Functional aspects of competitive tennis

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ABSTRACT

Torres-Luque G, Sánchez-Pay A, Bazaco MJ, Moya M. Functional aspects of competitive tennis. *J. Hum. Sport Exerc.* Vol. 6, No. 3, pp. 528-539, 2011. Tennis is a sport that is characterized by intermittent dynamics, with intervallic moderate and high-intensity efforts due to repetitive actions of short-duration and high intensity. This review analyzes aspects such as the game's temporal structure, oxygen consumption, heart rate, lactate levels, and the effects of playing in heat. Knowledge of the contextual and functional characteristics of competitive tennis provides important information for improving the design of players training programs. **Key words:** TENNIS, GAME CONTEXT, HEART RATE, LACTATE.

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INTRODUCTION

Competitive tennis has developed greatly in the last few decades, justifying the proliferation of numerous research studies that attempt to determine the physiological and contextual demands that have the greatest impact on performance, with the objective of guiding training sessions and optimizing the profile of the tennis player, both those in their formative years as well as those in peak performance.

The objective of this study is to review the aspects related to the characteristics of tennis competition, including physical, contextual, and functional (anthropometric parameters, cardiorespiratory parameters such as oxygen consumption, heart rate, etc.), that can contribute to the tennis player's profile and consequently should be kept in mind when planning training sessions.

MATCH ACTIVITY

Tennis is a sport that is characterized by intermittent dynamics, with intervallic moderate and high-intensity efforts due to repetitive actions of short-duration and high intensity (Kovacs, 2007). The continual repetition of short actions for a prolonged time results in the accumulation of total match durations that can vary between one and five hours, depending on whether the matches are played to three or five sets (Bergeron et al., 1995; Christmass et al., 1998; Hornery et al., 2007a). However, an average duration of one hour and thirty minutes for a match played to three sets has been established (Bergeron et al., 1995; Kovacs, 2007; Torres-Luque et al., 2011).

The regulations allow for a 20 s rest between points and a 90 s rest between court end changes (ITF, 2006). This variation means that the percentage of real time play is heterogeneous on the different surfaces, but the consensus among various authors is that it constitutes approximately 20-26% of the total time (Christmass et al., 1995; Christmass et al., 1998; Kovacs, 2004; Reilly and Palmer, 1995; Smekal et al., 2001; Kovacs, 2004; Ferrauti et al, 2003; Morante et al., 2005; Fernández-Fernández et al., 2007, 2008; Méndez-Villanueva et al., 2007; Torres-Luque et al., 2011).

In general, this results in a work-to-rest ratio of approximately 1:2 – 1:4 (Elliott et al., 1985; Christmass et al., 1998; Kovacs, 2007; O'Donoghue and Ingram, 2001; Reilly and Palmer, 1995; Smekal et al., 2001; Torres-Luque et al., 2011). Further, more extreme ratios of between 1:3 and 1:5 can be found (Kovacs, 2007; Kovacs et al., 2004). Even if studies show lower values of 1:2.3 and 1:1.8 (Fernández-Fernández et al., 2009) are veteran players and advanced recreational level respectively.

With regard to the duration of a point, in general, an average of 6-10 s has been found (Morante et al., 2005; Fernandez et al., 2006; Kovacs, 2007; Hornery et al., 2007a; Fernandez-Fernandez, 2007, 2008). However, for this parameter, there are differences due to the surface as well as the player's gender. A point's duration is shorter on grass, lasting approximately 2-3 s for males and approximately 4 s for females (O´Donoghue and Ingram, 2001). On fast surfaces, males' points tend to have a duration of about 6-7 s, while females' points tend to last 7-8 s, according to some studies (O´Donoghue and Ingram, 2001; Kovacs, 2004). On clay, the duration is approximately 7-8 s, and according to recent studies, there is less difference between genders (Fernández-Fernández et al., 2007; Méndez-Villanueva et al., 2007).

Observing the large variability that exists in the duration of a point, it is understood that the number of hits per play is directly affected by this factor and therefore depends on variables such as the type of ball, the game surface (clay, hard court, or grass), the gender of the players, and the tactical strategy that they use (Fernández et al., 2006). From this type of information, Verlinden et al (2004) concluded that in Roland Garros the average number of hits per point for males was 4.5 while females used 5.8 hits per point. In Wimbledon, males needed 2.6 hits while females used 3.2 hits to finish the play (Verlinden et al., 2004).

ANTHROPOMETRY

In sport, one of the anthropometric factors that is most well-known is the percentage of body fat. Although tennis players have lower values than sedentary individuals, they are not comparable to athletes from other sports. Body fat percentage is determined by age and the athlete's athletic level. Kibler et al., (1988) found values of 16-22% for males and 21-23% for females in a group of high level tennis players between 14 and 19 years of age. However, Unierzyski (1995) found body fat values of 14-15% for 11-14 year old male and female tennis players. In the most recent studies, the percentage of body fat for junior players is approximately 13% (Torres et al., 2004), and these values tend to decrease slightly when the player perfects their game through training and advanced age, reaching values between 8 and 10% (Bergeron et al., 1995). It is documented that these values are always considerably higher in females, with values of approximately 19-21% (Bergeron et al., 1991; Therminarias et al., 1991; Kovacs, 2007). In this case, this is not affected by age, as long as the tennis player has reached a mature adult development (Therminarias et al., 1991). In summary, the percent of body fat in male tennis players is <12%, while for female players it is <23% (Kovacs, 2007), and these values are somewhat different from those in other sports such as track and field or gymnastics.

In addition to this parameter, somatotype also intervenes in the tennis player's profile. Elliott et al. (1989) observed that both male and female 14-15 year-old players had ectomesomorphic somatotypes, in a sample of 120 adolescent tennis players. However, in the junior age group there was a difference by gender: males were mesoectomorphic and females were endomesomorphic. In a recent study of elite junior players, these somatotype profiles were corroborated (Sanchez-Muñoz et al., 2007), making evident that this parameter has not changed for players that are still developing. It is necessary to study more in depth the progression in peak performance and observe its involvement as decisive for performance.

MAXIMAL OXYGEN UPTAKE

In general, tennis players have a maximal oxygen consumption (VO_{2max}) of approximately 45-65 $mL \cdot kg^{-1} \cdot min^{-2}$ (Bergeron et al., 1991; Reilly and Palmer, 1995; Kraemer et al., 2000; Girard and Miller, 2004; Kovacs, 2007), though these values are higher in male players than in female players (Urhausen et al., 1990; Reilly and Palmer, 1995; König et al., 2001). Values of 55-65 $mL \cdot kg^{-1} \cdot min^{-2}$ are common for athletes of anaerobic activities more so than for athletes taking part in aerobic activities (Green et al., 2003); thus, this demonstrates the importance of the mixed characteristics of this sport.

Differences in maximal oxygen consumption have been observed in relation to age, and the lowest values have been found in youth, while junior players and female adult players who are young but mature have higher values (Therminarias et al., 1990). Though this is logical it is interesting to follow the progression of this parameter, as it may be another aspect for detecting talented youth in tennis.

Regarding oxygen consumption during tennis play, studies have demonstrated that average values are approximately 23 – 29 ml·kg^{-1}·min^{-2} (Ferrauti et al., 1998; Smekal et al., 2001; Fernandez et al., 2005), and these values are higher in regional or club players (Girard and Miller, 2004). However, these values represent an average intensity of approximately 50% of the VO_{2max}, and this value is higher when the level of the player is lower.

There are also differences in oxygen consumption according to game style. It has been observed that when a player is serving, offensive actions have average VO_{2max} values slightly higher than when the player is defending (30.8 ± 5.7 vs. 27.5 ± 5.1 mL·kg^{-1}·min^{-2} (Smekal et al., 2001). However, it has also been observed that, depending on a more offensive game style (serve and volley) or a more defensive game style (baseliner) there are large differences. Defensive players have higher values when compared to offensive players (Bernardini et al., 1998), and those players that have a neutral game style have values somewhere in between.

The court surface also seems to affect oxygen consumption, though these data are somewhat controversial. For instance, Girard and Miller (2004) demonstrated that average values for oxygen consumption on clay courts are higher than on hard courts; however, Murias et al. (2007) demonstrated a lower fluctuation on clay courts, despite the fact that they observed higher values in other parameters such as HR, lactate concentration, and distance covered. This seems to provide evidence for the need for more studies about this subject in order to suggest how training should be oriented. However, it should not be forgotten that in tennis there are many short displacements, and lateral displacements are a constant in this sport. It is in these lateral movements where the highest VO_{2max} values are obtained (Williford et al., 1998).

HEART RATE

Tennis has a continual and intermittent characteristic, where players run short distances of roughly 3 m, with an approximate total of 8-12 m per point (Deutsch et al., 1998). This type of displacement is done at a high intensity, but the game's regulations require a 20 s break between points and a 90 s break when players change ends of the court (ITF, 2006), which means that the heart rate (HR) continually changes, increasing during play and decreasing during rest periods (Bernardini et al., 1998). Average values in tennis singles are 140–160 beats·min^{-1} (Elliott et al., 1985; Groppel and Roetert, 1992; Bergeron et al., 1991; König et al., 2001; Ferrauti et al., 2001; Girard et al., 2006; Hornery et al., 2007b; Murias et al., 2007), even veteran players (Fernández-Fernández et al., 2009), which represents approximately 70-80% of the maximum HR (Reilly and Palmer, 1995; Christmass et al., 1998; Torres et al., 2004). However, at certain moments of the match, HR can reach values of 190-200 beats·min^{-1} (Smekal et al., 2001; Girard and Miller 2004; Torres et al., 2004), demonstrating the cardiac demands to which the tennis player is subjected.

Heart rate is influenced by various factors such as time of day and environmental conditions, and tennis is generally played in a warm environment (Kovacs, 2006b). Further, tennis has a high aerobic component mostly due to the breaks (Bergeron et al., 1991), although actual time in action is where the cardiac demand is highest due to the continual changes of direction, sprinting, hitting, etc., which demonstrates the performance level of the athlete.

A recent study informed of an average HR of approximately 161 beats·min^{-1}, reaching 166 beats·min^{-1} when the player is serving (Fernández-Fernández et al., 2007), which should be kept in mind to adapt training sessions to this. A HR of approximately 160-182 beats·min^{-1} has been observed for trained players when executing drills (Reid et al., 2008).

Although higher HR have always been calculated when the player serves as compared to when he or she returns the serve (Elliott et al., 1985; Davey et al., 2003; Fernández-Fernández et al., 2007), it is when there is a change in game surface that there is controversy. Hornery et al. (2007b) found a higher HR on hard surfaces when compared to clay while Murias et al (2007) found the opposite, with higher HR on clay. The variability is different in regard to the sample, but it is important to highlight that the HR is used in tennis training sessions as a control measurement of intensity. It is therefore important to understand this variability to be able to focus the sessions more specifically, as it would be more coherent to work with this variability when there are moments of high cardiac demand to be better prepared for the reality of tennis competition.

Table 1. *Heart rate, lactate concentrations, and oxygen consumption during tennis play.*

Reference	**Level (sex)**	**Heart rate** (beats·min^{-1})	**Lactate** (mmol·L^{-1})	**VO_2 on court** (ml·kg^{-1}·min^{-2})	**Court**
Bergeron et al. (1991)	Division I (M)	144.6 ± 13.2			Hard
Reilly and Palmer (1995)	Top Club (M)	144 ± 19	1 ± 0.6		Hard
Ferrauti et al. (1998)	National (M and F)			23.1 ± 3 (F) 24.2 ± 2 (M)	Hard Hard
Smekal et al. (2001)	National (M)	151 ± 19	2.07 ± 0.88	29.1 ± 5.6	Clay
Ferrauti et al. (2001)	National (M)	142.5 ± 12.7	1.67 ± 0.49	25.6 ± 2.8	Hard
Girard and Miller (2004)	Club (M)	172 ± 17.2 181 ± 11.9		37.9 ± 7.5 40.3 ± 5.7	Hard Clay
Torres et al. (2004)	Junior (M)	158.4 ± 8.51			Hard
Fernandez et al. (2005)	International (M)		3.79 ± 2.03	26.6 ± 7.2	Clay
Hornery et al. (2007)	International (M)	152 ± 15 146 ± 19			Hard Clay
Girard et al. (2006)	Regional and National (M)	144 ± 8			Hard
Mendez-Villanueva et al. (2007)	International (M)		3.8 ± 2		Clay
Fernández-Fernández et al. (2007)	Junior (F)	161.2 ± 5.1	2.03 ± 0.8		Hard
Murias et al. (2007)	National (M)	135 ± 21 143 ± 22	1.16 ± 0.34 1.65 ± 0.60	27.48 ± 2.46 26.33 ± 3.25	Hard Clay
Fernandez-Fernandez et al. (2008)	International (F)		2.2 ± 0.9		Clay

LACTATE

Blood lactate is measured to determine the contribution of anaerobic glycolysis in the production of energy during exercise (Viru and Viru, 2003). In a sport such as tennis, it is well documented that the values of lactate are not high, being approximately 2-3 $mmol \cdot L^{-1}$ (Therminarias et al., 1990, 1995; Bergeron et al., 1991; Reilly and Palmer, 1995; Girard and Miller, 2004; Fernandez-Fernandez et al., 2007, 2008). Further, higher values have been cited, such as 4-5 $mmol \cdot L^{-1}$ (Therminarias et al., 1995; Christmass et al., 1995), and even 8 $mmol \cdot L^{-1}$ for professional players (Fernández et al., 2005) and 10 $mmol \cdot L^{-1}$ which must have been reached by players who were not very well trained (Therminarias et al., 1990). In spite of some isolated values, current studies maintain that the average concentration of blood lactate is approximately 2–4 $mmol \cdot L^{-1}$ (Fernandez-Fernandez et al., 2007, 2008; Méndez-Villanueva et al., 2008).

As observed in aforementioned parameters such as oxygen consumption or HR, the variability of lactate concentration according to time of incidence in the match has also been analyzed. However, the reports have been contradictory, as some authors do not find differences in the concentration between the action of serving and that of returning the serve (Smekal et al., 2001; Fernández-Fernández, 2007), with values of approximately 2-2.5 $mmol \cdot L^{-1}$. On the other hand, some authors do find differences (Fernandez et al., 2005; Méndez-Villanueva et al., 2007), citing values of about 4 $mmol \cdot L^{-1}$, which is higher when a player is serving. Nonetheless, there seems to be more consensus in the fact that lactate concentration is significantly higher on clay surfaces than on hard courts (Girard and Miller, 2004; Murias et al., 2007). This is relevant, since in tennis there are two large rest periods, although on clay the duration of the points is greater (Fernández-Fernández et al., 2007; Méndez-Villanueva et al., 2007), and thus there is a higher lactate concentration. This highlights the importance of the direction that training sessions should take in relation to the player's game style, the surface, and the competition's characteristics.

It has been observed that in standard tennis drills the values of lactate concentration vary from 2-4 $mmol \cdot L^{-1}$, with higher HR of 160-180 $lat \cdot min^{-1}$, attempting to produce adaptations that are more specific to the tennis match (Reid et al., 2008).

This application to training sessions is interesting, although it must be kept in mind that the level of lactate in the blood expresses in reality the relationship between the influx of lactate from the active muscles and the outflow of lactate from the blood toward the places where the processes of oxidation occurred. When the exercise activity is of moderate or low intensity, the rate of piruvate formation (which begins the production of future lactate) is in equilibrium with its speed of oxidation (Viru and Viru, 2003).

In tennis, the following are observed: large fluctuations in HR, values of maximal oxygen consumption on the court of approximately 50-60% of VO_{2max}, and lactate concentrations that do not exceed 4 $mmol \cdot L^{-1}$, and it must be kept in mind that the regulations allow a rest period between points and end changes (ITF, 2006).

PLAYING IN WARM CONDITIONS

A tennis tournament often requires that athletes have to compete in several matches in one day (singles and doubles), and sometimes on consecutive days, being able to get to prolong this situation for two weeks (Bergeron et al., 2007). Many tournaments are played under high temperature and humidity, sometimes increasing thermal stress, can lead to problems of heat and hydration for tennis players, both from a performance perspective, as health and safety (Kovacs, 2009).

Therefore, due to the continual intermittent, high intensity efforts maintained throughout the match, one of the aspects that most worries a tennis player is maintaining an optimal body temperature (Kovacs, 2006a). Despite the fact that tennis is not a sport that puts a player at risk, whenever it is hot though normal (Morante and Brotherhood, 2008), the aspects that stand out most are weight loss, sweat, plasma volume and electrolyte changes, as it is important that they remain as constant as possible during the competition so that other factors that are related to performance are not compromised.

Tennis players have a competition weight loss that varies between 0.5 and 1.5 kg, depending on the environmental characteristics, temperature, intake, intensity of the match, etc. (Elliott et al., 1985; Therminarias et al., 1991; Mitchell et al., 1992; Girard et al., 2006), while sweat loss can be between 0.5 and 3 L per hour, depending on the conditions (Bergeron et al., 1995; Bergeron, 2003), even junior tennis players (Bergeron, 2009). Despite the fact that the relationship between work time and rest time in tennis fluctuates between 1:2-1:4 (Reilly and Palmer, 1995; Smekal et al., 2001; Kovacs, 2007), and the tennis player has a 90 s rest period during the changes of court end where he or she can take in liquids, fluid replacement generally does not compensate for fluid loss (Therminarias et al., 1991; Mitchell et al., 1992), but to help reduce the rise in body temperature (Kovacs, 2009) Fluid intake by tennis players is not done in large quantities, and the normal amount is approximately 1 L per hour. Although that is not quite sufficient, a higher volume could cause gastrointestinal discomfort (Kovacs, 2006a). There is a risk for decreased athletic performance starting at a 2% loss in body fluids (Hornery et al., 2007a), though values of 1-2.7% have been observed in tennis (McCarthy et al., 1998; Girard et al., 2006; Torres-Luque and Villaverde, 2007). With 2.5% losses, serving, sprint capacity, and power are all affected (Magal et al., 2003). Therefore, since players play in a hot environment during a prolonged time, and since they can have fluid intake, the process of hydration and dehydration is important for this sport and to prevent a possible decrease in performance. In fact, changes in plasma volume (PV) during moderate or intense exercise are due to liquid displacement from the intravascular space toward interstitial and intracellular compartments of the active musculature (van Beaumont et al., 1981). The changes in PV are quite variable as they depend on the fluid replacement of the athlete, but it has been confirmed that the increase or maintenance of the PV is possible in long-duration sports if an adequate fluid intake is carried out, which favors exercise execution and avoids dehydration (Houmard et al., 1991; Speedy et al., 2000). On the other hand, it is interesting to emphasize that the changes in PV can change from negative to positive if the athletes are acclimated to the environmental conditions (Houmard et al., 1991), which is common in tennis because of its competition system. However, the data are controversial due to such large variations that exist from one study to another. Along these lines, there seems to be consensus in tennis in regard to the lack of variation or increase in PV (Bergeron et al., 1991; Mitchell et al., 1994; Kavasis, 1995; Torres-Luque and Villaverde, 2007) due to the regulations of the sport, as the rest periods between sets allow for a continual hydration (Kovacs, 2006b). Bergeron et al. (1995) observed a slight decrease in the PV after a warm-up (-0.7 ± 5.3%) that increased as the match went on, and resulted in an increase of 2.3 ± 4.1% at the end of the game and 5.1 ± 8.3% five minutes after the game. In a sport such as tennis, where players can take in solids and/or liquids freely throughout the competition during rest periods, this fluid replacement may be adequate for the demand (Bergeron et al., 1995; Bergeron et al., 2007; Torres-Luque and Villaverde, 2007).

Electrolyte balance is associated with the hydration-dehydration process, keeping in mind that sweat usually involves the loss of large quantities of sodium (Na^+) and potassium (K^+), and the decrease in potassium is one of the causes of cramps that can limit tennis performance (Kovacs, 2006a) with its short, high intensity movements. In a study with adolescent female players, it was observed that with good fluid intake before and during the match, despite increases in Na, decreases in K, and weight loss, PV remained positive and did not limit performance in a match lasting 100 min (Torres-Luque and Villaverde, 2007).

In relation to sweat losses, it should be highlighted that Bergeron et al. (2003) observed sweat losses of 89.8 mmoL per hour of match, surpassing the average daily intake which was 87-174 mmoL per day, advising a daily intake of sodium calculated to avoid muscular cramps, which is very important in competitions lasting various days. In 1995, Bergeron et al. (1995) studied male and female players and calculated that in three days of tournament play in a hot environment, sodium sweat loss was 158.7 mmoL per day for males and 86.5 mmoL for females, and potassium losses were 31.3 mmoL per day for males and 18 mmoL for females. It was observed that with a controlled intake, it is possible to alleviate the negative effect in competition.
Therefore, if the daily intake is adequate and the liquid intake during matches is monitored, electrolyte loss and PV changes can remain constant, which implies a guarantee of confronting practices and competitions with success.

CONCLUSION

Tennis is a sport with intermittent characteristics, but the temporal structure, HR, and VO_2 are modified in relatively constant intervals in relation to gender, court surface, and game style, and knowledge about these factors is critically important in order to prepare specific training sessions.

As tennis is generally played in a hot environment, there is weight loss due to sweat, which requires monitoring of fluid intake in order to lessen PV and electrolyte losses that can limit performance.

REFERENCES

1. BERGERON MF, LAIRD MD, MARINIK EL, BRENNER JS, WALLER JL. Repeated-bout exercise in the heat in young athletes: physiological strain and perceptual responses. *J appl physiol*. 2009; 106:476-485. doi:10.1152/JAPPLPHYSIOL.00122.2008 [Back to text]
2. BERGERON M, MARESH C, ARMSTRON L, SIGNORILE J, CASTELLANI J, KENEFICK R, LAGASSE K, RIEBE D. Fluid - electrolyte balance associated with tennis match play in a hot environment. *Int J Sport Nutr*. 1995; 5(3):180-193. [Abstract] [Back to text]
3. BERGERON M, MARESH C, KRAEMER W, ABRAHAM A, CONROY B, GABAREE C. Tennis: A physiological profile during match play. *Int J Sport Med*. 1991; 12(5):474-479. doi:10.1055/s-2007-1024716 [Back to text]
4. BERGERON MF, MCLEOD KS, COYLE JF. Core body temperature during competition in the heat: national boys' 14's junior tennis championships. *Brit J Sport Med.* 2007; 41:779-783. [Full Text] [Back to text]
5. BERGERON MF. Heat cramps: fluid and electrolyte challenges during tennis in the heat. *Journal Science Medicine Sport*. 2003; 6:19-27. doi:10.1016/S1440-2440(03)80005-1 [Back to text]
6. BERNARDINI M, DE VITO G, FALVO ME. Cardiorespiratory adjustment in middle-level tennis players: are long term cardiovascular adjustments possible? In: T Reilly, M Hughes, A Lees (Eds.). *Science and Racket Sports I*. London: E & FN Spon; 1998. [Back to text]
7. CHRISTMASS M, RICHMOND S, CABLE N, ARTHUR P, HARTMANN P. Exercise intensity and metabolic response in singles tennis. *J Sport Sci*. 1998; 16:739-747. doi:10.1080/026404198366371 [Back to text]

8. CHRISTMASS M, RICHMOND S, CABLE N, HARTMANN P. A metabolic characterisation of singles tennis. In: T Reilly, M Hughes, A Lees (Eds.). *Science and Racket Sports*. London: E & FN Spon; 1995. [Abstract] [Back to text]
9. DAVEY PR, THORPE RD, WILIAMS C. Simulated tennis matchplay in a controlled environment. *J Sport Sci*. 2003; 21:459-467. doi:10.1080/0264041031000101926 [Back to text]
10. DEUTSCH E, DEUSTCH SL, DOUGLAS PS. Exercise training for competitive tennis athletes. *Strength Conditioning*. 1998; 20:14-19. [Back to text]
11. ELLIOTT B, ACKLAND T, BLANSKY B, HOOD K, BLOOMFIELD J. Profiling junior tennis players Part 1: morphological, physiological and psychological normative data. *Australian Journal of Science and Medicine in Sport*. 1989; 21(3):14-21. [Abstract] [Back to text]
12. ELLIOTT B, DAWSON B, PYKE F. The energetics of singles tennis. *J Hum Movement Stud.* 1985; 11:11-20. [Back to text]
13. FERNÁNDEZ J, FERNÁNDEZ-GARCÍA B, MÉNDEZ-VILLANUEVA A. Activity patterns, lactate profile and ratings of perceived exertion (RPE) during professional tennis singles tournament. In: M Crespo, P Mclnerney, D Miley (Eds.). *Quality coaching for the future. 14 th ITF worldwide coaches workshop*. London: ITF; 2005. [Full Text] [Back to text]
14. FERNANDEZ J, MENDEZ-VILLANUEVA A, PLUIM B. Intensity of tennis match play. *Brit J Sport Med*. 2006; 40:387-391. [Full Text] [Back to text]
15. FERNÁNDEZ-FERNÁNDEZ J, MÉNDEZ-VILLANUEVA A, FERNÁNDEZ-GARCÍA B, TERRADOS N. Match activity and physiological responses during a junior female singles tennis tournament. *Brit J Sport Med*. 2007; 41:711-716. [Full Text] [Back to text]
16. FERNÁNDEZ-FERNÁNDEZ J, SANZ-RIVAS D, FERNÁNDEZ-GARCÍA B, MENDEZ-VILLANUEVA A. Match activity and physiological load during a clay-court tennis tournament in elite female players. *J Sport Sci*. 2008; 30:1-7. doi:10.1080/02640410802287089 [Back to text]
17. FERNÁNDEZ-FERNÁNDEZ J, SANZ-RIVAS D, SÁNCHEZ-MUÑOZ C, PLUIM MB, TIEMESSEN I, MENDEZ-VILLANUEVA A. A comparison of the activity profile and physiological demands between advanced and recreational veteran tennis players. *J Strength Cond Res*. 2009; 23(2):604-610. [Full Text] [Back to text]
18. FERRAUTI A, CHULZ H, STRÜDER HK. Metabolism in tennis and running with similar oxygen uptake and duration. *Int J Sports Med*. 1998; 19:(Suppl 22). [Back to text]
19. FERRAUTI A, BERGERON M, PLUIM B, WEBER K. Physiological responses in tennis and running with similar oxygen uptake. *Eur J Appl Physiol*. 2001; 85:27-33. doi:10.1007/s004210100425 [Back to text]
20. FERRAUTI A, WEBER K, WRIGHT PR. Endurance: basic, semi-specific and specific. In: M Reid, A Quinn, M Crespo (Eds.). *Strength and conditioning for tennis*. London: ITF; 2003. [Back to text]
21. GIRARD O, LATTIER G, MICALEF JP, MILLET GP. Changes in exercise characteristics, maximal voluntary contraction, and explosive strength during prolonged tennis playing. *Brit J Sport Med*. 2006; 40(6):521-526. [Full Text] [Back to text]
22. GIRARD O, MILLET GP. Effects of the ground surface on the physiological and technical responses in young tennis players. In: A Lees, J-F Kahn, IW Maynard (Eds.). *Science and Racket Sports III.* Routledge; Taylor & Francis Group; 2004. [Abstract] [Back to text]
23. GREEN JM, CREWS TR, BOSAK AM, PEVELER WW. A comparison of respiratory compensation thresholds of anaerobic competitors, aerobic competitors and untrained subjects. *Eur J Appl Physiol*. 2003; 90:608-613. doi:10.1007/s00421-003-0892-5 [Back to text]
24. GROPPEL D, ROETERT P. Applied physiology of tennis. *Sports Med*. 1992; 14(4):260-268. [Abstract] [Back to text]

25. HORNERY D, FARROW D, MÚJIKA L, YOUNG W. An integrated physiological and performance profile of professional tennis. *Brit J Sport Med*. 2007b; 41(8):531-536. [Abstract] [Back to text]
26. HORNERY D, FARROW D, MÚJIKA L, YOUNG W. Fatigue in tennis. Mechanisms of fatigue and effect on performance. *Sport Med*. 2007a; 37(3):199-212. [Abstract] [Back to text]
27. HOUMARD JA, WHEELER WS, MCCAMMON MR, HOLBERT D, ISRAEL RG, BARAKAT HA. Effects of fitness level and the regional distribution of fat on carbohydrate metabolism and plasma lipids in middle – to older – aged men. *Metabolism*. 1991; 40(7):714-719. doi:10.1016/0026-0495(91)90089-F [Back to text]
28. INTERNATIONAL TENNIS FEDERATION. *Rules of tennis*. London: ITF; 2006. [Back to text]
29. KAVASIS K. Fluid replacement needs of young tennis players. In: T Reilly, M Hughes, A Lees (Eds.). *Science and Racket Sports* I. London: E & FN Spon; 1995. [Abstract] [Back to text]
30. KIBLER W, MCQUEEN C, UHL T. Fitness evaluations and fitness findings in competitive junior tennis players. *Clin Sport Med*. 1988; 7(2):403-16. [Abstract] [Back to text]
31. KÖNIG D, HUONKER M, SCHMID A, HALLE M, BERG A, KEUL J. Cardiovascular, metabolic, and hormonal parameters in professional tennis players. *Med Sci Sport Exer.* 2001; 33(4):654-658. [Full Text] [Back to text]
32. KOVACS M. A comparison of work/rest intervals in men´s professional tennis. *Med Sci Sport Exer*. 2004; 33:654-658. [Full Text] [Back to text]
33. KOVACS M. Applied physiology of tennis performance. *Brit J Sport Med*. 2006b; 40:381-386. [Full Text] [Back to text]
34. KOVACS M. Hydration and temperature in tennis – A practical review. *Journal of Sports Science and Medicine.* 2006a; 5:1-9. [Full Text] [Back to text]
35. KOVACS M. Tennis physiology. Training the competitive athlete. *Sports Med*. 2007; 37(3):189-198. [Abstract] [Back to text]
36. KOVACS MS, STRECKER E, CHANDLER WB. Time analysis of work/rest intervals in men's collegiate tennis. *J Strength Cond Res*. 2004; 18:e364. [Back to text]
37. KOVACS MS. Heat and hydration recovery in tennis. In: MS Kovacs, TS Ellenbecker, WB Kibler (Eds.). *Tennis recovery: A comprehensive review of the research*. Boca Raton, Florida: USTA; 2009. [Back to text]
38. KRAEMER W, RATAMESS N, FRY A, TRIPLETT-MCBRIDE T, KOZIRIS P, BAUER J, LYNCH J, FLECK S. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *Am J Sport Med.* 2000; 28 (5):626-633. [Abstract] [Back to text]
39. MAGAL M, WEBSTER MJ, SISTRUNK LE, WHITEHEAD MT, EVANS RK, BOYD JC. Comparison of glycerol and water hydration regimens on tennis-related performance. *Med Sci Sport Exer*. 2003; 35(1):150-156. [Full Text] [Back to text]
40. McCARTHY PR, THORPE RD, WILLIAMS C. Body fluid loss during competitive tennis match-play. In: T Reilly, M Hughes, A Lees (Eds.). *Science and Racket Sports I*. London: E & FN Spon; 1998. [Back to text]
41. MÉNDEZ-VILLANUEVA A, FERNÁNDEZ-FERNÁNDEZ J, BISHOP D, FERNANDEZ-GARCÍA B, TERRADOS N. Activity patterns, blood lactate concentrations and ratings of perceived during a professional singles tennis tournament. *Brit J Sport Med.* 2007; 41:296-300. [Full Text] [Back to text]
42. MITCHELL J, COLE K, GRANDJEAN P, SOCZACK R. The effect of a carbohydrate beverage on tennis performance and fluid balance during prolonged tennis play. *Journal of Applied Sport Science Research*. 1992; 6(3):174-180. [Abstract] [Back to text]

43. MITCHELL J, GRANDJEAN P, PIZZA F, STARLING R, HOLTZ R. The effect of volume ingested on rehydration and gastric emptying following exercise – induced dehydration. *Med Sci Sport Exer*. 1994; 26(9):1135-1143. [Abstract] [Back to text]
44. MORANTE S, BROTHERHOOD J. Match Characteristics of Professional Singles Tennis. *Medicine and Science in Tennis*. 2005; 10(3):12-13. [Full Text] [Back to text]
45. MORANTE SM, BROTHERHOOD JR. Thermoregulatory responses during competitive singles tennis. *Brit J Sport Med*. 2008; 42:736-741. [Abstract] [Back to text]
46. MURIAS JM, LANATTA D, ARCURI CR, LAIÑO FA. Metabolic and functional responses playing tennis on different surfaces. *J Strength Cond Res*. 2007; 21(1):112-117. [Abstract] [Back to text]
47. O'DONOGHUE P, INGRAM B. A notational analysis of elite tennis strategy. *J Sport Sci.* 2001; 19:107-115. doi:10.1080/026404101300036299 [Back to text]
48. REID M, DUFFIEL R, DAWSON B, BAKER J, CRESPO M. Quantification of the physiological and performance characteristics of on-court tennis drills. *Brit J Sport Med*. 2008; 42(2):146-151. doi:10.1136/bjsm.2007.036426 [Back to text]
49. REILLY T, PALMER J. Investigation of exercise intensity in male singles lawn tennis. In: T Reilly, M Hughes, A Lees (Eds.). *Science and Racket Sports I*. London: E & FN Spon; 1995. [Abstract] [Back to text]
50. SÁNCHEZ-MUÑOZ C, SANZ D, ZABALA M. Anthropometric characteristics, body composition and somatotype of elite junior tennis players. *Brit J Sport Med*. 2007; 41:793-799. [Full Text] [Back to text]
51. SMEKAL G, VON DUVILLARD S, RIHACEK C, POKAN R, HOFMANN P, BARON R, TSCHAN H, BACHL N. A physiological profile of tennis match play. *Med Sci Sport Exer.* 2001; 33(6):999-1005. [Full Text] [Back to text]
52. SPEEDY DB, NOAKES TD, ROGERS IR, HELLEMANS I, KIMBER NE, BOSWELL DR, CAMPBELL R, KUTTNER JA. A propective study of exercise – associated hyponatremia in two ultradistance triathletes. *Clinic Journal Sport Medicine*. 2000; 10(2):136-141. [Abstract] [Back to text]
53. THERMINARIAS A, DANSOU P, CHIRPAZ-ODDOU M, QUIRINO A. Effects of age on heart rate response during a strenuous match of tennis. *J Sport Med Phys Fit.* 1990; 30:389-396. [Abstract] [Back to text]
54. THERMINARIAS A, DANSOU P, CHIRPAZ M, ETERRADOSSI J, FAVRE–JUVIN A. Cramps, heat stroke and abnormal biological responses during a strenuous tennis match. In: T Reilly, M Hughes, A Lees (Eds.). *Science and Racket Sports I*. London: E & FN Spon; 1995. [Abstract] [Back to text]
55. THERMINARIAS A, DANSOU P, CHIRPAZ M, GHARIB C, QUIRINO A. Hormonal and metabolic changes during a strenuous tennis match. Effect of ageing. *Int J Sports Med*. 1991; 12(1):10-16. doi:10.1055/s-2007-1024647 [Back to text]
56. TORRES G, CABELLO D, CARRASCO L. Functional differences between tennis and badminton in young sportsmen. In: A Lees, J-F Kahn, IW Maynard (Eds.). *Science and Racket Sports III.* Routledge; Taylor & Francis Group; 2004. [Abstract] [Back to text]
57. TORRES-LUQUE G, CABELLO-MANRIQUE D, HERNÁNDEZ-GARCÍA R, GARATACHEA N. An analysis of competition in young tennis players. *Eur J Appl Physiol*. 2011; 11(1):39-43. [Abstract] [Back to text]
58. TORRES-LUQUE G, VILLAVERDE C. Plasma volume and electrolyte changes after a female single tennis match. *Apunts. Medicina de l´esport.* 2007; 156:169-174. [Full Text] [Back to text]
59. UNIERZYSKI P. Influence of physical fitness specific to the game of tennis, morphological and psychological factors on performance level in tennis in different age groups. In: T Reilly, M Hughes, A Lees (Eds.). *Science and Racket Sports I*. London: E & FN Spon; 1995. [Abstract] [Back to text]

60. URHAUSEN A, COEN B, WEILER B, KINDERMANN W. Evaluation of physical performance and training monitoring. *Leistungssport.* 1990; 5:29–34. [Back to text]
61. VAN BEAUMONT W, UNDREKOFLER S, VAN BEAUMONT S. Erythrocyte volume, plasma volume and acid base changes in exercise and heat dehydration. *J Appl Physiol.* 1981; 50:1255-1262. [Abstract] [Back to text]
62. VERLINDEN M, VAN RUYSKENSVELDE J, VAN GORP B, DE DECKER S, GOOSSENS R, CLARIJS JP. Effect of gender and tennis court surface properties upon strategy in elite singles. In: A Lees, J-F Kahn, IW Maynard (Eds.). *Science and Racket Sports III.* Routledge; Taylor & Francis Group; 2004. [Abstract] [Back to text]
63. VIRU A, VIRU M. *Análisis y control del rendimiento deportivo*. Barcelona: Paidotribo; 2003. [Abstract] [Back to text]
64. WILLIFORD H, SCHARFF M, GAUGER S, DUEY W, BLESSING D. Cardiovascular and metabolic costs of forward, backward and lateral motion. *Med Sci Sport Exer*. 1998; 30(9):1419-1423. [Abstract] [Back to text]

