ORIGINAL ARTICLE

Activity patterns, blood lactate concentrations and ratings of perceived exertion during a professional singles tennis tournament

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

Br J Sports Med 2007;**41**:296–300. doi: 10.1136/bjsm.2006.030536

See end of article for authors' affiliations

Correspondence to:
Dr A Mendez-Villanueva, EU de Magisterio, Departamento de Didáctica, Universidad de Alcalá, C/Madrid, 1, 19001 Guadalajara, Spain; amendezvillanueva@yahoo.com

Accepted 8 November 2006
Published Online First 19 January 2007

Objective: To examine the game characteristics and physiological (ie, blood lactate concentration) and perceptual (ie, rating of perceived exertion, RPE) responses during actual tennis competition in professional performers.
Methods: Eight trained and internationally ranked (Association of Tennis Professionals rankings) male tennis players were studied during singles matches (best of three sets) played on an outdoor clay court surface during a professional, invitational tournament. Blood lactate concentrations (n = 53) and RPE (n = 113) were determined at selected changeovers during the game. The variables describing the characteristics of the matches, (a) duration of rallies (DRs); (b) rest time (RT); (c) effective playing time (EPT); and (d) shots per rally (SR), were determined from video recordings.
Results: The mean (SD) values for the match-play activity variables were DR 7.5 (7.3) s, RT 16.2 (5.2) s, EPT 21.5 (4.9%), SR 2.7 (2.2) shots. Average blood lactate concentration and RPE values were 3.8 (2.0) mmol/l and 13 (2). Blood lactate concentrations and RPE values were significantly higher ($p<0.01$) in service games than in receiving games. Both blood lactate concentration and RPE values were significantly correlated with SR and DR ($r = 0.80$ to 0.28; $p<0.001$).
Conclusions: Blood lactate concentrations and RPE were found to be influenced by the characteristics of the match and the playing situation (ie, serving or returning). These specific situations might be used to alter the overload training stimulus during tennis on-court practice.

Competitive success in modern tennis requires high technical and skill abilities.[1 2] In addition, to reach the international performance level tennis players may also need to posses specific physiological attributes such as aerobic fitness, muscle strength and power.[3 4] Knowledge about the activity profiles and physiological responses to match play is therefore essential for the design of effective training programmes in a complex sport such as tennis. Several studies have previously described the physiological demands of singles tennis using match activity analysis, heart rate, blood lactate concentration and/or oxygen uptake measurements.[5–12] The information obtained from these studies has provided coaches and sport scientists with the basis for the physiological preparation of competitive tennis players. However, this information has mostly been gained from simulated tennis match-play studies where it is difficult to truly replicate standard match conditions. Presently, it is unknown whether results obtained in those simulation studies can be extrapolated to actual tennis match play.

A further limitation of most previous investigations is that they have examined the physiological responses of regional and national-level tennis players. Long-term processes of adaptation owing to years of training and match play in professional tennis players can induce a number of chronic physiological and metabolic adaptations such as changes in heart size, maximum oxygen uptake, onset of lactate production, heart rate, blood pressure and hormonal regulation.[3] Acute physiological and metabolic responses to exercise have been reported to be influenced by training status.[13] As a consequence, the acute physiological responses previously described during simulated tennis match play in low- to average-level tennis players might be different from those obtained during an actual tennis tournament in high-level athletes.

Research identifying factors that might influence the physiological responses of tennis match play is limited.[10 12 14] In this regard, the patterns of physical activity and recovery (described by the duration of rallies and the effective playing time), the tactical behaviour of players (defensive vs offensive playing) and the playing situation (serving or receiving) have been reported to influence physiological mediators such as heart rate, blood lactate concentration and oxygen uptake.[10 12] To date, however, there are no empirical studies describing the rating of perceived exertion (RPE) responses to official tennis match play. RPE is a valid measure of exercise monitoring and prescription owing to the observed association between RPE and more objective physiological markers of intensity, such as heart rate or oxygen consumption.[15] Moreover, RPE response was found to be a good measure to estimate energy demands during a simulated singles tennis match.[16] Therefore, using a match protocol developed by Smekal *et al*[12] we also investigated factors that may influence the physiological–perceptual responses of actual singles tennis match play. A greater understanding of these responses will assist in the development of match-specific training programmes. The purpose of this study was to examine the activity patterns, blood lactate concentrations and perceived exertion responses during singles tennis match play in professional performers.

Abbreviations: ATP, Association of Tennis Professionals; CV, coefficient of variation; DRs, duration of rallies; EPT, effective playing time; RPE, rating of perceived exertion; RT, rest time; SR, shots per rally; TEM, technical error of measurement; W:R, work-to-rest ratio

Table 1 Descriptive group results of selected variable analysed

Variable	Mean (SD)	Range
Lactate (mmol/l)	3.8 (2.0)	1.0–8.6
RPE (6–20)	13 (2)	9–17
Total match time (min)	105.0 (35.7)	85.4–160.0
EPT (%)	21.5 (4.9)	13.8–28.6
DR (s)	7.5 (7.3)	0.6–53.7
RT (s)	16.2 (5.2)	3.7–40.2
W:R ratio	0.5 (0.3)	0.1–1.9
SR	2.7 (2.2)	1–17

DR, duration of rally; EPT, effective playing time; RPE, rating of perceived exertion; RT, resting time between rallies; SR, shots per rally; W:R ratio, work-to-rest ratio.

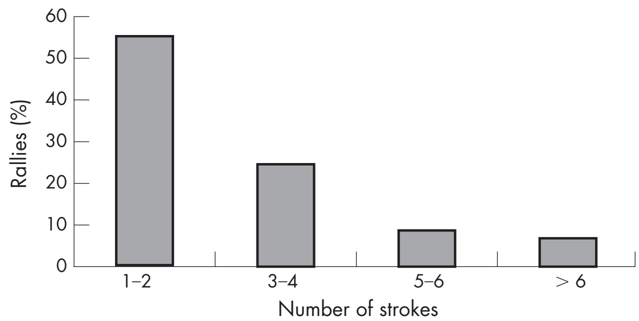

Figure 2 Number of strokes per player per rally.

METHODS

Subjects

Eight well-trained, professional, male tennis players (age 27.0 (4.4) years; height 182.9 (5.2) cm; body mass 80.6 (7.5) kg) participated in this study. Seven of them had an Association of Tennis Professionals (ATP; men's professional tennis association) singles ranking (three players in the top 100 and four players between positions 200 and 500 of the ATP rankings) at the time of the study. Among the subjects there were four ATP tournament winners and one Davis Cup winner. All the subjects had reached at least one final in a national or an international tournament within the last 2 years (eg, ATP, Future or Challenger Tournaments). All subjects were fully informed of the experimental procedures before providing written informed consent to participate in the study, which was approved by the institutional research ethics committee. The study was also previously approved by the contest organising committee.

The tournament

All measurements were taken during a 3-day invitational professional singles tennis tournament held in a local tennis club. Players were invited by the contest organising committee. The acceptance/rejection to participate in the tournament was based on player-dictated schedule conflicts and/or financial claims. Every player received fixed prize money, after agreeing to participate, and variable prize money based on the final position achieved at the end of the tournament.

The tournament format was based on elimination heats. That is, the eight players contested in four quarterfinals, with the winner of each one passing to the next round until reaching the final. Therefore, the total number of matches was seven (four quarterfinals, two semifinals and the final). All the matches (best of three sets) were conducted on an outdoor clay court surface. The mean (SD) climatic conditions during the matches were air temperature 20 (1)℃, humidity 76% (6%), wind speed 1.4 (0.3) m/s. International Tennis Federation rules were used to govern the scoring and time characteristics for the matches. A set of four new balls (Dunlop Fort, Carlsbad, California, USA) were used in the first seven games and then every ninth game for the rest of the match. Fluids were available throughout the matches.

Blood lactate concentration

Blood lactate concentration (n = 53) was determined from 25 µl capillarised blood samples drawn from the ear lobe and collected into heparinised tubes. All the blood samples were taken while the players were seated during selected changeover breaks in play, which occur every three games, and were later analysed in duplicate by an electroenzymatic method (Analox Micro Stat GM7, Analox Instruments, London, UK). The number of blood samples was, therefore, variable, depending on the duration of the match (ie, two or three sets). In same cases, players prevented us from sampling blood. In most cases, players were ''upset'' by the current score (normally, when they had lost an important game) and they preferred to be sitting and concentrating for the next game, without any external disruption.

Ratings of perceived exertion

Ratings of perceived exertion were obtained using the 15-category Borg RPE scale.[15] The scale was explained before the exercise. The subjects were asked: ''how hard do you feel the exercise was?'' during selected changeovers while they were sitting. Subjects had to give ratings corresponding to their sensations during the last game.

Match analysis

The game analysis of tennis singles was determined by filming each match. Video recordings were collected using two cameras

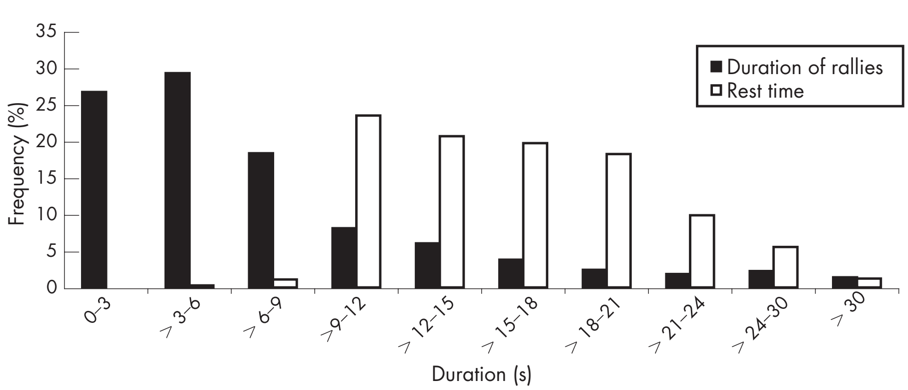

Figure 1 Mean percentage of playing time intervals (duration of rallies) and recovery (rest time between rallies).

(Sony Handycam, DCR-HC24E, Japan) positioned 2 m away from the side of the court, at the level of the service line and approximately 2 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 all seven matches were performed by the same experienced researcher.

A modified match protocol developed by Smekal *et al*[12] was used to monitor and record the duration of each game and each rally, the duration of the rest intervals between games, the number of shots per rally and the total duration of the matches. From these data, the following variables were calculated for the 264 games analysed: (1) the duration of rallies (DR in seconds); (2) the rest times between rallies (RT in seconds); (3) the work:rest ratio (W:R; the ratio of duration of rallies to rest times); (4) the effective playing time (EPT; expressed as a percentage of the total time of play in a game); and (5) the number of strokes per rally (SR). DR was recorded from the time the service player hit the ball in the first serve to the moment when one of the players won the point. Changes between changeovers were excluded from the resting time. 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 single duration of rallies) performed in specific game. SR was quantified as the number of balls hit by the players from the first service to the end of the point.

Statistical analyses

Reproducibility of the results obtained by the player's activity analysis was established by assessing the intratester test–retest reliability, in which one match was analysed twice by the same researcher. Reliability of measurements was performed using the methods described by Hopkins.[17] The technical error of measurement (TEM) was calculated for the intraindividual test–retest competition analysis variables (ie, DR, RT, W:R, EPT and SR) and expressed as a mean coefficient of variation (CV). The TEM quantifies the random error of a test score (ie, the differences between measured scores and the true scores) as a result of ''technological error'' and/or ''biological error''.[17] Precision of the estimates of TEM are shown as 95% likely limits (confidence limits), which represent the limits within which the true value is 95% likely to occur. The physiological–perceptual responses of tennis match play, and the variables describing the characteristics of the matches, were calculated as mean (SD) values for all games analysed. The Kolmogorov–Smirnov test (with Lilliefor's correction) was used to test data for normality. 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, SR, and DR) and the physiological–perceptual responses (ie, blood lactate concentrations and RPE) obtained at the end of each game examined was determined using Pearson's product moment correlation analysis. 95% CIs were also calculated. SPSS V.12, was used for statistical calculations. The level of significance was set at $p<0.05$.

RESULTS

Reliability

The TEM, expressed as CV, with the 95% CI for each variable, was as follows: DR 1.9% (95% CI 1.7% to 2.2%), RT 1.4% (95% CI 1.2% to 1.6%), W:R 1.7% (95% CI 1.5% to 1.9%), EPT 0.6% (95% CI 0.3% to 4.1%), and SR 0.0% (95% CI 0.0% to 0.0%).

Match analysis

Table 1 shows the variables describing the characteristics of the matches (ie, DR, RT, W:R, EPT and SR). Figure 1 shows the mean distribution of work (ie, DR) and recovery (ie, RT) periods at given time intervals during the games. Most of the rallies (about 56%) lasted between 1 and 6 s. When combined with rallies lasting between 6 and 9 s (about 18%), this represented about 75% of all the rallies documented during all the matches. Approximately 82.1% of the rest intervals between rallies were between 9 and 21 s in duration. Figure 2 displays the number of strokes performed per player during the 264 games analysed.

Physiological–perceptual responses

Table 1 displays the physiological–perceptual responses of tennis match play, and the variables describing the characteristics of the matches, for all games analysed. The mean blood lactate concentration ($n=53$) was 3.8 (2.0) mmol/l. The average blood lactate concentration ranged from 1.9 to 5.5 mmol/l per match. Individual values ranged from 1.0 to 8.6 mmol/l. Blood lactate concentrations were significantly higher ($p=0.02$) after service games (4.6 (2.5) mmol/l; $n=27$) than after receiving games (3.2 (1.4) mmol/l; $n=26$; fig 3). The mean RPE value ($n=113$) was 13 (2; somewhat hard). The average RPE values ranged from 11 to 15 per match. Individual values ranged from 9 to 17. As with blood lactate concentrations, RPE values were significantly higher ($p<0.001$) following service games (13.5 (1.9); $n=58$) than following receiving games (12.0 (2.0); $n=55$, fig 3).

Relationships between variables

Table 2 lists the correlation coefficients between blood lactate concentration and RPE values. The variable most strongly correlated with the parameters obtained in the match analysis (ie, SR and DR) was blood lactate concentration ($r=0.80$; $p<0.001$), indicating that 64% of the variance in blood lactate concentrations could be explained by the duration of the game or by the number of strokes performed in the game when players were serving. Conversely, in receiving games the relationship between blood lactate concentrations and both SR and DR was found to be low and non-significant ($r=0.26$–0.28; $p>0.1$). RPE values also showed a better correlation with the match analysis variables in service games than in receiving games.

DISCUSSION

To the authors' knowledge, this is the first study reporting physiological (ie, blood lactate concentration) and perceptual (ie, RPE) responses in professional tennis players during actual tennis match play. We have also examined these physiological–perceptual loads in conjunction with individual patterns of match-play activity. Our results show that the activity patterns of top-class tennis players are characterised by intermittent exercise, consisting of short (1–9 s) bouts interspersed with short (10–20 s) recovery bouts, interrupted by periods of longer duration (60–90 s). The physiological and perceptual responses to this movement pattern are relatively moderate blood lactate concentrations and RPE values during the match. We also found that the blood lactate and RPE responses were influenced by DR and SR (long rallies and/or high number of strokes per rally resulted in higher metabolic and perceptual load) and by type of play (higher in service than in receiving games). Our results provide coaches and fitness trainers with valuable information to aid in the prescription and physiological assessment of sports-specific training activities for elite tennis players.

The mean duration of rallies and rest periods in the matches studied was 7 and 16 s, respectively. This establishes a W:R of 1:2.2—that is, elite tennis players rested 2.2 s for every second of work performed during the rally. These results are similar to those reported in a previous study showing a mean duration of

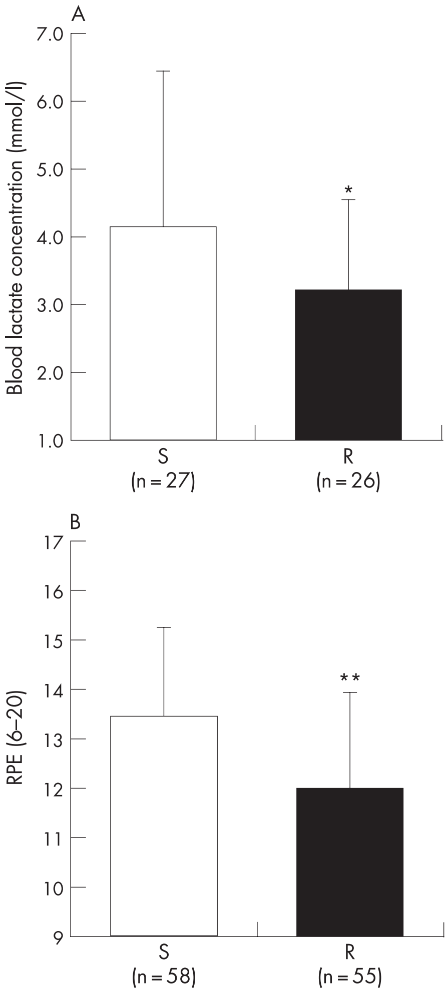

Figure 3 Blood lactate concentrations (A) and ratings of perceived exertion (B) of service games (S) and return games (R). Values are represented as mean (SD). *p<0.05; **p<0001.

work and rest periods of 5–10 and 10–16 s, respectively (a W:R ratio of about 1:1 to 1:5).[7] The frequency distribution of work periods and the ratio between work and rest periods obtained in this study might be used to develop individual, intermittent, training protocols for tennis players.

Blood lactate concentration has often been used as an indicator of energy production from glycolytic processes during exercise.[18] Previous studies with lower-standard tennis players have revealed that mean blood lactate values remain relatively low (1.5–3.0 mmol/l) during match play.[7] In this study, mean (SD) blood lactate values were 3.8 (2.0) mmol/l, with individual values >8 mmol/l. The higher blood lactate concentrations in this study may reflect the more intense nature of professional tennis tournaments and/or an increased intensity of matches as the playing standard improved. Moreover, these relatively high blood lactate concentrations might be related to the style of play of the players tested in this study. All the players investigated were clay-court specialists, who can be classified as a baseliners (players who predominately prefer the game from the baseline).[12] In this regard, it has been reported that markers of exercise intensity (ie, oxygen uptake, blood lactate concentrations, heart rate) are higher in games in which both players are baseliners.[12]

In accordance with Reilly and Palmer,[10] the playing situation (serve vs return) influenced the physiological responses, with servers recording significantly higher blood lactate concentrations than receiving players (fig 3). These differences can be attributed to the more active and dominant role of the server in dictating the game.[10] Specifically, the higher blood lactate concentrations of the service players could be the consequence of the high number of short rallies (>50% of rallies recorded in this study had 1–2 strokes, fig 2). These rallies are either aces or service winners (return faults) or winners by the second shot of the server. In all these cases, the intensity and duration of the servers activity is higher compared with the return player.

Our results are, however, in contrast to those reported by Smekal *et al*,[12] showing similar metabolic responses in service and return play. These contrasting results may be linked to differences in players' technical standards (ie, national level without ATP ranking) or testing conditions (ie, non-competitive matches, players wearing a portable analyser) used in the study of Smekal *et al*.[12] One practical application that can be derived from the higher blood lactate values observed when players are serving is that the playing situation (ie, service) can be used as a means of physiological overload during tennis practice.

To the authors' knowledge, no published studies have reported changes in RPE in professional tennis players during an official competition, although previous studies have reported RPE responses during tennis match play under non-competitive conditions in lower-level tennis players.[16 19] Although difficult to compare, mean values of RPE obtained in this study (table 1) are in the range of those obtained by Girard *et al*[19] during a 3 h tennis match. The highest RPE values obtained in this study (= 17) confirm that there are periodic increases in exercise intensity during tennis match play.[12] Differences in RPE between serving and receiving players (fig 3) give further

Table 2 Correlations between physiological (ie, blood lactate concentration) and perceptual (ie, ratings of perceived exertion) values, and variables describing the characteristics of the game

	RPE								
	All games (n = 113)			Service games (n = 58)			Return games (n = 55)		
	R	p Value	95% CI	R	p Value	95% CI	R	p Value	95% CI
SR	0.44	0.000	0.29 to 0.56	0.52	0.000	0.33 to 0.68	0.28	0.05	0.05 to 0.49
DR	0.39	0.000	0.24 to 0.52	0.50	0.000	0.30 to 0.66	0.30	0.04	0.07 to 0.50
	Blood lactate concentration								
	All games (n = 53)			Service games (n = 27)			Return games (n = 26)		
SR	0.57	0.000	0.37 to 0.72	0.80	0.000	0.62 to 0.90	0.26	0.25	−0.11 to 0.57
DR	0.51	0.000	0.30 to 0.68	0.80	0.000	0.62 to 0.90	0.28	0.21	−0.09 to 0.58

DR, duration of rallies; Lac, blood lactate concentration; RPE, rating of perceived exertion; SR, shots per rally.

What is already known on this topic

- Previous studies have described the physical and physiological demands of singles tennis match play.
- However, most of the current information has been gained from simulated tennis competition, where standard match conditions are often disrupted. Moreover, previous investigations have examined low- to average-level tennis players.

What this study adds

- This study provides physical and physiological–perceptual data during actual tennis competition in a group of professional performers.
- This information can be used in the development of match-specific training programmes.

support to previous evidence of different physiological responses related with the playing situation.[10]

It was also the intent of this study to investigate the relationship between physiological responses (ie, blood lactate concentration) and RPE responses, and in turn, their association with variables describing the characteristics of the matches. The results indicate that there were increases in blood lactate concentrations and RPE in response to increases in DR or SR, with better correlations in service than in receiving games (table 2). These data provide support for a functional link among the three main effort continua (physiological, perceptual and physical demands) during tennis match play.[20] Therefore, DRs and/or the number of strokes per rally during on-court practice can be conveniently manipulated to ensure that adequate physiological stimulus is provided and player's individual objectives are achieved.

CONCLUSIONS

We have reported, for first time, the patterns of physical activity associated with physiological (ie, blood lactate concentration) and perceptual (ie, RPE) responses in singles tennis play during an actual competition. Our results showed corresponding increases in both blood lactate concentration and RPE measures as the DRs increased, for higher SRs, or as the player was serving. Thus, all these situations might be used by coaches in the programming of an overload training stimulus during tennis practice.

ACKNOWLEDGEMENTS

We thank the players involved in the tournament, especially Esteban Carril, as well as the Dionisio Nespral Tournament organising committee.

Authors' affiliations

Alberto Mendez-Villanueva, Faculty of Physical Activity and Sport Sciences, Department of Didactics, University of Alcala, Madrid, Spain
Jaime Fernandez-Fernandez, Department of Functional Biology, University of Oviedo, Oviedo, Spain
David Bishop, Team Sport Research Group, School of Human Movement and Exercise Science, The University of Western Australia, Perth, Western Australia, Australia
Benjamin Fernandez-Garcia, Department of Morphology and Cellular Biology, University of Oviedo, Oviedo, Spain; Sports Medicine School, University of Oviedo, Oviedo, Spain
Nicolas Terrados, Sports Medicine Center of Principado de Asturias, Avilés, Spain

Competing interests: None declared.

REFERENCES

1 **Smekal G**, Pokan R, Von Duvillard SP, *et al.* Comparison of laboratory and ''on-court''-endurance testing in tennis. *Int J Sports Med* 2000;**21**:242–9.
2 **Vergauwen L**, Spaepen AJ, Lefevre J, *et al.* Evaluation of stroke performance in tennis. *Med Sci Sports Exerc* 1998;**30**:1281–8.
3 **König D**, Huonker M, Schmid A, *et al.* Cardiovascular, metabolic, and hormonal parameters in professional tennis players. *Med Sci Sports Exerc* 2001;**33**:654–8.
4 **Müller E**, Benko U, Raschner C, *et al.* Specific fitness training and testing in competitive sports. *Med Sci Sports Exerc* 2000;**32**:216–20.
5 **Bergeron MF**, Maresh CM, Kraemer WJ, *et al.* Tennis: a physiological profile during match play. *Int J Sports Med* 1991;**12**:474–9.
6 **Christmass MA**, Richmond SE, Cable NT, *et al.* Exercise intensity and metabolic response in singles tennis. *J Sports Sci* 1998;**16**:739–47.
7 **Fernandez J**, Mendez-Villanueva A, Pluim BM. Intensity of tennis match play. *Br J Sports Med* 2006;**40**:387–91.
8 **Elliott BC**, Dawson B, Pyke F. The energetics of single tennis. *J Hum Mov Stud* 1985;**11**:11–20.
9 **Ferrauti A**, Bergeron MF, Pluim BM, *et al.* Physiological responses in tennis and running with similar oxygen uptake. *Eur J Appl Physiol* 2001;**85**: 27–33.
10 **Reilly T**, Palmer J. Investigation of exercise intensity in male single lawn tennis. *J Sports Sci* 1993;**11**:543–58.
11 **Smekal G**, Von Duvillard SP, Pokan R, *et al.* Changes in blood lactate and respiratory gas exchange measures in sports with discontinuous load profiles. *Eur J Appl Physiol* 2003;**89**:489–95.
12 **Smekal G**, Von Duvillard SP, Rihacek C, *et al.* A physiological profile of tennis match play. *Med Sci Sports Exerc* 2001;**33**:999–1005.
13 **Baldwin J**, Snow RJ, Febbraio MA. Effect of training status and relative exercise intensity on physiological responses in men. *Med Sci Sports Exerc* 2000;**32**:1648–54.
14 **Girad O**, Millet GP. Influence of the ground surface on physiological and technical responses in young tennis players. In: Lees A, Kahn JF, Maynard I, eds. *Science and racket sports*. Vol III. London: Routledge, 2004:93–105.
15 **Robertson RJ**, Noble BJ. Perception of physical exertion: methods, mediators and applications. In: Holloszy JO, eds. *Exercise and sport sciences reviews.* Baltimore, MD: Williams and Wilkins, 1997:407–52.
16 **Novas AMP**, Rowbottom DG, Jenkins DG. A practical method of estimating energy expenditure during tennis play. *J Sci Med Sport* 2003;**6**:40–50.
17 **Hopkins WG**. Measures of reliability in sports medicine and science. *Sports Med* 2000;**30**:1–15.
18 **Krustrup P**, Mohr M, Steensberg A, *et al.* Muscle and blood metabolites during a soccer game: implications for sprint performance. *Med Sci Sports Exerc* 2006;**38**:1165–74.
19 **Girard O**, Lattier G, Micallef JP, *et al.* Changes in exercise characteristics, maximal voluntary contraction and explosive strength during prolonged tennis playing. *Br J Sports Med* 2006;**40**:521–6.
20 **Lagally KM**, Robertson RJ, Gallagher KI, *et al.* Perceived exertion, electromyography, and blood lactate during acute bouts of resistance exercise. *Med Sci Sports Exerc* 2002;**34**:552–9.

COMMENTARY

This study is excellently prepared in methods, statistics and in the presentation of the data. It is the first study worldwide presenting valid tournament data of blood lactate concentrations in professional singles tennis matches. Because of the uniqueness of the presented data, I have no major concerns. However, the practical relevance of the data—for example, adjusting the training load—is not discussed sufficiently.

Alexander Ferrauti
Ruhr-University Bochum, Faculty of Sports Sciences, Bochum, Germany; alexander.ferrauti@rub.de