Journal of Strength and Conditioning Research, 2007, 21(3), 909–914

GAME ANALYSIS AND ENERGY REQUIREMENTS OF ELITE SQUASH

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ABSTRACT. Girard, O., R. Chevalier, M. Habrard, P. Sciberras, P. Hot, and G.P. Millet. Game analysis and energy requirements of elite squash. *J. Strength Cond. Res. 21(3):909–914. 2007.*—The aim of this study was to describe the game characteristics and energy requirement in elite squash. Seven players (ranked 1–25 in their national federation, including the world number 1) performed a squash-specific incremental test to volitional exhaustion and 3 squash games simulating competition. Pulmonary gas exchanges, heart rate (HR), and blood lactate concentration ([LA]) were recorded by portable analyzers. Energy expenditure ($EE_{\dot{V}O_2}$) was evaluated by indirect calorimetry. Temporal structure was determined from video recordings. The mean oxygen uptake ($\dot{V}O_2$), HR, $EE_{\dot{V}O_2}$, and [LA] were 54.4 ± 4.8 ml·min⁻¹·kg⁻¹ (86 ± 9% of $\dot{V}O_2$max reached in the incremental squash test), 177 ± 10 beats·min⁻¹ (92 ± 3% of HRmax), 4,933 ± 620 kJ·h⁻¹, and 8.3 ± 3.4 mmol·L⁻¹, respectively. Time spent >90% of $\dot{V}O_2$max and HRmax was 24 ± 29% and 69 ± 18% of the total match duration, respectively. [LA] was correlated ($R = 0.87$; $p = 0.01$) with time spent >90% of $\dot{V}O_2$max. The mean rally duration yielded 18.6 ± 4.6 s, and 34.6% of the rallies were <10 s, and 32.6% were >21 s. The effective playing time was 69.7 ± 4.7%. World-standard squash is predominantly a high-intensity aerobic activity with great emphasize on the anaerobic energy systems and a high uncertainty in the course of match play. To improve squash results, coaches should plan training according to the characteristics of the sport. By showing the contribution of the different energy pathways and variables easily controllable during training sessions (e.g., HR, rally duration, lactate), the accurate prescription of conditioning session is improved.

KEY WORDS. cardiopulmonary responses, oxygen uptake, blood lactate, performance, racquet sport

INTRODUCTION

Squash consists of repeated, short, high-intensity, intermittent bouts. The rallies have a duration of 5–20 seconds interspersed by shorter resting periods of about 7–8 seconds (14, 21, 27). Most studies on the physiologic profile of squash players have included maximal oxygen uptake measurements on treadmill and have shown that aerobic fitness is important in players of various standards (11, 17, 24, 30). Nevertheless, it was suggested that endurance-type training has to be limited because it might induce an increase in the magnitude of the fast-to-slow shift in muscle myosin heavy chain phenotype, thus reducing strength, speed, and explosiveness (19). A limitation of testing in laboratories is that it is nearly impossible to design a protocol that can reflect the specific muscular and movement patterns of a particular sport. This is especially true in ball games or racquet sports like squash, in which laboratory settings cannot simulate the physiologic characteristics of this intermittent activity, including many dynamic lower-limb (e.g., repeated accelerations, decelerations, turns, and jumps) and upper-limb (e.g., shoulder internal/external rotations, forearm pronation, wrist flexion) movements (6, 10, 29).

To date, only a few studies on squash have reported physiologic variables other than laboratory-based assessments of aerobic pathway (13, 21). In addition, little has been reported on energy requirements of real squash match play on the basis of blood lactate concentration ([LA]) (18, 31) or heart rate (HR) (11, 24, 31) measurements. It was shown that HRmax in squash competitions was close to the age-related maximum and that the mean HR often exceeded 75% of this value (13). On-court oxygen uptake ($\dot{V}O_2$) values have been estimated from HR recorded during squash singles against players of similar standard and were ~80% of $\dot{V}O_2$max (15, 32) in trained players. However, it is well documented that this way of estimating $\dot{V}O_2$ is inaccurate because on-court HR can be influenced by factors such as ambient temperature, humidity, stress of competition, or use of the arms (15, 18, 32). It is also known that this method overestimates the $\dot{V}O_2$ response during intermittent exercise (1).

Recently, portable gas analyzers have been used in racquet sports such as tennis (28) to measure the energy expenditure of players. To the best of our knowledge, in squash, the study of Todd et al. (31) is the only one in which $\dot{V}O_2$ was averaged continuously (15 seconds) during short (3-minute) competitions in 12 county-level players. In this latter study, the mean intensity was estimated at 75% of $\dot{V}O_2$max. Several authors (13, 17, 24) have reported that low-skill athletes respond in a different way than their higher skilled counterparts, mainly because of processes of adaptation within the cardiovascular system (e.g., economy of heart function, improved peripheral vascularization, preponderant action of the vagal system, or a combination of factors) (12). For example, Reilly and Halsall (24) have reported that HR and rating of perceived exertion (RPE) responses to squash match play were ~12–20% higher in a group of recreational players than in a group of regular competitors. Therefore, cardiopulmonary responses to competition in elite squash players remain unclear.

Thus, the aim of this study was to describe the characteristics of squash and to determine the energy requirements during test matches in elite players.

METHODS

Experimental Approach to the Problem

The protocol developed in this study involving subjects performing 3 squash games aimed to simulate physiologic responses to actual squash competition. The experimental design was mainly descriptive. Numerous dependent variables were measured during (physiologic and temporal structure variables) as well as before and after (subjective

FIGURE 1. One subject in action with the portable gas analyzer.

and metabolic variables) squash singles. These dependent variables were used to describe the characteristics of elite squash to determine the temporal structure and the energy requirements. Physiologic, subjective, and metabolic variables were also compared between the 3 squash games, and a coefficient of variation (CV = [*SD*/mean] × 100) was calculated for each variable. The present study's findings could then be used to plan training with greater precision.

Subjects

Seven well-trained male squash players (age 24.9 ± 4.1 years; height 177.0 ± 5.9 cm; body mass 72.1 ± 6.1 kg) participated in the study. Participants were ranked 1–25 in their national squash federation and competed in professional squash tournaments. Three were ranked within the top 50 by Professional Squash Association (PSA) ranking, including the current number 1 and current World champion. The mean time spent in training during the 6 months preceding the experiments was 22.8 ± 2.9 $h\cdot wk^{-1}$. The program focused on squash-specific aerobic and anaerobic capabilities enhancement and included (a) on-court aerobic exercises, (b) repeated sprints, (c) plyometric exercises, and (d) resistance exercises. The human subjects committee of the local university approved the study, and all participants signed informed consent.

Experimental Design

Subjects were tested in early June during a precompetitive period (a month before a major tournament). Two experimental sessions were conducted during a 10-day testing period: (a) a squash-specific continuous incremental test to volitional exhaustion (squash test, ST) for determination of $\dot{V}O_2$max and (b) a set of 3 squash games (SG) simulating competition. Squash trials were performed on an indoor synthetic squash court (Figure 1). In the 24 hours before each session, players were requested to refrain from consuming caffeine and alcohol. Testing sessions were conducted under standard environmental conditions (temperature ~25° C, relative humidity ~60%) at the same time of day.

The following gas exchange variables were collected with a breath-by-breath portable gas analyzer (K4b^2; Cosmed, Rome, Italy): $\dot{V}O_2$, respiratory exchange ratio (RER), minute ventilation ($\dot{V}$E), and breathing frequency (Bf). HR was recorded by the K4b^2 with athletes wearing a chest belt (Polar Electro, Kempele, Finland). The gas analyzer was calibrated before and after each trial with a 3-L syringe (Hans Rudolph Inc., Dallas, TX) and a known gas concentration (16.0% O_2 and 5.0% CO_2). RPEs were recorded with the Borg 6-20 scale, and 25-μL capillary blood samples were taken from the fingertip and analyzed for [LA] with the Lactate Pro (LT-1710; Arkray, Japan) portable analyzer after warm-up, at the point of volitional fatigue, after a 3-minute recovery period during ST, and 30 seconds after each game during SG.

Procedures

Incremental Squash Test. All participants performed a squash-specific incremental test to volitional exhaustion (ST) (as previously described by Girard et al. [10]). Briefly, it consisted of repeated displacements replicating the squash game, at an increasing speed on the court. $\dot{V}O_2$max and HRmax were determined as the highest 30-second mean values. Three criteria were used to determine maximal efforts: (a) a plateau or leveling-off in $\dot{V}O_2$, defined as an increase of <1.5 $ml\cdot min^{-1}\cdot kg^{-1}$, despite a progressive increase in exercise intensity; a final RER of ≥ 1.1; a final HR $>95\%$ of the age-related maximum. Time to exhaustion (T_e, seconds) was recorded.

Squash Games. After a standardized warm-up lasting 5 minutes (PSA rules), each participant carrying the gas analysis system performed a set of 3 competitive SG against a player of similar standard. A 2-minute rest period separated each SG. SG were performed according to the "point-per-rally scoring" in which a point was scored at the end of every rally regardless of whether the winner held serve or not. In accordance with the rules applied in professional men tournaments since 1988, the first player accounting for 11 points was declared the winner. Nevertheless, winning or loosing SG was likely inconsequential to the players since they were asked to compete 3 games, whatever the score of the first 2 games.

The following cardiopulmonary variables (e.g., $\dot{V}O_2$, RER, $\dot{V}_E$, Bf, and HR) were determined as mean values (5 seconds of data). Times sustained above 90 and 95% of $\dot{V}O_2$max and HRmax (determined from ST) were determined. $\dot{V}O_2$ and RER were used to calculate energy expenditure ($EE_{\dot{V}O_2}$, $kJ\cdot h^{-1}$) by indirect calorimetry (23). The intergame recovery periods were not taken into consideration for analysis. To investigate if the metabolic responses of a player were influenced by the performance level of his opponent, differences between the ranking of the 2 players (Δ_{Rank}) were correlated with the differences between their mean $\dot{V}O_2$ during the game ($\Delta\dot{V}O_2$).

The temporal structure of squash singles was determined by filming each game with a video camera (JVC, Ottawa, Ontario, Canada). From the tapes, a researcher timed the duration of each rally, which allowed to calculate the following mean variables: a) duration of rallies (DR, seconds); b) rest time between the rallies (RT, seconds); c) exercise-to-rest ratio (ERR, ratio of DR to RT; a nondimensional variable); d) total playing time (TPT, seconds); real playing time (RPT, seconds) corresponding to the sum of DR; e) effective playing time (EPT, ratio of RPT to TPT, %). In addition, the number of points that occur in each game (total points) was measured.

Statistical Analyses

Mean and standard deviations were calculated for all variables. The normality of the distribution of the variables and the homogeneity of variance were tested and accepted. A 1-way repeated measures analysis of variance was

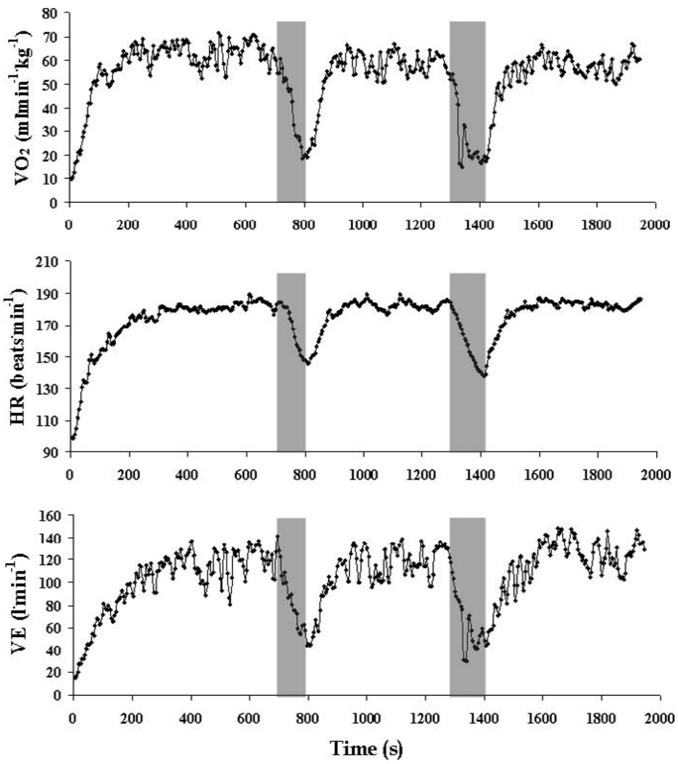

FIGURE 2. Oxygen uptake ($\dot{V}O_2$), heart rate (HR), and minute ventilation ($\dot{V}E$) of 1 player performing squash games. Values are mean 5-second intervals. The shadowed areas indicate intergame recovery periods.

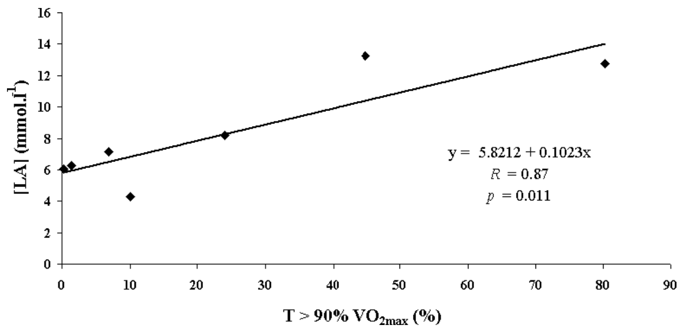

FIGURE 3. Relationship between time sustained over 90% of $\dot{V}O_2max$ ($T > 90\%$ $\dot{V}O_2max$, %) and blood lactate concentration ([LA]) ($n = 7$). T > 90% $\dot{V}O_2max$ was expressed as a percentage of total playing time.

used to compare measures in the 3 SG. When differences were identified, a post hoc Tukey test was used to determine where they lay. Pearson correlation coefficients were used to examine relationships between selected variables. For all statistical analyses, $p \leq 0.05$ was accepted as the level of statistical significance (SigmaStat 2.3; Jandel Corporation, San Rafael, CA).

RESULTS

Incremental Squash Test

The ST led to the following maximal values measured in the last stage: (a) T_e 1,056 ± 180 seconds with 12.6 ± 2.8 completed stages; (b) $\dot{V}O_2max$ 63.6 ± 3.0 ml·min^{-1}·kg^{-1}; (c) HRmax 193.0 ± 7.9 beats·min^{-1}; (d) RER 1.10 ± 0.06; (e) $\dot{V}Emax$ 149.0 ± 15.2 L·min^{-1}; (f) RPE 16.1 ± 1.7; (g) [LA] 12.1 ± 5.1 mmol·L^{-1} at the point of volitional fatigue and 9.6 ± 4.6 mmol·L^{-1} after a 3-minute recovery period.

Squash Games

Cardiopulmonary Variables. After an initial rapid rise from the resting values to the first minutes of SG, physiologic variables (e.g., $\dot{V}O_2$, HR, $\dot{V}E$) remained stable throughout SG and decreased markedly only during intergame recovery periods (Figure 2). The mean $\dot{V}O_2$ and HR of 21 games were 54.4 ± 4.8 ml·min^{-1}·kg^{-1} and 177 ± 10 beats·min^{-1}, respectively. These mean values were 86 ± 9% (67–94%) and 92 ± 3% (87–96%) of $\dot{V}O_2max$ and HRmax, respectively, determined from ST. The mean values of 21 games resulted in $\dot{V}E$ = 102.6 ± 12.1 L·min^{-1}, Bf = 47.9 ± 4.8 breaths·min^{-1}, and RER = 0.94 ± 0.06. [LA] and RPE were 8.3 ± 3.4 mmol·L^{-1} and 15.0 ± 1.8, respectively. $EE_{\dot{V}O_2}$ was 4,933 ± 620 (3,604–5,450) kJ·h^{-1}. Differences in physiologic variables between the 3 games are presented in Table 1. Times sustained >90 and 95% of $\dot{V}O_2max$ and HRmax were 24 ± 9% and 14 ± 23%, and 69 ± 18% and 32 ± 25% of TPT, respectively. [LA] and time spent >90% of $\dot{V}O_2max$ were correlated ($R = 0.87$; $p = 0.011$; Figure 3). Either $\dot{V}O_2$ or HR ($R = 0.87$; $p = 0.01$ and $R = 0.84$; $p = 0.02$, respectively) were correlated with RPE. The Δ_{Rank} was correlated ($R = -0.93$; $p = 0.02$) with $\Delta\dot{V}O_2$ (Figure 4).

Temporal Structure. Mean temporal structure variables for each SG are listed in Table 2. No difference in TPT duration was observed between the 3 games (504 ± 215, 499 ± 101, and 426 ± 89 seconds in games 1, 2, and 3, respectively; $p > 0.05$). DR did not differ between the 3 games (19.5 ± 4.5, 19.5 ± 4.6, and 16.8 ± 4.8 seconds in games 1, 2, and 3, respectively; $p > 0.05$). It is clear from Figure 5 that no DR occurred more frequently than another, so 34.6% of the time, the ball was in play 10

TABLE 1. Physiological variables for each squash game during test matches in elite players ($n = 7$).*

Variable	Game 1	Game 2	Game 3
$\dot{V}O_2$ (ml·min^{-1}·kg^{-1})	56.5 ± 4.6	53.9 ± 4.5	51.8 ± 7.2‡
HR (beats·min^{-1})	172.0 ± 8.4	178.8 ± 8.3†	179.6 ± 13.1§
$\dot{V}E$ (L·min^{-1})	97.4 ± 10.5	103.3 ± 11.8	104.0 ± 19.0
B_f (breaths·min^{-1})	45.6 ± 5.2	48.1 ± 4.7	49.4 ± 5.7‡
RER	0.93 ± 0.05	0.95 ± 0.06	0.92 ± 0.08
[LA] (mmol·L^{-1})	6.8 ± 3.2	9.2 ± 4.0	8.7 ± 4.4
RPE (points)	15.3 ± 2.9	14.4 ± 1.6	15.4 ± 2.4

* Values are mean ± *SD*. $\dot{V}O_2$ = oxygen uptake; HR = heart rate; $\dot{V}E$ = minute ventilation; $\dot{V}CO_2$ = carbon dioxide production; B_f = breathing frequency; RER = respiratory exchange ratio; [LA] = blood lactate concentration; RPE = rate of preceived exertion.
† $p < 0.05$ for difference between game 1 and game 2.
‡ $p < 0.05$.
§ $p < 0.05$ for difference between game 1 and game 3.

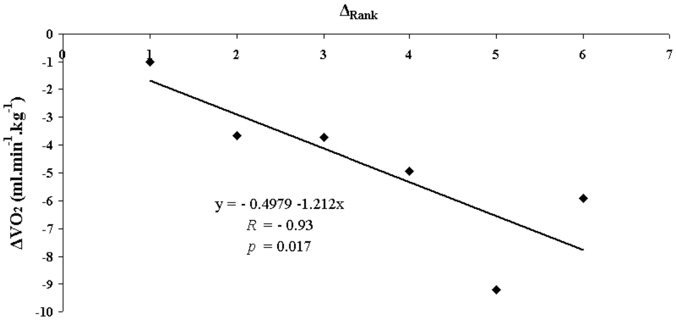

FIGURE 4. Relationship between the difference in the ranking of 2 players (Δ_{Rank}) and the difference in their mean $\dot{V}O_2$ ($\Delta\dot{V}O_2$) during squash singles (n = 7).

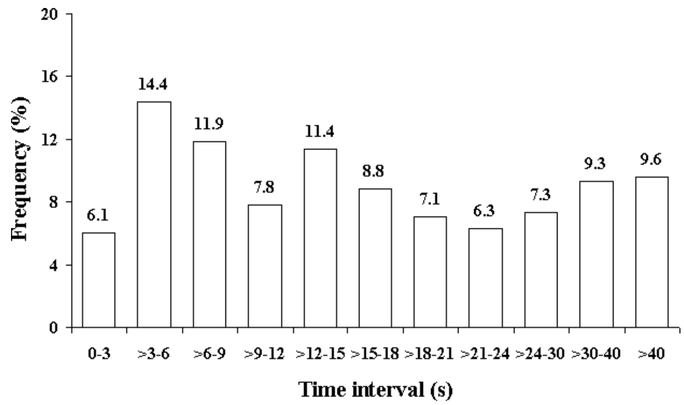

FIGURE 5. Mean percentage of playing time intervals.

seconds or less, and 32.6% of rallies were >21 seconds in duration.

DISCUSSION

This study provides a novel insight to metabolic and cardiopulmonary responses to on-court squash match play in elite players of professional standard, including the World number 1 player. This emphasizes that the technical characteristics of SG (e.g., mean duration of a game = 8 minutes; minimum of 3 games per match; effective playing time = 70 ± 5%; mean duration of a rally = 19 ± 5 seconds, with one-third of the rallies longer than 21 seconds; exercise-to-rest ratio = 2.4 ± 0.6) induce elevated aerobic and anaerobic responses (mean intensity 86% of $\dot{V}O_2$max; one-fourth of the play time >90% of $\dot{V}O_2$max; mean [LA] > 8 mmol·L^{-1}) and energy expenditure. In addition, in this study we confirm that elite squash players have high aerobic power when compared with other racquet sport players of similar standard.

Physiologic Responses During Squash Games

In racquet sports such as squash, the specific technical skills have been presented as the predominant factors and the physiologic demands are often underestimated (13, 14). To date, metabolic responses to actual squash competition in elite players are unknown. To the author's knowledge, this study is the first in which cardiopulmonary variables were recorded breath-by-breath (5 seconds) in squash players of professional standard.

Aerobic Component of the Sport. In this study, the mean duration of a game was ~8 minutes. This is in line with durations recorded during World-standard competitions (e.g., World Championship 2004 in Doha, Qatar, December 2004; official results from PSA) ranging between 5 and 15 minutes. Despite the length of the games, participants were operating at 86% of $\dot{V}O_2$max (92% HRmax). These values are slightly higher than those reported in previous studies with lower level players. Numerous publications have reported that mean game intensity throughout a match is about 80–85% of HRmax (8, 24, 31). Nevertheless, Brown and Winter (4) have also reported stable HR corresponding to 90% of HRmax during competitive matches. A similar trend was noted for $\dot{V}O_2$. However, despite a dissimilar $\dot{V}O_2$ measurement method, the mean intensity of squash singles reported in this study (86% $\dot{V}O_2$max) was higher than the 60–80% of $\dot{V}O_2$max observed earlier. Montpetit et al. (22) with 3 × 1-minute gas collection bags (Douglas bags) during a 25-minute game estimated the mean intensity at 57 and 63% of $\dot{V}O_2$max for recreational and elite players, respectively. More recently, a mean value of 75% of $\dot{V}O_2$max was reported from 15-second measurements during squash competitions in 12 county-level players (31). Not surprisingly, the current energy expenditure ($EE_{\dot{V}O_2}$ = 4,933 kJ·h^{-1}) in elite players playing against opponents of similar level was higher than the values reported in medium-skill players (2,850 kJ·h^{-1}) (21). The well-trained nature of the participants might explain the differences. It is also well understood that higher HR values occur when playing against an opponent of similar standard (18). $EE_{\dot{V}O_2}$ in squash is largely higher than in tennis. For example, Seliger et al. (26) have reported a mean $EE_{\dot{V}O_2}$ of 2,608 kJ·h^{-1} in 16 top 50 nationally ranked tennis players from Czechoslovakia completing a 10-minute-long indoor training match. One possible explanation could be the smaller EPT in tennis (20–30% (28)) than in squash (50–70% (21); 70 ± 5%, this study).

Anaerobic Component of the Sport. The relatively high [LA] values (up to 8 mmol·L^{-1}) during SG indicate that, during the frequent periods of high intensity, muscular energy is derived from anaerobic glycolysis. The strong correlation found between [LA] and time spent >90% of $\dot{V}O_2$max tends to confirm this observation, which is supported by others (27), showing that during intense competition and particularly toward the end of the match, [LA] can exceed 10 mmol·L^{-1}. There is also evidence that in squash, [LA] can reach generally higher values (5–8 mmol·L^{-1} (18, 32)) than in tennis (3–6 mmol·L^{-1} [7, 28]), in which the longer rest intervals provide ample opportunities for oxidative metabolism to predominate. This shows again that the EPT is a key difference between these 2 activities and their metabolic responses. Ferrauti et al. (9) provided substantial data supporting this statement. These authors have shown that a 5-second shorter recovery duration between repeated sprints and drills in

TABLE 2. Temporal structure variables for each squash game during test matches in elite players (n = 7).*

Variable	Mean	*SD*	Minimum	Maximum
DR (s)	18.6	4.6	14.1	23.5
RT (s)	8.0	1.8	5.9	10.8
ERR	2.4	0.6	1.8	3.3
TPT (s)	1,505	242	1,227	1,820
RPT (s)	1,050	168	844	1,293
EPT (%)	69.7	4.7	64.5	76.5
Total points	56.6	3.0	51.0	60.0

* Min = minimum; Max = maximum; DR = duration of rallies; RT = rest time between points; ERR = exercise-to-rest ration; TPT = total playing time; RTP = real playing time; EPT = effective playing time.

tennis players resulted in less complete restoration of phosphocreatine, leading to increased demands on anaerobic glycolysis to maintain the rate of energy production and therefore higher [LA] values (9). These results are supported by Brooks (2), who has shown that lactate can be locally oxidized or transported from production sites to oxidative muscle fibers (e.g., type I or IIa) for subsequent oxidation during exercise and recovery periods. However, [LA] measured infrequently (pre- and postgame) can only reflect the exercise intensity immediately before sampling. For example, Christmass et al. (7) reported that, in tennis, several rallies of high intensity and long duration are likely to have caused a prompt increase in lactic acid production. Consequently, the contribution of the anaerobic glycolytic response to SG cannot be estimated accurately from single blood lactate measurements.

Intermittent Exercise. Despite the start-and-stop nature of the game, physiologic variables (e.g., $\dot{V}O_2$, HR) during SG were not decisively different from recovery periods between the points and did not show distinct variations throughout a game (Figure 2). This phenomenon occurs in other racquet sports such as tennis (28). The breath-by-breath method used in this study allowed the assessment of time spent near $\dot{V}O_2$max and HRmax and therefore provided an accurate reflection of the intermittent characteristics of squash. Robinson et al. (25) suggested that the optimal improvement in aerobic fitness is induced by exercise sustained between 90 and 100% of $\dot{V}O_2$max (25). The present relative time spent near $\dot{V}O_2$max shows that SG is comparable to classical intermittent running alternating 30 seconds at the speed associated with $\dot{V}O_2$max and 30 seconds of active rest (20). These results are in line with previous ones (24, 31), illustrating a considerable stress on the cardiovascular system during matches. This is confirmed by the correlations found between subjective (RPE) and physiologic measures (e.g., $\dot{V}O_2$, HR) of game intensity. According to RPE, the whole group in this study exercised subjectively harder than the 14 competitors (16 vs. 12–13) tested by Reilly and Halsall (24). However, the amount of high-intensity exercise varied between games and participants, as illustrated by the differences in [LA], DR, RPE, or times sustained >90% of $\dot{V}O_2$max and HRmax between participants. This could be because of the quality of the opponent, motivation, or tactical factors (13), in turn determined partly by the player's metabolic and technical characteristics. In addition, the negative correlation reported between Δ_{Rank} and $\Delta\dot{V}O_2$ shows that the cardiopulmonary responses of a player are influenced to a great extent by the level (and probably technique or style) of his or her opponent (Figure 4). In other words, a player will be more economical against a lower-level counterpart than against a player of similar standard. This result highlights the dual nature of this activity. Moreover, $\dot{V}O_2$ was higher in game 1 than in game 3, whereas the participants increased their mean HR in the process of the match. This phenomenon might be caused by a hypovolemia induced by progressive dehydration because the players were not allowed to drink during intergame recovery periods. In this context, fluid losses reaching 2.4 $L\cdot h^{-1}$ have been reported in England national-level players (3). If hydration strategies are not appropriate, dehydration can occur after <30 minutes at a temperature of 25° C and leads to more precocious fatigue.

Match Characteristics

Interestingly, the frequency distribution shows that no rally duration occurred more often than any other (27), emphasizing the high degree of uncertainty in the course of SG. For example, 35% of the time intervals were <10 seconds and 33% were >21 seconds. This is very different from badminton matches between highly skilled performers, in which the 3–6-second interval represented 40% of the total moves and the time intervals <10 seconds and >21 seconds were 80 and 1%, respectively (5). The present findings compare with previous ones indicating that 80% of rallies last <20 seconds and 49% last ≤10 seconds in professional and grade A players (21). Other data indicate that the mean duration of a rally is ~5–20 seconds (27), whereas rest intervals between points have a mean of 7–8 seconds (21, 27). A possible explanation for the relatively long DR recorded in this study could be the higher standard of the players. Docherty (8) reported that highly skilled players played longer than those with a lower level. It could be speculated that the observed decrease in DR from games 1 and 2 to game 3 reflects fatigue.

Practical Applications

Squash is a sport that is played professionally (PSA) and in major competitions such as the Commonwealth or Asian Games and was close to be included to the 2012 Olympics program. Besides multifaceted sessions targeted on technical and tactical features, conditioning programs designed to improve both aerobic and anaerobic capabilities are required in elite squash players. This study on the physiologic responses to competition in elite performers, including the current World champion, is of interest for coaches and athletes because it is known that the adaptations to training have to be sport-specific in overloading the muscular and cardiovascular systems involved. The results of this study have shown that both aerobic and anaerobic energy systems are highly taxed during squash match play for energy supply through adenosine triphosphate restoration. Therefore, a high percentage of elite training loads should include repetitive displacements (with stroke) of high intensity (80–90% $\dot{V}O_2$max/85–90% HRmax) and moderate duration (15–20 seconds) with short recovery (8–10 seconds). Moreover, the results of Brown et al. (3), demonstrating changes in $\dot{V}O_2$max from junior to senior squash elite levels, suggest that training programs also have to focus on developing players' aerobic power. Coaches should, therefore, train specifically for endurance by means of repeated sprint exercises (e.g., 10 × 6 seconds with 20 seconds rest) and anaerobic (e.g., 8 × 15 seconds with 30 seconds rest) and aerobic interval training (e.g., 16 × 15 seconds with 10 seconds rest or 8 × 40 seconds with 15 seconds rest) is advisable for elite squash players (20). This type of training is known to induce increases in both glycolytic and oxidative enzyme activities, maximal power output, and $\dot{V}O_2$max (16). However, as shown in Figure 5, the range of rally duration is quite large, and the player also has to sustain longer work intervals (up to 3 minutes) to improve his relative endurance. In addition, regular squash-specific incremental tests are required to monitor an athlete's training changes and to prescribe training intensities on an individual basis at the different periods of the season. This can be done according to the recently proposed specific incremental fitness test for squash players (10) because this test was shown to be valid to detect change in one player's fitness level and can be combined with the training of sport-specific technical elements. It is of interest that this test is now regularly used in at least 2 national teams and a sport institute.

CONCLUSION

The mean intensity (86 and 92% of $\dot{V}O_2$max and HRmax, respectively) sustained during squash singles suggests a predominant contribution of aerobic metabolism to energy requirements. However, the high-intensity periods were long enough to cause relatively high [LA] levels. On the whole, the long durations of time spent near $\dot{V}O_2$max and the concomitant high [LA] indicate that squash at elite level is an anaerobic-aerobic activity that requires a wide range of metabolic and technical qualities. Overall, field-based metabolic assessments appear to provide useful information on energy requirements during racquet sport competitions.

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