



## Physiological Responses and Match Characteristics in Professional Tennis Players During a One-Hour Simulated Tennis Match

by

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*The purpose of this study was to investigate the effects of serve and return game situations on physiological responses and match characteristics in professional male tennis players during one hour-long simulated singles tennis matches. Ten internationally ranked tennis players (age  $22.2 \pm 2.8$  years; body height  $180.7 \pm 4.4$  cm; body mass  $75.9 \pm 8.9$  kg) participated in this study. Their physiological responses were measured using two portable analyzers during indoor hard court matches. Ratings of perceived exertion were also determined at the end of the game. The variables describing the characteristics of the matches determined from video recordings were: (a) duration of rallies; (b) rest time; (c) work-to-rest ratio; (d) effective playing time; and (d) strokes per rally. Significant differences ( $p < 0.05$ ) were found between serving and returning conditions in an hour-long simulated singles tennis match in terms of oxygen uptake, a heart rate, ratings of perceived exertion, pulmonary ventilation, respiration frequency and a respiratory gas exchange ratio. In addition, both the heart rate and ratings of perceived exertion responses were moderately correlated with the duration of rallies and strokes per rally ( $r = 0.60$  to  $0.26$ ;  $p < 0.05$ ). Taken together, these results indicate that the serve game situation has a significant effect on the physiological response in an hour-long simulated tennis match between professional male tennis players. These findings might be used for the physiological adaptations required for tennis-specific aerobic endurance.*

**Key words:** game-based training, performance analysis, racket sports, tennis match activity.

### Introduction

Tennis, a game that requires running at different speeds, acceleration, deceleration, turns, changeovers, strokes, sprints, sliding and upper arm involvement, is an anaerobic sport with aerobic breaks between the rallies, making players perform short bursts of high-intensity exercise interspersed with periods of rest or low-intensity activities over a prolonged period (2-4 hours) (Fernandez et al., 2006; Murias et al., 2007; Reid et al., 2013). In Grand Slam tournaments, tennis matches between top ranked professional players can last in excess of 5 hours (Kovacs, 2007).

Consequently, tennis players need to possess tennis-specific physiological characteristics, such as aerobic fitness, muscle strength and power to reach the optimum match performance level (Kovacs, 2006). Thus, it is important to assess the relevant physical characteristics and measure physiological responses to simulated tournament match-play to enable the design of effective tennis on-court practice programs for professional tennis players.

A number of studies have focused on physiological demands of tennis, investigating

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factors such as body composition and anthropometry (Fernandez et al., 2014; Girard and Millet, 2009), a heart rate (HR) (Baiget et al., 2005; Fernandez et al., 2009b, 2010), blood lactate concentration (LA-) (Martin et al., 2011; Mendez-Villanueva et al., 2010; Smekal et al., 2001), maximum oxygen uptake ( $VO_{2max}$ ) (Botton et al., 2011; Fargeas-Gluck and Leger, 2012; Fernandez et al., 2010), the rate of perceived exertion (RPE) (Fernandez et al., 2008, 2011; Mendez-Villanueva et al., 2010) and energy expenditure (EE) (Botton et al., 2011; Fernandez et al., 2009b, 2010). Further studies have investigated performance responses in matches, using methods such as time-motion analysis (Gomes et al., 2011; Vickery et al., 2014) and activity profiles (Fernandez et al., 2007, 2008, 2009b) in players of different levels.

Identifying the physiological determinants of performance is crucial for athletes and involves monitoring training and assessing performance. In this regard, the physical demands of the game have been reported to lead to acute physiological responses during simulated tennis match play (Fernandez et al., 2009a). Several factors affect tennis performance in addition to the level of ability of the players concerned. In addition to physical, technical and tactical factors, the physiological responses can also be influenced by the playing situation (e.g., serve vs. return games). Differences in match characteristics, such as duration of a rally and stroke per rally related to different playing situations, have also been reported to affect match play physiological responses, with the average HR, RPE and LA- being significantly higher for serving than return games (Fernandez et al., 2009a). It has been observed that match characteristics and physiological responses differ significantly for male and female singles tennis matches (Fernandez et al., 2007; Mendez-Villanueva et al., 2007). Mendez-Villanueva et al. (2007) investigated physiological demands of a male professional singles tennis tournament, finding higher LA- and RPE in matches with longer rallies and higher numbers of strokes per rally. Conversely, some physiological responses such as the HR,  $VO_2$  and LA- did not differ significantly between serve and return games in tennis players (Smekal et al., 2001).

Although previous studies (Fernandez et al., 2008, 2009b) had investigated physiological

responses and match characteristics across different match duration, gender and performance levels, no studies performed in-depth examinations of the effects of serve and return game situations on physiological responses and match characteristics in professional tennis players during a 1 hour-long simulated tennis match. Thus, the purpose of this study was to investigate the effects of serve and return game situations on physiological responses and match characteristics of professional tennis players during a 1 hour-long simulated tennis match.

## Material and Methods

### Subjects

Ten professional male tennis players (age  $22.2 \pm 2.8$  years; body height  $180.7 \pm 4.4$  cm; body mass  $75.9 \pm 8.9$  kg; mean  $\pm$  SD) participated in this study. At the time of the study, the players involved trained 20 - 30 hours per week and had International Tennis Numbers (ITN) ranging from 1 to 2 (average  $369.3 \pm 24.7$  points), corresponding to an Association of Tennis Professionals (ATP) ranking of between 800 and 1600 and a national ranking of between 1 and 20. All of the participants were right-handed tennis players. Their mean training experience with the focus on tennis-specific skills, aerobic and anaerobic training as well as strength training was approximately 6-8 years. All of the players were notified of the research procedures, requirements, benefits, and risks before informed consent was given. Written informed consent was obtained from all the subjects. This study was approved by the research ethics committee of the Gazi University and was performed in a manner consistent with the institutional ethical requirements for human experimentation in accordance with the Declaration of Helsinki.

### Experimental Design

All players (no players were physically limited or injured) completed a total of two randomized simulated singles matches on an indoor hard court in their transitional period; each match lasted one hour and the players had one day of rest between the two matches. Each match was played by 2 different players of the study. This study was performed over two weeks and included 3 experimental sessions: 1 - laboratory tests (anthropometrics and a treadmill test); 2 - on-court assessment (the ITN test); 3 - one hour of

simulated singles tennis match play during which players were monitored using a portable breath-by-breath automated gas analysis system (K4b<sup>2</sup>, Cosmed, Rome, Italy) and match notational analysis. The tests were conducted between 9:00 and 12:00. Similar temperatures (26-28°C) and relative air humidity levels (42-48%) were maintained throughout all stages of the study. The participants were asked not to drink caffeinated beverages or take other stimulants for the 3 hours prior to the test and to avoid strenuous exercise for 24 hours prior to the physical and laboratory tests. During the matches, the Borg scale (RPE 6-20) was applied immediately after the end of every game in order to measure perceived exertion. Each player was individually filmed and the characteristics of the matches were monitored for the entire duration of the match.

### **Procedures**

#### *Laboratory Measurements*

Anthropometric measurements, including body height and mass were obtained for each volunteer. During the measurements the subjects wore light clothing and were barefoot. Body mass was measured to the nearest 0.1 kg using calibrated scales (Seca, Germany), while height was measured to the nearest 0.1 cm using a calibrated stadiometer (Holtain Ltd., England). Bioelectrical impedance analysis (BC-418, Tanita, Tokyo, Japan) was used to determine body fat and a basal metabolic rate (BMR). All players completed a treadmill test (T150, Cosmed, Rome, Italy) to calculate HR<sub>max</sub> and VO<sub>2max</sub> values. The test consisted of an initial 3 min continuous workload of 9 km·h<sup>-1</sup> with an increase of 0.5 km·h<sup>-1</sup> every minute at a constant gradient of 0% until exhaustion (Girard et al., 2006). During the test, respiratory gas exchange measures were obtained using the K4b<sup>2</sup> and recorded at 5 s intervals. The heart rate was recorded using the K4b<sup>2</sup> with athletes wearing a chest belt (Polar T31, Kempele, Finland). The flow, volume and gas analyzers were calibrated prior to each test according to the manufacturer's instructions. The highest 30 s mean HR and VO<sub>2</sub> values measured during the test were used as maximum values (HR<sub>max</sub> and VO<sub>2max</sub>). Criteria for determination of VO<sub>2max</sub> included a plateau in VO<sub>2</sub> despite an increase in the workload, RER > 1.1, and HR > 90% of predicted HR<sub>max</sub> (Fernandez et al., 2009b).

#### *On-Court Testing*

The International Tennis Number Test (ITN) is an objective on-court assessment tool based on a set number of tennis-specific tasks (i.e., ball control, accuracy, power) and was developed to enable players to benchmark their tennis level against themselves and others worldwide (ITF, 2004). The ITN on court assessment was performed according to the instructions provided by the International Tennis Federation (ITF). A ball machine (Tennis Tutor Plus, Sports Tutor Inc. USA) was used to feed balls to the tested players.

#### *One-Hour Simulated Tennis Match*

All the players performed a standardized warm-up for 10 minutes prior to each match; the warm-up involved ground strokes (players were asked to play the balls to the center of the court), volleys plus overhead shots (one player on the baseline, the other playing volleys) and serve practice. Each subject completed a total of 2 single one-hour simulated tennis matches with one day of rest in between on an indoor hard court, and all the matches were played according to the rules of the ITF (Ojala and Häkkinen, 2013). All the players were equipped with a polar chest-belt telemetry monitor to record their HR. A set of 4 new balls (Wilson Usopen, Chicago, USA) was used for each match. Two portable K4b<sup>2</sup> devices were used to measure the VO<sub>2</sub>, HR, RER, RF and VE values during the matches. Only negligible differences were found in the VO<sub>2</sub> values between the two analyzers in our laboratory comparison (Girard et al., 2006). Energy expenditure was calculated from the VO<sub>2</sub> values using 5 kcal·L<sup>-1</sup> O<sub>2</sub> as the caloric equivalent. The values were averaged for the 60 minutes of each match to obtain total energy expenditure. The players were allowed to drink water to preserve their hydration state during the 90 s recovery periods, which occurred approximately every 15 min (when the players changed ends at the completion of a game). Exercise intensity was also measured using the rating of perceived exertion scale (RPE 6-20) after the end of every game (Borg, 1982).

#### *Match Activity*

Each player was individually videotaped using two video cameras (50 Hz, 25 frame per second) (JVC GZ-MG37E, Japan) positioned 2 m from the side of the court, at the level of the serve line and approximately 6 m above the court for the entire duration of the match (Fernandez et al.,

2008). A specialized tennis analysis program (Motionpro, version 8.5.1. USA) was used for the analysis of the matches, and the analysis of all of the matches was performed by the same experienced researcher. A match protocol developed by Smekal et al. (2001), which had been shown to be reliable (Fernandez et al., 2007, 2008; Mendez-Villanueva et al., 2007, 2010) was used to monitor and record the duration of each game and each rally, the duration of the rest intervals between games and changeover breaks, as well as the number of shots per rally. On the basis of these data, the following variables were calculated for each game: 1- the duration of the rallies in seconds (DR); 2 - the rest time in seconds, not including changes of ends (RT); 3 - the work-to-rest ratio, not including changes of ends (W:R); 4 - effective playing time (EPT; expressed as a percentage of the total time when the ball was in play during a game); and 5 - strokes per rally (SPR; strokes·min<sup>-1</sup>). The DR was recorded from the time the server hit the first serve to the moment when one of the players won the point (Fernandez et al., 2007; Mendez-Villanueva et al., 2007). The EPT was determined by dividing the entire playing time of a game (from the beginning of the first rally until the end of the last rally) by the real playing time (sum of the duration of rallies) in a game. In addition, the following variables were calculated for each game: 6 - frequency of strokes in effective playing time (SF); 7 - game number (GN); 8 - total serves per match (TS); 9 - first serves per match (FS), 10 - second serves per match (SS); and 11 - total shots per match including serves (TSM).

### Statistical analysis

The data are reported as the mean and standard deviation. Before using parametric tests, the assumption of normality was confirmed using the Kolmogorov-Smirnov test (with Lilliefors' correction). A paired t-test was performed on each dependent variable, including VO<sub>2</sub>, HR, %HR<sub>max</sub>, RPE, EE, V<sub>E</sub>, RER and RF to compare differences between serve games and return games. The relationship between variables describing the match characteristics (DR, SPR) and physiological responses (HR and RPE) obtained at the end of each game examined was determined using Pearson product moment correlation analysis. All statistical analysis was performed using IBM SPSS Statistics version 22 and the level of statistical

significance was established at  $p < 0.05$ . Effect sizes (ES – Cohen's  $d$ ) were also calculated to determine the practical difference between serve games and return games. ES values of 0.20–0.49, 0.50–0.79, and 0.8 and above were considered to represent small, medium, and large differences, respectively (Cohen, 2013). In addition, 95% Confidence Intervals (95% CI) were calculated for the differences between the mean values for each of the estimated variables. The inter-individual variability of VO<sub>2</sub>, HR, %HR<sub>max</sub>, RPE, EE, V<sub>E</sub>, RER and RF between the serve games and return games was quantified using the coefficient of variation (CV).

## Results

The physical and physiological characteristics of the tested players are shown in Table 1.

Table 3 shows the subjects' average VO<sub>2</sub>, HR, %HR<sub>max</sub>, RPE, EE, V<sub>E</sub>, RER and RF responses during serve and return games. There were significant differences between serve games and return games in terms of VO<sub>2</sub> ( $t = 50.907$ ;  $p < 0.05$ ; small ES: 0.38; 95%CI: 2.01 to 2.17) and HR ( $t = 54.619$ ;  $p < 0.05$ ; small ES: 0.43; 95%CI: 7.51 to 8.07). Significant differences were also found between the serve games and return games in terms of %HR<sub>max</sub> (42.461;  $p < 0.05$ ; medium ES: 0.73; 95%CI: 3.61 to 3.96), RPE ( $t = 6.806$ ;  $p < 0.05$ ; small ES: 0.36; 95%CI: 0.82 to 1.43) and EE ( $t = 10.526$ ;  $p < 0.05$ ; medium ES: 0.58; 95%CI: 20.33 to 31.46). Furthermore, serve games showed significantly higher responses than return games in terms of V<sub>E</sub> ( $t = 18.447$ ;  $p < 0.05$ ; small ES: 0.15; 95%CI: 4.04 to 5.00), RER ( $t = 3.071$ ;  $p < 0.05$ ; small ES: 0.05; 95%CI: 0.00 to 0.01) and RF ( $t = 14.945$ ;  $p < 0.05$ ; small ES: 0.12; 95%CI: 1.79 to 2.39).

Table 4 shows the correlation coefficients between HR and RPE values. The variables were moderately correlated with the SPR and DR obtained in the match analysis ( $r = 0.60$ ,  $p = 0.000$ ;  $r = 0.52$ ,  $p = 0.001$ , respectively). In addition, the correlation in serve and return games was found to be low and significant. Similarly, RPE values showed a statistically significant difference with higher correlations with the SPR and DR in serve games than in return games ( $r = 0.40 - 0.36$ ,  $p = 0.000$  vs.  $r = 0.31 - 0.26$ ,  $p < 0.05$ , respectively).

**Table 1***Physical and physiological characteristics of the tested players*

Variables	mean±SD
Age (years)	22.2±2.8
Body Height (cm)	180.7±4.4
Body Mass (kg)	75.9±8.9
BMI (kg/m <sup>2</sup> )	23.2±2.3
Body Fat (%)	10.9±4.1
BMR (kcal·day <sup>-1</sup> )	1984±175
VO <sub>2max</sub> (ml·min <sup>-1</sup> ·kg <sup>-1</sup> )	49.8±1.2
HR <sub>max</sub> (beat·min <sup>-1</sup> )	195.2±1.5

*BMI = body mass index; BMR = basal metabolic rate;*

*VO<sub>2max</sub> = maximum oxygen uptake; HR<sub>max</sub> = maximum heart rate.*

*Values are expressed as the mean±SD*

**Table 2***One-hour simulated tennis matches analysis*

Physiological Variables	mean±SD
VO <sub>2max</sub> (ml·min <sup>-1</sup> ·kg <sup>-1</sup> )	26.6±2.7
HR (beat·min <sup>-1</sup> )	142.7±9.5
%HR <sub>max</sub> (%)	73.1
RPE	12.7±2.1
EE (kcal·h <sup>-1</sup> )	568±58.8
V <sub>E</sub> (L·min <sup>-1</sup> )	67.2±15.2
RER (ratio)	0.98±0.08
RF (number·min <sup>-1</sup> )	39.8±8.4
Notational Variables	
EPT (%)	26.3±3.2
SPR (shots)	3.9±2.9
SF (shots·min <sup>-1</sup> )	43.3±3.4
DR (s)	6.7±4.7
W:R ratio	1:3
RT (s)	20.2±4.7
GN (number)	16.8±1.9
TS (number)	111.5±12.5
FS (number)	64.2±8.4
SS (number)	47.3±10.1
TSM (number)	546.3±40.4

*VO<sub>2</sub> = oxygen uptake; HR = mean heart rate; %HR<sub>max</sub> = maximum heart rate;*

*RPE<sub>-20</sub> = rating of perceived exertion; EE = energy expenditure;*

*V<sub>E</sub> = pulmonary ventilation; RER = respiratory gas exchange ratio;*

*RF = respiration frequency; EPT = effective playing time; SPR = shots per rally;*

*SF = frequency of the shot; DR = duration of the rally; W:R = work-to-rest ratio;*

*RT = resting time; GN = number of games per match; TS = total serves per match;*

*FS = first serves per match; SS = second serves per match;*

*TSM = total shots per match; Values are expressed as the mean±SD*

**Table 3***Differences between serve and return games during one-hour simulated tennis matches*

Physiological Variables	Serve Games		Return Games		MD	%95CI	ES
	Mean±SD	CV (%)	Mean±SD	CV (%)			
VO <sub>2max</sub> (ml·min <sup>-1</sup> ·kg <sup>-1</sup> )	27.6±2.8*	10.33	25.6±2.1	8.40	2.0	2.01, 2.17	0.382
HR (beat·min <sup>-1</sup> )	146.6±9.4*	6.41	138.8±8.1	5.83	7.8	7.51, 8.07	0.426
%HR <sub>max</sub> (%)	74.9±1.7*	2.27	71.1±1.8	2.53	3.8	3.61, 3.96	0.735
RPE	13.5±1.8*	13.48	12.0±2.1	17.66	1.5	0.82, 1.43	0.359
EE (kcal·h <sup>-1</sup> )	581.4±24.4*	4.19	555.5±23.0	4.14	25.9	20.33, 31.46	0.578
V <sub>E</sub> (L·min <sup>-1</sup> )	69.5±15.8*	22.41	65.0±14.5	22.44	4.5	4.04, 5.00	0.148
RER (ratio)	0.99±0.09*	9.09	0.98±0.08	8.16	0.0	0.00, 0.01	0.058
RF(number·min <sup>-1</sup> )	40.7±9.4*	23.20	38.7±7.5	19.34	2.0	1.79, 2.34	0.120

VO<sub>2</sub> = oxygen uptake; HR = mean heart rate; %HR<sub>max</sub> = maximum heart rate;  
 RPE = rating of perceived exertion; EE = energy expenditure; V<sub>E</sub> = pulmonary ventilation;  
 RER = respiratory gas exchange ratio; RF = respiration frequency.  
 CV: Coefficient of variation; MD: Mean Difference; %95CI: %95 Confidence Interval  
 (%95CI was estimated for the difference between two means);  
 ES: Effect Size (Absolute value); \*Significant difference from return games,  
 p<0.05. Values are expressed as the mean±SD

**Table 4***Correlations between physiological and perceptual values and match characteristics*

	All games (n = 168)		Serve games (n = 84)		Return games (n = 84)	
	r	p	r	p	r	p
HR						
SPR	0.60	.000*	0.54	.007*	0.41	.017*
DR	0.52	.000*	0.46	.020*	0.34	.031*
RPE						
SPR	0.48	.000*	0.46	.027*	0.31	.027*
DR	0.43	.000*	0.39	.009*	0.26	.041*

HR = mean heart rate; SPR = shots per rally; DR = duration of rally;  
 RPE = rating of perceived exertion. \*Significant relationship. p<0.05

**Table 5**  
*Summary of studies examining the effects of serve and return game situations*

References	Variables			Physiological Variables					
	Age (year)	Sex	N	Game design	HR (bpm)	LA (mmol·L <sup>-1</sup> )	RPE (6-20)	V <sub>E</sub> (L·min <sup>-1</sup> )	VO <sub>2</sub> (ml·min <sup>-1</sup> ·kg <sup>-1</sup> )
Fernandez et al. (2007)	17.3±1.9	F	8	Serve	166±15*	2.3±0.6	NR	NR	NR
				Return	156±19	2.3±0.9			
Fernandez et al. (2008)	17.0±2.4	F	8	Serve	NR	2.2±0.9	12.2±2.4	NR	NR
				Return	NR	2.2±0.7	12.0±2.3		
Villanueva et al. (2010)	27.0±4.4	M	8	Serve	NR	4.4±2.4*	13.5±1.9*	NR	NR
				Return	NR	3.0±1.3	12.2±2.0		
Villanueva et al. (2007)	27.0±4.4	M	8	Serve	NR	4.6±2.5*	13.5±1.9*	NR	NR
				Return	NR	3.2±1.4	12.0±2.0		
Smekal et al. (2001)	26.0±3.7	M	20	Serve	152±18	2.1±0.9	NR	59.2±12.9	29.5±5.7
				Return	150±20	2.0±0.9	NR	59.2±12.7	28.6±5.5

*F= female; M= male; n= sample size; NR= not reported; HR= heart rate;*

*LA= blood lactate concentration; RPE= rating of perceived exertion;*

*V<sub>E</sub> = pulmonary ventilation; VO<sub>2</sub>= oxygen uptake;*

*\*Significant difference from return games.  $p < 0.05$ . Values are expressed as the mean±SD.*

## Discussion

The purpose of this study was to investigate the effects of serve and return game situations on the physiological responses and match characteristics in professional tennis players during a one-hour simulated tennis match. To the best of our knowledge, the present study was the first to undertake such a thorough examination of these effects. The main findings are that physiological responses in terms of VO<sub>2</sub>, HR, %HR<sub>max</sub>, EE, VE, RER and RF were higher in serve games and, secondly, that serve games also induced greater internal load responses (RPE) (Table 3). We also found that physiological and perceptual responses associated with match characteristics such as SPR and DR were relatively moderate HR and RPE values during a one-hour simulated tennis match. Physiological responses, such as HR and perceptual responses measured in this study in terms of RPE were higher in serve game situations compared when returning a serve; these responses were affected by the number of strokes per rally and long rallies, resulting in a higher metabolic and perceptual load.

Previous studies focused on physiological and match activity responses of tennis players

during match play found that they were affected by several factors including the type of surface (Fernandez et al., 2010; Martin et al., 2011; Murias et al., 2007; Reid et al., 2013), gender (Fernandez et al., 2007; Fernandez et al., 2008; Girard and Millet, 2009), the level of ability (Fernandez et al., 2009b), thermal stress (Duffield et al., 2011) and a training regime (Fernandez et al., 2010; Fernandez et al., 2011). In another previous study, findings showed that no single variable strongly explained tennis performance (Kovacs, 2007). All these variables have been found to affect in-match activity and therefore individual physiological responses during matches.

HR monitoring is the most popular indirect method of estimating intensity of exercise and it also appears to be the most practical and low-cost method (Murayama and Ohtsuka, 1999). In this study, exercise intensity was determined by monitoring the HR, %HR<sub>max</sub> and RPE levels during the matches. It was found that the serve game situation had an effect on the HR and %HR response; professional male tennis players showed lower HR and %HR responses in return games (Table 3). According to previous studies, %HR responses ranged from 70-80% in singles tennis matches (Fernandez et al., 2009a; Kovacs, 2007). Thus, our findings are consistent with those

of previous studies. However, a similar study found higher HR responses than our study (Fernandez et al., 2007). Furthermore, we also found a positive relationship between the HR and measured match characteristics (e.g., DR, SPR, when serve and return games are compared). The HR responses showed statistically significantly higher correlations with DR and SPR ( $r = 0.54$  and  $r = 0.46$ , respectively) during serve games than they did in return games (0.41 and 0.34, respectively) (Table 4). Taken together, these results indicate that the playing situation (serve or return game) affected the HR responses in the present study. The study results also showed a higher relationship between HR responses and DR and SPR compared with a similar study (Fernandez et al., 2007). The differences in the HR and its relationship with DR and SPR may be explained by gender (e.g., male vs. female), age (e.g., older vs. younger) and the exercise protocol (e.g., a simulated match vs. an actual competition).

Although HR monitoring is a very common method of measuring the intensity of exercise, several factors (e.g., psychological stress, emotion, score, etc.) can also affect HR responses in professional tennis match play; thus, different measurement tools should be used in combination with the HR (Ojala and Häkkinen, 2013). When investigating a sport such as tennis, which includes maximal and submaximal contraction activities related to eccentric loading associated with the HR, the RPE might help to determine the level of perceived exertion (Girard et al., 2006). The RPE is also considered a viable method for tracking the internal load using low cost, easily accessible procedures to ascertain the individuals' global perception of training effort (Dishman et al., 1987). Furthermore, RPE responses can also reflect the combined physiological, biomechanical and psychological stress/fatigue imposed on the body during exercise (Buchheit and Laursen, 2013). This study found significant differences in the RPE responses between serve and return games (13.5 and 12.0, respectively) (Table 3). These values are similar to those found in previous studies (Mendez-Villanueva et al., 2007, 2010). Mendez-Villanueva et al. (2010) reported that servers had a higher physical strain due to the high number of short rallies consisting of either aces or serve winners. In addition, factors

such as high shot frequency and higher numbers of total serves per match might influence the level of physiological responses during the match. It is clear that the intensity and duration of activities are higher for the players who serve than for those who return the ball (Fernandez et al., 2007). Further evidence of the increased exertion associated with serving compared with returning can also be observed in the finding of higher correlations between the RPE and SPR or DR in previous studies (Mendez-Villanueva et al., 2007, 2010).

The determination of match activity in tennis matches is as important as the examination of physiological responses in the matches. The mean duration of rallies and strokes per rally in the matches studied were 6.7 s and 3.9 s respectively. These results are lower than those in previous studies which reported higher duration of rallies and lower strokes per rally value in matches with male singles (Murias et al., 2007; Smekal et al., 2001). Our W:R result is higher than that found in previous studies (Fernandez et al., 2007; Mendez-Villanueva et al., 2007, 2010). Potential reasons for these differences include the court surface, players' gender, their performance level and playing conditions (Table 5). In addition to these differences, high shot frequency, total serves per match and long and fast rallies in matches influence the level of physiological responses (Fernandez et al., 2009a). These findings indicate that tennis players are involved in more strenuous activity when serving than when returning, resulting in higher likelihood of anaerobic exercise during serve games compared with return games. Thus, the higher intensity in serve games might cause physiological responses of tennis players to have a closer relationship with match characteristics.

There are some limitations that need to be acknowledged and addressed regarding the present study. One of them concerns the lack of other markers of the physiological load (e.g., LA-). Tennis is mostly a high intensity anaerobic activity, thus, the HR may not be the best variable to evaluate the training load placed on the players. The evaluation of LA concentration, distance covered or the speed of locomotion could be more informative variables. Another is the court surface affecting the level of physiological responses in matches. Further research is required

to investigate the combination of LA-, HR and RPE responses to evaluate physiological responses related to match activity characteristics in different courts.

Table 5 provides a summary of studies examining the effects of serve and return game situations on physiological responses and tennis match characteristics.

## Conclusion

This study documented physiological responses and match characteristics of professional male tennis players during a one-hour simulated tennis match. Significant differences were found between serving and

returning conditions in an hour-long simulated singles tennis match in the observed physiological responses in terms of oxygen uptake, the heart rate, ratings of perceived exertion, pulmonary ventilation, respiration frequency and the respiratory gas exchange ratio. In addition, DR and SPR were moderately correlated with the observed HR and RPE values. These results indicate that the serve game situation has an effect on the physiological response in an hour-long simulated tennis match between professional male tennis players. Taken together, these findings might be useful when considering physiological adaptations required for tennis-specific aerobic endurance training in planning periodization.

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