 7.6	67.0 ± 13.0	68.3 ± 11.6	67.4 ± 11.3	66.0 ± 13.3	71.3 ± 16.1
Wimbledon	72.5 ± 6.7 $^{\#}$	71.9 ± 13.9	70.8 ± 13.7	71.9 ± 9.2	70.3 ± 20.5	73.8 ± 15.5
US Open	72.7 ± 8.5 $^{\#\#\#}$	71.4 ± 13.4	81.6 ± 9.4	72.0 ± 14.0	76.8 ± 10.4	72.8 ± 12.9
2nd serve points won (%)						
Australian Open	50.9 ± 10.6	50.5 ± 14.6	51.2 ± 15.2	47.2 ± 18.8	50.3 ± 9.9	51.0 ± 18.3
Roland Garros	49.6 ± 7.9	50.4 ± 20.6	51.9 ± 17.6	50.9 ± 20.3	45.4 ± 20.1	52.5 ± 22.0
Wimbledon	52.8 ± 6.6	54.2 ± 17.2	56.3 ± 17.5	54.4 ± 15.3	49.1 ± 19.5	53.8 ± 21.7
US Open	51.8 ± 11.4	52.3 ± 13.1	51.0 ± 13.3	53.6 ± 17.4	52.3 ± 14.9	54.1 ± 22.4

Table 3. Serve performance parameters for all Grand Slam tournaments. Data are presented as means and standard deviation of the mean. Significantly different from 1st set ($*P* <0.05; $$*P* <0.01; $$$*P* <0.001). Significantly different from 2nd set (€ *P* <0.05; €€ *P*<0.01; €€€ *P* <0.001). Significantly different from US Open (***P* <0.01). Significantly different from Wimbledon (@ *P*<0.05; @@ *P*<0.01; @@@ *P*<0.001). Significantly different from Roland Garros (#*P*<0.05; ### *P*<0.001).

Comparison of pacing strategies according to Grand Slam tournaments

There was no significant association between Grand Slam tournaments and type of pacing strategy used (*P* =0.875). “Variable” (around 45%), “all-out” (between 12.5 and 16.7%), and “negative split” (between 0 and 4.2%) pacing strategies were used in similar proportions all Grand Slam tournaments (Figure 4). “Parabolic” strategy was used 2 times more in Roland Garros (29%) than in Wimbledon (12%). “Constant” strategy was 3 times more used in Wimbledon (27%) than in Roland Garros (8%).

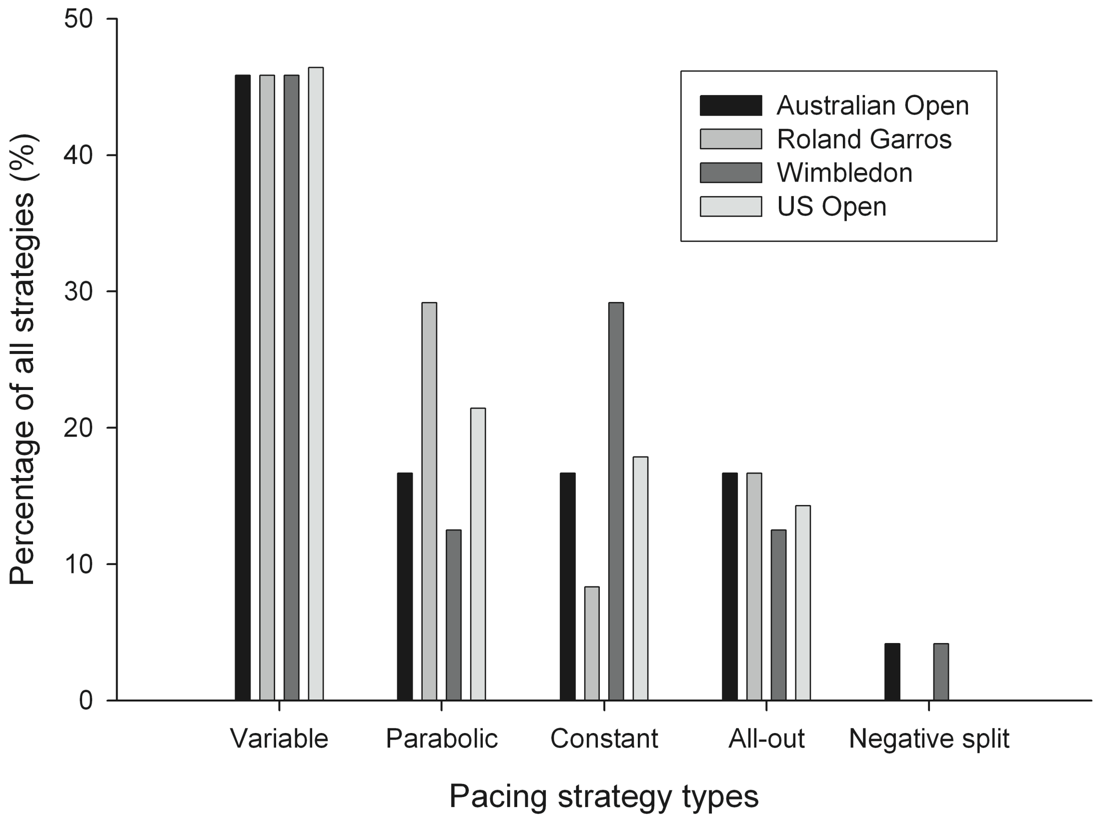

Figure 4. Proportions of pacing strategies about 1st serve velocity used according to the Grand Slam tournaments

DISCUSSION

This study was conducted to establish the prominence of different serve pacing strategies in professional tennis players and their relationship with performance outcome by retrospectively analyzing 5-set matches. The main result was that Fisher exact test (pacing strategy x match outcome) demonstrates a trend towards an association between pacing strategy used and match outcome. There is no significant association between players' ATP ranking and type of pacing strategy used. Serve velocity and serve points won are decreased in losers while they are increased or kept constant in winners during the 5th set of match.

There was no significant difference across the five sets in percentage of "1st serve in" between sets for winners and losers. However, our findings show significant differences in percentages of 1st and 2nd serve points won for winners and losers. During the 5th set, winners won significantly more points after their 1st (+ 13%) and 2nd serves (+ 27%) than losers. This may relate to serve velocity, given that, 1st serve velocity is significantly higher (+ 1.4 $m \cdot s^{-1}$) for winners than for losers for the 5th set. Moreover, between the 1st and last sets, mean 2nd serve velocity for losers shows a 0.9 $m \cdot s^{-1}$ decrease. These results are in line with previous findings who noted a significant relationship between serve velocity and probability of winning the point [22]. By executing faster serves, winners are logically placing greater time constraints on their opponent's return, potentially affording them an advantage for winning the point [23]. However, the higher percentages of points won after 1st and 2nd serves in winners reported in this study were probably caused not only by faster serves but also by the interaction between serve velocity and spin rate or serve location [24 25].

Repartition of different serve pacing strategies is meaningful for tennis players and coaches. Muscle activation and exercise intensity are centrally regulated in response to intrinsic (i.e. physiological, biomechanical and cognitive) and extrinsic sensory feedbacks necessary to maintain physiological homeostasis [26 27]. Based on the "central governor hypothesis", it seems logical that the uppermost players select "variable" strategy to adjust their serve velocity to match circumstances (score evolution, match duration, power struggle, fatigue feelings). Indeed, whatever the Grand Slam tournament and the playing surface, players mainly used "variable" pacing strategy (45%) and with this strategy, they won the match in 56% of the cases. A lot of questions and/or feelings cross players' minds between points and during change-overs throughout a long tennis match [28]. According to Noakes (2009), athletes could regulate their effort due to afferent sensory feedbacks and questions such as: "Have I sufficient energy reserves to finish the match?", "Am I able to win a 5-set match, have I done this before?", "Will my muscles be damaged?", "How much effort do I still have to do to win the match?", etc. [29]. Consequently, the variable strategy appears effective since it could allow tennis players to continuously adapt and regulate their serve velocity based on this complex process involving peripheral sensory feedbacks and anticipated workload remaining.
"Constant" pacing strategy is mainly used when exercise duration is unknown [30]. In our study, players frequently use this strategy (18%). The percentage of this strategy increases to 27% in best-ranked players. Those results are the consequence that tennis match duration is hard to predict. Under stable external conditions, a constant pace is "optimal" for prolonged events such as running, swimming, rowing, and cycling [19] because metabolic resources are conserved during exercise to improve athletes' energy efficiency. In rugby, "constant" strategy has been observed in studies that reported no evident deterioration in high-intensity activity performed during match [31 32]. Moreover, more successful Canadian national and international caliber pursuit and track cyclists used more constant pace race profiles, whereas less successful riders did not [33]. Our results are in accordance with this previous study since the "constant" strategy is more frequently observed in best-ranked players (< Top 20: 27%) than in others (> Top 20: 15%). Moreover, 1st and 2nd serve velocities do not significantly change between sets for winners. All these findings suggest that best tennis players are able to spread their energy to conserve a constant 1st serve velocity throughout the match. One may also hypothesize that the best-ranked players have a better experience of 5-set matches that helps them to more frequently choose constant strategy. Indeed, experience has been suggested to influence pacing strategy of athletes [34]. "Constant" strategy greatly varies from one Grand Slam tournament to the other (only 8% in Roland Garros vs. 27% in Wimbledon). Different factors may explain this result. Firstly, rallies and match duration are usually

shorter in Wimbledon than in Roland Garros [35]. Moreover, it has been shown that the serve has a greater importance for winning a match on grass courts than on clay [36 37]. Consequently, it appears easier and much more crucial for tennis players to maintain constant their serve performance in Wimbledon than in Roland Garros.

"All-out" strategy is twice as common in > Top 20 (18%) than by < Top 20 players (9%) and twice as common for losers (22%) than for winners (8%). When players used "all-out" strategies, they lost the match in 73% of cases. It is difficult to know if players voluntarily chose this kind of strategy before match according to situational influences (i.e. level of opponent, number of consecutives matches already played in tournament for example) or if "all-out" strategy is primarily a consequence of fatigue generated by the current 5-set match. That risk-taking could be a resolute strategy for players with reduced physical abilities caused by previous strenuous matches or injuries. Since they know that their energy stocks are limited, they try to shorten match duration. This behavior could also be a conscious strategy chosen by players who think that their best chance to win the match needs a relatively fast starting serve pacing strategy and to maintain that level performance as long as possible to put pressure on their opponent. It seems that low-ranked players (> Top 20) give priority to this strategy when they compete against best-ranked players (< Top 20), maybe because they underestimate their chance to win the match if its duration is prolonged. Adoption of this tactic has been seen during a number of high-level competition events. For example, cyclists are often seen attempting to break away from the main group of riders during numerous road cycling events (such as Tour de France), presumably for the purpose of winning the race stage [19]. However, such a tactic is seldom successful (only 27% players in this study won their match with this strategy) and instead often results in a progressive decrease in exercise intensity (from the 2nd set to the last one for 1st serve ball velocity), maybe due to disturbances in physiological homeostasis. This progressive decrease in ball velocity observed with "all-out" strategy is meaningful for coaches because it may indicate player's physical limitation, his inability to repeat powerful serves during a prolonged period. "All-out" strategy does not seem influenced by the playing surface, since it varies between 12 and 17% of all strategies used in the different Grand Slam tournaments.

1st and 2nd serve velocities significantly decrease in the last sets of match for losers. These results are in line with previous findings reporting increases in RPE, decreases in EMG activity and modifications in serve biomechanics responsible for velocity decline during prolonged tennis events [8 13 9 6 7]. Moreover, Gomes et al. (2014) reported an increase in muscle soreness and muscle damage appearance that impairs players' performance after a 3-hour tennis match [11]. None of the previous studies cited about fatigue influence on serve performance compared winners and losers' data. Consequently, we can only express a hypothesis about the fact that 5-set matches did not affect winners' serve velocities in this study. We may suppose that winners were physically stronger and better prepared for prolonged matches than losers. Consequently, they could better delay the onset of fatigue and thus its appearance. One may also suppose that winners managed their effort in a better way during 5-set matches than losers.

"Parabolic" strategy concerns 20% of players and 22% of winners. This strategy is two times more used in Roland Garros (29%) than in Wimbledon (12%). In tennis, one may suppose that this strategy reflects the concept of "transient" or "temporary" fatigue previously observed in soccer [17]. This term refers to a period of deliberately reduced intensity in performance after the most intense period of sport matches [38]. During that reduced intensity period, a player may down-regulate energy output for serve during the 3rd and/or 4th sets to preserve energy for later and crucial match periods (5th set for example). One of the best examples of this strategy is the success of Santoro against Safin during Roland Garros 2001. After the match, Santoro admitted that he has voluntarily decreased his effort during the 4th set to recover and be ready to win the 5th set. He said "at the end of the third set I felt I had to drop the fourth. I know it was a risk but I needed a rest. After that it was a flawless performance." (http://www.rediff.com/sports/2001/jun/02safin.htm). According to the flush model [39], there is always a reserve for muscle recruitment (the security reserve) that can be used for the so called "end-spurt" when the athlete is at his highest level of peripheral fatigue. One may suppose that an increased motivation in the 5th set counteracts fatigue sensations and allows players to dip into his security reserve to increase serve velocity.

"Negative split" strategy concerns only 4% of players for which an increase in 1st serve velocity is observed over the duration of match, set after set. However, all players who adopt this strategy won their match. Indeed, adoption of such a pacing strategy is thought to be efficient in prolonged exercise performance by reducing rate of carbohydrate depletion [40], lowering excessive oxygen consumption [41] and/or limiting accumulation of fatigue-related metabolites (i.e. inorganic phosphate, potassium and hydrogen ions) early on in the exercise task [40 42]. It is believed that this strategy may be the result of an increase in motor unit recruitment [43] and the use of the anaerobic energy reserve [44]. However, it is curious that relatively few players used "negative split" strategy, given the attention this type of pacing has received in previous literature for different sports [19]. Further studies are necessary to confirm our results about the use of "negative split" strategy in tennis players and its influence on success.

Our results reveal differences of serve performance between Grand Slam tournaments. In Wimbledon, 1st serve in was significantly higher in comparison with all other Grand Slam tournaments. In Roland Garros, 1st serve points won was significantly lower in comparison with all other Grand Slam tournaments. Those results are similar to previous studies about serve performance parameters of professional players in different playing surfaces [45 46]. Indeed, the speed of playing surfaces influences the players' tactical behavior. For example, at Wimbledon, increasing the percentage of 1st serve in is a key element of successful play on grass, because it puts the opponent under stress and may hinder its return. A more aggressive and attacking game is commonly associated with faster surface, such as grass [47]. Conversely, the clay of Roland Garros slows the ball down and reduces the advantage of the server.

This study presents limitations. First, our results reveal only a trend towards an association between pacing strategy used and match outcome. It is well known that p values depend upon sample size but our study provides a retrospective analysis of pacing profiles in professional tennis players only for data limited to a single year. As a consequence, some flexibility is desirable to interpret our p value. Moreover, the comparison of pacing strategies between the intermittent tennis activity and the continuous effort of other sports (cycling, rowing, running) may be delicate. No intervention was performed, and no physiological, biomechanical or psychological data were collected; therefore, mechanisms underpinning the observed results are hypothetical. More research is required to establish if perturbations in serving performance are primarily a consequence of fatigue, pacing or tactical and situational influences. Further studies focusing on the relationships between pacing strategies, court surfaces and match outcome are necessary.

Conclusion

This is the first study that provides an insight into pacing behavior in professional tennis players during 5-set Grand Slam matches. For players and coaches, pacing strategy may be a variable to take into account during pre-match strategy or post-match analyses. Authors are conscious that it is really difficult for a tennis player to know if the match will last 3, 4 or 5 sets. However, in some cases, players may anticipate duration and difficulty of match according to their opponent's level, their head-to-head opponent. For example, if ATP number 1 is drawn to play a qualifier in first round of a Grand Slam tournament, he should choose a pacing strategy that suits a three-set match but if he is going to play against one player member of the ATP top 5 in a semi-final for example, he may expect a tough and long match. Consequently, he could adopt a pacing strategy that suits a five-set match. In this case, defining strategic recommendations is instructive for tennis players. The current results can provide guidelines for coaches and competitors to follow when they expect a long tennis match, since pacing strategy used by players tends to exert an influence on 5-set match outcome. It appears that players should favor 'negative-split', 'variable' and 'parabolic' strategies in order to win 5-set matches and avoid 'all-out' strategy. Indeed, according to the data of this study, when players used 'variable' and 'parabolic' or 'negative-split' strategies; they respectively win the match in 56 – 100 % of cases. But, when they used 'all-out' strategy, they lost the match in 73 % of cases. Consequently, 'all-out' strategy appears inefficient. Finally, data show that serve velocity and serve points won are decreased for losers while they are increased or kept constant for winners during the 5th set of the match. Post-match analysis of serve statistics (serve velocity, percentage of serve in, points won) during 5-set matches is meaningful for tennis coaches because it can provide insight and information about player's physical fitness level. For example, an acute decrease in 1st serve velocity during the 5th set may reveal a player's physical weaknesses. In this way, pacing strategy used should be a key factor for consideration when coaches determine specific training programs to prepare high level tennis players for 5-set tennis matches [48]. A conditioning program should focus on power endurance development to delay fatigue effects [49] and avoid decreases in serve velocity during the 5th set. In this way, explosive tennis-specific strength training with medicine balls and dumb-bells are recommended with emphasis on leg drive, trunk and shoulder rotations [49], since they are important contributors to serve velocity [50] [51]. Moreover, motor imagery can be an interesting tool for helping players to maintain their serve performance. Indeed, it has been shown that motor imagery improves serve performance during high intensity intermittent training in young tennis players [52].

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Conflict of interest statement

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