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Analysis of the distances covered and technical actions performed by professional tennis players during official matches

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ABSTRACT

The purpose of this study was to analyse the physical and technical performances of professional tennis players during official matches. The trajectories of eight players were obtained during matches, using an automatic tracking method. The distances covered and technical performances were analysed for the first and second sets. The athletes covered (mean ± standard deviation) a total of 1702.4 ± 448.2 m in the first set, 1457.6 ± 678.1 m in the second set and 3160.0 ± 880.1 in the entire match. No differences were found between the sets for the physical variables (lateral and forward displacements, distance covered per rally, per game and per set, and the percentage of time spent in each range of velocity). However, the distances covered by the athletes during the rallies in which they were serving (median = 5.2; interquartile range (IQR) = 6.7 m) were statistically smaller than when they were returning (median = 6.2; IQR = 7.7 m). Forehand ground stroke proficiency decreased from the first (mean ± standard deviation: 75.2 ± 4.11%) to the second set (mean ± standard deviation = 65.5 ± 14.3%). In conclusion, tennis players did not present reduced physical performance from the first to the second set.

Introduction

Over the last 15 years, the demands of tennis matches have shifted from a technical and tactical predominance to a highly physically demanding sport across all age groups (Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009). It is, therefore, essential to develop specific, effective and time-saving training programmes that take into account the body of knowledge concerning the various activities of tennis players during matches (Hoppe et al., 2014). Many researchers (Fernandez, Mendez-Villanueva, & Pluim, 2006; Fernandez-Fernandez, Sanz-Rivas, & Sanchez-Munoz, et al., 2009; Hoppe et al., 2014; Mendez-Villanueva, Fernandez-Fernandez, & Bishop, 2007; Reid & Duffield, 2014) have investigated the physical demands of tennis, mainly by measuring the physiological responses (such as heart rate, blood lactate and oxygen uptake), analysing the activity profile (number of shots performed, duration of periods of work and rest) and quantifying the profile of player running activity during matches.

The global positioning system (GPS) is a frequently used method to access player displacement. This microtechnology has been used to evaluate the physical performance of athletes during training situations and simulated matches (Gallo-Salazar et al., 2015; Reid et al., 2013). However, the use of GPS in official competitions is limited for various reasons: (1) according to the ATP (Association of Tennis Professionals) rules, players are not allowed to use any electronic devices during official matches (ATP, 2014), (2) GPS units have limitations in capturing motion on indoor courts due to the impact of the roof on the satellite signal and (3) accuracy in high-speed zones is limited (Vickery et al., 2014).

Although most studies have evaluated players during unofficial matches, it is recognised that competitiveness can influence motion characteristics (Fernandez-Fernandez, Sanz-Rivas, & Sanchez-Munoz, et al., 2009; Hornery, Farrow, Mujika, & Young, 2007), and official matches with balanced opposition may demand more from physical abilities. Recent advances in image processing have permitted tracking of player trajectories during official matches using videogrammetry (Figueroa, Leite, & Barros, 2006). This technology allows determination of the position, trajectory and technical actions performed by the players in field settings without requiring carriage of any instrument, enabling evaluation of the kinematics of displacements in real competitions.

Due to the technological advances, physical strain as quantified by the distance covered in different velocity ranges and the concurrent technical performance as inferred from stroke production can be analysed (Reid & Duffield, 2014). The accurate quantification of these variables may better characterise the physical/technical demands of a given sport and help coaches to better plan specific training sessions, taking into account specific conditioning activities and recovery strategies (Barros et al., 2007; Duffield, Reid, Baker, & Spratford, 2010).
Therefore, the purpose of this study was to analyse the physical and technical demands of official tennis matches. Specifically, we were interested in investigating whether there are decrements in physical and technical performance during the matches and the physical demands of the match when players are serving and returning. Based on previous studies (Fernandez-Fernandez, Sanz-Rivas, & Sanchez-Munoz, et al., 2009; Hoppe et al., 2014; Murias, Lanatta, Arcuri, & Laino, 2007; Reid & Duffield, 2014), we hypothesised that tennis players would present decreases in physical and technical performance over the course of official matches. In addition, we expected players to cover greater distances when they were returning the ball, compared to the serving player.

Methods
Participants and procedures
This study was a cross-sectional and descriptive analysis of a professional tennis competition. This study was approved by the Ethics Committee of the State University of Londrina (protocol 171.683). Eight professional tennis players were analysed during four matches of an international tournament, level Future, organised and regulated by the ATP, played on an outdoor clay court. All players were characterised as baseline players after the analysis of the videos by two expert tennis coaches. Two digital cameras recorded the matches, with an acquisition frequency of 30 Hz. The cameras were fixed on a tripod and positioned in high places around the court. Each camera covered half the court, with an overlapping region between them (Figure 1). The images were transferred to a computer and synchronised by identifying fast events identified by both cameras, such as the bounce of the ball. All games had ball boys, so the athletes were not required to move to retrieve balls. During data collection, the temperature oscillated between 14.0°C and 29.9°C and relative humidity between 20% and 60% (data provided by the Agronomic Institute of Paraná – IAPAR, Brazil).

Automatic tracking system
Player trajectories were obtained using the automatic tracking system (Figueroa et al., 2006). The two automatic procedures of segmentation and tracking provided the position of the players throughout the match (Figure 1). The purpose of segmentation is to separate the objects of interest (players) from other elements in the image (the court and advertising

Figure 1. Camera images with overlapping regions (A) and the results of the segmentation (B) and tracking (C) processes.
boards). The segmentation applied in DVideo system considers topographic relief defined by the player, because this region presents different colour intensities against the background. After the process involving the morphological filtering, the image is binarised and connected regions are labelled and named blobs (Figure 1B).

The data obtained after the segmentation corresponds to a set of discrete points (blobs); however, they are not associated with the trajectories of their players. To solve this problem, we used the graph theory. The blobs have spatial and temporal information. The spatial information considers shape, size and colour of the blobs, while the temporal information explores the relation between blobs in different frames. Finally, the tracking of the players is performed by a minimal path searching in the graph. The players’ location in the image is determined by the position of the players’ feet in the blob. This can be done by finding the maximum y-coordinates of the blobs and their middle point in the x-coordinates (Figure 2).

Prior to the matches, the coordinates of 16 control points of the court in relation to the coordinate system associated with the court (x-axis associated with anteroposterior direction and y-axis with mediolateral direction) were measured. The corresponding projections of these points on the image were determined using the software DVideo. Homography parameters and image-processing objects were calculated based on the direct linear transformation and 2D coordinates relative to the coordinate system were obtained. Finally, we filtered the trajectories of players using a Butterworth low-pass filter of third-order and cut-off frequency of 0.4 Hz, defined after spectral and residual analysis.

The accuracy of the measurements was obtained using the tracking test. A participant was requested to walk, run and sprint exactly on the lines of the court, with known distances measured previously. The circuit covered by the participant resulted in a total distance of 137.1 m. The same tracking procedures were applied and the distance covered obtained by the tracking system was 136.8 m, resulting in an error of 0.2%.

Recording of technical actions

DVideo software was used to register the technical actions performed by the players. This process was performed by a single operator who watched the match through the DVideo software interface. When each technical action was performed, the operator identified it with the mouse on a bar (serve, forehand, backhand, volley, slice and smash). Subsequently, the operator provided information as to whether the action had been performed correctly or not, and which player performed the action.

Variables

All the variables were calculated for 644 rallies during the matches, considering only the first and second sets. Rally duration was determined by the number of frames between the start (a valid serve) and the end of the rally, considering the acquisition frequency of the camera.

The distance covered by each player was calculated as the cumulative sum of the distance covered between two consecutive frames. As additional information, the distance covered over the duration of the match was normalised, expressed in metres per minute (m · min⁻¹). The distances covered were presented per rally, per game, per set, and when players were serving and returning.

Forward and lateral displacements were calculated based on the movements that the athlete performed in the x- and y-axis. These oscillatory movements that the athlete performs to reach the ball and return to the baseline centre court yield a waveform signal. For the lateral displacements, we calculated the distance covered in each lateral displacement based on local maxima and minima of the signal (Figure 3). Equally, the same procedures were used to obtain forward displacements performed in the x-axis. Lateral displacements lower than 0.5 were ignored in order to avoid computing small body oscillations such as the ones performed during the split step. Forward displacement lower than 1.0 m were ignored in order to avoid computing body oscillations related to the strokes movements.

From the time–position curve obtained for each player, the time–velocity curve was numerically derived, after which we calculated the percentage of time spent in each range of velocity: walking 0–7 km · h⁻¹, jogging 7.01–12 km · h⁻¹, striding 12.01–18 km · h⁻¹ and sprinting 18.01–24 km · h⁻¹.

Finally, we analysed the technical performances for the ground strokes (first and second serve, forehand and backhand), between the relative frequency of correct and incorrect actions. Correct performance was considered as a stroke where the ball remained within the limits of the opponent’s area of the single court and incorrect performance as the strokes that stopped at the net or fell outside the limits of the opponent’s court.

**Statistical analysis**

Prior to each analysis, data normality was tested using the Lilliefors test (Lilliefors, 1969). The variables that showed normal distribution were presented as mean and standard deviation, and the variables with non-normal distribution as median and interquartile range (IQR). The paired sample t-test was used to compare the relative frequency of right technical actions performed by the players between the sets. The Wilcoxon rank-sum test was used to compare the forward, lateral displacements and the distances covered by the players between the first and second sets and to compare the distances covered by the players when they were serving and returning.

Two-way analysis of variance was used to compare the percentage of time spent in each velocity range according to two factors: velocity ranges (with four factor levels) and match sets (first and second sets). Previously, a Box–Cox transformation was performed in order to reduce anomalies such as non-additivity, non-normality and heteroscedasticity. When differences were found in the F-test, Tukey’s honestly significant difference criterion was performed as a post hoc test. All the statistical analysis was performed using MATLAB environment and the statistical significance was set at 5% for all analyses.

**Results**

Figure 4 presents an example of player trajectories during one game of the match. From these trajectories during the rally moments, we compared the physical performance of the athletes between the first and the second sets of the matches (Table 1). No statically significant differences were found for the physical performance variables between the sets. Complementarily, the athletes covered a total of 1702.4 ± 448.2 m (mean ± standard deviation) in the first set, 1457.6 ± 678.1 m in the second set and 3160.0 ± 880.1 in the entire match. Players performed (median and IQR) a total of 92.5 (31.0) and 59.5 (52.5) lateral displacements, 25 (12.5) and 15 (17.5) forward displacements during the first and second sets, respectively. The distances covered by the athletes during the rallies in which they were serving (median = 5.2; IQR = 6.7 m) were statistically smaller ($P < 0.01$) than the distances when they were returning (median = 6.2; IQR = 7.7 m). No differences were found between the rally durations for the first (median = 4.6; IQR = 4.5 s) and second (median = 4.3; IQR = 4.0 s) sets.
Table 1. Technical and physical performance during the first and second sets, expressed as mean ± standard deviation.

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>1st Set</th>
<th>2nd Set</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance covered per set per minute (m · min⁻¹)</td>
<td>44.9 (2.8)</td>
<td>45.4 (3.6)</td>
<td>0.69</td>
</tr>
<tr>
<td>Distance per rally (m)</td>
<td>5.8 (7.2)</td>
<td>5.3 (6.6)</td>
<td>0.10</td>
</tr>
<tr>
<td>Distance per game (m)</td>
<td>117.7 (94.4)</td>
<td>102.9 (92.6)</td>
<td>0.15</td>
</tr>
<tr>
<td>Lateral displacement (m)</td>
<td>2.0 (2.1)</td>
<td>2.0 (2.4)</td>
<td>0.66</td>
</tr>
<tr>
<td>Forward displacement (m)</td>
<td>2.0 (3.1)</td>
<td>2.3 (3.8)</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Technical performance

- % Correct 1st serve: 61.6 ± 12.0 vs. 64.1 ± 11.5, P = 0.69
- % Correct 2nd serve: 78.4 ± 14.8 vs. 72.9 ± 21.1, P = 0.61
- % Correct ground strokes – forehand: 75.2 ± 11.1 vs. 65.5 ± 14.3, P = 0.04
- % Correct ground strokes – backhand: 77.2 ± 5.6 vs. 82.8 ± 10.0, P = 0.47

Table 2 also presents the technical performances of the athletes during the first and the second sets of the matches. A significant decrease (P = 0.04) was found only for the forehand ground strokes.

Table 2 presents the percentage of total time spent in different ranges of velocities during rallies in the first and second sets of the matches. The statistical analysis presented no effect between the sets (F(1, 2576) = 1.26; P = 0.31) or for the interaction between sets and velocity ranges (F(3, 2576) = 1.05; P = 0.4). However, there was a significant difference between the ranges of velocities (F(3, 2576) = 1202.21; P < 0.01). The post hoc tests showed that all ranges of velocities differed from each other (P < 0.05).

Discussion

The aims of this study were to quantify the physical and technical demands of official tennis matches and to analyse whether there are decrements in physical and technical performance during the match. Such information is essential for developing specific, effective and time-saving training programmes for high-level tennis players and for the preparation of young prospective players who aim to play professionally.

The major findings were as follows: (1) professional tennis players did not present decreased physical performance during the match; (2) when the player was serving, the distances covered during the rally were shorter compared to returning player distances and (3) players maintained technical efficacy during the match, with the exception of forehand ground stroke performances, which decreased from the first to the second set.

Rally durations were shorter than those previously reported (Fernandez-Fernandez, Sanz-Rivas, & Sanchez-Munoz, et al., 2009), which presented 6.3 ± 4.1 s for advanced and 7.6 ± 5.5 s for recreational advanced players. In another study (Murias et al., 2007) with adolescent players, rally durations were also longer, compared to our results (8.8 ± 3.3 s on clay courts and 7.2 ± 4.4 s on hard courts). In the present study, the rally durations were shorter than the ones reported in the literature; therefore, it is understandable why the distance covered per game presented by Murias et al. (2007) was greater (11.6 ± 1.5 m for clay courts and 9.3 ± 1.8 m for hard court) than the distance reported herein. These findings highlight the different match profiles between levels and categories which should be considered during training sessions. Games and rallies may be shorter due to an aggressive strategy employed by the players during the Future tournaments (e.g., more winners or forced error). This specific characteristic should be taken into account while planning training drills to these players, who probably rely more on a high rate of creatine phosphate utilisation and on muscle power than on lactate-producing system and endurance characteristics (Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009).

Although the rally profile of the present study was different from those presented in the literature, the total distance covered by the players was similar to those presented previously by Fernandez-Fernandez, Sanz-Rivas, Sanchez-Munoz, et al. (2009) and Murias et al. (2007), who reported mean values from 3173.9 ± 226.0 to 3568.9 ± 532.2 m. These differences could lead to the interpretation that the matches we analysed presented a greater number of rallies. However, this statement should be viewed with caution, since the present study evaluated official matches with no predetermined duration, while previous studies controlled total match duration and investigated simulated matches. In addition, the distances covered may be profoundly influenced by external factors such as number of sets, court surface, type of balls used, temperature, and the physical, technical, tactical and physiological characteristics of the players (Fernandez et al., 2006; Fernandez-Fernandez, Sanz-Rivas, & Sanchez-Munoz, et al., 2009). Thus, further studies should focus on the analysis of official matches in order to avoid a possible under- or overestimation of the real match demands according to these external factors. Furthermore, given the lack of literature quantifying extended matches, it is likely that the external and internal loads were magnified compared to the average duration of match plays (Reid & Duffield, 2014).

Rallies occur predominantly on the baseline, which requires the players to constantly return to the middle of the court from the baseline after moving away from it to hit the ball (Palut & Zanone, 2005). Given the characteristics of tennis movement, this study also quantified the length of the lateral and forward displacements performed by players. Thus, both length and number of displacements performed by the players are important to characterise the intensity and volume of the match and should be used by coaches to better prepare athletes for competitions and for the development of physical tests similar to real match situations. In this research, an exploratory analysis showed that forward displacements were less frequent than lateral displacements but they presented a greater length (based on the IQR). These findings suggest a specific physical training for forward and lateral...
displacement, the former with lower volume and greater distance covered. It is important to highlight that we investigated essentially baseline players, so it may be expectable that serve and volley players would perform more forward displacements. Since both forward and lateral displacements in tennis generally involve a rapid displacements and change of direction to return to the baseline position, it is possible that athletes would be benefited by field-based power training methods such as plyometrics (Fernandez-Fernandez, Sanz-Rivas, Saes de Villarreal, & Moya, 2015; Loturco et al., 2015). Future studies should also characterise these physical variables considering different styles of play.

In the present study, the distances covered in situations where players were serving and returning were statistically different. We expected that when a given athlete was serving, he would travel a shorter distance during the game, compared to the athlete who was returning the serve. This outcome may be justified by the fact that the serving player has the possibility to command the starting point, performing more powerful and well-directed serves, leading the opponent to cover greater distances to return the ball. Since tennis is an intermittent sport with short high-intensity efforts followed by short rest periods (Hoppe et al., 2014), the results of the present study may suggest that return games are more intense than serving games. To the best of our knowledge, this is the first study to present these data and deserves attention because it can drive coaches to develop specific training drills. Coaches could improve the technical and tactical performance of the serve (e.g., power, variability of ball spin and direction, and improvement in the percentage of correct first serves) to spare the player from the physical exertion related to displacements to reach the following ball. On the other hand, players should train with more short displacements and the corresponding footwork, in drills aimed at training for ball hitting. In this case, the participation of the cardiorespiratory system in drills repetitions cannot be ruled out, and monitoring of physiological responses can be advised to control internal training loading (Fernandez-Fernandez et al., 2011).

The percentage of time in each range of velocities was also not different from the first to the second set. It was found that the athletes spent greater periods of the rally at low speeds (0–7 m·s⁻¹) and sprints did not occur frequently, because the athletes spent less than 0.5% of the total time of the rally in this speed range (18–24 m·s⁻¹). These results are very similar to two other studies in the literature (Fernandez-Fernandez, Sanz-Rivas, & Sanchez-Munoz, et al., 2009; Hoppe et al., 2014). The first compared advanced and recreational tennis players and observed that, at both levels, the players spent the majority of their time at low velocities and, surprisingly, recreational tennis players reached higher speeds. The second study evaluated adolescent tennis players during simulated matches looking for decrements in performance during the course of matches. As in the present study, the athletes spent the majority of their time at low velocities. It is probable that the dimensions of the court and tennis characteristics do not allow the athletes to reach higher velocities (i.e., top-speed sprinting). However, tennis cannot be considered a low-to-moderate intensity sport (Hoppe et al., 2014). Possibly, the number of accelerations and decelerations that should be properly quantified using accelerometers constitutes the main locomotor loading during court games played in reduced spaces (Boyd, Ball, & Aughey, 2013).

In general, the variables related to physical performance did not decrease from the first to the second set, contradicting our initial hypothesis. This is possibly related to a low degree of glycogen depletion, accumulation of by-products, dehydration and hyperthermia during two sets of tennis match play (Hornery et al., 2007). However, it should be highlighted that during more prolonged and intense rallies, transient fatigue may take place, as inferred from blood lactate accumulation and increased perception of effort (Mendez-Villanueva, Fernandez-Fernandez, Bishop, & Fernandez-Garcia, 2010). It is possible that the rest periods between points and during changeovers are long enough to avoid permanent fatigue. Nevertheless, physiological, neuromuscular and psychological perturbations may be exacerbated in unusually prolonged matches and with consecutive days of match play (Reid & Duffield, 2014). Therefore, for further practical recommendations to be made, other studies should explore the occurrence of fatigue in more prolonged and consecutive official matches.

Although it is unclear whether fatigue can interfere with locomotor performance, it can decrease technical performance (Davey, Thorpe, & Williams, 2002, 2003). Our results showed that player forehand ground stroke performance reduced significantly during the match. Similar results were reported previously in the literature (Davey et al., 2002), which demonstrated that after a training session, the error rate of the forehand and backhand increased by 9 ± 2%. In another study (Davey et al., 2003), it was observed that the accuracy of ground strokes reduced between the beginning and middle of an endurance capacity test and between the beginning and the point of voluntary fatigue. In a previous study (Wu, Shih, Yang, Huang, & Chang, 2010), the consistency of forehand ground stroke reduced when comparing the results obtained before and after a simulated game using the Loughborough Tennis Skill Test. Finally, a recent study (Lyons, Al-Nakeeb, Hankey, & Nevill, 2013) revealed that the accuracy of ground strokes reduced after induction of high-intensity fatigue in athletes, compared to the rest conditions. Thus, because our results presented a decrease of roughly 10% in correct forehand strokes and because of the similarity to the above-mentioned studies, this may have been related to fatigue. It should be pointed out that caffeine partly reversed this effect during tennis match play, reinforcing the participation of the central nervous system in the decreased technical proficiency (Gallosalazar et al., 2014). It is possible that a combination of mental fatigue and increased perception of effort can be responsible for the partial technical impairment found herein (Gescheit, Cormack, Reid, & Duffield, 2015).

Contrariwise, for the other technical variables, players did not present performance decreases. These findings may be related to behavioural changes performed by players to avoid this decrease in successful performance. One of the strategies adopted by athletes to keep stroke efficiency is to reduce its speed (Ferrauti, Pluim, & Weber, 2001; Hornery et al., 2007; Vergauwen, Spaepen, Lefevre, & Hespel, 1998). Accordingly, this strategy may be related to Fitts’ law which
states that an increase in movement speed causes decreases in accuracy (Fitts, 1954; Hornery et al., 2007). Since forehand is classically the players’ favourite stroke, no reduction in stroke speed may be expected as a player reaches fatigue, leading to a performance decrease during the match, as reported in our results. However, further studies are needed to analyse high-level matches associating tennis skills with physiological measures so that we can better understand the effects of fatigue on technical performance in tennis.

Conclusion

The results presented in this study allowed characterisation of the distances covered by professional tennis players during official matches and understanding of the behaviour of the technical proficiency of the main tennis strokes. The results showed that there was no reduction in physical performance during the match; however, a decrease was observed in the technical performance of forehand ground strokes. Furthermore, players usually covered greater distances when they were returning, compared to the player who was serving. Our study also presented new analyses, such as the volume and length of the lateral and forward displacements. The results provided valuable insights for coaches to better plan and prescribe physical training and test drills for professional tennis players, by taking into account the specific match demands of an official high-level tennis tournament.

Disclosure statement

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