

REVIEW

Intensity of tennis match play

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This review focuses on the characteristics of tennis players during match play and provides a greater insight into the energy demands of tennis. A tennis match often lasts longer than an hour and in some cases more than five hours. During a match there is a combination of periods of maximal or near maximal work and longer periods of moderate and low intensity activity. Match intensity varies considerably depending on the players' level, style, and sex. It is also influenced by factors such as court surface and ball type. This has important implications for the training of tennis players, which should resemble match intensity and include interval training with appropriate work to rest ratios.

(hard or grass) giving them the ability to move forward to the net, whereas strong baseliners tend to be more effective on slow surfaces (clay).

In this article, characteristics of tennis match play will be described using point duration, work-rest intervals, heart rate, oxygen consumption (VO_2), blood lactate concentrations, and rating of perceived exertion (RPE).

MATCH ACTIVITY

Tennis match play is characterised by intermittent exercise, alternating short (4–10 second) bouts of high intensity and short (10–20 second) recovery bouts, interrupted by several periods of longer duration (60–90 seconds).⁸ All of these recovery periods are controlled by ITF rules, which establish the maximum rest times. Since 2004, these rest times are 20 seconds between points, 90 seconds between changeovers, and 120 seconds between sets.⁹ Generally, the mean duration of work and rest periods during a tennis match are 5–10 seconds and 10–20 seconds respectively (a work to rest ratio of about 1:1 to 1:4) (table 1).^{10–16} Rallies in women's singles matches are significantly longer than rallies in men's singles matches. In addition, there are differences in mean rally times between low to average level and high level tennis players, which may be explained by increased match activity for high level players—that is, high level players hit the ball harder, which results in shorter rallies.

The duration of a tennis match is often more than an hour and in some cases more than five hours,¹¹ and effective playing time—that is, percentage of the total playing time in a match—amounts to 20–30% on clay courts and 10–15% on fast court surfaces.¹⁷ During this time, a tennis player runs an average of 3 m per shot and a total of 8–12 m in the course of a point,¹⁸ completing 300–500 high intensity efforts during a best of three sets match. The number of directional changes in an average point is four,¹⁹ and rallies during a match typically last less than eight seconds (five to seven). Players average 2.5–3 strokes per rally, depending on their game style, ball type (1, 2, or 3), surface, sex, and tactical strategy.^{2–6, 7} About 80% of all strokes are played within 2.5 m of the player's ready position. About 10% of strokes are made with 2.5–4.5 m of movement with primarily a sliding type movement pattern, and fewer than 5% of strokes are made with more than 4.5 m of movement and a running type movement pattern.¹⁷

COURT SURFACE AND SEX

Court surface has been reported to influence match activity in elite level tennis players.⁴ On slow surfaces, such as the clay courts used in the

Today, tennis is a world class competitive sport attracting millions of players and fans world wide. A constant programme of tournaments and events takes place throughout the year. Competitive tennis is played under the rules of the International Tennis Federation (ITF), and its competitions range from top professional events—for example, the Grand Slams and the Olympic Tennis Event—to the entry level ITF men's and women's circuits, including tournaments and team events for junior, seniors, and wheelchair players. The Association of Tennis Professionals (ATP) and the Women's Tennis Association (WTA) tours which comprise more than 60 (WTA) to 80 (ATP) tournaments, in about 40 countries, are organised in different categories, which reflect prize money and ranking points. Thus there are many different opportunities for all levels of players to compete in any given week of the year. In addition, tennis is a common recreational sport, which is enjoyed by people of all standards.

Tennis is characterised by quick starts and stops, repetitive overhead motions, and the involvement of several muscle groups during the different strokes, which fluctuate randomly from brief periods of maximal or near maximal work to longer periods of moderate and low intensity activity.¹ In addition, tennis is the only major sport to be played on a wide variety of surfaces, with different ball types, and matches are played as the best of three or five sets. Modifications to the scoring system, match duration, playing surface, and ball type are known to affect the physical and physiological demands of tennis match play.^{2–7} Accordingly, these variables might dictate the type of athlete who will be successful in tennis. Generally, players with a powerful serve prefer fast surfaces

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Table 1 Notational analysis in tennis

Reference	Level (sex)	Rally time (s)	Effective playing time (%)	Work to rest ratio	Surface
O'Donoghue & Ingram ⁴	International (M and F)	6.3 (1.8)	–	–	Hard
		7.7 (1.7)			Clay
		4.3 (1.6)			Grass
		5.8 (1.9)			Hard
Smekal <i>et al</i> ²	National (M)	6.4 (4.1)	16.3 (6.6)	1:3.4	Clay
Reilly & Palmer ¹⁰	Top club-standard (M)	5.3 (1.0)	27.9 (3.9)	1:2.5	Hard
Christmass <i>et al</i> ¹¹	State (M)	10.2	23.3 (1.4)	1:1.7	Hard
Elliot <i>et al</i> ¹²	College (M)	4.0–4.3	26.5 (3.5)	1:3.1	Hard
Girard & Millet ^{6*}	Regional (M)	7.2 (1.7)	–	–	Clay
		5.9 (1.2)			Hard
Docherty ¹³	Range of abilities (M)	10.0	–	1:1.8	Hard
Fernandez <i>et al</i> ⁴	International (M)	7.5 (7.3)	18.2 (5.8)	1:2.2	Clay
Weber <i>et al</i> ⁵	National (M)	5.08	16.4	–	Hard
Kovacs ¹⁶	International (M)	5.99	–	1:2.6	Hard

Values are mean or mean (SD).

–, No study variable; *young tennis players.

French Open, both men and women players have significantly longer rallies than on any other surface, whereas on fast surfaces, such as the grass courts used at Wimbledon, rallies are significantly shorter than on other Grand Slam surfaces (table 1). Results also show rallies in women's singles matches to be significantly longer (7.1 seconds per rally) than those in men's singles matches (5.2 seconds per rally), which is related to contributory factors such as the style of play—for example, men tend to serve and volley more than women. In addition, the effective playing time is longer for women, which may be associated with the longer point and game duration. The proportion of baseline rallies at the French Open is higher (51% of points) than at the other Grand Slam tournaments, and shortest at Wimbledon (19% of points).^{4–16} These data reflect the different demands and strategies used by players on different court surfaces—for example, a more attacking game is associated with a faster surface such as grass—and suggest that several factors, such as sex and surface, have a significant influence on match activity. These observations imply that training components should have court surface and sex specificity, so that players have more aerobic training when preparing for slower surfaces and if they are female.

BALL TYPE

As previously mentioned, ball type is known to affect the physical and physiological demands of tennis players. The ITF²⁰ recently amended the rules of tennis in relation to the range of ball types that may be used during competition. Different ball types (type 1, 2 and 3) are used in relation to the court surface, regulating the speed of the game according to the surface. The type 1 ball (fast speed) is identical with the standard ball except that it is harder and lower bouncing, and is therefore intended for play on slow pace court surfaces—that is, most clay courts and other types of unbound mineral surface. The type 2 (medium speed) ball is the standard ball and is identical with the specification that existed before 2000. It has a medium bounce and is therefore intended for play on medium/medium fast pace court surfaces—that is, most hard courts. Finally, the type 3 (slow speed) ball is about 6% larger in diameter than the standard ball. It is higher bouncing and therefore the slowest of the three ball types, intended for play on fast pace court surfaces—that is, natural grass or artificial turf. The differences between the balls are minimal in terms of size and flight characteristics, but enough to result in a faster or slower pace rating—for example, the time to travel to the baseline for a simulated first and second serve (just clearing

the net) of 10 and 16 milliseconds is greater for the type 3 ball than the type 2 ball. These differences may influence performance and the physiological responses from players. Recently it has been reported that the mean percentage accuracy and mean percentage consistency recorded during a field test were greater for the type 3 than the type 2 ball, suggesting a clear effect of ball diameter on tennis performance, as well as a reduced physiological strain.⁷ Coaches and players should be aware of these differences in order to prepare for different tournaments during the season, but further research is needed to examine other characteristics and player responses when playing with different types of tennis balls.

GAME INTENSITY

Estimates of exercise intensity in tennis have been described using heart rate,^{11–15} VO_2 , blood lactate concentrations,^{2–21–22} RPE,^{14–23} and estimates of total energy expenditure.²³ The tactical behaviour of players (defensive versus offensive), the playing situation (serving or returning), the variety of surfaces, ball diameter, and some environmental factors have been reported to influence the patterns of physical activity and recovery (described by the duration of rallies and the effective playing time), and the underlying physiological mediators such as heart rate, lactate or VO_2 .^{2–7–10–24} Measuring all of these variables during play provides a greater understanding of the overall intensity and physiological stress occurring during tennis play, improving the knowledge of the physiological profile of the game, which could benefit the development of optimal training protocols according to sport specific demands.

The average physiological responses to tennis match play have been reported to be rather modest, with mean exercise intensities generally less than 60–70% of maximum oxygen uptake ($\text{VO}_{2\text{MAX}}$)^{11–25} and mean maximum heart rates of 60–80%.¹⁷ Owing to the intermittent nature of the game (periods of high intensity interspersed with recovery periods), mean values are not sufficient for us to understand fully the demands of tennis. Therefore the description of the high intensity periods themselves is probably more relevant, because it is during these crucial periods that matches can be won or lost and a player's physical condition could be an important influencing factor.

HEART RATE

Heart rate recorded during match play has been used to measure physiological strain and estimate energy expenditure when comparing an individual's heart rate- VO_2

relation.^{2 11 24} The mean heart rate in trained players aged 20–30 years ranges between 140–160 and 94 (15.6) to 164 (15.8) beats/min during singles and doubles tennis competitions respectively,^{13–15} rising to 190–200 beats/min during long and fast rallies (table 2),^{2 6 21} reflecting phases of high activity, which involve both the upper and lower body.^{25–29} When comparing serve and return games, Smekal *et al*² found that heart rates were similar. However, differences in heart rate according to playing situation—that is, whether a player is serving or returning—have been noticed. Elliot *et al*¹² reported significantly higher heart rates for the server than for the receiver. These results have been attributed to the higher intensity needed for players to “hold their serve” and the more active role of the server within the game.²⁵

Heart rate responses should be interpreted with caution, because heart rate does not always reflect VO_2 variations during a match. Novas *et al*²³ showed how VO_2 recovered faster and more completely than heart rate, and that the heart rate to VO_2 ratio was increased during recovery periods. When heart rate measurements are converted into VO_2 on the basis of individual heart rate- VO_2 relations observed during submaximal continuous exercise, factors confounding the relation between heart rate and VO_2 during intermittent exercise should be considered—that is, despite the start and stop nature of the game, heart rate is not significantly different between rallying and recovery, or else it is even slightly increased during the recovery periods between rallies.^{11 22} Thus the relation between heart rate and VO_2 overestimates the physiological responses during tennis play. In addition, heart rate responses during play can be affected by other factors such as dehydration and thermal stress—that is, heart rate is correlated with body temperature, and thus the climate influences its course.^{30 31} Therefore these factors should be considered when heart rate measures are used to evaluate stress intensity during a tennis match or when designing training protocols.

OXYGEN CONSUMPTION

The $\text{VO}_{2\text{MAX}}$ of tennis players has been documented in several studies (table 3). In general, mean $\text{VO}_{2\text{MAX}}$ values reach 45 ml/kg/min in female players and 55 ml/kg/min in male players.²⁵ These moderately high levels of aerobic power are higher than the values reported for untrained middle aged persons,²⁵ but lower than those reported for players of other intermittent team sports such as rugby³² and soccer³³ and similar to other racket sports such as badminton.³⁴ Continuous measurement of VO_2 during match play is an

interesting variable from which to glean information about intensity of play during a match. Moreover, the profiling of tennis players by this method—that is, differentiating defensive from offensive players—may also serve as a reference from which to provide practical information about suitable conditioning for different players. The recent introduction of new portable gas analysers used to measure average and peak intensities of tennis match play now provide data that are much more valid.² Studies using these new analysers have reported VO_2 levels during tennis play ranging from 23 to 29 ml/kg/min (table 3). This corresponds to about 50% of $\text{VO}_{2\text{MAX}}$, with values ranging from 46% to 56% of $\text{VO}_{2\text{MAX}}$.^{2 5 6 35} In relative terms, there is little difference between measurements of VO_2 during tennis play recorded in professional¹⁴ and international or regional players,^{2 6 11 22} but no one has yet managed to provide accurate and valid VO_2 values for top ranked professional players. Studies have reported lower on-court values of VO_2 for male than for female players, and lower values for adults than for younger players,^{6 14} which were attributed to differences in sex and higher intensities of play in younger players. Another significant difference is the time of play recorded, with studies using a segment of a match (a set)²⁹ or a time restricted match,^{2 11} which obviously affects the VO_2 responses. It is also important to highlight the influence of a player's tactical behaviour—for example, baseline play or serve and volley—on VO_2 .² There is evidence that the style of play (offensive versus defensive) influences the demands of the game—that is, higher energy demands for a baseline player compared with an offensive player. Therefore it would be of interest to determine the physiological profiles of players with different tactical behaviours in order to optimise specific training programmes—for example, to prepare an offensive player (hard court specialist) who wants to achieve a good result in the French Open (clay court).

LACTATE CONCENTRATIONS

Exercise intensity in tennis has been investigated by using measurements of lactate concentration.^{25 30} These studies reveal that, in general, lactate concentrations and hence muscle acidity remain low (1.8–2.8 mmol/l) during tennis match play (table 2).^{17 24 35} However, during long and intense rallies, the circulating lactate concentrations may increase,¹¹ up to 8 mmol/l, suggesting increased involvement of anaerobic glycolytic processes to supply energy.² It is of interest that Smekal *et al*² did not find any significant differences in lactate concentrations when comparing service and return

Table 2 Heart rate, lactate concentration, and rating of perceived exertion during tennis match play

Study	Sex	HR (beats/min)	LA (mmol/l)	RPE	Court
Seliger <i>et al</i> ⁶	M	143 (13.9)	–	–	–
Weber <i>et al</i> ⁵	M	147 (10.5)	2.15	–	Hard
Kindermann <i>et al</i> ²⁷	M	145 (19.8)	2.0 (0.5)	–	–
Schmitz ²⁸	M	143 (12.4)	2.59 (1.02)	–	Clay
Bergeron <i>et al</i> ²²	M	144 (13.2)	2.3 (1.2)	–	Hard
Reilly & Palmer ¹⁰	M	144 (19.0)	2.0 (0.4)	–	Hard
Novas <i>et al</i> ²³	F	146 (20)	–	4 (1)*	Hard
Girard & Millet ^{6,†}	M	181 (11.9)	3.08 (1.12)	–	Clay
		172 (17.2)	2.36 (0.47)	–	Hard
Ferrauti <i>et al</i> ²¹	M-F	–	1.53 (0.65)	–	–
Fernandez <i>et al</i> ²⁹	M	147 (15)	4.0 (1.1)	12.5 (2.1)**	Clay
Fernandez <i>et al</i> ⁴	M	–	3.79 (2.03)	13 (2.1)**	Clay
Smekal <i>et al</i> ²	M	151 (19)	2.07 (0.88)	–	Clay

Values are mean (SD).

*1–10 RPE scale; **6–20 RPE scale; †young tennis players.

HR, Heart rate; LA, lactate concentration; RPE, rating of perceived exertion; –, no study variable.

Table 3 Maximal oxygen uptake (VO_2MAX) under laboratory conditions and oxygen consumption (VO_2) during tennis play

Study	Sex (number)	Level	VO_2MAX (ml/kg/min)	VO_2 on court (ml/kg/min)	% VO_2MAX^*	Court
Seliger <i>et al</i> ⁶⁶	M (16)	National	–	27.3 (5.5)	50	–
Ferrauti <i>et al</i> ²¹	M and F (12)	National Senior	41.1 (6) (F) 47.5 (4.3) (M)	23.1 (3.0) (F) 24.2 (2.0) (M)	59.2 (7.0) (F) 54.3 (3.1) (M)	Hard
Reilly & Palmer ¹⁰	M (8)	Top club	53.2 (7.3)	–	–	Hard
Vodak <i>et al</i> ⁶⁹	M and F (25–25)	Top club	50.2 (5.7) (M) 44.2 (5.4) (F)	–	–	–
Christmass <i>et al</i> ¹¹	M (8)	State level	54.2 (1.89)	–	74.4 (5.1)	Hard
Kraemer <i>et al</i> ⁶⁰	F (30)	College	49.4 (4.4)	–	–	–
Bergeron <i>et al</i> ²²	M (10)	State level	58.5 (9.4)	–	–	Hard
Girard & Millet ⁶	M (7)	Club standard†	50.3 (3.9)	40.3 (5.7) 37.9 (7.5)	80.1 (10.8) 71.6 (15.3)	Clay Hard
Smekal <i>et al</i> ⁷	M (20)	National	57.3 (5.1)	29.1 (5.6)	51.1 (5.6)	Clay
Fernandez <i>et al</i> ⁴	M (6)	International	58.2 (2.2)	26.62 (3.3)	46.4 (7.2)	Clay

Values are mean (SD).

*With regard to laboratory test; †young tennis players.

games, in contrast with Fernandez *et al*,¹⁴ who found that blood lactate concentrations were significantly higher ($p = 0.02$) in service games (4.61 (2.50) mmol/l) than in return games (3.20 (1.35) mmol/l), with maximal values of 8.6 mmol/l, for professional players under “real” match play conditions—that is, an actual professional tournament. These differences can be attributed to the more active and dominant role of the server in dictating the game¹⁰ and to an increased intensity of matches as the playing standard increased.

Although the literature shows similar lactate concentrations during tennis match play, this should be treated with caution, as many factors, including individual fitness, emotional stress, time of measurement, and environmental conditions, may affect the results.³² Lactate concentrations are only a reflection of the balance between lactate production and clearance. Furthermore, sampling times are restricted to natural breaks in matches or disruptions to standard match conditions and only reflect the level of activity during the few minutes before sampling.³³

Relatively high lactate concentrations during long and intense rallies^{2, 14} may determine the outcome of crucial situations in the game. Although the periods of walking and rest during match play are probably sufficient to allow players to metabolise lactate effectively, when recovery between rallies is too short, running speed for stroke preparation and stroke speed is decreased.⁵ It is therefore important to prepare players properly to deal with these high intensity play situations with interval training.

RPE

Perceived exertion can be defined as “the subjective intensity of effort, strain, discomfort and/or fatigue that is experienced during physical exercise”.³⁶ To date, there is little information describing the RPE responses to actual tennis match play (table 2) although RPE scales have been used during aerobic exercise, resistance training,³⁷ and field sports,³⁸ indicating that this method is a good indicator of global internal load.

Novas *et al*²³ monitored RPE during 60 minutes of simulated match play in which a player reported an RPE score for the entire session at the end of the match. The results of the study showed that RPE can be used to estimate the energetic cost of playing tennis on an individual basis. Fernandez *et al*¹⁴ monitored individual perceived exertion during seven matches of professional players, under “real” match conditions and found significantly higher values in service games than in return games. Also, RPE values correlated significantly with the variables describing the characteristics of the matches—for example, strokes per rally and duration of rallies—showing a better correlation with the

match analysis variables in service games. These results (values ranged from 11 or “easy” to 14 or “somewhat hard”) indicate that RPE may be a valuable tool for coaches, because it provides relatively reliable and valid information about a player’s physical effort during competition, but further investigation is required.

CONCLUSIONS

Training programmes and fitness characteristics of tennis players have changed dramatically over the last 10–15 years. A tennis match involves a combination of low and high intensity periods, and tennis can be considered to be an intermittent anaerobic sport with an aerobic recovery phase. Observations from notational analysis, as well from monitoring the players’ exercise intensity—that is, through data describing the physiological characteristics of tennis players—provide considerable information on the physical

What is already known on this topic

- Tennis is a repetitive sprint sport, with medium to high aerobic and anaerobic demands; mean exercise intensities are generally less than 60–70% VO_2MAX and mean maximum heart rates are 60–80%
- The mean duration of work and rest periods during a tennis match are 5–10 seconds and 10–20 seconds respectively (a work to rest ratio of about 1:1 to 1:4); training should be tennis specific and include interval training of 5–15 seconds, with rest periods of 10–60 seconds

What this study adds

- Court surface, sex, ball type, match duration, and style of play influence the proportion of aerobic to anaerobic demands on players: slower surfaces, type 3 balls, longer match duration, baseline play, and being female increase the aerobic demands, whereas fast surfaces, type 1 balls, shorter match duration, serve and volley play, and being male increase the anaerobic demands
- In addition to heart rate, lactate concentration, and VO_2 measurements, RPE can be used to monitor training

demands of the game as well as the activity patterns used—that is, playing time and rest periods. All this information can be used by coaches and fitness trainers to establish optimum training programmes and tactics for their players.

The greatest training benefits occur when the training stimulus simulates the specific movement patterns and physiological demands of the sport.⁴¹ The information presented in this article suggests that the aerobic and anaerobic alactic energy systems are the major energy pathways during tennis play. However, although the overall intensity during a match is medium to submaximal, lactate concentrations may increase during long and decisive rallies. Collectively, these findings suggest the need for specific training of the anaerobic alactic, anaerobic glycolytic, and aerobic energy systems in tennis players. Interval training methods, characterised by distances and activities specifically related to competition, should be pursued. This means that training should include exercises that last 5–20 seconds, with appropriate ratios of work to rest periods (20 seconds to 1 min) of 1:3 to 1:5.

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COMMENTARY

This review highlights applied physiological data that can be useful for coaches who are wishing to design training drills based on performance at a number of levels. The review also highlights differences between male and female athletes. Given that the review has shown disparity in ball type and physiology, this would be an interesting area to explore, particularly when other sports with changes in ball size—for example, table tennis—have extensively studied the effects both physiologically and biomechanically.

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