A Review of the Activity Profile and Physiological Demands of Tennis Match Play

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SUMMARY

THE AIM OF THIS REVIEW IS TO PROVIDE A BRIEF INSIGHT AND UNDERSTANDING OF THE PHYSICAL AND PHYSIOLOGICAL DEMANDS OF COMPETITIVE TENNIS MATCH PLAY. IT ALSO PROVIDES USEFUL INFORMATION THAT MAY HELP STRENGTH AND CONDITIONING COACHES TO IMPLEMENT EFFECTIVE TRAINING PROTOCOLS TO IMPROVE ON-COURT TENNIS PERFORMANCE.

INTRODUCTION

Today, tennis is a world-class competitive sport attracting millions of players and fans worldwide. Professional tennis players travel and compete extensively year round, with tournaments on the professional men's and women's calendars numbering, for example, 603 and 473, respectively, in 2008, including tournaments and team events for junior, seniors, and wheelchair players. Thus, there are many different opportunities for all level 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 playing abilities.

Tennis has evolved from a technical/tactical game, based on style and finesse to the current fast paced, explosive sport based on physical abilities, where 210 km/h serves are common (56). Therefore, to be competitive and successful, tennis athletes will need a mixture of speed, agility, and power combined with medium to high aerobic capabilities. This successful performance cannot be defined by one predominating physical attribute; tennis demands a complex interaction of physical components. Underlying these physical components are cognitive and psychological processes. Players must display supreme reactive, anticipatory, and decision-making capacities while possessing the mental rigor to cope with ensuing fatigue and the pressures of match-deciding points and significant extrinsic rewards (e.g., ranking, money endorsements) (48).

The evolution of tennis play over the last 20 years has led to an increased interest in tennis research, and several groups (4–10,23–34,36–38,46–48,54–57, 65–70) have been working to create an interdisciplinary sport science approach to further understand the interaction between the different sport science disciplines (e.g., biomechanics, physiology) and performance in tennis. The aim of this review is to provide a brief insight and understanding of the physical and physiological demands of competitive tennis match play. It also aims to provide useful information that may help strength and conditioning coaches to implement effective training protocols to improve on-court tennis performance.

COMPONENTS OF PERFORMANCE IN MODERN TENNIS

In racket sports such as tennis, the sport-specific technical skills are predominant factors (e.g., racket and ball handling skills and stroke skills, such as service skill) (91). Nevertheless, it is widely accepted that to execute advanced shots and to compete effectively against progressively more elite opponents, players require higher levels of physical fitness (79). Increasing evidence suggests that motor skills such as power, strength, agility, speed, and explosiveness, as well as mental strength, and a highly developed neuromuscular coordinating ability correlate with tournament performance (54,85). If the athlete is not in a good condition, essential characteristics in tennis such as technique, coordination, concentration, and tactics might not be brought into play in long matches as

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premature fatigue can impair virtually all tennis-specific skills (38,48,65).

MATCH ACTIVITY DURING TENNIS PLAY

Tennis match play is characterized by intermittent exercise, alternating short (4-10 seconds) bouts of high-intensity exercise and short (10-20 seconds) recovery bouts interrupted by several resting periods of longer duration (60-90 seconds) (27,56,83). All these recovery periods are controlled by International Tennis Federation rules, which establishes the minimum and maximum rest times. Since 2002, these resting times are 20 seconds between points, 90 seconds between change-overs, and 120 seconds between sets (49). The duration of a tennis event is often greater than an hour and in some cases lasts for 5 hours (e.g., Australian Open 2009 men's final: 4 hours 23 minutes) with a typical average match time of 1.5 hours (56), in which effective playing time (percentage of the total time of play in a game) amounts to approximately 20 to 30% on clay courts and to 10 to 15% on hard court surfaces (27,56,83). During this time, a tennis player runs an average of 3 m per shot and a total of 8 to 15 m in the pursuit of one point, completing from 1,300 to 3,600 m per hour of play, depending on the player's level (amateur or advanced) and court surface (slow or fast) (20,30,74). The number of directional changes in an average point is 4 (20,28,74,79). Players average 2.5 to 3 strokes per rally, and approximately 80% of all strokes are played within less than 2.5 m, with the player in a standing position (33). Approximately 10% of all strokes are made with 2.5 to 4.5 m of movement with primarily a sliding-type movement pattern, and fewer than 5% of all strokes are made with greater than 4.5 m of movement and a running-type movement pattern (distance recorded immediately after each stroke and needed to reach the stroke position) (33). This information should be taken into account when designing specific and nonspecific training sessions.

FACTORS AFFECTING MATCH ACTIVITY

Previous research has shown that activity profile during tennis match play can be altered by several factors intrinsic to the sport, such as type of surfaces (clay, green set), gender, different tactical behaviors (attacking or baseline players), or thermal stress (47,69,78,91). All these variables can affect the activity profile of a tennis match, as well as the individual physiological responses to the game.

COURT SURFACE

The impact of tennis court surface on the physical demands of match play has been previously documented, with longer rallies and more strokes per rally on slow (clay) than on fast surfaces (green set) (67,74,78). Court speed is determined primarily by the friction between the ball and the court surface (coefficient of friction) and somewhat by the coefficient of restitution. The more the friction, the more the ball slows down. In slow surfaces, such as clay courts, the higher coefficient of restitution and coefficient of friction result in a high and relative gentle bounce (41). This provides the player with more time to hit the ball than on faster surfaces, allowing players to reach more balls and eventually play longer duration points (78). Data related to latest tennis research studies conducted on different court surfaces under actual tournament conditions are presented in Table 1.

As presented in Table 1, it appears that the previously reported differences in rally duration between slow and fast courts (74,78) are getting smaller (14,28,29) in the last few years. Brown and O'Donoghue (14) have recently showed that rally durations have increased in men's singles at all 4 grand slam tournaments while they have decreased in women's singles at all the tournaments except Wimbledon. These differences may be related to the introduction of new balls in 2006, as an attempt by the ITF to reduce the variation in the game between different surfaces trying to compensate for the

Table 1
Match activity profile reported under real tournament conditions

Reference	Sex	DR (s)	RT (s)	SR (n)	EPT (%)	W:R	Surface
14	M	7.6					Clay
65	M	7.5	16.2	2.7	21.5	1:2.2	Clay
74	M	7.4	19.4				Clay
46	M	7.5	17.2	4.5			Clay
14	F	7.3					Clay
29	F	7.2	15.5	2.5	21	1:2.1	Clay
78	F	9.1	18.2				Clay
78	M	3.8	19.5				Grass
46	M	6.7	25.1	4.7			Hard
14	M	5.5					Grass
78	F	6.2	17.1				Grass
14	F	6.3					Grass
28	F	8.2	17.7	2.8	21.9	1:2.1	Green set

DR = duration of rallies; RT = rest time; SR = strokes per rally; EPT = effective playing time; W:R = work to rest ratio; M = male; F = female.

surface effect of the court (50). We recently reported that the impact of court surface on rally duration was not evident during female tennis tournaments undertaken either on clay court (29) or on hard court (28). Somehow surprisingly, we found slightly longer rallies (8.2 ± 5.2 seconds) on hard court (green set) than on clay court (7.2 ± 5.2 seconds). In these 2 studies (28,29), players adopted the so-called *defensive behavior* (playing deep balls from the baseline) regardless of the surface. This suggests that some other factors such as tactical behavior (91), or the type of ball used (50), might also impact the activity patterns (rally duration) independently of court surface.

TACTICAL BEHAVIOR

As previously mentioned, tactical behavior of players might alter the activity profile during play. Previous studies reported that when the player in control of the rally was an offensive player, the average duration of the rallies was significantly shorter than a whole-court player or a defensive one (91,90). However, this information has been obtained under simulated tennis match conditions, and therefore, caution should be applied when extrapolating these results to actual tournament conditions. Moreover, although a player can assume a specific role (e.g., defensive or offensive) during most of the games, the strategy could change according to the game circumstances. Worth noticing that, may be related to the above-mentioned changes introduced by the IFT in 2006 (50), the number of serve-and-volley players is apparently decreasing in today's professional tennis. Thus, it appears that the all-court player is the player's role that coaches would like to train to be competitive in tomorrow's tennis.

GENDER

Differences in activity profile between male and female competitive tennis have been reported with women playing significantly less strokes per second, hit fewer aces, won fewer service games, and committed more double faults (18,78). However, in the last few years, the female's game has seen some changes (e.g., serves over 180 km/h are now common) and, as previously mentioned, there is a reduced variability in the activity profile between male and female players (14). As depicted in Table 1, Fernandez-Fernandez et al. (28,29) found similar activity profiles in female players than in previous studies conducted with male players under actual or simulated playing conditions (17,37,46,56,67,78). However, as recently reported by Brown and O'Donoghue (14), there are still some differences between males' and females' game (e.g., men still serve with more accuracy and women play significantly more baseline rallies than men). Caution should be applied when comparing studies, due to the different factors (e.g., style of play, standard of the opponent) that can influence the playing pattern (37,46).

THERMAL STRESS

Exercise-induced heat stress and hyperthermia are potential health- and performance-damaging characteristics of prolonged exercise in moderate to hot conditions, a situation often confronting tennis players (48). The extreme on-court playing temperatures are often accompanied by prolonged match durations. Thus, heat stress can readily reduce on-court performance, and it can also threaten a player's health and safety. In this regard, Morante and Brotherhood (68–70) showed that changes in rectal temperature (e.g., being higher) were associated with longer rallies and, therefore, higher effective playing time (e.g., players reached high internal temperatures with long rallies) during a simulated match play, although no temperature effect was found on physiological responses during play (68–70). In a similar vein, Hornery et al. (46) reported players' core body temperatures exceeding 38.5°C and 39.0°C, shortly after match commencement during 3 professional tennis tournaments. As a result, players tended to have longer recovery times between points and be less accurate during the service situation.

The information presented in this section has led to a better understanding of the demands players are exposed during competitive tennis match play and can help coaches to establish a range of game characteristics that could be useful in defining training practices and strategic aspects of play. Unfortunately, there are still many aspects, such as age-related differences (e.g., juniors versus adults) in match play responses or the impact of multiple matches per day, which are likely to affect the activity profile and the physiological responses to the game that have received little scientific attention. Additional research should be done to provide a specific framework for developing players.

PHYSIOLOGICAL DEMANDS OF MODERN TENNIS

Physical exertion during tennis involves high-intensity efforts interspersed with periods of variable duration and low-intensity activity, during which active recovery (between points: 20 seconds) and sitting periods (between changeover break in play: 90 and 120 seconds) take place (33). Thus, metabolic demands alternate between energy provision for bouts of high-intensity work and replenishing energy sources and restoring homeostasis during the intervals in between (2). While the critical phases of play during tennis match play such as serve, several strokes, quick changes of direction, and short accelerations are likely to be metabolically dependent on anaerobic pathways of energy supply, these are superimposed on a background of largely aerobic submaximal activities. Therefore, when designing training programs, it is important to understand the nature of the sport and train the energy systems that predominate during match play (55).

GAME INTENSITY

Estimates of exercise intensity in tennis are useful to tennis coaches and physical trainers to monitor progress in order to train in the most productive and efficient manner (54). Game intensity during tennis match play has been described using heart rate (HR) (17,26,37), oxygen consumption ($\dot{V}O_2$) (25,91,90), blood lactate concentrations (LA) (26,28,66,91), ratings of perceived exertion (RPEs) (28,29,36,65,77), and estimations of total energy expenditure (30,77) (Figure 1). In this review, the main focus will be on game intensity data obtained during actual tennis match play (e.g., tennis tournament). In addition, some information on $\dot{V}O_2$ responses obtained during simulated tennis match play will be presented, due to the impossibility of obtaining such information during actual tournament conditions. As previously mentioned, some of the factors that affect match activity (playing situation and different surfaces) have also been reported to influence the underlying physiological variables (HR, LA, or $\dot{V}O_2$). Moreover, it is important to highlight that "intensity" in tennis might come from other nonphysiological sources, such as psychological factors (28). In this regard, research (4,43,63) reported that competitive situations (tennis competition, table tennis, and golf competition) elicited substantial increases in some physiological markers (blood pressure and HR), suggesting that the overall pattern of effects for competition is also indicative of increased mental stress and releasing hormones such as cortisol, adrenaline, and noradrenaline (34,41).

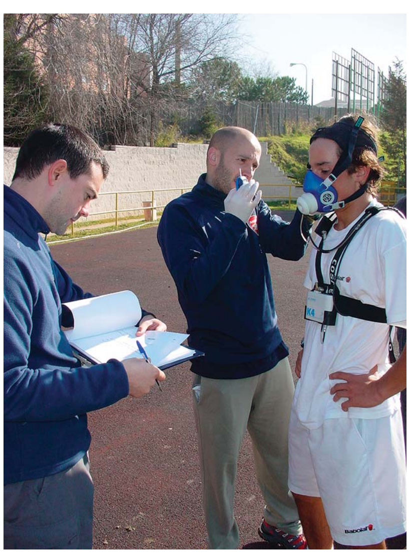

Figure 1. Example of a combined ($\dot{V}O_2$, HR, LA, and RPE) player's monitorization during a training session.

HEART RATE

HR measurements are used to provide information about the psychophysiological stress associated to match play (54). The mean HR in 20- to 30-year-old trained players ranges between 140 and 160 and 94 ± 15.6 and 164 ± 15.8 beats per minute during singles and doubles tennis competitions, respectively, which corresponds to values between 70 and 80% of HR_{max}. HR can rise up to 190 to 200 beats per minute during long and fast rallies (27,56,71), reflecting phases of high activity, with values around 100% of HR_{max} (27,56). Average HR values should not be the sole measurement of exercise intensity, as this would not accurately represent the intermittent nature of tennis match play (56). The description of high-intensity periods during a female tennis tournament revealed that players spent about 13% of the total match time at exercise intensities higher than 90% HR_{max}, suggesting that the contemporary game might be more demanding than previously reported (8,17).

It seems important to highlight differences in HR considering the playing situation (serve versus return position). Several studies reported significantly higher HR values for the server than for the receiver, both in male and female players under actual tournament conditions (28,66). These results have been attributed, among others, to the greater physical activity (more strokes per rally) of servers (51,82), which may lead to a higher energy expenditure and intensity. Service situation is an important way to win the rally, either directly through an ace or indirectly through the advantage in the rally following a good serve. As such, to be competitively successful, winning service games is almost a "must" (28). Therefore, the higher HR values observed in service players might also be related to a higher psychological stress and sympathetic activity due to the need to win the games with the serve (see above) (45). These factors have to be considered when HR measures are used for the evaluation of intensity during a tennis match or when designing training protocols (e.g., using the service situation as a means of physiological overload during practice).

LACTATE CONCENTRATIONS

LA, which is frequently used to estimate exercise intensities during tennis match play, may provide information about the energy production from glycolytic processes (59). In this regard, Mendez-Villanueva et al. (66) reported increased LA in response to increases in the activity profile (e.g., longer rallies and more strokes per rally), supporting the usefulness of LA for monitoring exercise intensity during match play. LA levels during actual tennis match play have been reported to be rather low, with average values ranging from 1.8 to 2.8 mmol/L (28,29,66). However, during long and intense rallies, increases in circulating LA levels (up to 8 mmol/L) can occur under actual match play conditions, suggesting an increased participation of glycolytic processes to energy supply (66).

Mendez-Villanueva et al. (66) recently reported higher LA concentrations in service than in return games during actual tennis match play, which might

Figure 2. Player using a portable gas analyzer.

be related to an increased glycolytic contribution of server's activity (maximum effort during the first serve) (66,82). In contrast, Fernandez-Fernandez et al. (28,29) found similar LA concentrations in service and return games in female players competing on both slow and fast surfaces. This could be related to the fact that female players generally use the serve more strategically (serve with less power and more spin), which might equalize the metabolic responses in serve and return play, in contrast with men's singles tennis (29). While caution should be taken when interpreting LA concentrations attained during competitive matches as many factors, including individual fitness and time of measurement, may affect the results (19), it seems important to implement appropriate training interventions to prepare players to overcome the relative high LA values reported after long-duration rallies (66).

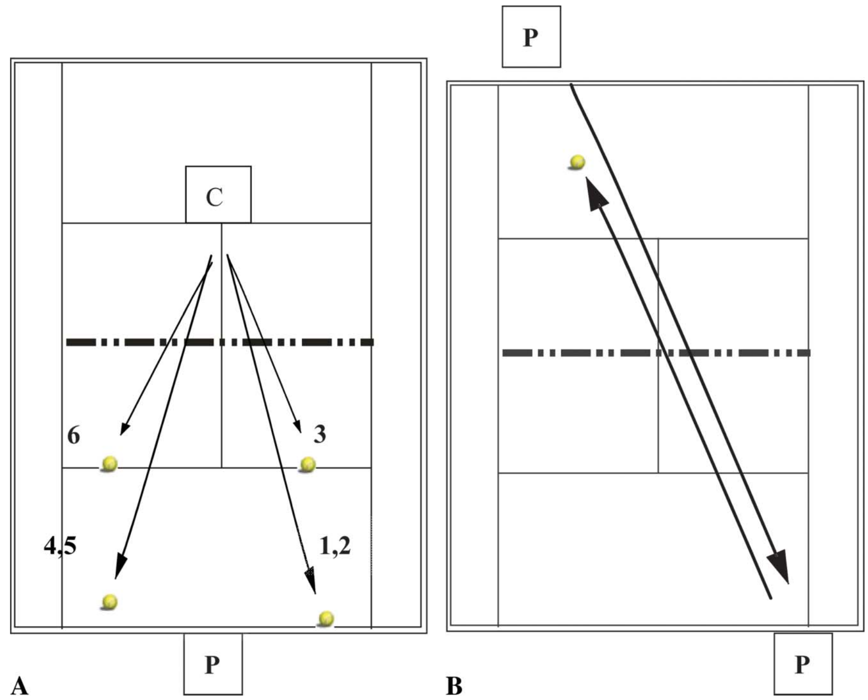

Figure 3. Examples of on-court aerobic sessions. (a) Example of an on-court interval training protocol: P player; C: coach feeding balls; alternate defensive and offensive forehand (1–3) and backhand strokes (4–6); (4 × 3-minute/90-second rest; 90–95% of HR_{max}). (b) Example of an on-court basic aerobic exercise: crosscourt forehand against crosscourt forehand from the baseline (2 × (4 × 5 minutes)/3- to 5-minute rest; intensity: 80% HR_{max}).

RATE OF PERCEIVED EXERTION

RPE can be defined as "the subjective intensity of effort, strain, discomfort, and/or fatigue that is experienced during physical exercise." Measurement of RPE through the Borg's RPE scale (13) is a valid index of exercise intensity owing to the observed association between RPE and more objective physiological markers, including HR and $\dot{V}O_2$ (84). Previous studies have described RPE responses during tennis match play in professional male and female players (28,66) under actual tournament conditions and in lower-level male and female players under simulated match conditions (36,66). Results are equivocal due to the different RPE scales used and the match play conditions (simulated versus actual tennis tournament). However, recent research (29,66), using the 15-point RPE scale, showed mean values ranging from 11 or "light" to 14 or "somewhat hard" with peak value of 17 or "very hard," confirming periodic increases in exercise intensity during tennis match play. Moreover, results of Mendez-Villanueva et al. (66) indicate that there were increases in RPE in response to increases in the match activity (more duration of rallies or more strokes per rally), suggesting a link between physiological, perceptual, and physical demands in professional male tennis match play. Regarding playing position (service versus return), there are differences between male and female competition, with significant greater RPE values reported by service than return players in male's competition (66). No significant differences were found during a female competition (28). It should be noted, however, that RPE values not only do refer to the perception of effort and the "feeling" of fatigue but can also describe associative thoughts (e.g., a player's tactics in relation to the opponent) (1,92).

OXYGEN UPTAKE

Continuous measurement of $\dot{V}O_2$ during match play is an interesting variable from which to glean information about intensity of play during a match (27,91,90). The use of portable gas analyzers allows valid measurements of average and peak intensities during tennis match play (91) (Figure 2). Moreover, the profiling of tennis players through this method (differentiate defensive from offensive players) may also serve as a reference to provide practical information about proper conditioning for different players. Due to the obvious limitations imposed by tournament competition, $\dot{V}O_2$ measurements are not available during actual tennis match play. Studies that have addressed this issue during simulated tennis match play reported values ranging from 23 to 29 $mL \cdot kg^{-1} \cdot min^{-1}$ (27,56). These values correspond to approximately 50% of maximal oxygen uptake ($\dot{V}O_2max$), with lower $\dot{V}O_2$ values for players considered offensive (serve-and-volley players) than for defensive players (baseline game) (27,56,91).

In relative terms, there is little difference between $\dot{V}O_2$ measurements during tennis play of professional (26) and national or regional players (91,90), but no one has yet managed to provide accurate and valid $\dot{V}O_2$ values of top-ranked (e.g., top 20) professional tennis players. As previously mentioned for the HR, average $\dot{V}O_2$ values do not represent all the patterns of physical activity in tennis competition. In this regard, Smekal et al. (91) reported peak $\dot{V}O_2$ values close to 50 $mL\cdot kg^{-1}\cdot min^{-1}$ during a simulated match play, representing ~80% of $\dot{V}O_2max$. As suggested by the authors, these values can serve as a guide for energy requirements required to sustain periods of high-intensity tennis match play.

FLUID REPLACEMENT AND TEMPERATURE IN TENNIS

Competitive tennis is typically played outdoors in warm and hot environments, and it is well established that exercise is prematurely terminated in hot conditions (76). Sometimes, lengthy match durations, extreme on-court environments, and compromised hydration status are a combination of likely contributors to the manifestation of fatigue and associated suboptimal performances (48). Therefore, there is a need for tennis coaches, strength and conditioning specialists, and medical staff to understand the effects of temperature and hydration status on the health and performance of tennis players (57). For a detailed review of these topics, the reader is referred to several previous reviews (48,57,88).

HYDRATION

Few studies have systematically examined the effect of levels of dehydration on performance in tennis and reported the rate of fluid loss or the total fluid loss as a percentage of body mass during competition or simulated match play equating to 1.0 to 2.5 L/h, 2.3, and 2.7%, respectively (5,12,57,61). Many players probably compete with some deficit in the normal range of body water content (5). This condition is known as "hypohydration" or "dehydration" (87). The ramifications of body fluid loss are dramatic as deficits as little as 2% are widely recognized to govern decrements in athletic performance (40). The resultant reduction in plasma volume increases susceptibility to heat stress or hyperthermia and other related adverse conditions such as muscular cramps and exercise-induced exhaustion (12,16,21,88). Tennis-specific studies affirmed poor hydration practices of tennis players (10,9,46), with players beginning to play already significantly dehydrated for a first match, during a national boys' 14s junior tennis championship (10). However, the findings of several studies (47,94) suggest that maintenance of hydration status through provision of water alone or with a carbohydrate supplementation is not accompanied by sustained skill proficiency (serve and

Table 2
Training schedule for tennis players to improve aerobic performance in preparation for a season

Date/period	General guidelines	Examples
Week 1/preparation	4 sessions/wk	45–60 min/session
	Extensive continuous method	Alternative activities (swimming; biking)
	Intensity: 60–75% HR_{max}	
Week 2/preparation	3 sessions/wk	On-court: tennis-specific games; adapted match situations
	Extensive interval and fartlek workouts	Off-court: 40–60 min (fartlek: constant speed change with a variable sequence of short intensive, extensive, and longer recovery periods); 4 × 120 s with 90-s rest
	Intensity: 70–95% HR_{max}	
Week 3/preparation	3 sessions/wk	On-court exercises (Figure 3)
	Work at lactate threshold levels	
	Extensive-intensive interval and fartlek workouts	Off-court: 6 × 3-min/3- to 4-min rest; 10 × 30"/30" rest; 10 × 60"/90" rest
	Intensity: 80–95% HR_{max}	
Week 4/preparation	2 sessions/wk	On-court exercises (Figure 4)
	Begin with anaerobic training	
	Short intensive interval workouts	Off-court: 2 × (8 × 15") (15"/5' rest)
	Intensity: 90–100% HR_{max}	

ground stroke velocity and accuracy, serve kinematics, and perceptual skill), although carbohydrate intake offered physiological advantages (increased blood glucose and reduced pre-exercise thermal sensation) (47,53). Thus, the effects of hydration/dehydration on tennis performance are presently unclear.

PLAYING TENNIS IN THE HEAT

During tennis competition, the increase in body heat load can be endogenous due to increases in player's metabolic rate (42,48) and/or exogenous (ambient environment) (68). As previously mentioned, tennis is often played in hot environments. When it is played under these conditions for extended periods, there is an increased possibility that players will experience symptoms of fatigue and, subsequently, heat injury. Previously, studies have found temperature-related impairments during intermittent exercise (22,39,72). It is likely that the attainment of high internal temperatures can impair central nervous system function, resulting in a reduced level of central cognitive or neural drive to the muscle, which might in turn decrease muscle function (42). Morante and Brotherhood (60,68) showed that as rectal temperature and skin temperature become higher, players rated their comfort as being increasingly warm, during a simulated tennis match play, although core temperature remains within safe levels. As previously mentioned, this situation may lead to a decrease in performance (e.g., longer recovery times between points and be less accurate during the service situation). This situation may predispose players to premature fatigue, with mentioned performance decrements, and even a heat illness (46,69). To overcome the reduced exercise capacity associated with the heat, a number of precooling methods (water immersion, ice jackets, cold air exposure, and water spraying) have been used to cool the body prior to exercise, with the greatest benefits likely associated with prolonged endurance type exercise (80). Hornery et al. (47) showed that precooling and intermittent cooling interventions during a prolonged simulated tennis match play afforded physiological advantage (reduced pre-exercise thermal sensation) but did not affect performance. Excessive heat storage was not induced due to temperate environmental conditions (21.2 ± 0.3°C and 50.4 ± 0.5% humidity). Thus, no performance benefits (due to no thermal-induced challenge) were associated with the cooling strategy. However, more research is needed to identify the health- and performance-related benefits of different cooling strategies carried out under tournament conditions before sound recommendations can be made.

PRACTICAL APPLICATIONS

Tennis is a complex sport requiring a mixture of physical, technical/tactical, and psychological skills. Moreover, the physical and physiological requirements of tennis players can vary depending on the players' level, playing style, sex, or court surface, among others. Furthermore, climatic conditions (e.g., heat) can have an important effect on subsequent performance. All these characteristics have important implications when designing training programs for tennis players. Based on the information provided in this review, the following recommendations to train competitive tennis players can be made:

- As previously mentioned, the critical phases of a tennis match (serve, strokes, and quick accelerations to the ball) are likely to be metabolically dependent on anaerobic pathways of energy supply, which would be superimposed on a background of largely aerobic submaximal activities (resting periods between points and games). Thus, it is clear that the training of competitive players should focus on improving their ability to repeatedly perform high-intensity exercise and to recover rapidly from it. This is done by regularly carrying out performing aerobic and anaerobic training.
- From a physiological point of view, aerobic training should aim to improve the oxidative capacity of muscle specifically used during play (improving the capacity of the cardiovascular system to transport and use oxygen). Thus, a larger percentage of the energy required for intense actions (e.g., short sprints) can be supplied aerobically, allowing the player to work at higher work rates for prolonged periods while maintaining a good technical performance as well as mental concentration toward the end of the match when fatigue might appear (48,65).
- To enhance aerobic fitness (optimum aerobic power levels), it has been suggested that using high intermittent exercise may be more effective in improving aerobic components than lower exercise intensities, such as traditional low-intensity aerobic training (11,15). However, there are certain athletes who might benefit from periods of traditional aerobic training (players with moderate aerobic levels or above the desired playing weight). This training should be done in the off-season, so that more specific training can be done prior to the competitive period (Table 2).
- With the current training schedules of competitive tennis players and due to most of their training time devoted to low- to moderate-intensity technical and tactical on-court training (in physiological terms, it could be classified as low- to moderate-intensity aerobic training) (81), supplemental aerobic training should mainly focus on high-intensity aerobic exercise (15,58). In this regard, more than an increase in maximal aerobic values ($\dot{V}O_2max$), the physiological goal should be to increase the rate of rise in oxygen uptake during brief intense actions (3). This can be accomplished by the use of intense interval training (58).
- Both on-court and off-court training drills should be implemented when prescribing high-intensity aerobic training. Some conditioning drills focussing on aerobic training, which can be implemented on a tennis

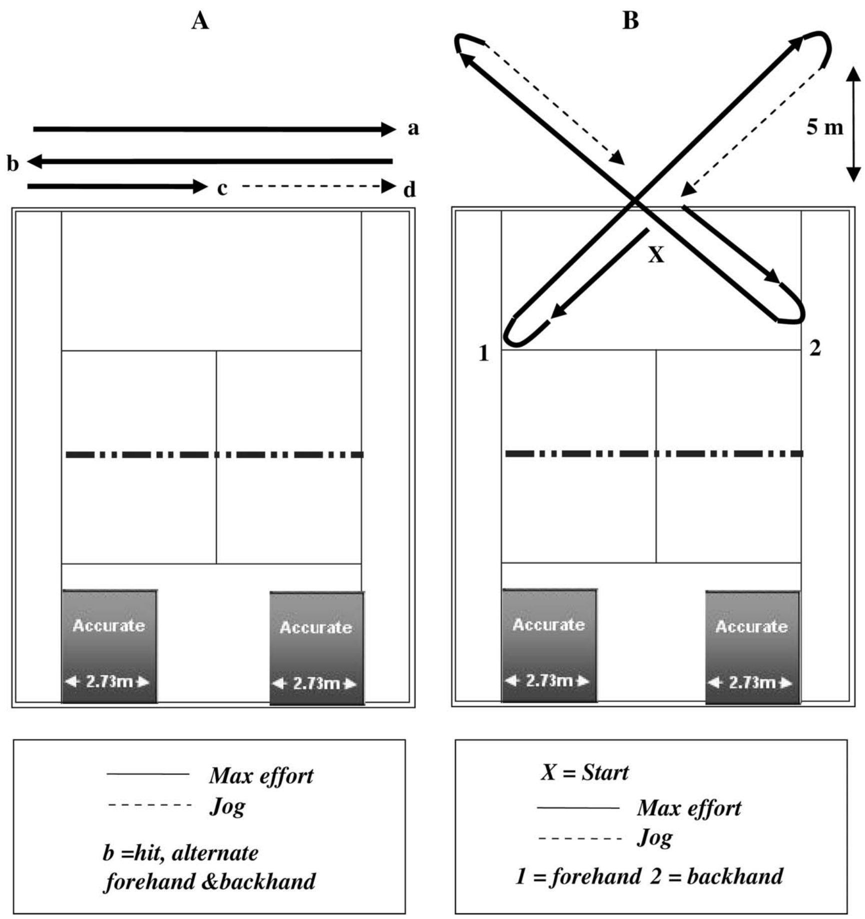

Figure 4. The 60 s "suicide" (a) and "big X" (b) drills. Adapted from Reid et al. (81).

court, are described in Figure 3. Also, exercises presented in Figure 4 (6 × 60-second "suicide drill" and "big X drill") can be useful (55,81,57), with physiological responses similar to maximum in-game values (LA = 7.6 ± 1.1 mmol/L) (56,81), and recommended to fit the profile of a highly intensive on-court drill, as described in the training literature (33). Using on-court–specific exercises such as the example presented in Figures 3 and 4, players have an alternative means for working aerobic efficiency and capacity while maximizing training time with the ball. Moreover, it would be interesting to include "accurate" target zones, to evaluate individual shot performance during the execution of these exercises (81). However, off-court drills (Table 3) are also needed because the technical demands of the game (ball handling skills and stroke skills) limit the attainment of high physiological intensities that are certainly needed to ensure an effective training regimen (15,44,73,86).

- In tennis, most of the game activities (strokes and rapid changes in direction) are rather brief and require the rapid development of muscle force that metabolically appears to be associated with a high rate of creatine phosphate utilization. On the contrary, LA producing energy system (as previously mentioned) appear not be highly stimulated during competitive tennis match play (27,56). Thus, most of training drills should be designed to demand the players the performance of short periods (<10 seconds) of maximal intensity exercise with enough rest in between efforts to allow athletes to reproduce maximal or near-maximal performance in subsequent bouts. LA production training (drills between 15 and 50 seconds) should also be carried out regularly with the goal of improving player's ability to perform high-intensity exercise for longer periods (3,2,35). Specific on-court movements (preferably without the racket) are preferred to ensure the attainment of the desired (maximal) intensities and that local muscle adaptations can be fully transferred to actual match play (62). General guidelines for this kind of training are presented in Table 4.
- The long and demanding competitive calendar of tennis players sometimes prevents strength and conditioning

Table 3
Examples of off-court high-intensity aerobic exercise

Repetitions	Mode	Intensity	Recovery
4 × 4 min	Stationary cycling (90 rpm); treadmill running (1% incline); running	90% HR_{max}	90 s active (60–70% HR_{max})
15 s/15 s (volume: 35 min)	Running (track and field court)	90–95% HR_{max}	15 s active (70% HR_{max})
30 s/30 s (volume: 35 min)	Running (track and field court)	90–95% HR_{max}	30 s active (70% HR_{max})

Table 4
General guidelines for anaerobic (e.g., PC utilization, LA production training) training

Exercise (s)	Rest (s)	Intensity	Repetitions
2–5	>50	Maximal	5–20
5–10	>100	Maximal	5–10
15–50	3–5 times exercise duration	70–100%	2–10

PC = creatine phosphate.

coaches to structure an optimal perdiodization plan. As a practical suggestion, a minimum number of 8 training weeks is recommended for junior tennis players to overcome a hard competitive calendar. Moreover, the inclusion of competitive cycles of 3 weeks interspersed with 2 weeks of recovery and training would be very useful to best prepare players physically (recovery and injury prevention programs) and mentally for competition.

- Given the apparent health implications, and the less clear performance-related effects, of poor hydration practices, sport scientists should seek to provide players with individualized hydration regimens (48). This is imperative during hot humid conditions, such as those often occurring during tournament tennis, particularly as thirst is a poor indicator of hydration status (7,16) and ad libitum fluid consumption often leads to involuntary dehydration (5,48). Although it is beyond of this review to provide exhaustive information regarding heat and hydration issues, there are some general guidelines to offer.
- As previously mentioned, many tennis players begin play or training dehydrated, so drinking plenty of fluids (water and sport drinks) throughout the day is totally recommended. It is important to make sure the player is euhydrated before play, taking as a "gold standard" the American College of Sports Medicine recommendation to consume between 400 and 600 mL of water 2 hours before exercise (57). Hydration schedules should be developed individually by the trainer, coach, and athlete by measuring fluid loss (checking the weight before and after practice/competition, measuring how much water is consumed, and checking the urine color [should be fairly light colored or almost clear]) (52).
- During practice or competition, it is important to drink at each changeover or rest time, completing a hydration schedule during play from 1.2 to 1.6 L/h (57). Moreover, for many players with high rates of fluid consumption on-court (>1 L/h), a combination of sport drink and water often works best.
- Post-practice or match hydration should begin immediately, drinking 150% of any remaining fluid deficit (5). If there is another match on the same day, nutrient replacement (emphasizing fluids, electrolytes, and carbohydrates) should begin immediately. Bergeron et al. (6), recently showed how 1 hour of complete rest, cool down, and rehydration was generally effective in eliminating any apparent carryover effects that would have resulted in greater thermal and cardiovascular strain during 2 subsequent exercise bouts (80 minutes of intermittent exercise). Players should ingest liquid and/or solid carbohydrates to aid in glycogen resynthesis (the body uses them faster in the heat and they help to store more water). Moreover, when playing in the heat, sodium supplementation before and after should be consumed at a rate of ~1.5 g/L (adding some salt to the diet), replacing electrolytes lost during sweating (57).
- A good level of aerobic fitness and an appropriate level of body fat can give players a big advantage in order to tolerate the heat, reducing heat storage, and effectively regulating body temperature (89).
- A good way to acclimatize to the heat is a progressive training (e.g., four 30- to 45-minute sessions of intermittent exercise) under hot conditions. It prompts certain physiological changes that reduce the risk of heat illness and helps to perform better (76,93). Even though full heat acclimatization can take up to 2 weeks (75), 2 to 3 days' training using specific protocols (low volumes with adequate intensities) can really help. Moreover, clothing designed for the heat is preferable (light colors, breathable).

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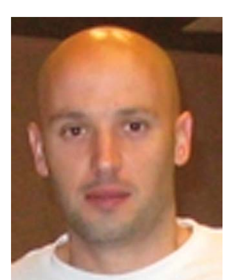

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