A physiological profile of tennis match play

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ABSTRACT

SMEKAL, G., S. P. VON DUVILLARD, C. RIHACEK, R. POKAN, P. HOFMANN, R. BARON, H. TSCHAN, and N. BACHL. A physiological profile of tennis match play. *Med. Sci. Sports Exerc.*, Vol. 33, No. 6, 2001, pp. 999–1005. **Purpose:** The aim of this investigation was to examine physiological demands of single match play in tennis. **Methods:** 20 players performed 10 matches of 50 min. Respiratory gas exchange measures (RGEM) and heart rates (HR) were measured using two portable systems. Lactate concentration was determined after each game. The average oxygen uptake ($\dot{V}O_2$) of 270 games was 29.1 ± 5.6 mL·kg^{-1}·min^{-1} (51.1 ± 10.9% of $\dot{V}O_{2max}$). Average $\dot{V}O_2$ for a game ranged from 10.4 to 47.8 mL·kg^{-1}·min^{-1} (20.4 and 86.8% of $\dot{V}O_{2max}$). Average lactate concentration (LA) was 2.07 ± 0.9 mmol·L^{-1} (ranging from 0.7 to 5.2 mmol·L^{-1}). Furthermore, we monitored the duration of rallies (DR), the effective playing time (EPT), and the stroke frequency (SF). The average values of 270 games were DR: 6.4 ± 4.1 s, EPT: 29.3 ± 12.1%, SF: 42.6 ± 9.6 shots·min^{-1}. **Results:** Multiple regression revealed that the DR was the most promising variable for the determination of $\dot{V}O_2$ in match play (r = 0.54). The body surface area (BSA) and EPT were also entered into the calculation model. In games of two defensive players, $\dot{V}O_2$ was significantly higher than in games with at least one offensive player. **Conclusion:** Our results suggest that energy demands of tennis matches are significantly influenced by DR. The highest average $\dot{V}O_2$ of a game of 47.8 mL·kg^{-1}·min^{-1} may be regarded as a guide to assess endurance capacity required to sustain high-intensity periods of tennis matches compared with average $\dot{V}O_2$ of 29.1 mL·kg^{-1}·min^{-1} for the 270 games. Our results suggest that proper conditioning is advisable especially for players who prefer to play from the baseline. **Key Words:** TENNIS FIELD TEST, LACTATE, OXYGEN UPTAKE

Scientifically based training protocols depend on the specific demands of certain type of sports. In sports with intermittent activity like tennis, physiological demands imposed on the athletes during competition cannot be simulated in controlled laboratory settings and therefore have to be determined during real match play. Only limited data on tennis play performance exist in literature. Some studies have monitored heart rate (HR), metabolic, and hormonal responses during match play (2,7–9,11,13,14,17,20,21,24,29). Lactate concentrations (LA) have been used to estimate the intensity in tennis competition (2,13,19,21,24,25,29). However, LA measurement is problematic when associated with the intensity of physical stress, especially in sports with intermittent loads such as tennis. Despite their stop-and-start nature, these sports have a high aerobic component because high-energy phosphates used for immediate energy requirements of muscles are predominately resynthesized by oxidation during recovery periods without essential conversion of pyruvate to lactate (12). Therefore, measurement of oxygen uptake ($\dot{V}O_2$) also includes the amount of $\dot{V}O_2$ required to restore high-energy phosphates in recovery between rallies, games, and sets. Respiratory gas exchange measures (RGEM) can be monitored continuously and are not associated with relatively long half-life periods like lactate (4,6). In addition, $\dot{V}O_2$ is less influenced by psychological stress and mental concentration (1).

Limited data are available regarding RGEM during tennis match play. In an earlier study, Seliger et al. (25) selected 16 male subjects from the top 50 players in Czechoslovakia and measured $\dot{V}O_2$ during 10 min of tennis match play. In this study, the expired air was collected in Douglas bags for the measurement of average $\dot{V}O_2$. In another study, Ferrauti et al. (13) measured $\dot{V}O_2$ in 12 senior tennis players (6 male and 6 female) during tennis competitions.

The main purpose of our study was to measure the RGEM of young elite tennis players during ten 50-min tennis single matches to assess the energy requirements of tennis players in real time. Continuous measurement of $\dot{V}O_2$ was a variable of interest to obtain information about average and peak intensities of tennis match play. Benefiting from recent development of portable systems, it was possible to measure RGEM (in 10-s intervals) for both tennis players.

In addition, we also investigated factors that significantly influence the energy demands of tennis match play. In this context, we considered the pattern of physical demand and recovery (described by the duration of rallies and the effective playing time), the pace of a match (described by the

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frequency of shots performed in the rallies), the tactical behavior of players (defensive vs offensive playing), and the playing situation (serve or returned play). This consideration was supported by previous investigations, which reported higher HR and LA in matches with higher effective playing time (21,29), and higher HR in service-games, when compared with return games (21).

MATERIALS AND METHODS

Subjects

Twenty healthy male volunteers (age 26.0 ± 3.7, height 181.0 ± 5.7 cm, weight 73.2 ± 6.8 kg, body surface area (BSA) 1.92 ± 0.12 m^2) participated in the study. BSA was estimated from height and weight as suggested by Gehan and George (15). All participants were tennis players of the two highest leagues in Austria. Concerning national ranking of the players, one of them was ranked under the top 30, three were ranked under the top 50, six were ranked under the top 100, and the rest was ranked under the top 200. None of them had an ATP ranking. Our test design consisted of two tests: a maximal treadmill test and a field test for match analyses. All players were subjected to a maximal treadmill test to gain information about individual aerobic power and aerobic capacity of players ($\dot{V}O_{2max}$; $\dot{V}O_2$ at a blood lactate levels of 4.0 $mmol \cdot L^{-1}$). These laboratory data were used as reference values for the comparison between the individual aerobic capacities of players and the $\dot{V}O_2$ demand of tennis competition. The human subjects committee of the University of Vienna approved the study and all subjects signed informed consent.

Experimental Procedures

Treadmill testing. The exercise was performed on a Jäger LE 6000 motorized treadmill (Jäger, Würzburg, Germany). The maximal treadmill test consisted of an initial workload of 8 $km \cdot h^{-1}$, with an increment of 2 $km \cdot h^{-1}$, every 3 min at constant grade of 1.5%. The test ended with voluntary exhaustion of subjects. Blood samples from hyperemic earlobe were taken after completion of each stage and immediately at the end of each test for analysis of LA. RGEM were measured using a portable telemetry system (Cortex Metamax, Germany) and recorded after 10-s intervals. HR was determined by means of a chest-belt telemetry monitor (Polar NV, Finland), which was transmitted to the portable system. The volume calibration of the system for gas analysis was conducted before each test day and the gas calibration was performed before each test. Blood LA was determined by the full-enzymatic method utilizing Eppendorf ESAT 6661 (Eppendorf, Hamburg, Germany) in both the treadmill tests and the field tests.

Field testing. One week after the treadmill testing, the tennis players performed the field test. Both players were equipped with a portable system for gas analysis (Cortex Metamax). As in the laboratory, RGEM were calculated in intervals of 10 s. Before each match, subjects performed a standardized warm-up for 10 min. In the beginning, both subjects played ground strokes for 2 min (players were asked to play the balls to the center of the court), volleys plus over head plays for 6 min (one player on the baseline, the other playing volleys), and services for 2 min. After the warm-up, a blood sample in the amount of 20 μL was taken from the earlobe again. Two min after the warm-up, the single match play started. The matches were limited to 50 min plus the time required to finish the last game. After each game, there was a break of 30 s for blood collection and subsequent LA analysis. Blood samples from hyperemic earlobe were taken 5–10 s after completion of each game. The 20 players who participated in our study performed 10 test matches (135 games). The matches were conducted on an indoor clay court. A set of six new balls (Kennex, Carlsbad, CA) were used for each test.

A match protocol was developed to monitor and record the duration of each game and each rally, the number of shots per rally, the duration of change-over breaks, and the total duration of the test. The protocol also included information about the points won or lost by the serving and receiving player. From these data, the following variables were calculated for each game: 1) the duration of rallies (DR in s); 2) effective playing time (effective playing time (EPT) expressed in percent of the total time of play in a game); and 3) effective playing time including breaks between the games (EPT+b expressed in percent of the total time of a match), and the frequency of shots (SF in $shots \cdot min^{-1}$). 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. The effective playing time including breaks (EPT+b) was determined by dividing the entire playing time of a match (from beginning of the first rally until the end of the last rally) by the real playing time (sum of all rallies performed in the specific match). The SF was calculated by dividing the duration of the rally by the number of shots performed in the rally. For the calculation of SF we only considered rallies where the ball crossed the net at least three times.

We also attempted to investigate if the player's style (defensive or offensive type play, and play from the baseline or serve-volley play) influenced the $\dot{V}O_2$ of tennis match play. Therefore, the 10 matches of our study were divided into two groups of games. When selecting subjects, we accounted for the classification in both groups (defensive or offensive). Three experts, who were familiar with the style of play of all subjects had to classify the players as offensive or defensive players. In one group we had 63 games (5 matches) performed by defensive players (subjects preferred to play from the baseline). In the other group, there were 72 games (5 matches) with at least one offensive player (players who preferred serve-volley play).

Statistics

Statistical analyses were conducted using Statistica software (Version 5.1 StaSoft, Inc.). The results were expressed as mean ± SD. Data obtained for games performed by two defensive players were compared with games performed by at least one offensive player using unpaired-sample *t*-tests. The unpaired-sample *t*-test was also used to calculate differences between serve-and-return games. The level of significance was set at $P < 0.01$. For the calculation of $\dot{V}O_2$ of tennis match play (270 games), all predictor variables which showed a correlation of $P < 0.05$ (Pearson product moment correlation) with $\dot{V}O_2$ play were included in a forward stepwise linear multiple regression procedure. The same statistical procedure was used for the calculation of LA during tennis match play.

RESULTS

The treadmill tests led to following mean values at maximal load: 1) $\dot{V}O_2$ was 57.3 ± 5.1 $mL \cdot kg^{-1} \cdot min^{-1}$; 2) running velocity of 16.4 ± 1.4 $km \cdot h^{-1}$; 3) HR of 193 ± 9 bpm; 4) pulmonary ventilation (V_E) of 131.2 ± 16.4 $L \cdot min^{-1}$; and 5) blood LA of 10.61 ± 2.04 $mmol \cdot L^{-1}$. We also determined average RGEM corresponding to a LA at 4.0 $mmol \cdot L^{-1}$ ($\dot{V}O_2$: 45.7 ± 5.2 $mL \cdot kg^{-1} \cdot min^{-1}$; running velocity: 12.6 ± 1.9 $km \cdot h^{-1}$; HR: 172 ± 10 bpm; and V_E: 92.6 ± 12.6 $L \cdot min^{-1}$).

The field tests in our study consisted of 135 games played in 10 matches. To assess the physiological responses and demands of tennis match play, $\dot{V}O_2$, HR, V_E, and LA were calculated as mean values for all games performed by all players (270 games). $\dot{V}O_2$, HR, and V_E were first determined as mean values (10-s data) for each game. LA was measured after each game. The average $\dot{V}O_2$ of 270 games was 29.1 ± 5.6 $mL \cdot kg^{-1} \cdot min^{-1}$. This average value was 51.1 ± 10.9% of $\dot{V}O_{2max}$ measured on treadmill and 64.6 ± 15.5% of $\dot{V}O_2$ determined from blood LA at 4 $mmol \cdot L^{-1}$ on treadmill. For a single game, the average $\dot{V}O_2$ ranged from 10.4 to 47.8 $mL \cdot kg^{1} \cdot min^{-1}$. These average values calculated for a game with the lowest and highest $\dot{V}O_2$ were 20.4 (86.8%) of the $\dot{V}O_{2max}$ and 24.8 (110.3%) of the $\dot{V}O_2$ calculated at blood LA of 4.0 $mmol \cdot L^{-1}$. The average LA for 270 games was 2.07 ± 0.88 $mmol \cdot L^{-1}$. Average LA ranged from 0.7 to 5.2 $mmol \cdot L^{-1}$ per game. Average values of 270 games yielded HR (151 ± 19 bpm) and V_E (59.2 ± 12.8 $L \cdot min^{-1}$). In addition, the variables describing the characteristics of the matches (DR, EPT, and SF) were determined as mean values of 270 games. The mean value for the EPT+b was calculated for 10 matches. The average values of 270 games resulted in 6.4 ± 4.1 s for DR, 29.3 ± 12.1% for EPT and 42.6 ± 9.6 shots per minute for SF. Calculating mean values for EPT+b (mean values of 10 matches) was 16.3 ± 6.6%. There was a high correlation between EPT and EPT+b of r = 0.99.

A forward stepwise linear regression was used to select the most promising independent variables for determination of $\dot{V}O_2$ of tennis match play (270 games). The following independent variables were considered to effect energy demands: EPT, DR, SF, $\dot{V}O_{2max}$ on treadmill, $\dot{V}O_2$ calculated at LA of 4.0 $mmol \cdot L^{-1}$ on treadmill, the maximal running speed on treadmill, the running speed calculated at LA of 4.0 $mmol \cdot L^{-1}$, and the BSA of the players. In the first step of linear multiple regression, DR was included into the multiple regression model. This single variable yielded 29.1% (r = 0.54) of the variance in $\dot{V}O_2$ for tennis match play. Combining all other variables into the model, the BSA and the EPT increased the r-values significantly. The final model revealed a correlation of r = 0.58 (see Fig. 1). When performing the same statistical procedure (and the same variables) for calculation of LA, results were similar to $\dot{V}O_2$. A multiple regression for the duration of rallies was again included into the model in the first step (r = 0.56). In this case only BSA increased the correlation significantly (r = 0.65).

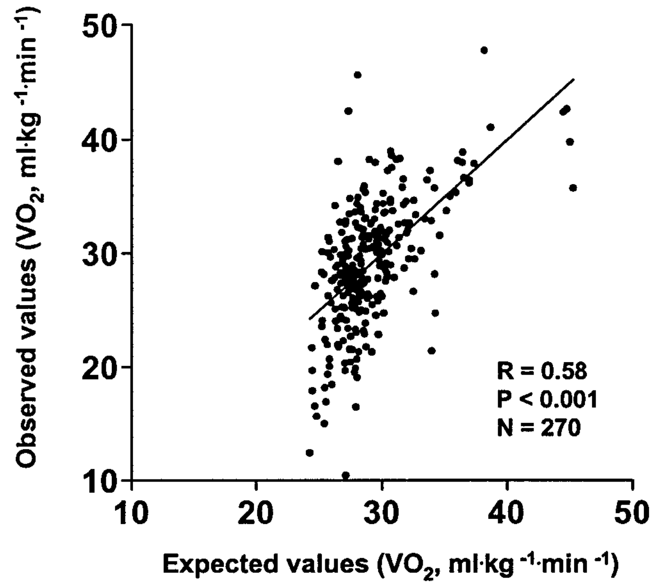

FIGURE 1—Heart rate (HR), lactate concentration (LA), and oxygen uptake ($\dot{V}O_2$) of two male tennis players (P1, P2) performing a single tennis match (MaP). The results of MaP are shown in the middle graph.

We also investigated the influence of tactical behavior (defensive or offensive players = play from the baseline or serve-volley play) in relation to the energy demands of tennis competition. The 10 matches of our study were divided into two groups of games. In one group we had 63 games (5 matches) performed by two defensive players (subjects who were known to prefer play from the baseline). In the other group, there were 72 games (5 matches) with at least one offensive player (players who preferred to serve and volley). Three experts who were familiar with the style

TABLE 1. Oxygen uptake ($\dot{V}O_2$), heart rate (HR), pulmonary ventilation (V_E), lactate concentration (LA), effective playing time (EPT), duration of rally (DR) and frequency of shots (SF) of two groups of games.

Variables	Games "Defense"	Games "Offense"	Sig.
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	30.8 ± 5.7	27.5 ± 5.1	$P < 0.001$
HR (bpm)	158 ± 16	145 ± 19	$P < 0.001$
V_E ($L \cdot min^{-1}$)	61.5 ± 13.3	57.0 ± 12.1	$P < 0.01$
LA ($mmol \cdot L^{-1}$)	2.5 ± 0.9	1.7 ± 0.7	$P < 0.001$
EPT (%)	29.3 ± 12.1	20.3 ± 8.2	$P < 0.001$
DR (s)	8.2 ± 5.1	4.8 ± 1.8	$P < 0.001$
SF ($strokes \cdot min^{-1}$)	42.6 ± 9.6	47.1 ± 6.9	$P < 0.001$

Games "defensive" (126 games) performed by two defensive players; Games "offensive" (144 games) performed by at least one offensive player. Values are mean ± SD and significant differences (Sig.).

TABLE 2. Oxygen uptake ($\dot{V}O_2$), heart rate (HR), pulmonary ventilation (V_E), and lactate concentration (LA) of 135 service games and return games.

Variables	Service Games	Return Games	Sig.
$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	29.5 ± 5.7	28.6 ± 5.5	$P > 0.20$
HR (bpm)	152 ± 18	150 ± 20	$P > 0.27$
V_E (L·min^{-1})	59.2 ± 12.9	59.2 ± 12.7	$P > 0.99$
LA (mmol·L^{-1})	2.1 ± 0.9	2.0 ± 0.9	$P > 0.29$

Values are mean ± SD and significant differences (Sig.).

of play of all subjects had classified the players with regard to offensive or defensive style of play. There was a complete agreement among the three experts in classification of offensive or defensive players. When comparing games performed by two defensive players with games with at least one offensive player, $\dot{V}O_2$ (as well as HR, V_E, LA, DR, and EPT) were significantly higher in games performed by two defensive players (Table 1). Comparing serve-and-return games the energy demands were similar and not significantly different (Table 2).

DISCUSSION

In racket sports such as tennis, the sport specific technical skills are predominant factors (23,26). In contrast to these technical demands, the physiological demands of tennis match play are often not sufficiently defined and therefore underestimated. However, the player's physical fitness can be a decisive factor that may make a difference between success and failure in tournament tennis. Thus, physiological profiling of tennis players may become a crucial factor in designing physical conditioning programs according to sport specific demands.

The development of portable systems, reduced in size and weight, allows the monitoring of RGEM during tennis match play. By using two systems, we were able to monitor RGEM for both participating players simultaneously (Fig. 2). Measuring RGEM (especially $\dot{V}O_2$) was of particular interest for us, because $\dot{V}O_2$ reflects energy demands that cannot be detected by metabolic variables (such as LA). This is especially true for sports with intermittent load profiles in which short peak loads are interrupted by long periods of low intensities or recovery. During the short, high-intensity periods, the high-energy phosphate bonds (ATP, CrP) are predominately utilized, whereas, during longer periods of low intensity or in recovery, these phosphate bonds are largely regenerated by oxidation. Occasionally in games with long rallies, the oxidative mechanism of energy supply has to be supported by anaerobic glycolysis (16,27,28). However, LA can be oxidized locally in the working muscles or transported to other muscles for oxidation during recovery or rest (5,22). This process requires oxygen and therefore can be detected by means of respiratory gas exchange measures. Another advantage of respiratory gas exchange variables is that they can be monitored continuously. They are not associated with long half- life periods like lactate (3,4,10) and therefore reflect physiological responses to the actual activity patterns.

In our on court test series of 270 games, 135 games were played by 20 players. As previously mentioned, we were particularly interested in $\dot{V}O_2$. $\dot{V}O_2$ was first calculated as mean values (10 s data) for each game. These average $\dot{V}O_2$ values for each game were calculated as average values for all games performed by all players (270 games). The average $\dot{V}O_2$ of 270 games was 29.1 ± 5.6 mL·kg^{-1}·min^{-1}. This value resulted in 51.1 ± 10.9% of the $\dot{V}O_{2max}$ and 64.6 ± 15.5% of the $\dot{V}O_2$ determined from LA at 4.0 mmol·L^{-1} on treadmill. The $\dot{V}O_{2max}$ values of our subjects are compara-

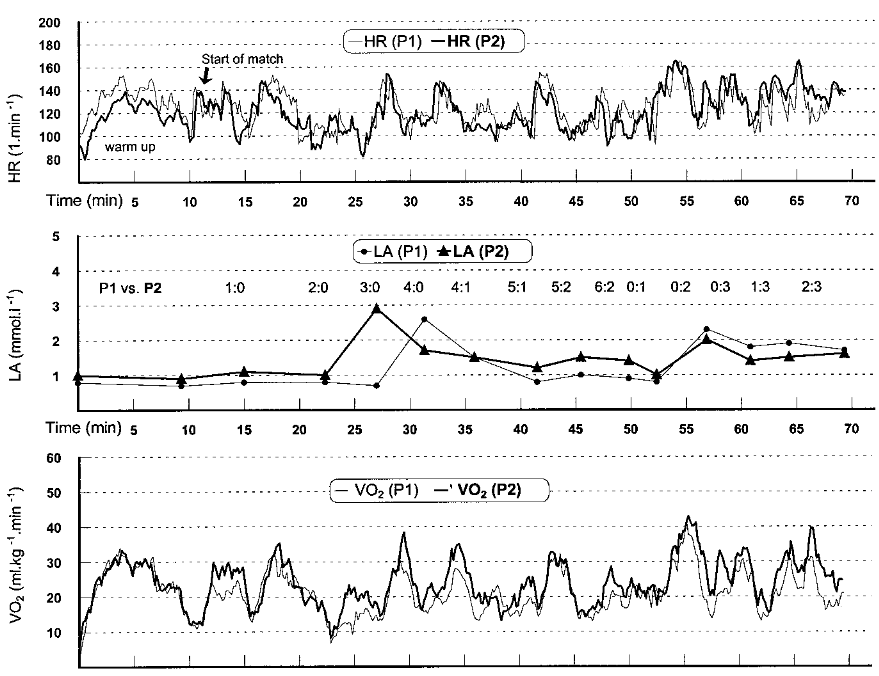

FIGURE 2—Forward stepwise multiple linear regression analysis for the dependent variable $\dot{V}O_2$ of tennis match play (270 games). Independent variables entered into the regression model: DR (duration of rallies), BSA (body surface area), and EPT (effective playing time).

ble to those reported for male U.S. collegiate players (6) but lower than those reported for world class professional players (18). From the average $\dot{V}O_2$ values of 270 games, we concluded that the average energy demands of tennis match play are rather low. Comparing our data with the literature, only a few $\dot{V}O_2$ data are available that were measured during tennis competition. In 1973, Seliger (25) selected 16 male players from the top 50 in Czechoslovakia and monitored the average $\dot{V}O_2$ during 10 min of match play. He found $\dot{V}O_2$ to range from 24–28 $mL \cdot kg^{-1} \cdot min^{-1}$ (mean 27.3 ± 5.5 $mL \cdot kg \cdot min^{-1}$). This value corresponds to approximately 50% of maximal aerobic power of the subjects. In another study, Ferrauti et al. (13) measured RGEM during tennis play. In this study, the investigators measured $\dot{V}O_2$ for 12 senior tennis players (6 male and 6 female) and reported average $\dot{V}O_2$ values of 24.2 ± 2.0 $mL \cdot kg^{-1} \cdot min^{-1}$ (54.3 ± 3.1% $\dot{V}O_{2max}$) for male subjects and 23.1 ± 3.0 $mL \cdot kg^{-1} \cdot min^{-1}$ (59.2 ± 7.0% $\dot{V}O_{2max}$) for female subjects. These average $\dot{V}O_2$ values observed for men were about 19% below the values presented in our study. Also the HR values reported by Ferrauti et al. (13) (140.1 ± 15.5 bpm for men and women) were lower than those recorded in our study (151 ± 19 bpm). These discrepancies are largely the result of differences in the age (47.0 ± 5.0 yr vs 26.0 ± 3.7 yr in our study) and fitness levels (mean $\dot{V}O_2$max of 39.0 ± 5.1 $mL \cdot kg^{-1} \cdot min^{-1}$ for women and 45.4 ± 12.9 $mL \cdot kg^{-1} \cdot min^{-1}$ for men vs 57.3 ± 5.1 $mL \cdot kg^{-1} \cdot min^{-1}$ in our subjects).

We proceeded from the assumption that average values do not represent all the patterns of physical activity in tennis competitions. Therefore, we also focused on high physical demands, which may occur over longer periods in tennis matches. We calculated the highest average for $\dot{V}O_2$ observed for the entire game. The value of 47.8 $mL \cdot kg^{-1} \cdot min^{-1}$ represented 76.7% of the $\dot{V}O_{2max}$ and 110.3% of the $\dot{V}O_2$ at LA at 4.0 $mmol \cdot L^{-1}$ for the players determined during the treadmill test. This $\dot{V}O_2$ value determined for a game may represent uncommonly high-intensity games (i.e., long, straining rallies of two baseliners, in a hot and humid environment). Thus, high-intensity games may serve as a guide for energy demands required to sustain high-intensity periods predominantly by aerobic mechanisms of energy supply.

The DR, EPT, and SF were variables used to describe the characteristics of a match. Like $\dot{V}O_2$, these variables were also calculated as mean values of 270 games (DR: 6.4 ± 4.1 s; EPT: 29.3 ± 12.1%; SF: 42.6 ± 9.6 shots per minute). The EPT corresponded to 16.3 ± 6.6% (mean value of 10 matches) when including the breaks between the games. This value yielded a ratio between physical activity and recovery of 1 to 3.4 within the games and 1 to 6.1 when the breaks between the games were included. There was a correlation of r = 0.99 between the EPT and EPT+b (data of 10 matches). We only utilized one of the two variables for our statistical analysis. In our study, we used the EPT because this variable could be calculated for every game. Our results for DR and EPT are in agreement with those presented by other studies (Table 3).

TABLE 3. Tennis match analyses: data published in previous studies investigating tennis single match play.

Variables	*N*	DR (s)	EPT (%)	Court
Weber et al. (29)	18	5.08	16.4	Hard
Schmitz (24)	16	7.17 ± 0.7	19.0 ± 2.8	Clay
Reilly and Palmer (21)	8	5.3 ± 1.0	27.9	Hard

Average heart rate (HR), lactate concentration (LA, $mmol \cdot L^{-1}$), oxygen uptake ($\dot{V}O_2$, $mL \cdot kg^{-1} \cdot min^{-1}$) of tennis match play, court surface and $\dot{V}O_{2max}$ measured in a laboratory setting.

Finally, we attempted to ascertain if the elected study variables would influence the energy demand of tennis match play. Within this context, we considered variables describing the characteristics of the match (DR, EPT, and SF). In addition, we were interested in variables referring to the unspecific endurance capacity of the players (the $\dot{V}O_{2max}$ on treadmill, $\dot{V}O_2$ calculated at LA of 4.0 $mmol \cdot L^{-1}$ on treadmill, the maximal running speed on treadmill, and the running speed determined at LA of 4.0 $mmol \cdot L^{-1}$), and the BSA of players. A forward stepwise linear regression was used to determine the most promising independent variables for the determination of $\dot{V}O_2$ in tennis match play (270 games). Results of statistical analyses revealed that DR and EPT were significant contributors for the calculation of $\dot{V}O_2$ in tennis match play. In addition, the BSA of the players was included in the multiple regression model. The forward linear stepwise regression calculated DR (r = 0.54) as the predominant predictor variable. Adding all other variables into the regression model, the BSA was negatively correlated with $\dot{V}O_2$ and EPT increased the r-value significantly. The final model revealed a correlation of r = 0.58 (Fig. 1). These results agree with previous investigations (21,29) that reported significantly higher physiological responses (higher HR and LA) in matches with longer rallies and higher EPT. Practically speaking, our results demonstrate that the $\dot{V}O_2$ in tennis match play is significantly influenced by the characteristics of a match (duration of the rallies) and by anthropometric data. However, these data also show that we were not able to derive the oxygen cost of the respective activity pattern from our study variables with satisfactory precision. This is not surprising because movement patterns in tennis are very complex and depend on variety of factors that cannot be easily described.

When performing the same statistical procedure (with the same independent variables) for the calculation of LA results were similar for those determined for $\dot{V}O_2$. DR was again calculated as the most promising variable (r = 0.56) and BSA again increased the correlation (r = −0.65) significantly. Statistical analyses did not reveal a significant contribution of the subjects' endurance capacity to LA in tennis competition. Our results are in agreement with previous studies (2,13,19,21,24,29) which also found that the endurance capacity of players was sufficient to fulfill the energy demands for tennis matches without much contribution from the anaerobic mechanisms of energy supply (Table 4).

TABLE 4. Tennis match analyses: data published in previous studies during tennis single match play.

Variables	Sex	N	HR	LA	$\dot{V}O_2$	Court	$\dot{V}O_{2max}$
Seliger et al. (25)	M	16	143.0 ± 13.9	—	27.3 ± 5.5	—	—
Weber et al. (29)	M	18	147.5 ± 10.5	2.15	—	Hard	—
Kindermann et al. (19)	M	12	145.9 ± 19.8	2.0 ± 0.5	—	—	—
Schmitz (24)	M	16	143.4 ± 12.4	2.59 ± 1.02	—	Clay	—
Bergeron et al. (2)	M	10	144.6 ± 13.2	2.3 ± 1.2	—	Hard	58.5 ± 9.4
Reilly and Palmer (21)	M	8	146.0 ± 19.0	2.0 ± 0.4	—	Hard	58.5 ± 9.4
Ferrauti et al. (13)	M_{sen}	6	—	1.53 ± 0.65	24.2 ± 2.0	—	—
	F_{sen}	6	—	—	23.1 ± 3.0	—	—

$_{sen}$, seniors; —, no study variable.
Average duration of rally (DR), effective playing time excluding breaks between the games (EPT), effective playing time including breaks between the games (EPT_{inbr}).

There is also evidence that the style of play (offensive vs defensive) profoundly influenced energy demands. Games in which both players were baseliners (players who predominately prefer the game from the baseline) resulted in a significantly higher $\dot{V}O_2$ (Table 1). In addition, EPT, DR, HR, V_E, and LA were also significantly higher (Table 1). In games with at least one offensive player, we found significantly higher values for SF. In contrast to the results of Reilly and Palmer (21), the energy demands in our study proved to be similar in respect to serve-and-return play (Table 2).

We concluded that: 1) Our study of 270 games of elite male tennis players during match competition resulted in an average energy expenditure ($\dot{V}O_2$) of 29.1 $mL \cdot kg^{-1} \cdot min^{-1}$ (51% of $\dot{V}O_{2max}$). For the intensities observed in our study, ATP restoration for energy supply was primarily achieved by aerobic mechanisms. 2) The highest average $\dot{V}O_2$ of 47.8 $mL \cdot kg^{-1} \cdot min^{-1}$ calculated for a whole game may be regarded as a reference for matches with uncommonly high intensities. In addition, it may also serve as a guide for aerobic capacity requirements to sustain even high-intensity periods of tennis match play predominately through aerobic mechanisms of energy supply. 3) In our study, the energy demands were significantly influenced by DR (long rallies resulted in higher physiological loads). 4) Games performed by two defensive players (baseliners) resulted in longer rallies and higher energy demand compared with games with at least one offensive player. 5) Therefore, proper conditioning is advisable, especially for tennis players who prefer a play from the baseline.

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