Spinal Cord (2016) 54, 229–233

www.nature.com/sc

ORIGINAL ARTICLE

Match activity and physiological load in wheelchair tennis players: a pilot study

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Study design: There is a lack of information about the physiological and psychological parameters in competition that shows a comprehensive profile of the demands of the game situation.
Objective: The aim of the present study was to examine the activity patterns and physiological–perceptual responses (heart rate (HR), blood lactate concentrations (LA) and the rate of perceived exertion (RPE), respectively, during singles wheelchair tennis (WT) matches.
Methods: A total of four WT players played three matches each. HR, LA and RPE were measured during each match. An activity pattern analysis was performed during all matches. Furthermore, LA and RPE were compared between service and return games.
Results: The results show a mean (s.d.) total match time of 69.04 (2.3) minutes, an effective playing time of 17.65% (0.03%), a work:rest (W:R) time ratio of 1:4.6 (0.48) and a rally length of 7.04 (4.44) seconds. Most of the points end in three or fewer shots. The mean (s.d.) physiological load during the matches were as follows: HR 124.25 (24.7) beats per minute, $\%HR_{max}$ 66.31% (4.5%), LA 1.41 (0.43) mmol l^{-1} and RPE 12.45 (1.91). No significant differences were found in LA and RPE between service and return games ($P>0.05$).
Conclusions: In this descriptive study, match activity and physiological load in WT are described. Match activities are similar to conventional tennis, although the physiological load is lower. Service and return situations show similar physiological and perceptual responses. These results might be used to develop specific interval training protocols for a male WT player.
Spinal Cord (2016) **54,** 229–233; doi:10.1038/sc.2015.107; published online 30 June 2015

INTRODUCTION

Wheelchair tennis (WT) is an adapted sport. Recent research indicates that a WT match is moderate to high in aerobic fitness.[1–5] Most of the studies related to the physiological demands of WT conclude that it is a healthy sport.[1,2,5]

WT players have 20 s to rest between points and 90 s between changes of side,[6] the same rule as in conventional tennis. The total time (TT) of a singles WT match is between 50 and 80 min.[3–5,7,8] The intermittent nature of WT, with regular permitted rest times, means that the effective playing time (EPT) is around 15–20% of the TT; this is equivalent to a ratio of work:rest (W:R) time of around 1:1–1:4.[4,7,9] The working time is represented by the rally duration, which typically lasts between 4 and 10 s.[7,9,10]

The intermittent nature of the sport in a WT match means that the players have intermittent exercise bouts and a multitude of rest periods over a long duration.[11] In this sense, the heart rate (HR) is between 120 and 140 b.p.m., with a 65–75% of maximum HR and a maximal oxygen uptake (VO_{2max}) estimation of between 50 and 68%.[1–5,12] There is no information related to other variables such as blood lactate concentration (LA) or rates of perceived exertion (RPE) in game situations.

The activity patterns and physiological demands of competition should be used in the exercises to improve the training sessions.[13] There is a lack of information about the LA and RPE in competition that shows a comprehensive profile of the demands of the game situation. To know the physiology demands of the competition can help coaches and trainers to develop specific training programs in WT players. Furthermore, the aim of the present study is to examine the activity patterns and physiological–perceptual responses (HR, LA and RPE) during singles WT matches.

METHODS

Experimental approach to the problem

To determine the physiological demands of a singles WT match, a pilot study was designed and four advanced WT male players ($n=4$) were recruited. The variables analysed were used to describe the physiological responses in players and to know which physiological profile the WT players fitted.

Subjects

Four competitive WT male players (Table 1) participated in this study. They were the four top ranked national players and in the top 110 International Tennis Federation (ITF) rankings at the time.

All of the players were involved in regular tennis competitions at national and international levels. All players were highly trained with an average of five sessions a week, competing in about 10 tournaments a year. All the participants were right-handed tennis players. This study was approved by the ethics committee of the Royal Spanish Tennis Federation, and all subjects provided a written informed consent before participation.

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Received 16 February 2015; revised 24 April 2015; accepted 19 May 2015; published online 30 June 2015

Table 1 Participant characteristics

Subject	*Gender*	*Age (years)*	*Height (m)*	*Weight (kg)*	*Nature of disability*	*Years since injury*	*Years practicing tennis*
1	Male	19	1.65	53	Spine bifida[a]	19	6
2	Male	40	1.43	52	Osteogenesis imperfect	40	20
3	Male	46	1.80	70	Amputation[b]	27	13
4	Male	34	1.76	65	Amputation[b]	12	11
Mean	–	34.75	1.66	60.00	–	24.50	12.50
s.d.	–	11.58	0.17	8.91	–	12.01	5.80

Abbreviation: s.d., standard deviation.
[a]Spine bifida = L5-S1.
[b]Amputation = Complete amputation of right leg.

Table 2 Mean, standard deviation (s.d.) and range for match analysis

	Mean	*s.d.*	*Range*
Match analysis			
Total time (min)	69.04	2.30	65.75–71.03
Effective playing time (min)	12.19	2.06	10.20–15.97
Resting time (min)	56.86	2.66	50.95–60.12
Set duration (min)	34.52	5.39	25.62–43.73
Rally duration (s)	7.04	4.44	1.00–35.00
Effective playing time (%)	17.65	0.03	15.30–20.50
Resting time (%)	82.35	0.03	77.50–84.70
Strokes per rally	3.18	1.96	1.00–15.00
W : R	1 : 4.6	0.84	1 : 3.4–1 : 5.5
Physiological and perceptual demands			
RPE	12.45	1.91	8–16
LA	1.41	0.43	1.10–2.70
HR_{avg} (b.p.m.)	124.25	24.70	106.48–150.67
HR_{max} (b.p.m.)	163.25	11.55	152–179
$\%HR_{max}$ (b.p.m.)	76.31	4.50	70.97–80.15

Abbreviations: HR_{avg} (b.p.m.), heart rate average; HR_{max} (b.p.m.), heart rate maximum teorical; $\%HR_{max}$ (b.p.m.), percentage of heart rate average of HR_{max}; LA, blood lactate concentration (mmol l^{-1}); RPE, ratings of perceived exertion; s.d., standard deviation; W:R, work-to-rest ratio. Values are mean.

Procedure

Three experimental sessions with six total matches were conducted during a national WT team stage. In each session, two matches were played, and they had 12 h rest until the next session.

Each match started with a 5-min standard warm up. Then, a single, best of three, tie break set match was played with new balls (Wilson US Open). Play was according to the ITF rules for a clay court.[6] The time limits for changeovers and breaks between points were strictly enforced. The mean temperature during match play was 20–22 °C. All matches were finished in two sets.

Physiological measurements

Heart rate. All players were equipped with a Polar Team 2 (Polar, Kempele, Finland) telemetry monitor to record HR before the warm up. HR was recorded every second from the start to the end of the match. The data were analysed with the Polar Team 2 software, indicating HR mean as a standard deviation.

All data were screened to ensure outliers (HR scores of 0 or >220) were not present. HR_{max} was estimated for each participant ($HR_{max} = 200$ b.p.m. - age). This equation has the same standard error (that is, 12–15 b.p.m.) than 220-age and has been used by different authors to be the most adapted equation by these population.[1,14,15] Estimation of HR_{max} enabled the determination of exercise intensity for each participant during each activity condition.

Blood lactate concentration. A drop of capillary blood was extracted from the earlobe with the intention of evaluating the changes in LA during the match (Lactate Pro, Kyoto, Japan). The LA samples were taken during the changes of end in games 1, 3, 5, 7 and so on, until the end of the match. A total of 55 samples were taken.

Rates of perceived exertion. RPE were obtained using the 15 category (scale from 6 to 20) Borg RPE scale.[16] All players were acquainted with the use of the scale. The RPE samples were taken during the changes of end in the games 1, 3, 5, 7 and so on, until the end of the match. A total of 58 samples were taken.

Match analyses

Each match was filmed using a Panasonic HC-V700 (Panasonic, Tokyo, Japan) super wide-angle camera. The videotapes were later replayed on a monitor for computerised recording of their activity patterns. The analyses of all six matches were performed by the same experienced researcher. Each match was monitored and recorded for subsequent analysis. Rallies duration and the shots per rally were encoded as has been carried out in other studies.[17–19] From these data, the following variables were calculated for the six matches analysed:

- Rallies duration, from the time the service player hit the ball at the first serve to the moment the point finished in seconds;
- TT, from the beginning of the first serve until the end of the last point of the match in minutes; and
- Shots per rally, which was quantified as the number of balls hit by the players from the first service to the end of the point.

The following variables were then developed:

- Effective playing time (EPT), which was determined by the sum of the single length of all rallies in minutes;
- Resting time (RT), which was determined by the sum of the break time between points (obtained by subtracting the start time of the point from the finish time of the previous point) in minutes;
- W:R, the ratio of duration of rallies to rest times;
- EPT percentage (EPT%), which was expressed as a percentage of the TT of play in a match and was determined by dividing the TT by the EPT and
- RT percentage (RT%), which was expressed as a percentage of the TT of play in a match and was determined by dividing the TT (from the beginning of the first rally until the end of the last rally) by the RT (sum of the break time between points).

A total of 24 855 s were analysed with 1983 shots distributed over 623 total points. Therefore, the changes between changeovers were excluded from the RT.

Statistical analyses

Data analysis was conducted using IBM SPSS version 20.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (mean, s.d.) were obtained for all physiological–perceptual responses from participants and presented in the matches. Shapiro–Wilk and Levene tests were used to confirm the normality and homogeneity of variance, respectively. Independent-sample *t* tests were used to calculate differences between service and return games. The level of significance was set at $P \leqslant 0.05$.

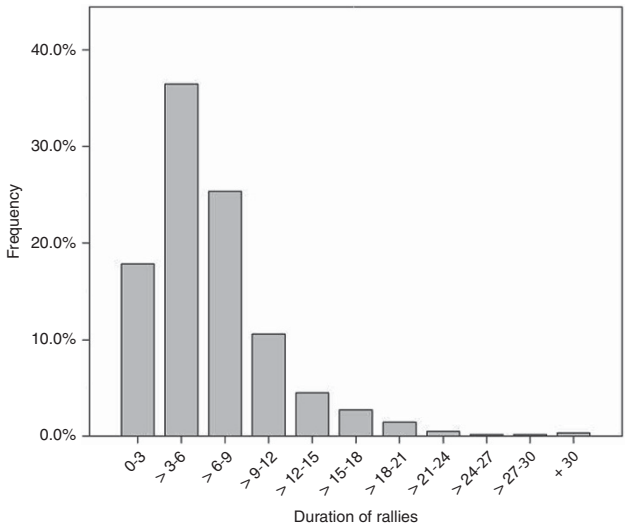

Figure 1 Distribution of rallies duration during the matches. Most of the rallies (about 55%) lasted between one and six shots and 80% finished between one and nine shots. Distribution of the duration of rallies at 3 s.

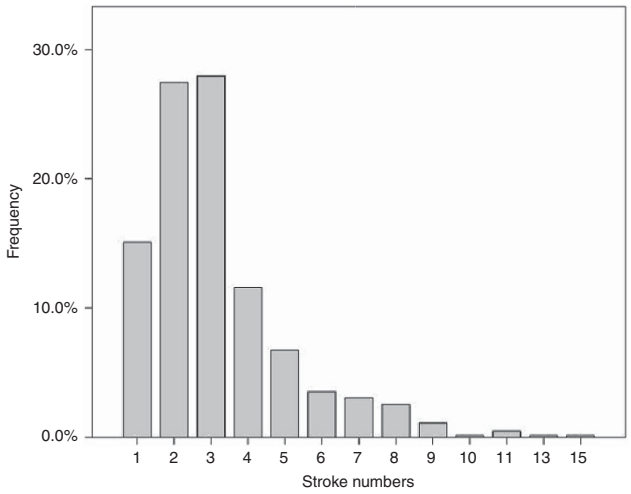

Figure 2 The number of strokes performed per player during the 12 sets analysed. Most of the rallies (about 70%) finished between one and three shots and 92% lasted between one and six. Distribution of the numbers of shots per point for all matches.

RESULTS

Table 2 shows the match analysis and physiological and perceptual demands of the WT matches. In the match analysis part, the variables describing the characteristics of the matches are shown. The TT was 69.04 ± 2.30 min, with a range of between 65.75 and 71.03 min. The EPT and RT percentages show values between 15.30% and 20.50% and 77.50% and 84.70%, respectively. Consequently, the results show that the W:R ratio is $1{:}4.6 \pm 0.84$. The next part shows the physiological–perceptual demands of tennis match play for all matches analysed. The HR_{max} (200 - age) was 163.25 ± 11.55 b.p.m. The HR average for all WT players was 124.25 ± 24.70 b.p.m., (76.31 ± 4.50% of HR_{max}). Specifically, the player with spine bifida had a $\%HR_{max}$ lower (70.97 ± 3.45) compared with the amputee players (77.18 ± 6.32) or player with osteogenesis imperfect (79.92 ± 4.03).

The mean LA ($n = 55$) was 1.41 ± 0.43 mmol l^{-1} with a ranged between 1.10 and 1.98 mmol l^{-1}. Moreover, the mean of the RPE value ($n = 58$) was 12.45 ± 1.91 (somewhat hard).

Furthermore, there are no significant differences in LA ($P = 0.879$) after service games (1.42 mmol l^{-1}; $n = 26$) and after receiving games (1.40 mmol l^{-1}; $n = 29$). As in the LA, there are no significant differences in RPE ($P = 0.915$) after service games (12.61; $n = 28$) than after receiving games (12.62; $n = 29$).

DISCUSSION

Control over a greater number of perceptual and physiological parameters can show a more accurate view of the needs of competition. To our knowledge, this is the first study to evaluate the physiological responses HR and LA with RPE and activity patterns in a WT male player. These parameters have shown the importance of taking into account the type of injury in WT players to improve the specific training.

Match analysis

Data from the present study show a total match time close to 70 min (Table 2). These values are similar to those in hard court play[3,4] but slightly lower than those recorded on clay courts,[8] which obtained values higher than 80 min. The differences are close to 10 min; this may be due to differences with the selected sample.

The EPT was 12.19 ± 2.06 min (Table 2), representing 17.65% of the TT. These data are slightly higher than official matches on hard courts[4] and lower than unofficial matches on hard courts.[7,9] There are no studies on clay courts in relation to EPT; hence, we cannot compare between surfaces.

The percentage of EPT and RT shows a W:R ratio of 1:4.6, which is similar to that recorded by other studies.[4,7] This reaffirms the intermittent nature of this discipline, where there are higher values for RT in comparison with EPT, allowing the players preparation time for the next point.

Regarding the rally duration, the data from this study show a mean of 7.04 s per point (Table 2). The other data found in hard court, which focused on high-level international players, were higher than 9 s.[9,10] Although points are observed with duration of up to 35 s (Table 2), almost 80% of them end within 9 s (Figure 1). There is a tendency to a lower distribution of rally duration in recreational level.[7]

Although it has been concluded that points lasting 15 shots have a stroke per rally mean of 3.18, this is similar to other WT studies with 4 strokes per rally on hard courts.[9,10] Therefore, in spite of the differences in sample and playing surface, in this case, the values are closer between the studies.

Physiological and perceptual demands

The WT players in the present study had a $\%HR_{max}$ of 76.31 ± 4.50 in a game situation. The findings from the present study are therefore consistent with those, which have been reported in other WT studies of between 65 and 75% of maximum HR on hard courts.[1–5,12]

This study is the first to take samples of HR on clay courts; hence, we cannot compare our values with other studies on the same surface. The playing surface has an implication for physiological player responses; in fact, conventional tennis studies show differences in HR between clay courts and hard court.[20] Our results are similar to other studies in WT on hard courts and lower than the mean in conventional tennis on clay courts.[20] Therefore, more studies are necessary to evaluate the possible differences in the intensity of the game in relation to the playing surface.

In any case, the $\%HR_{max}$ is slightly higher than 75% according to other studies in WT with high level players[3,5] and higher compared

with recreational level players (68–69%).[1,4] This may be because the high level players move faster and cover more distance per match than low level players.[5] No studies have been found in other adapted racket sport. Compared with other studies in intermittent sports, ours results show $\%HR_{max}$ lower than wheelchair basketball[2,3] or wheelchair fencing.[2] This could be due to a difference in W:R ratio during a game.[3] Specifically, $\%HR_{max}$ shows lower values in a player with spine bifida than the others three players, with variation in the percentage of 7.12%. This result is consistent with other studies that suggest that the physiological measures are lower as higher level of injury has the player.[21] In our case, we too have the same result concerning physiological measures, lower values of HR response, but our players have not a higher level of spinal cord injury, and according the the pattern game of this player, very offensive, and with the length of the rallies and the number of strokes per point shorter, it seems reasonable to think that his lower heart rate values are according to his pattern activity profile. Although it is only one player with spine bifida, the differences in $\%HR_{max}$ should be considered in design of exercises, and future research should compare the HR responses of a larger number of players with spinal cord injury and players with amputations or non-spinal cord injury. Nevertheless, WT is considered a sport of moderate-to-high intensity.[3–5] Although WT and conventional tennis players have the same rest time between points and games,[6] the $\%HR_{max}$ in WT match is lower than that found in conventional tennis with high level players.[22] These differences are mainly due to the nature of each modality (use to upper members, ball speed or velocity of displacement) and should be taken into account by coaches.

LA has often been used as an indicator of energy production from glycolytic processes during exercise.[19] The LA obtained in the present study was 1.41 ± 0.43 mmol l^{-1}. The LA values in WT previously were just from the training sessions[23] and were slightly higher than 2 mmol l^{-1}. The LA in the present study was lower than that found in wheelchair basketball and wheelchair rugby in training session[23] or wheelchair basketball in game situation.[24] No studies have been found in adapted racket sport about LA in game situation. In comparison with conventional tennis players, our data are lower than professional males[19] (3.8 ± 2.0) or pro-competition male players.[20] This reaffirms the view that the intensity is lower in WT than in conventional tennis and shows to the coaches the differences between modalities. Despite the fact that the intensity of play is high (75% HR_{max}), the rally duration (7.04 s) means that there is not enough time for LA to be determined as a variable that limits performance. In fact, all data are related; WT is played at high intensity (75% HR_{max}), with high rest times (RT/EPT ratio is 1:4.6) and low concentrations of lactate (mean 1.41 mmol l^{-1}).

The RPE values in this study were 12.45 ± 1.91. These values are similar to those obtained in training sessions[23] (~12) and slightly lower at the end of each set[9] (12.8 ± 1.8 in the first and 13.2 ± 2.5 in the second set). Although the perceptual response to this activity profile is characterised by moderate RPE, there are values greater than 15 (Table 2), suggesting that there are periods of greater intensity throughout the match. There is more information about RPE in conventional tennis than WT, and more studies are needed to better understand the functional behaviour of WT.

Service and return situation

Game play makes up about 90% of the points and will usually end up with five hits or less (Figure 2). The results show that, in the serve and return shots, there are more than 40% of the points. The data reflect that serving/returning scenarios are vital in WT. The physiological responses in conventional tennis are influenced by the playing situation (service vs return). In our study, there are no significant differences in RPE or lactate measurements in service and return play; the WT player shows similar perceptual and physiological responses in both situations. We did not find any study in WT that takes this aspect into account. In conventional tennis, the service situation has significantly higher values in physiological responses than the returning situation.[19] The lack of differences in service and return situations could be due to a low number of strokes per rally (3.18), where most of the points end between two and three shots (Figure 2). Although the quality of each shot is not evaluated in our study, it could be said that it is important to carry out tasks in a short duration with emphasis on effectiveness in a training session on court.

Our study had some limitations. An important limitation is the low number of subjects; hence, it difficult to draw strong conclusions about the activity pattern and physiological and perceptual demands of male WT players on clay courts. Also, it is important to consider that the values obtained refer to a clay court surface in unofficial matches. It would be interesting to increase the number of subject groups.

In conclusion, WT is an intermittent sport, where the players are hitting the ball about every 7 s. The work/rest relationship means that the HR is between 106 and 150 b.p.m., which represents 70–80% of $HR_{max;}$ hence, it can be considered a moderate-to-high intensity sport. Further research is still necessary, as values depend on the kind of injury, playing surface and different competitive levels. These results might be used to develop specific interval training protocols for a male WT player training in relation to this intensity according to the W:R ratio.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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