ORIGINAL ARTICLE

Match activity and physiological responses during a junior female singles tennis tournament

Jaime Fernandez-Fernandez, Alberto Mendez-Villanueva, Benjamin Fernandez-Garcia, Nicolas Terrados

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See end of article for authors' affiliations

Correspondence to: Jaime Fernandez-Fernandez, University of Leon, Campus de Vegazana, s/n 24071, Spain; jauma_fernandez@hotmail.com

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Objective: To assess physiological load in conjunction with individual patterns of match-play activity in junior female tennis players during actual singles tennis competition.
Methods: Eight elite junior female tennis players (n = 8; mean (SD) age, 17.3 (1.9) years) took part in a 2 day invitational tournament. Activity pattern analysis was performed during competitive matches. Heart rate and blood lactate concentrations were measured during selected changeovers breaks in play.
Results: The activity profile of junior female players were: rally duration, (mean (SD)) 8.2 (5.2) s; rest time between rallies, 17.7 (6.5) s; effective playing time, 21.9 (3.8)%; strokes per rally, 2.7 (1.7); changes of direction per rally, 2.3 (1.4). The mean (SD) heart rate and blood lactate concentration recorded during the matches were 161 (5) beats/min and 2.0 (0.8) mmol/litre. Heart rate and blood lactate concentration values were influenced by the characteristics of the match and mean (SD) heart rate was significantly higher ($p = 0.004$) during service games (166 (15.4) beats/min) than in return games (156 (19.6) beats/min), while blood lactate concentrations were not significantly different ($p = 0.83$) between service (2.3 (0.6) mmol/litre) and return games (2.3 (0.9) mmol/litre). We found a significant ($p<0.05$) positive relationship between rally duration, strokes per rally, changes of direction and blood lactate and heart rate responses, with stronger correlations when the players were serving.
Conclusions: The physiological (ie, blood lactate and heart rate) responses associated with match play were influenced by the characteristics of the match (rally duration, strokes per rally and changes of direction), with higher heart rate on service position. Training programs should reflect these demands placed on female players during competitive match play.

The physical aspects related to singles tennis performance have been quite well studied in male participants.[1–6] Tennis match play is characterised by short bouts of intermittent exercise interrupted by several periods of longer duration and lower intensity.[7] Matches vary substantially in duration, often lasting more than an hour and in some cases more than 5 h.[4 7–9] Most matches consist of work and rest periods of 5–10 s and 10–20 s, respectively, interspersed with longer rest periods (ie, 90 s between changeover breaks).[7] During each point, players typically hit the ball an average of 2–3 times and make four directional changes per rally.[10 11] Match activity, however, can be influenced by factors such as court surface, ball type and sex.[12 13] In this regard, O'Donoghue and Ingram[12] have reported that rallies analysed in Grand Slam women's singles matches were significantly longer (7.1 s/rally) than those in men's singles matches (5.2 s/rally), together with a greater proportion of baseline rallies in women's singles. In addition, women played significantly less strokes/s, hit fewer aces, won fewer service games and committed more double faults. Although this study provides information about differences in activity patterns between men's and women's singles, to date, no previous study has documented the activity patterns of elite female junior tennis players.

The physical aspects of the game have been reported to influence acute physiological responses during on-court practice.[6 7] For example, Mendez-Villanueva *et al*[6] have found that activity patterns (eg, rally duration) can influence the physiological demands in men's singles tennis, with higher blood lactate concentrations in matches with longer rallies and a higher number of strokes per rally. Thus, as activity profile during men's and women's singles tennis has been reported to be significantly different,[12] the associated physiological responses might also differ. However, to the best of our knowledge, the physiological load during competitive tennis in junior female players has never been investigated. Consequently, the purpose of the present study was to investigate the patterns of physical activity and the physiological load associated with elite junior female singles tennis during an invitational tennis tournament.

METHODS

Participants

Eight well trained, junior female tennis players (mean (SD) age 17.3 (1.9) years; height, 167 (6.3) cm; body mass, 55.2 (2.1) kg) participated in the study. All the players had a national or international ranking. Six of them had a Women's Tennis Association (WTA) singles ranking (between positions 400–500, n = 2; 600–700, n = 2; 700–800, n = 2; >800, n = 2)) and among the subjects there were six National singles and doubles championship winners in different categories (ie, under 14 and under 16). Written informed consent was obtained, and the study was approved by the Institutional Human Ethics Committee at the University of Oviedo. The study was previously approved by the tournament organising committee.

Experimental set-up

All measurements were taken from players during a 2 day invitational singles tennis tournament held in a local tennis club. Before every match, subjects carried out a standardised warm-up for 5 min consisting of ground strokes (players were

Abbreviations: ANOVA, analysis of variance; HR, heart rate; ITF, International Tennis Federation

asked to play the balls to the centre of the court), volleys plus overhead (one player on the baseline, the other playing volleys), and serves. Physiological measurements were performed at selected changeover breaks in play (that occurred at the end of the first, third and every subsequent odd game of each set) throughout the match. Thus, all the measurements were obtained without disrupting the normal course of tennis competition. The number of measurements taken for each player was variable, depending on the duration of the match (ie, two or three sets) and the number of games contested in each set. More specifically, the range of blood samples was 7–12 (minimum and maximum, respectively) per match. All the measurements were taken when players rested seated on a chair. At that time, player's heart rate (HR) was collected and a blood sample was also taken (fig 1).

The tournament

Players were invited by the contest organising committee, and every player received a fixed payment after acceptance of participation, plus a variable amount of prize money based on the final position achieved at the end of the tournament. The tournament was a knock-out format. Therefore, the eight players contested four quarter-finals (ie, to the best of three sets), with the winner of each passing to the next round until reaching the final, all controlled by the rules of the International Tennis Federation (ITF) and conducted on an indoor Greenset® court surface. The mean (SD) climatic conditions during the matches were: air temperature 20 (1)℃ and humidity 76 (6)%. Fluids were available throughout the matches.

Physiological measurements

HR was monitored and recorded at 5 s intervals during the matches using a chest monitor and wrist receiver (Polar S610, Kempele, Finland), which were placed on every player before the warm-up. Blood lactate concentrations were determined from 25 ml capillarised blood samples drawn from the ear lobe collected into heparinised tubes and were later analysed by duplicate by means of an electro-enzymatic method (Analox Micro Stat GM7; Analox Instruments Ltd, London, UK). All the blood and HR samples were taken while the players were seated during changeover breaks in play, as previously mentioned.

Match analyses

The activity profile of tennis singles was determined by filming each match with two video cameras (Sony DCR-HC17E, Sony Corp., Tokyo, Japan) positioned 2 m away from the side of the court, at the level of the service line and approximately 6 m above the court. Each player was individually tracked for the entire duration of the match. The videotapes were later replayed on a monitor for computerised recording of their activity patterns. The analyses of matches were all performed by the same experienced researcher. A modified match protocol developed by Smekal *et al*[5], that has been previously reported to be reliable,[6] was used to monitor and record the duration of each game and each rally, the duration of the rest intervals between games and changeovers breaks, the number of strokes per rally, and the total duration of the matches (ie, during service and return games). From these data, the following variables were calculated: (1) rally duration (s); (2) strokes per rally; (3) rest time between rallies (s); (4) effective playing time (%); and (5) changes of direction per rally. Rally duration was recorded from the time the service player served the first ball in to the moment when one of the players won the point. Strokes per rally were quantified as the number of balls hit by the players from the first serve in to the end of the point. For rally duration and strokes per rally, the time for first serve faults, as well as the stroke for the serve fault, and the time between first and second service were excluded from the analysis. Rest time between rallies was recorded from the moment one of the players won the point to the moment the next ball was brought into play again. Effective playing time was defined as the real playing time (sum of all the rally durations) divided by the total match duration multiplied by 100. Changes of direction were quantified as the number of multidirectional movements during every single rally, from the first service to the end of the point.

Statistical analyses

We analysed 76 games during the tournament and calculated differences between serve (n = 38) and return games (n = 38). Mean (SD) were calculated for each of the variables analysed and mean (SE) are presented in fig 4. Normality of the variables was analysed by the Kolmogorov–Smirnov test (with Lilliefor's correction). Inspection of the possible differences in activity patterns (ie, duration of rallies, strokes per rally and changes of direction) and the physiological responses (ie, HR and blood lactate concentrations) between matches played in different rounds (ie, quarter finals, semi-finals and final) for each set played (ie, first, second and third set) were carried out using repeated-measures analysis of variance (ANOVA). As these preliminary analyses failed to reveal significant interactions between conditions, the values were combined for the purposes of the present analyses. Independent-sample t tests were used to calculate differences between serve-and-return games. The relationship between variables describing the characteristics of the match (ie, duration of rallies, strokes per rally and changes of direction) and the physiological responses (ie, blood lactate and HR) obtained at the end of each game examined was determined using Pearson product moment correlation analysis. A total of 95 confidence limits were also calculated. The SPSS statistical software package (V.12, SPSS Inc., Chicago, Illinois) was used for statistical calculations. The level of significance was set at $p<0.05$.

RESULTS

Match activity

The variables describing the characteristics of the matches are shown in table 1. Figure 2 shows the mean distribution of work (ie, rally duration) and recovery (ie, rest time between rallies) periods at given time intervals during the 76 games analysed. The duration of the majority of the rallies (~41%) were between 1–6 s, and when combined with rallies between 6–9 s (~25%) this represents ~65% of total points performed during the tournament. More than 80% (82.7%) of the rest times between rallies were between 9–24 s (rest times between games, changeover breaks in play and between sets, which were 27 (9) s, 90 s and 180 s respectively, were not taken into

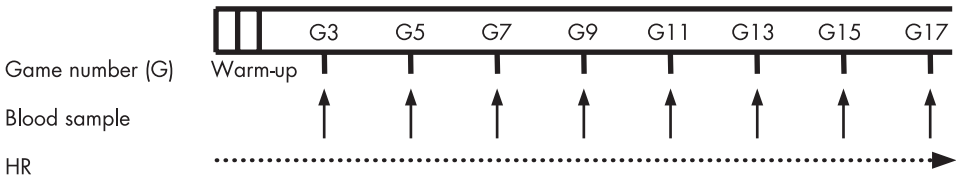

Figure 1 Example of the timing for blood lactate and heart rate (HR) collection during a tennis match with a final result of 6-3 and 6-2. Data collection was carried out at selected changeovers breaks in play throughout the match while players were seated.

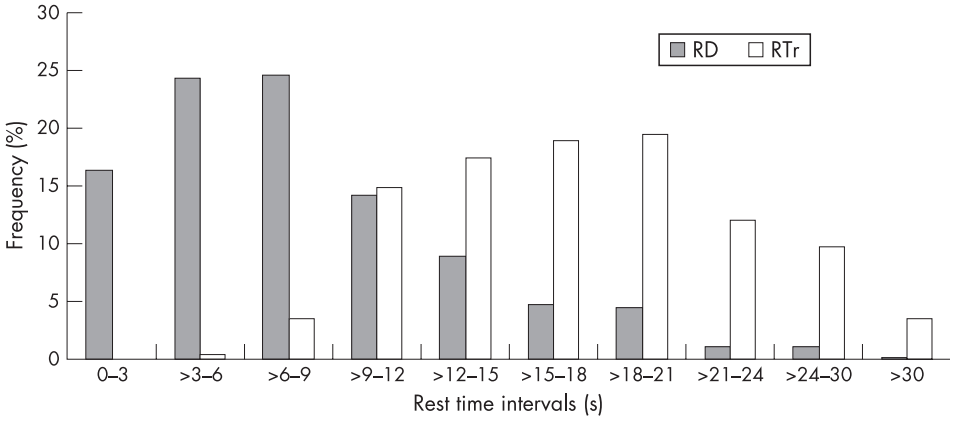

Figure 2 Mean percentage of playing time intervals (rally duration) and recovery (rest time between rallies) of all the matches.

account). Over 50% (50.8%) of all rallies demanded players to execute between 1 and 2 strokes. When combined with rallies demanding between 3 and 4 strokes, this accounted for more than 80% (83.2%) of all rallies (fig 3).

Physiological responses

The physiological responses of tennis match play are displayed in table 1. To assess the physiological demands of tennis match play, blood lactate and HR were calculated as mean (SD) values for all games performed by players. HR was significantly higher ($p = 0.004$) during service games (166.4 (15.4) beats/min; $n = 38$) than in return games (156.1 (19) beats/min; $n = 38$) (fig 4B). In contrast, blood lactate concentrations were not significantly different ($p = 0.83$) between service (2.3 (0.6) mmol/litre; $n = 38$) and return games (2.3 (0.9) mmol/litre; $n = 38$) (fig 4A).

Relationship between variables

The variables describing the characteristics of the match (ie, rally duration, strokes per rally and changes of direction) were significantly correlated with HR and blood lactate, when all games were analysed together (table 2). Analysing serve and return games separately we found significant correlations between blood lactate and match analysis parameters (ie, rally duration, strokes per rally and changes of direction), with stronger correlations when the players were serving. Conversely, the relationship between HR and match analysis parameters was found to be low when the players were serving and non-significant when the players were in return games (table 2).

DISCUSSION

The present study is the first to describe the activity profile and associated physiological load of women's singles tennis math play. The results showed that match activity of top junior female tennis players consists of short bouts (1–8 s) of exercise and short recovery periods (11–20 s), interspersed by several periods of longer duration recovery (ie, 27–180 s) between games and changeovers. The physiological responses to this activity pattern are relatively moderate HR values and modest blood lactate concentrations. We also found that the cardiovascular strain (ie, HR) was higher in the service situation than in the return, and it was influenced by the characteristics of the match (rally duration, strokes per rally and changes of direction), with a higher load during long rallies, characterised by a greater number of strokes and more changes of direction. In contrast, the similar blood lactate concentrations reported during service and return games, reflect similar glycolytic energy turnover during service and return situations. Thus, the present results provide specific information about the patterns of physical activity and the physiological load during top female junior singles that might be used by coaches and physical trainers to design specific physical conditioning programs according to these characteristics.

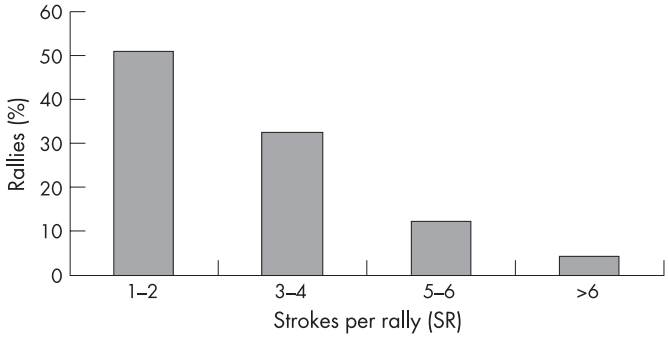

Figure 3 Number of strokes per rally.

Match analyses

The present motion-analysis characteristics (rally duration = 8.2 s and rest times between rallies = 17.7 s; breaks between games not included) establish a work-to-rest ratio per game of 1:2.1, which means that players rested 2.1 s for every second of work performed during the rallies. Work-to-rest ratios provide an objective means of quantifying the physiological requirements of an activity,[14] and this information might be used to develop individual, interval training protocols for junior female players.

Average values of rally duration in our study (8.2 s) are slightly longer than values reported for female tennis players under similar playing conditions (ie, an actual tournament), with rally durations of 7.1 s.[11] Rally duration values are also slightly higher than those previously reported for male tennis players under tournament conditions, with values ranging from 5.1–7.5 s.[6 8 11] As the available resting time between points, games and changeover breaks in play are the same in men and women (ie, following the ITF rules), effective playing time during female singles tennis is higher[12 15] than during singles tennis match play in males (18.2%).[6] Taken together, these findings show that gender influences the activity profile of tennis match play with junior females being typically engaged in longer duration efforts and higher effective playing times.

Physiological responses

The measurement of match HR provides a useful index of overall cardiovascular strain during competitive tennis match play.[4] The mean (SD) HR of players involved in the tournament

Table 1 Physical and physiological variables analysed

Variable	Mean (SD)	Range
Blood lactate (mmol/l)	2.03 (0.8)	1.2–4.6
HR (bpm)	161.2 (5.1)	120–188
Total match duration (s)	4838 (1467.4)	3180–6660
EPT (%)	21.95 (3.8)	15.89–25.9
RD (s)	8.20 (5.2)	0.89–33.0
RT (s)	17.72 (6.5)	4.32–59.9
CD (n)	2.35 (1.4)	0–9
SR (n)	2.79 (1.7)	1–11

HR, heart rate; EPT, effective playing time; RD, rally duration; RT, resting time between rallies; CD, changes of direction per rally; SR, strokes per rally.

was 161 (5) beats/min, which is higher than values previously reported in the two studies investigating female tennis players (141 (18) and 146 (20) beats/min).[16 17] Differences with regard to the exercise protocol (ie, simulated match play vs actual competition) employed by Novas *et al*[17] can explain the higher HR values obtained in the present study. Moreover these differences might be related to the older age of tennis players,[16] as maximal HR declines with advancing age,[18] and/or due to differences in environmental conditions.[19 20] Our HR results are also higher than other studies performed during actual tennis play in male players of a range of abilities reporting average values ranging from 140–150 beats/min.[2 5 8 21 22] The fact that women elicit higher absolute HR responses than men might be related to their higher maximum HR[23] and, as previously mentioned, with differences in physical activity patterns (ie, longer rallies and higher effective playing time in women). Indeed, we found a positive relationship between HR and physical strain (ie, longer rally duration, higher number of strokes and more changes of direction per rally) during tennis match play (discussed below).

In the present study, the playing situation (ie, service vs return games) affected HR responses. Comparing service and return games we found significantly higher ($p = 0.004$) HR values during service (166 (15) beats/min) than in return games (156 (20) beats/min), similar to the results obtained by several authors,[2 24 25] although these studies were performed with regional- to national-ranked male tennis players and under simulated conditions of play. These higher HR values recorded in service players can be attributed to the more demanding role of servers in dictating the game.[22 24] In this regard, servers are typically subjected to a higher physical strain reflected by the high number of short rallies (~50% of rallies recorded in the present study had 1–2 strokes; fig 2), due to either aces or service winners (return faults). In all these cases the intensity and duration of the server's activity is higher compared to the return player. In addition, the higher HR values observed in service players might reflect other factors such as psychological stress or emotion.[26] The service is an important aspect in modern tennis, and it is considered to be the key to the game.[27] Service situation is an important way to win the rally, either directly through an ace, or indirectly through the advantage in the rally following a good serve. As such, in order to be competitively successful, winning service games is almost a ''must''.[28] Thus, in addition to the greater physical load, the higher HR values observed in service players might also be related to a higher psychological stress and sympathetic activity due to the need to win the games with their serve.[29 30]

Blood lactate measurements, which are frequently used to estimate intensities in competition, might provide information about the energy production from glycolytic processes.[2 4–6 21 25] In the present study, mean (SD) blood lactate values were 2 (0.8) mmol/litre with individual values exceeding 4 mmol/litre.

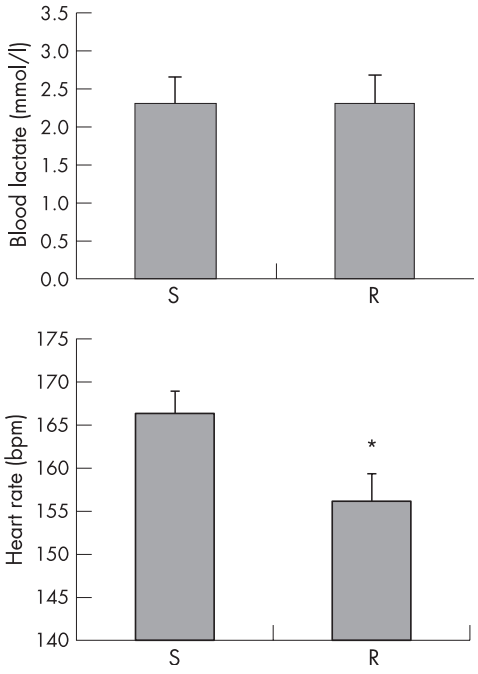

Figure 4 Blood lactate concentrations (A) and HR (B) responses during service games and return games. Values are mean (SE). S, service games (n = 38); R, return games (n = 38). *p = 0.004.

These values are higher than those previously reported for female players (1.2 (0.37) mmol/litre),[16] but in the range of values reported by other studies developed with males (1.8–2.8 mmol/litre),[8] suggesting a low to moderate contribution from glycolytic energy pathways to fuel tennis movements. Conversely to HR values, and in contrast to the results of Reilly and Palmer[22] and Mendez-Villanueva *et al*,[6] blood lactate levels were similar during serve and return games. These similar metabolic responses (ie, blood lactate) obtained in service and return situation suggest that the higher physical demands of service players are not related to an increased glycolytic contribution. However, care should be taken during competitive matches, as many factors, including individual fitness or time of measurement, might affect the results.[31] Moreover, it has been reported that blood lactate values do not accurately reflect muscle lactate values during high-intensity intermittent exercise (ie, a soccer match).[32]

Relationship between variables

We also attempted to ascertain if the variables describing the characteristics of the matches (ie, rally duration, strokes per rally and changes of direction) influence the physiological demands of junior female tennis match play. Our results indicate a significant positive relationship between rally duration, strokes per rally, changes of direction and blood lactate and HR responses, with stronger correlations when the players were serving (table 2). These results agree with previous research reporting significantly higher physiological responses in matches with longer rally duration and increased strokes per rally in male singles.[5 6] However, although significant, the correlations obtained between physiological (ie, blood lactate, HR) and the activity patterns (ie, rally duration, strokes per rally and changes of direction) in the present study, were moderate. This means that, apart from activity patterns, several other factors, which were not measured in the present study, such as exercise-induced muscle damage or psychological stressors (ie, current score, public, expectations) are likely to influence physiological responses during competitive tennis

Table 2 Correlation between physiological (ie, blood lactate concentration and HR) values and variables describing the characteristics of the game

	All games (n = 76)		Service games (n = 38)		Return games (n = 38)	
	r	p Value	r	p Value	r	p Value
Heart rate						
SR	0.38	0.001	0.34	0.035	0.19	0.261
RD	0.23	0.047	0.32	0.049	0.17	0.298
CD	0.25	0.027	0.31	0.055	0.16	0.345
Blood lactate						
SR	0.43	<0.001	0.49	0.002	0.43	0.009
RD	0.51	<0.001	0.40	0.002	0.45	0.006
CD	0.40	<0.001	0.44	0.006	0.41	0.013

SR, strokes per rally; RD, rally duration; CD, changes of direction.

matches.[33] These results must be taken into consideration when using individual playing patterns to prescribe training intensities. Nevertheless, the present results suggest that coaches and physical trainers could manipulate activity pattern parameters (ie, number of balls, rally duration, changes of duration) in order to provide a specific physiological stimulus during on- and off-court sessions.

CONCLUSIONS

We have documented the physical and physiological demands through the course of a junior female tennis competition. The present results show that the activity profile of these players is characterised by rallies of slightly longer duration and, therefore, higher effective playing times than the previously reported in male and female tennis competitions. The physiological (ie, blood lactate and HR) responses associated with match play were influenced by the characteristics of the match (rally duration, strokes per rally and changes of direction). Moreover, HR responses were higher in serving players than in returning players. These results might be used to develop match-specific interval training protocols for junior female players.

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What is already known on this topic

- The activity profile during men's and women's singles tennis has been reported to be significantly different and also to influence acute physiological responses during on-court practice in professional male tennis players.
- No previous study has documented the activity patterns of elite female junior tennis players and the physiological load during real tournament conditions has never been investigated.

What this study adds

- This study provides physical and physiological data through the course of an elite junior female tennis competition.
- This information might be used to develop individual interval training protocols for junior female players.

Authors' affiliations

Jaime Fernandez-Fernandez, University of Leon (Spain), Campus de Vegazana, Spain
Alberto Mendez-Villanueva, Faculty of Physical Activity and Sport Sciences, University of Alcala, Madrid, Spain
Benjamin Fernandez-Garcia, Department of Morphology and Cellular Biology, University of Oviedo, Oviedo, Spain
Nicolas Terrados, Sports Medicine Center of Principado de Asturias, Avilés, Spain

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