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ORIGINAL

RELATIONSHIP BETWEEN TECHNICAL AND PHYSIOLOGICAL PARAMETERS IN COMPETITION TENNIS PLAYERS

RELACIÓN ENTRE PARÁMETROS TÉCNICOS Y FISIOLÓGICOS EN TENISTAS DE COMPETICIÓN

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ABSTRACT

In recent years there has been an increased interest to assess physiological and technical parameters in tennis players; currently there are tests that allow registering these parameters in parallel on the tennis court. The aim of this study is to determine the relationships between technical and physiological parameters resulting from the application of a specific endurance test procedure for tennis players. 38 competitive male tennis players performed a continuous and incremental field test, recording technical (technical effectiveness [TE], point of decreasing TE [PDTE]) and physiological parameters (maximal oxygen uptake (VO_{2max}), first and second ventilatory thresholds (VT_1 and VT_2)). A significant relationship was found between PDTE and VT_2 ($r = 0.365$, $P < 0.05$) and between TE and VO_{2max} ($r = 0.459$, $P < 0.01$). In conclusion, players with a better aerobic profile tended to get better results in terms of TE and showed a tendency to decrease TE from the appearance of VT_2.

KEY WORDS: tennis, specific endurance, technical effectiveness, maximal oxygen uptake, ventilatory thresholds.

RESUMEN

Durante los últimos años ha aumentado el interés para evaluar parámetros fisiológicos y técnicos en jugadores de tenis, actualmente existen pruebas que permiten registrar paralelamente estos parámetros en la misma pista de tenis. El objetivo de este estudio es determinar las relaciones entre parámetros técnicos y fisiológicos derivados de la aplicación de una prueba de resistencia específica en tenis. 38 jugadores de competición realizaron una prueba continua e incremental y se registraron parámetros técnicos (efectividad técnica (ET), punto de disminución de efectividad técnica [PDET]) y parámetros fisiológicos (consumo máximo de oxígeno (VO_{2max}), primer y segundo umbrales ventilatorios [UV_1 y UV_2]). Se encontró una relación significativa entre PDET y UV_2 ($r=0.365$; $p<0.05$) y entre ET y VO_{2max} ($r=0.459$; $p<0.01$). En conclusión, los jugadores con mejor perfil aeróbico tendieron a obtener mejores resultados de ET y se observó una tendencia a disminuir la ET a partir de la aparición del UV_2.

PALABRAS CLAVE: tenis, Resistencia específica, efectividad técnica, consumo máximo de oxígeno, umbrales ventilatorios.

INTRODUCTION

In a tennis match a large number and variety of technical actions are performed. In Grand Slam tournaments, from 806 to 1445 hits have been recorded (Weber, 2003) and in a match with three sets, from 300 to 500 high-intensity efforts are performed (Fernández, Méndez-Villanueva and Pluim, 2006). In many cases, technical actions are performed at high execution speeds. When serving, players are capable of reaching a racket speed of 100 to 116 $km \cdot h^{-1}$, giving the ball a speed of 134 to 201 km·h^{-1} (Kovacs, 2007). For example, in South Korea in 2012, the tennis player Samuel Groth performed the quickest serve registered in an official ATP (Association of Tennis Professionals) tournament, with a speed of 263 km·h^{-1}. Most of these technical actions are done in an open game environment with a high level of accuracy. Even if it is very difficult to assess technical performance objectively in open game situations, the technical effectiveness (TE) hitting the ball in closed situations has been identified as a good parameter to predict the competitive performance of tennis players (Birrer, Levine, Gallippi and Tischler, 1986; Vergauwen, Spaepen, Lefevre, and Hespel, 1998; Smekal, Pokan, von Duvillard, Baron, Tschan and Bachl, 2000; Vergauwen, Madou and Behets, 2004; Baiget, Fernández, Iglesias, Vallejo and Rodríguez, 2014).

The ability of a tennis player to hit the ball, run and recover for the next point is, to a large extent, dependent on the physiological capacity to gain, transform and use energy (Renström, 2002). The average physiological intensity registered in simulated competitive matches is around 50% of the maximal oxygen uptake (VO_{2max}) (Fernández, Fernández, Méndez and Terrados, 2005; Ferrauti, Bergeron, Pluim and Weber, 2001; Murias, Lanatta, Arcuri and Laino, 2007; Smekal et al., 2003) and the average concentrations of lactate during the match are below 2.5 mmol·L^{-1} (Bergeron, Maresh, Kraemer, Abraham, Conroy and Gabaree, 1991; Ferrauti et al., 2001; Murias et al., 2007; Smekal et al., 2003), with match episodes where intensity increases these values up to 8 mmol·L^{-1} (Fernández et al., 2006).

During a match, there is an alternation of points with a single hit, like with a winning serve, and points played from the baseline using long and intense exchanges. The unpredictability of the duration of points, election of hits, strategy, total match time, opponent or weather conditions influence the physiological demands of tennis (Kovacs, 2006).

In recent years, there has been an increased interest in assessing physiological and technical parameters using specific protocols on the tennis court (Vergauwen, Spaepen, Lefevre and Hespel, 1998; Smekal et al., 2000; Vergauwen et al., 2004; Landlinger, Stöggl, Lindinger, Wagner and Müller, 2012; Baiget et al., 2014). Hit performance tests have been suggested to assess the players' ability to aim the ball at a given place on the court (Vergauwen et al., 1998; Vergauwen et al., 2004; Moya, Bonete, and Santos-Rosa, 2010) or to assess the speed and accuracy of the hit (Landlinger et al., 2012). To assess the specific endurance, most tests use incremental tests (Smekal et al., 2000; Baiget, Iglesias and Rodríguez, 2008; Girard, Chevalier, Leveque, Micallef and Millet, 2006; Ferrauti, Kinner and Fernandez, 2011; Baiget et al., 2014). Protocols exist that assess physiological and load parameters by simulating a hit (Girard et al., 2006) or hitting a ball fixed to a pendulum (Ferrauti et al., 2011). Specific endurance tests have also been suggested that allow assessing physiological and technical parameters in parallel using the hit accuracy register (Smekal et al., 2000; Baiget et al., 2008; Baiget et al., 2014). Even if different variables stemming from these tests have been described, such as physiological parameters like oxygen uptake (VO_2) (Smekal et al., 2000; Baiget et al., 2014) lactate in blood (Smekal et al., 2000) or ventilatory thresholds (VT) (Baiget et al., 2014); and technical parameters such as the percentage of good hits (TE) (Smekal et al., 2000; Baiget et al., 2008; Baiget, Iglesias, Vallejo y Rodríguez, 2011; Baiget et al., 2014) or the point of decrease in technical effectiveness (PDTE) (Baiget et al., 2008; Baiget et al., 2011) there is no known relationship between these variables from assessing them jointly.

AIMS

Given the relative importance of technical and physiological parameters in competition tennis and considering the possibilities offered by new protocols to assess these parameters jointly, it seems convenient to observe the relationships that exist between the different variables that could be assessed using a specific test. Therefore, the aim of this study is to determine the existing relationships between maximal and sub-maximal technical and physiological parameters stemming from using a specific tennis endurance test for competition players.

MATERIALS AND METHODS

The design of this study is descriptive and correlational, and shows the outcomes registered with the same sample and circumstances as those in the study published by Baiget et al. (2014).

Sample

38 male competition tennis players (18.2 ± 1.3 years; 180 ± 0.08 cm in height; 72.7 ± 8.6 kg in weight; mean ± SD) volunteered to participate in the study. They were selected according to their level of competition, which was assessed using the International Tennis Number (ITN) and was between 1 (elite) and 4 (advanced) (ITN 1= 8 players; ITN 2 = 10 players; ITN 3 = 9 players; ITN 4 = 11 players). 89.5% of participants had a right lateral dominance. Players had an average experience in competition training of 6.6 ± 2.0 years and on average received 3.7 ± 0.5 and 1.5 ± 0.4 hours of technical training - tactical and physical - respectively. All participants were members of high performance training centres for tennis.

Procedure

Maximal and sub-maximal technical and physiological parameters were registered with a Smekal et al. (2000) modified specific endurance test on a tennis court (Baiget et al., 2014). The test is a maximal, continuous and scaled protocol conducted by a ball machine (Pop-Lob Airmatic 104, France). Players performed alternate forehand and backhand hits with the rhythm set by the ball machine. Figure 1 shows the tennis court and the design of the protocol used.

Players were given instructions to adjust their movement speed so they would reach the area where they had to hit the ball at the time the ball bounced on the court.

To ensure the energy expenditure of hits in relation to the technique used remained homogeneous, players were only allowed lifted forehand and backhand hits. The test started with a ball throw frequency ($Ball_f$) of 9 shots·min^{-1} which was increased every 2 minutes at a ratio of 2 shots·min^{-1} until the players were no longer able to follow the rhythm set by the ball machine hitting two consecutive balls. The ball velocity (68.6 ± 1.9 km·h^{-1}, CV 2.7%) and the wind speed (V_{wind} < 2 m·s^{-1}) were constant and were monitored using a radar (Stalker ATS 4.02, EUA) and a digital anemometer (Plastimo, France). The angle and height at which the ball exited the machine in relation to the horizontal ground line was 13º and 41 cm, respectively. Tests were performed between the months of February and April, during non-competitive periods and using a standard, open-air tennis court with a hard surface and medium speed (Green Set®) that had previously been marked off with white sticky tape. 40 standard new tennis balls (BabolatTeam®, Japan) approved by the International Tennis Federation (ITF) were used. Players did not participate in any competition, test or training with high demand during 24 hours prior to the test. Registers started after a standard 18-min warm-up consisting in a general 10-minute continuous run, dynamic flexibility, several types of moves and races with acceleration, 5 min of specific warm-up with a low to moderate-intensity rallying in the centre of the court and 3 min of familiarization with the test going through the protocol with a $Ball_f$ of 9 shots·min^{-1}.

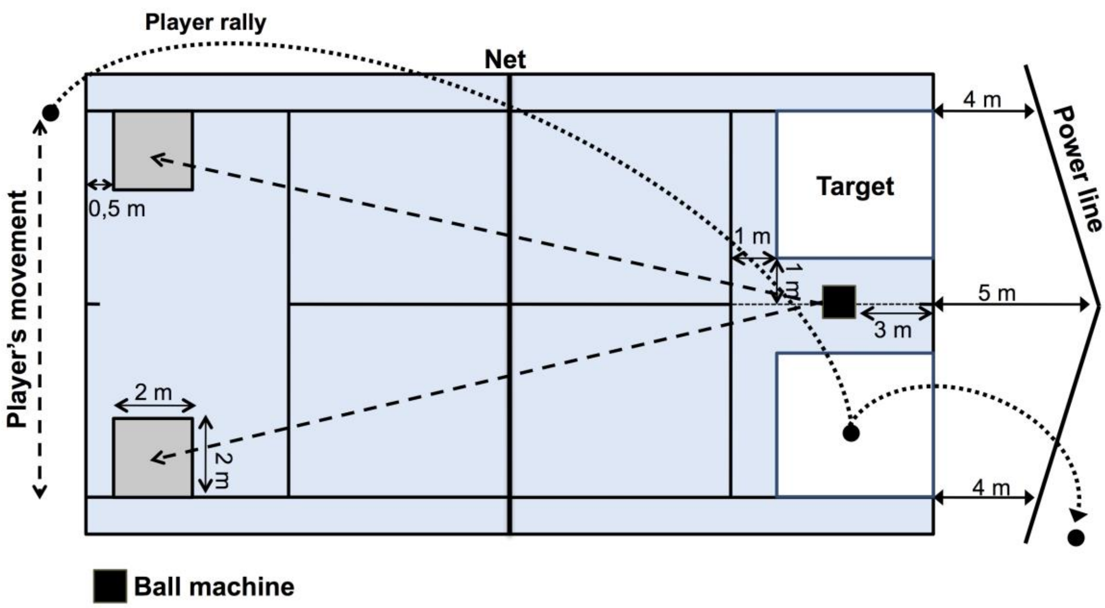

Figure 1. Test illustration (Baiget et al., 2014).

Physiological parameters

Gas exchange and pulmonary ventilation were registered continuously using a portable gas analyser (K4 b^2, Cosmed, Italy). Data were registered breath-by-breath and later processed at mean values every 15 seconds. Registrations began two minutes before each test (morning or afternoon) with the ambient air calibrated before each test.

The maximal physiological parameter was determined as the maximal oxygen uptake (VO_{2max}) and sub-maximal values were detected using ventilatory thresholds (VT) calculated with the changes in ventilatory parameters identifying the slope variation points or linearity rupture (Beaver, Wasserman and Whipp, 1986). VTs were determined using the model provided by Skinner and MacLellan (1980).

First ventilatory threshold (VT_1) was determined using the criteria of an increase in the ventilatory equivalent for oxygen (V_E/VO_2) without an increase in the ventilatory equivalent for carbon dioxide (V_E/VCO_2) and a non-linear increase in pulmonary ventilation (V_E).

Second ventilatory threshold (VT_2) was determined using the increase in the ventilatory equivalent for oxygen (V_E/VO_2) and in the ventilatory equivalent for carbon dioxide (V_E/VCO_2).

Maximal oxygen uptake (VO_{2max}) was determined by observing a plateau or levelling-off of VO_2 or when the increase between two consecutive period was lower than 150 $ml \cdot min^{-1}$.

Technical parameters

In parallel to the physiological register an objective assessment was made of the technical parameters registered in real time by calculating the relative frequencies (percentages) of successes and errors, assessing both the accuracy and the power of hits using areas marked-off on the court (figure 1). Players performed the hits from left to right of the court (right-backhand) moving laterally and aiming the ball into the marked-off area (target). Hits were considered successes or errors based on the accuracy criteria (a ball hit by the player should bounce in the target) and the power criteria (once the ball had bounced in the target, it had to go beyond the power line before bouncing a second time). For a hit to be considered successful it had to fulfil both requirements (accuracy and power).

Technical effectiveness (TE) (% of successful hits) is an objective assessment of the percentage of successful hits during the test following the accuracy and power criteria. It is the percentage of successful hits per period in 30-second intervals.

Point of decreasing technical effectiveness (PDTE) (period number) is the point of inflection determined by the last TE value of each period from where on the individual falls below his or her average TE (the arithmetic mean values during the whole test) and no longer surpasses this mean value (Baiget et al., 2008; Baiget et al., 2011).

Statistical analysis

Normal distribution of variables was assessed with the Kolmogorov-Smirnov test. The relationship between the quantitative variables was established with a lineal correlation analysis calculating Pearson's linear correlation coefficient (r). The level of signification was established at a value $p < 0.05$. All analyses were done using the SPSS statistics programme for Windows, version 15.0 (SPSS Inc., USA).

RESULTS

The test had a maximum average duration of 13:36 min:s corresponding to 6.6 ± 0.83 periods. Table 1 shows the relationship between the technical parameters, represented by the PDTE and TE; and physiological parameters, represented by VT_1, VT_2 and VO_{2max}. A weak, yet statistically significant, relationship is observed between PDTE and VT_2, which would suggest that players showed a tendency to decrease their TE as of VT_2. Separately, there is a moderately significant relationship between TE and VO_{2max}, indicating that players with a better aerobic profile tend to have a better TE and, consequently, make fewer errors in the test.

Table I. Coefficient correlations (r) between the technical parameters (PDTE and TE) and physiological parameters (VT_1, VT_2 y VO_{2max}) registered during the specific endurance test.

Technical parameters	Physiological parameters		
	VT_1 ($mL \cdot Kg \cdot min^{-1}$)	VT_2 ($mL \cdot Kg \cdot min^{-1}$)	VO_{2max} ($mL \cdot Kg \cdot min^{-1}$)
PDTE (period)	0.306	0.365*	0.332
TE (% effectiveness)	0.296	0.324	0.459**

*Significant correlation p<0.05; **Significant correlation p<0.01; PDTE: point of decreasing technical effectiveness; TE: technical effectiveness; VT_1: first ventilatory thresholds VT_2: second ventilatory threshold; VO_{2max}: maximal oxygen uptake.

PDTE was detected during the period 5.2 ± 1.1 corresponding to 80.6 ± 14.5% of the maximum period achieved. This point coincides with the period where VT_2 is observed in 10 players, representing 27.7% of all cases. A statistically significant relationship was found between the PDTE and the period where VT_2

is observed ($r=0.408$; $p<0.05$). Figure 2 gives an example of how the technical parameters (TE) and physiological parameters (VO_2 and VCO_2) during the test with one player. During the first stages a slightly positive evolution of TE is observed until the technical parameter PDTE and the sub-maximal physiological parameter VT_2 coincide in time (10:00 min:s; period 5); from then on TE drops sharply.

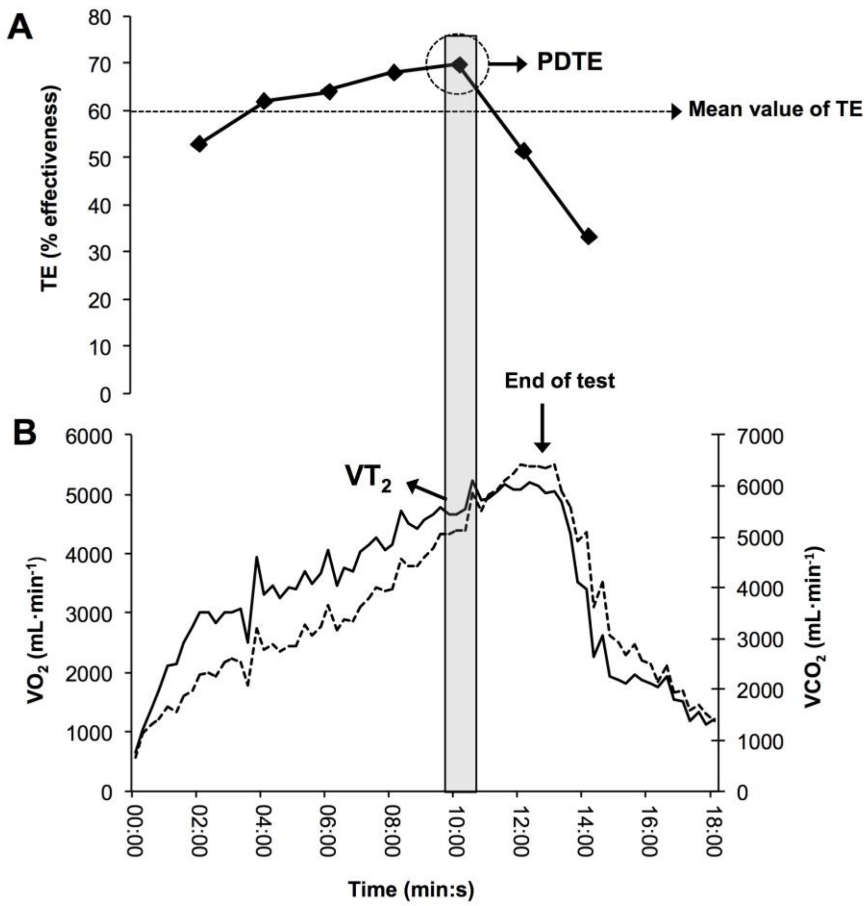

Figure 2. Evolution of Technical effectiveness (TE), oxygen uptake (VO_2) and carbon dioxide output (VCO_2) (B) during the test with one player. The point of decreasing technical effectiveness (PDTE) (A) and the second ventilatory threshold (VT_2) (B) are also shown. The darker strip indicated the coincidence in time for PDTE and VT_2.

DISCUSSION

The results of this study indicate that when performing a specific endurance test assessing technical and physiological parameters in parallel (Baiget, et. al., 2014), players with a better aerobic profile tend to get better results in terms of TE and that this TE tends to decrease as of the moment VT_2 is reached.

Competition tennis is a sport with a high demand both at a technical level and at a physiological level (Kovacs, 2007). Relationships have been observed between the competitive performance of competition players and technical and physiological parameters (Birrier et al., 1986; Vergauwen et al., 1998; Smekal et al., 2000; Vergauwen et al., 2004; Banzer, Thiel, Rosenhagen and Vogt, 2008; Baiget et al., 2014). Even though the physiological (Smekal et al., 2000; Baiget et al., 2008) and technical (Vergauwen et al., 1998; Vergauwen et al., 2004; Moya et al., 2010; Landlinger et al., 2012; Baiget et al., 2014) profiles of competition tennis players has been described in relation to endurance or ball hitting performance tests, there is little literature on the relationship between these parameters that determine performance.

The significant relationship found between the PDTE and VT_2 ($r=0.365$; $p<0.05$); and the PDTE and the period when VT_2 is observed ($r=0.408$; $p<0.05$), even if not a close one, shows that players clearly tend to lower their TE as of VT_2. This relationship could mean that players who reach this threshold with a higher load may experience the PDTE later on in time. In this same sense, relationships between the PDTE and the heart rate deflection point (HRDP) in competition players have also been described (Baiget et al., 2008). The evolution of the exposed TE of a player (figure 1) follows the line seen in the outcomes reported by Baiget et al. (2014), identifying 3 differential stages. A first stage of adaptation is observed (periods 1 to 3) where, even if the intensity is low, the level of TE is lower. Then a stage of moderate intensity is observed where the maximal effectiveness happens (periods 4 and 5) and, finally, after reaching VT_2, TE decreases gradually (periods 6 and 7).

With intensities higher than VT_2 the player would enter a stage of metabolic acidosis as a consequence of the increase in lactate concentration. This would cause a decrease in pH, which is a factor linked to the inhibition of the phosphofructokinase enzyme (PFK) and to a decrease in glycolysis which could contribute to the early fatigue process (Shephard and Astrand, 1996; Gómez, Cossio, Brousett and Hochmuller, 2010). This metabolic situation is related to a drop in muscle power (Sahlin, 1992) and would affect the player’s technical performance negatively, causing a drop in the TE. This could possibly be due to the interaction of several factors such as the decrease in hit synchronicity, reduced general dynamic coordination or an inadequate hit position. An accumulation of lactic acid in the muscle has a negative impact on the ball hitting performance in tennis. Lactate concentrations above 7-8 $mmol \cdot L^{-1}$ are associated with a decrease in both technical and tactical performance in tennis (Lees, 2003; Davey, Thorpe and Williams, 2002). Similarly, Davey et al. (2002) reported a big decrease in the precision of hits (69%) between the start of a specific intermittent test (Loughborough Intermittent Tennis Test) and the precision observed at the end of the test (35.4 ± 4.6 min); they attributed this to the high concentration of lactate in blood (9,6 ± 0,9 $mmol \cdot L^{-1}$).

On another note, given that tennis is a sport with marked alactic aerobic and anaerobic characteristics (König, Huonker, Schmid, Halle, Berg and Keul, 2001; Smekal et al., 2001; Elliott, Dawson and Pyke, 1985; Chandler, 1995; Renström, 2002) and that during competition it is very rare to work at intensities above the VT_2 or close to VO_{2max} (Ferrauti et al., 2001; Christmas, Richmond, Cable, Arthur and Hartmann, 1998; Smekal et al., 2003; Fernández et al., 2005), it can be hypothesized that tennis players are not specifically prepared for hits in a state of metabolic acidosis.

Considering the likely negative effect of lactate accumulation on ball hitting performance, it would be logical to think that a higher VT_2 would delay the appearance of fatigue in a progressive test and consequently a decrease in TE. For future research, it would be interesting to observe how the VT_2 level affects certain match situations; for instance, during a high-intensity and long play for points.

The quality of movement patterns and coordinating specific actions in tennis depends on the physiological effort made during short-term intermittent exercise (Kovacs, 2006). The relationship observed between TE and VO_{2max} ($r=0.459$; $p<0.01$) indicated that players with a better aerobic profile tend to have a better TE and therefore make fewer mistakes during the test. Even if the relationship between these two variables isn't very close, probably because tennis is a multi-factor sport and several factors are involved that may affect TE, it would seem that the level of endurance may affect technical components of TE, maybe due to the negative effects of fatigue on the player's technical performance. Fatigue moves in gradually virtually from the moment the effort starts (López Calbet and Dorado García, 2006). It is possible that players with a higher VO_{2max}, when faced with a same load or period, bear a lower relative physiological intensity and, therefore, participate with lower fatigue levels. Fatigue affects performance regarding racquet skills and is seen in a poor position game and with a decrease in the accuracy of hits (Lees, 2003; Fernández, 2007). Significant reductions have been observed in the speed of serves (3.2%) and the accuracy of forehand hits (21.1%) after an exercise inducing fatigue in competition players (Rota and Hautier, 2012). It is logical to consider that a higher VO_{2max} may contribute to obtaining better results in terms of TE in a progressive endurance test. It has been found that fatigue induced by specific tennis training with 2 hours of playing translates into a significant increase in the percentage of mistakes and into a significant decrease in the speed of the hit (Vergauwen et al., 1998).

Even if performance in tennis is of a multi-factor nature, it seems necessary to have adequate levels of resistance to face the demands of competition. A good aerobic capacity allows for an adequate recovery between points and maintaining the game intensity for the entire duration of the match (Konig et al., 2001; Smekal et al., 2001). In this sense it has been suggested that for an adequate competition performance, competition tennis players should have a VO_{2max} that is above 50 $ml \cdot kg \cdot min^{-1}$; however, extremely high levels (i.e. >65 $ml \cdot kg \cdot min^{-1}$) do not guarantee a better performance in this sport (Kovacs, 2007). Relationships have been found between competitive performance and maximal physiological parameters such as VO_{2max} (Baiget et al., 2014) or submaximal physiological parameters as VT_2 (Baiget et al., 2014) or HRDP (Baiget et al., 2008).

CONCLUSIONS

Players with a better aerobic profile tend to get better results in terms of TE in a specific endurance test assessing technical and physiological parameters in parallel; this is possibly because they participate with lower levels of fatigue during most of the test. TE tends to decrease as of the appearance of VT_2, which is likely to result from the impact of the accumulation of lactic acid on the technical performance of hits.

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