THE FRACTIONAL UTILISATION OF MAXIMAL OXYGEN CONSUMPTION DURING EXECUTION OF GROUNDSTROKES AND SIMULATED MATCH IN 14 TO 18 YEARS STATE-LEVEL SINGLES TENNIS PLAYERS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF TERMS USED

Backhand	A swing on the player's non-racket side of the body
Baseline	The back or end line of a tennis court
Crosscourt	A shot that travels diagonally across the court
Down-the-line	Directing the ball so that it parallels one of the sidelines rather than travelling from one side across to the other
Forehand	The stroke used to return a ball hit from the player's racket side
Groundstrokes	A hitting of forehand or backhand stroke after the ball has bounced
Maximal Oxygen Consumption (VO_{2max})	The point where further increase in load during incremental treadmill test fail to increase the oxygen consumption
Rally	A series of exchanges in hitting the ball back and forth the court. In matches, the exchange starts after the serve and ends when the ball is out of play

Simulated Match	A 60 minutes singles tennis match
Singles	A match played between two players

Pecahan Pengggunaan Oksigen Maksimum Ketika Melakukan Pukulan-bawah dan Perlawanan Simulasi dalam Kalangan Pemian Tenis Perseorangan Peringkat Negeri Yang Berumur Antara 14 ke 18 Tahun

ABSTRAK

Kajian ini dijalankan dengan tujuan mengenalpasti pecahan penggunaan oksigen maksimum (% VO_{2max}) ketika melakukan pukulan-bawah dan perlawanan tenis simulasi. Sepuluh pemain tenis lelaki peringkat negeri terlibat dalam kajian ini. Purata umur, tinggi, berat dan VO_{2max} bagi subjek-subjek tersebut masing-masing adalah 15.3 $\pm$ 1.2 tahun, 164.0 $\pm$ 7.4 cm, 52.3 $\pm$ 11.5 kg dan 51.7 $\pm$ 7.3 $ml \cdot kg^{-1} \cdot min^{-1}$. Kajian ini merangkumi 3 fasa iaitu ujian makmal (Fasa I), ujian di gelanggang (Fasa II) dan perlawanan tenis simulasi (Fasa III). Hasil kajian menunjukkan bahawa pecahan penggunaan oksigen maksimum (% VO_{2max}) ketika melakukan pukulan *forehand* dan *backhand* ialah 67.1 $\pm$ 15.2% dan 70.3 $\pm$ 13.6%, manakala bagi perlawanan simulasi ialah 69.3 $\pm$ 9.8% VO_{2max}. Pukulan *forehand* dan *backhand* menyebabkan peningkatan asid laktik dalam darah kira-kira 6 $mmol \cdot L^{-1}$ sekaligus menunjukkan penglibatan glikolisis anaerobik dalam penghasilan tenaga. Sebaliknya, ciri permainan yang bersela dan nisbah kerja-rehat 1 : 2.2, telah menyebabkan konsentrasi laktik dalam darah sebanyak 3.21 $\pm$ 0.2 $mmol \cdot L^{-1}$ selepas perlawanan tenis. Ini menunjukkan metabolisme aerobik adalah dominan ketika perlawanan tenis. Ia mungkin disebabkan laktik dalam darah telah dimansuhkan atau digunakan ketika sela rehat dalam permainan, yang didapati 2 kali ganda lebih lama dari jangkamasa kerja atau aktiviti. Purata kadar nadi ketika perlawanan simulasi (154.3 $\pm$ 15.4 $beats \cdot min^{-1}$) didapati lebih rendah

daripada purata kadar nadi pada ambang anaerobik dan sekaligus menjelaskan sebab paras laktik dalam darah didapati kurang daripada 4.0 $mmol{\cdot}L^{-1}$ ketika perlawanan tenis. Analisis video perlawanan tenis telah menunjukkan bahawa pemain lebih banyak melakukan pukulan *forehand* daripada *backhand* ($P<0.001$). Memandangkan terdapat persamaan pada kadar nadi dan VO_2 ketika melakukan pukulan *forehand* dan *backhand*, adalah dicadangkan agar pemain-pemain tersebut melakukan latihan pada kedua-dua pukulan tersebut secara seimbang. Ketika rali terpanjang dalam perlawanan tenis, purata kadar nadi dicatatkan sebanyak 174.9 ± 3.1 $beats{\cdot}min^{-1}$, sejajar dengan 84.5 + 2.2% VO_{2max}. Selain itu, purata rali dalam setiap 'game', jangkamasa rali dan bilangan pukulan bagi setiap rali didapati seperti berikut; 5.7 ± 2.4, 4.5 ± 1.5 saat dan 2.8 ± 0.8 pukulan. Kajian ini menyimpulkan bahawa pemain tenis peringkat negeri Kelantan mempunyai tahap kapasiti aerobik yang agak baik namun ia boleh ditingkatkan ke tahap antarabangsa menerusi latihan yang bercirikan daya tahan and bersela. Peningkatan pada VO_{2max} mungkin dapat meningkatkan intensiti permainan, begitu juga kadar pemulihan ketika sela rehat serta melengahkan keletihan ketika permainan tenis. Berdasarkan analisis video dan perkaitan kadar nadi dengan VO_2, adalah dicadangkan agar pemain-pemain tersebut untuk turut meningkatkan komponen anaerobik menerusi aktiviti berintensiti tinggi yang melibatkan beberapa siri ulangan dalam jangkamasa 5-8 saat.

The Fractional Utilisation of Maximal Oxygen Consumption During Execution of Groundstrokes and Simulated Match In 14 to 18 Years State-level Singles Tennis Players

ABSTRACT

The purpose of the present study was to determine the fractional utilisation of maximum oxygen uptake capacity (% VO_{2max}) during execution of groundstrokes and tennis match play. Ten male state-level tennis players participated in this study. Age, height, weight and VO_{2max} of the players were 15.3 ± 1.2 years, 164.0 ± 7.4 cm, 52.3 ± 11.5 kg and 51.7 ± 7.3 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively. This study was conducted in 3 phases: laboratory test (Phase I), on-court test (Phase II) and simulated match (Phase III). Fractional utilisation of VO_{2max} during execution of forehand and backhand strokes were 67.1 ± 15.2% and 70.3 ± 13.6% respectively, whereas tennis match play demanded 69.3 ± 9.8% of VO_{2max}. Execution of forehand and backhand strokes led to a blood lactate concentration of approximately 6 $mmol \cdot L^{-1}$, indicating the involvement of anaerobic glycolytic supply of energy. On the other hand, due to intermittent nature of the game and the work-rest ratio of 1 : 2.2, the post-match blood lactate was found to be 3.21 ± 0.2 $mmol \cdot L^{-1}$, reflecting an aerobic dominance of the game. It might be possible that the blood lactate was removed and was utilised during the rest pauses which were 2 times more than the work duration. Even the mean match heart rate (154.3 ± 15.4 $beats \cdot min^{-1}$) was lower than mean anaerobic threshold heart rate (164.7 ± 5.7 $beats \cdot min^{-1}$), signifying a lower blood lactate level less than 4.0 $mmol \cdot L^{-1}$ in a tennis match. Video analysis of the matches revealed that the players executed

more forehand strokes ($P<0.001$) than the backhand strokes. Since similar heart rate and VO_2 responses were observed for forehand and backhand strokes, it is suggested that the players should train themselves equally on both groundstrokes. During the longest rally, mean heart rate of the players was 174.9 $\pm$ 3.1 beats·min^{-1}, which corresponded to 84.5 $\pm$ 2.2% of VO_{2max}. In addition, rallies per game, mean rally duration and strokes per rally were found to be 5.7 $\pm$ 2.4, 4.5 $\pm$ 1.5 seconds and 2.8 $\pm$ 0.8 shots respectively. This study concluded that the Kelantan state-level tennis players possessed a moderately good aerobic capacity. This can be improved to the international standard through endurance and intermittent type of training. Improvement in VO_{2max} may increase the playing intensity of the match as well a better recovery in the rest pauses and also delay the onset of fatigue during tennis play. From video match analysis and the heart rate and VO_2 relationship, it is suggested that the players should also improve the alactic anaerobic component through short burst of repeated movements of 5-8 seconds durations.

CHAPTER 1

INTRODUCTION

Tennis is one of the popular racket sports in the world and is enjoyed by all standards and ages. Many tournaments are being organised at various levels among amateur and professional players, and even among recreational tennis players. Tennis is being played on various surfaces, such as hard court, clay court and grass court. The game is characterised by quick starts and stops, repetitive overhead motions, and the involvement of several muscle groups during execution of different strokes, fluctuating randomly from brief periods of maximal or near maximal work to longer periods of moderate and low intensity activity (Perry et al., 2004).

Tennis is of intermittent type of game and the physiological demand may vary largely depending on surface, equipment, tactical approach, duration of the match and by environmental factors such as temperature and humidity (Lees, 2003). Unlike a run in track events, where there is a set distance to cover, or unlike a soccer match, with a fixed time limit, tennis is very unpredictable. At international level, the match duration for 'best of three sets' in men usually takes about 1 hour and 30 minutes and can go on for three to five hours in 'best of five sets' matches (Therminiarias et al., 1991; Christmass et al., 1998; Kovacs, 2006). In general, a tennis match could possibly end with less than one hour or longer than 90 minutes. The duration of a tennis match depends on the skill of the player, court surface, biomechanical variables, like technique, and modern rackets of different materials like carbon, fibre-glass, graphite and titanium, and tactical approach during the match (Jones and Wood, 1991)

Tennis has often described as a game of continual emergencies because throughout the game, the ball travels at different velocities, a different type and rate of spin, be placed in different parts of the court (Groppel, 1986). The players also need to sprint to reach the ball, changing directions, stretching, lunging, stopping, and starting throughout the match (USTA, 1998). All these characteristics, combined with maintaining proper balance and technique. A good fitness level throughout a match is critical for optimal performance on the court. Thus, the likes of flexibility, strength and endurance, power, agility and speed, body composition, and aerobic and anaerobic fitness are very essential to improve the game performance (USTA, 1998).

The available literature highlights that singles tennis play is characterised by both the aerobic and anaerobic metabolic responses (Therminiarias et al., 1991; Christmass et al., 1998). The metabolic demands of tennis have long been characterised as being approximately 70% alactic anaerobic, 20% lactic anaerobic and 10% aerobic (Fox et al., 1974). Previous studies suggested that 88% of adenosine triphosphate (ATP) production during singles tennis play is derived from aerobic sources (Selinger et al., 1973), whereas Fox (1979) implied that this figure was only 30%. Studies by Friedman et al. (1984) and Elliot et al. (1985) however indicated that the exercise intensity in singles tennis play was somewhere between that of Selinger et al. (1973) and Fox (1979). Such contradictions in the literature are likely to be related to the methods used to determine the exercise intensity and metabolic responses in single tennis matches (Christmass et al., 1998). It may also be due to the variation of the levels of play, the duration of the points, and the intensity of play (Fox et al., 1974). In addition, factors such as playing style, surface, environment and velocity of shot also could influence the exercise intensity and metabolic response throughout tennis matches (Kovacs, 2006).

Measurement of heart rate (HR) during play has been used to assess exercise intensity on the basis of the linear relationship between heart rate and oxygen consumption (Elliot et al., 1985). Several studies have combined measurement of heart rate with measurement of the blood or plasma concentration of metabolites during singles tennis matches to provide more direct indications of the metabolic response, especially to understand the anaerobic phase (Bergeron et al., 1991; Therminiarias et al., 1991; Smekal et al., 2001; Fernandez et al., 2005).

After the serve and return, most points begin with an exchange of groundstrokes, which are known as rally (Jones and Wood, 1991). Prapavessis (1990) defined rally as an exchange of groundstrokes when both the players are in a state of equilibrium from the baseline with no advantage gained. Rally also has been defined as a series of exchanges in hitting the ball until the end of the point (Claxton, 1999). Therefore, to succeed in a rally, a tennis player is required to have good fitness level, physical and technical expertise (USTA, 1998; Elliot, 2006).

According to Sailes (1990), the forehand and backhand groundstrokes are the building blocks upon which most tennis players' games are built. In baseline play, consistency, control, and power are the keys to successful baseline groundstrokes. Besides, good footwork, anticipation, and early preparation are also important factors responsible for developing good groundstrokes (Jones and Wood, 1991).

In the present study, oxygen uptake, heart rate and blood lactate concentration were monitored in state-level tennis players with age ranging from 14 to 18 years during forehand and backhand groundstrokes. However, during simulated matches, the heart rate and blood lactate concentrations were studied. This study was designed to provide a near 'actual situation' to players' physiological response during execution of groundstroke test and simulated singles tennis match. Measuring each of these variables in this study provided a baseline profile which better identified the physiological response during execution of groundstrokes and overall intensity of a tennis match.

Recently, as seen on television/videos, most of the top international tennis players prefer to play at the baseline. With respect to other skills in tennis such as service and volley, it is observed that the players are more relying on their groundstrokes to win points. In addition, there is no available literature in recent time which provides this kind of information. As the groundstrokes become very important skill in singles' tennis matches now-a-days, it becomes essential to investigate the physiological responses, especially, during execution of both forehand and backhand strokes. In addition, to our knowledge, no such studies have been carried out to investigate the physiological responses during execution of groundstrokes. Some studies have been carried out to investigate the groundstrokes performance and its relation to fatigue in singles' tennis (Vergauwen et al., 1998; Davey et al., 2002).

1.1 Objectives of the Study

The objectives of this study are to determine:

1. The fractional utilisation of maximum oxygen consumption ($\%VO_{2max}$) during forehand and backhand groundstrokes in tennis and simulated match play.
2. The physiological status of Kelantan state-level tennis players of 14-18 years.
3. The anaerobic demands on the basis of whole blood lactate during execution of groundstrokes and the simulated matches.
4. The physical demands on the basis of work and rest pauses, number of forehand and backhand strokes, average rallies and average duration of rallies during simulated match play through video analysis.

1.2 The Significance of the Study

Findings of this study will supplement the specific knowledge of the physiological demands of forehand and backhand strokes during on-court drills, on the basis of direct oxygen cost measurement on a portable metabolic cart. In addition, findings of this study also will provide the information of characteristics of singles tennis match for state-level players. The available data in the published literature are on the basis of heart rate, since heart rate bears with a linear relationship with oxygen consumption. To our knowledge, no such studies have been carried out to investigate the fractional utilisation of maximal oxygen consumption using portable metabolic cart during execution of groundstrokes specifically. Furthermore, findings of this study could provide a baseline data for future studies on energy expenditure of the groundstrokes and tennis play in Malaysian state-level players.

1.3 Limitation of the Study

This study only involved Kelantan state-level tennis players who are aged between 14 to 18 years of age. Only male tennis players were recruited in this study. Due to the limited time frame and current demands of the game, this study only focused on forehand and backhand groundstrokes rather than other skills/drills in tennis game. This study was restricted only on a hardcourt surface due to the unavailability of other types of surfaces.

CHAPTER 2

LITERATURE RIVIEW

2.1 The Characteristics and Fitness Demands of the Game

Performance of singles tennis involves both aerobic and anaerobic (alactic and glycolytic) metabolism (USTA, 1998; Fernandez et al., 2006). In general, energy for muscle work is provided by instantaneous breakdown of adenosine triphosphate (ATP) present in the muscle cells. Hence, ATP must be continuously supplied during exercise (McArdle et al., 1996). Anaerobic energy metabolism involves two systems. The first and most immediate is called the phosphocreatine system or ATP-PC system. This energy system serves as the main source for ATP during singles intense muscle contractions (Green, 1997). In addition, Newsholme (1986) and McArdle et al. (1996) suggested that phosphocreatine provides an instant reservoir for resupply of ATP. Powers and Howley (2001) suggested the ATP-PC system supplies most of the energy during a very short maximal intensity work (approximately the first 10 seconds). After approximately 10 seconds of intense work, the predominant energy system derived from anaerobic glycolysis which the by-product is the lactic acid (McArdle et al., 1996; Sharp, 1998).

Theoretically, combined with the need for rapid movement and explosive stroke production implicate phosphocreatine as a key component of energy supply in tennis as the activities were executed in a short duration (USTA, 1998).

However, the duration of rallies may vary depending on the court surface and the opponent (Kovacs, 2006). In a long duration activity, the energy comes primarily from aerobic metabolism. Thus, whether the energy production is dominated by the ATP-PC system or glycolysis depends primarily on the length of the activity (Bursztyn, 1990; Astrand and Rodahl, 2003). Since tennis play is intermittent, the metabolic pathway of energy production varies depending on specifically what the player is doing at a given moment. Recovery from anaerobic work is performed aerobically, thus both aerobic and anaerobic energy systems are a factor in energy production in this sport (USTA, 1998; Chandler, 2000)

Tennis is a wonderful sport for players at all skill levels and an excellent form of exercise. Researchers characterise tennis as an intermittent activity due to short bouts of high or moderate exercise intensity interspaced with periods of rest between point or when the players change sides, every odd game (Therminarias et al., 1991; USTA, 1998). The overall intensity in tennis ranges between 60% to 70% of maximum oxygen uptake and the energy requirements are mainly provided by aerobic energy metabolism (Konig et. al., 2001). However, match intensity in elite tennis players was found to be between 73% and 81% of peak heart rate (Davey et al., 2003).

Aerobic fitness is very important in tennis (Buti et al, 1984). In general, the average maximal oxygen consumption (VO_{2max}) reach 45 to 55 $ml \cdot kg^{-1} min^{-1}$ for females and 55 to 65 $ml \cdot kg^{-1} min^{-1}$ for males (Buti et al., 1984; Keul et al., 1991; Konig et al., 2001). Christmass et al. (1998) found that the average VO_{2max} among state-level tennis players (24 ± 2 years) were 53.4 ± 1.8 $ml \cdot kg^{-1} min^{-1}$, ranged between 54.1 $ml \cdot kg^{-1} min^{-1}$ to 60.7 $ml \cdot kg^{-1} min^{-1}$. Recent study by Fernandez et al. (2005) reported that average VO_{2max} in international and national level tennis players (23.9 ± 2.5 years) was 58.2 ± 2.2 $ml \cdot kg^{-1} min^{-1}$.

Bernardi et al. (1998) measured the VO_{2max} values in middle-level non-professional tennis players, based on their style of play. Attacking players (hits the tennis ball hard and attempt to come to the net consistently) demonstrated the highest VO_{2max}, of 67 $ml \cdot kg^{-1} min^{-1}$, followed by baseline players (play the large majority of points from the baseline, hitting groundstrokes, and does not prefer to come to the net) at 66 $ml \cdot kg^{-1} min^{-1}$, and whole-court players (who plays from the baseline, but is very comfortable coming to the net) at 62 $ml \cdot kg^{-1} min^{-1}$. Therefore, competitive tennis players should posses a good aerobic fitness. As the duration of three to five sets of match could up for several hours, at the end of a match, the differences in physiological performance between opponents of similar technical and tactical ability may be crucial to success. To successfully endure tournament competition tennis players must be sufficiently prepared to meet this physiological challenge on several consecutive occasions.

The best way to train for tennis is by understanding the demands of the sport. Both aerobic and anaerobic fitness are crucial in tennis as the average duration of work was found to be between 5 to10 seconds (Docherty, 1982; USTA, 1998; Smekal et al., 2001; Kovacs, 2004b), but the duration of the match is up to several hours. In addition, during a match, the rest period between the points range from 10 to 25 seconds (O'Donoughue and Ingram, 2001; Kovacs, 2004b), and approximately 18 seconds as reported by Therminarias et al. (1991), with a maximum permitted rest period of 20 seconds between point and 90 seconds for every odd game, when the players change sides, by the International Tennis Federation (2006). Thus, low aerobic fitness would cause problem for the players to recover between points and games (Therminiarias et al., 1991), and the players likely to get tired towards the end of the match. Another advantage of a strong aerobic base is players would be able to endure the match as the match can last a long time.

The game begins with a service. If the opponent is able to return the serve, the game might continue with a rally until one of the players gets a point from a good hit or unable to return the ball or make a mistake. In squash, the duration of rallies can be as short as 1.5 seconds or as long as 10 minutes (Sharp, 1998), although periods of 3 to 10 seconds are more common across all racket sports (Lees, 2003), whereas Fernandez et al. (2006) suggested that rallies during match typically less than eight seconds (ranged from 5 to 7 seconds). In tennis specifically, a rally may last one stroke and 1.5 seconds, while several stokes usually lasts from 6 to 12 seconds (Therminarias et al., 1991). In addition, players averaged 2.5 to 3 strokes per rally, depending on their game style, ball type, court surface, sex and tactical strategy (Smekal et al., 2001; Cooke and Davey, 2005). With regard to the court surface, researchers suggested that fewer strokes per rally and shorter rally lengths on grass court when compared to synthetic surface (Lees, 2003). According to USTA (1998), a player may expend 300 to 500 short bursts of effort during a match. Since each short bursts of effort is an anaerobic activity (Kovacs, 2006), good anaerobic fitness could lead to success for tennis players (USTA, 1998).

Court surface has been reported to influence match activity in elite level tennis players (O'Donoughue and Ingram, 2001). There were fewer shots per rally and shorter rally duration on grass compared to synthetic surface (Hughes and Clarke, 1995). On slow surfaces, such as the clay courts used in French Open, both men and women players have significantly longer rallies than any other surface (O'Donoughue and Ingram, 2001; Smekal et al., 2001). O'Donoughue and Ingram (2001) also reported the mean rally duration of 92 minutes and 46 seconds of simulated tennis match play on hardcourt was 3.8 $\pm$ 0.1 seconds, ranged from 1.0 to 24.0 seconds. The mean rally duration was only 3.69 seconds on grass court (Wimbledon 1996) as reported by O'Donoughue and Liddle (1998). In addition, points having an average duration of between 3 to 15 seconds on some of the faster surfaces such as grass, carpet and indoor (Hughes & Clark, 1995; Christmass et al., 1998).

O'Donoughue and Ingram (2001) and Fernandez et al. (2006) reported that the average rally duration in tennis varies from 4 to 8 seconds. Previously, USTA (1998) noted that most points in tennis irrespective of what type of court surface, last less than 10 seconds. Smekal et al. (2001) reported that, in a 50 minutes match, the average rallies duration among national level tennis players was 6.4 $\pm$ 4.1 seconds. However, this duration varies considerably according to the player's standard, playing style, fitness level, gender and court surface (O'Donoughue and Ingram, 2001; Therminarias et al., 1991). In extent to the players' playing style, Bernardi et al. (1998) reported the mean and standard deviation of rally duration found to be varied when the player in control of the rally was an attacking player (4.8 ± 0.4 sec), a whole court player (8.2 ± 1.2 sec), and a baseline player (15.7 ± 3.5 sec). Furthermore, the proportion of points derived from baseline rallies at the French Open was found to be higher (51%) than at the other Grand Slam tournaments, and the shortest at Wimbledon (19% of points) (O'Donoughue and Ingram, 2001; Kovacs, 2004b).

The duration in racket sports competition can vary from as little as 6 min in squash (Sharp, 1998) to 5 hours or more in tennis (McCarthy-Davey, 2000), although duration of 20 to 90 minutes are more common across all racket sports (Bergeron et al., 1995; Lees, 2003). The match duration could vary and it depends on the match scoring system. At international level, the match usually played with 'best of three sets' of match format, while the 'best of five sets' of match format is used in Grand Slam tournament. Tennis matches were commonly found to be 90 minutes in 'best of three sets' (Christmass et al., 1998; Lees, 2003) and may up to 5 hours in 'best of five sets' match (McCarthy-Davey, 2000). In 1988 US Open best of five set men's singles final lasted 4 hours and 9 minutes (Chandler, 1995). During match play, tennis players must accelerate, decelerate, change direction, move quickly, maintain balance and generate optimum stroke production repeatedly (Chandler, 1995). Therefore, the tennis match sometimes could be played under a very stressful condition which in turn demanding a very high level of technical, tactical, physiological and psychological capacity for the players to perform well in a match (Christmass et al., 1998).

2.2 Notational Analysis

Analysis of time spent in actual play revealed that tennis players were involved in play for only five of the thirty minutes of game play, compared to 15 and 10 minutes respectively for squash and badminton (Docherty, 1982). The duration of a tennis match was often more than an hour and could reach 5 hours in some cases (Christmass et al., 1998). Smekal et al. (2001) found that the effective playing time among national level tennis (26.0 ± 3.7 years) players in 50 minutes match was 29.3 ± 12.1%. Some studies found that the total time of intense activity constitutes in average 25% of the total game time (Bergeron et al., 1991; Therminarias et al., 1991). Countless breaks between rallies and sets reduce actual playing time to around 20-30% of total match time, with an exercise-to-recovery ratio in men's singles of 1:2.5 (Bergeron et al., 1991; Groppel and Roetert, 1992).

Court surface and athletes' playing style have also been found to give some impact on the percentage of the playing time with respect to the total time of the match on clay courts (Bernardi et al., 1998). The researchers revealed that percentage playing time for the attacking players was approximately 21 ± 5.5%, 28.6 ± 4.2% for whole court players, and 38.5 ± 4.9% for baseline players. In an earlier study, Docherty (1982) reported that the percentage of playing time during match, on hardcourt, was approximately 20%. With regards to the effect of court surface on the percentage of playing time, it was observed to be around 20% to 30% on clay courts and 10% to 15% on fast court surfaces (Ferrauti et al., 2003).On hard-court surface, the percentage of playing time during tennis match was found to be varies from 20% to 30% of the total match time as reported by Bergeron et al. (1991).

In recreational tennis players, a larger variation in work-rest intervals were reported (Kibler and Chandler, 1995), particularly related to the skills levels of the participants (Chandler, 2000). Kibler and Chandler (1995) reported that the work-rest intervals on clay averaged 1:2.1 seconds in females and 1:1.7 seconds in males. The researchers also found that the average work-rest ratio on hard court surface was 1:2.3 seconds in females and 1:2.2 seconds in males (Kibler and Chandler, 1995).

A work-rest ratio was reported to be between 1:1 and 1:4 for state, national and international level players (Christmass et al., 1998; Smekal et al., 2001: Kovacs, 2004b). Christmass et al. (1998) revealed that the mean match characteristics in male state-level players (N=8; age: 24 ± 2 years) were: rally time, 10.2 ± 0.3 seconds; recovery time, 16.8 ± 0.2 seconds; work-to-recovery ratio, 1:1.7; number of shots per rally, 4.6 ± 0.1; number of rallies per game 6.9 ± 0.4; time in play as a percentage of total match time, 23.3 ± 1.4%.

2.3 Physiological Responses in Tennis

Numerous studies have been done to profile the demands of the tennis game by using oxygen consumption, heart rate and blood lactate concentration as the variables of the study (Ferrauti et al., 1998; Davey et al., 2003; Fernandez et al., 2006; Kovacs, 2006). There were also studies that had been carried out on certain age group of tennis players (Therminarias et al., 1990; Ferrauti et al., 1998) and based on player's style of play (Bernardi et al. 1998). There were a few studies which conducted the simulated match as a method to observe the physiological response during the match play (Bergeron et al., 1991; Therminarias et al., 1991; Smekal et al., 2001; Davey et al., 2003).

Estimates of exercise intensity in tennis have been described by using heart rate monitored throughout the tennis match (Docherty, 1982; Christmass et al. 1998). However, oxygen uptake, blood lactate concentrations (Bergeron et al., 1991; Smekal et al., 2001), and rate of perceive exertion or RPE (Novas et al., 2003) also can be used to estimate the exercise intensity in tennis and the total energy expenditure (Novas et al., 2003).

Heart rate is a practical method of monitoring intensity during practice. Physiological stress is associated with the elevation of heart rate and reflects the effort expended during short intense bouts of play. The heart rate generally increases rapidly at the onset of a match and remains elevated, with tendency to increase as the match progresses (Therminarias et al., 1991; Kovacs, 2006).

Maximal heart rates during matches are close to the age-related maximum, and the average heart rate throughout the match often exceeds 75%, which indicates a high effort during play (Lees, 2003). Davey et al. (2003) reported that the heart rate responses of 10 elite players (5 males, 21.7 $\pm$ 1.0 years; 5 females, 21.9 $\pm$ 1.3 years) to the simulated match play ranged from 140 to 157 beats·min^{-1}, which were approximately 73% to 81% of peak heart rate. Some previous studies indicated that the mean heart rate in 20 to 30 years old trained players ranges between 140 to 160 beats·min^{-1} during singles competitions, indicating an overall intensity of 60% to 70% of VO_{2max} (Morgan et al., 1987; Groppel and Roetert, 1992; Konig et al., 2001).

The heart rate variation during matches reflects the intermittent nature of tennis activity (Kovacs, 2006). A study by Christmass et al. (1998) found that the average heart rate in singles tennis match is 70-85% of maximum heart rate, compared to 60%-70% of maximum heart rate in doubles. Bergeron et al. (1991) reported that the average heart rate during 85 minutes of simulated match play among collegiate tennis players (20.3 $\pm$ 2.5 years) was found to be 144.6 $\pm$ 13.2 beats·min^{-1}. During or immediately after a rally, heart rate may reach values close to maximum heart rate (HR_{max}). Heart rate can rise as high as 190-200 beats·min^{-1} during long and fast rallies (Keul et al., 1970; Bargeron et al., 1991; Smekal et al, 2001), reflecting phases of high activity, which involve both upper and lower body musculature (Konig et al., 2001; Fernandez et al., 2005). In addition, the maximal muscular work of the arms and legs during high phases of high-intensity hitting can cause heart rates to reach near maximum (Holmyard et al., 1988; Therminarias et al., 1990). Heart rate values were also influenced by the style of play as attacking players attained a mean heart rate of 190 beats·min^{-1}, baseline players 200 beats·min^{-1}, and whole-court players 192 beats·min^{-1} (Bernardi et al., 1998).

Therminarias et al. (1991) reported that during a singles match, in skilled players (women; 21.2 $\pm$ 1.9 years), after the initial 5-6 minutes of play, mean heart rate rose up to 80-85% of the maximum heart rate and be maintained throughout the match. However, in middle-aged subjects (women; 46.6 $\pm$ 1.3 years) involved in a long and strenuous match, mean heart rate progressively increase up to maximum heart rate.

Davey et al. (2002) reported that mean heart rate of eighteen senior country tennis players (9 males, 20.7 $\pm$ 0.9 years; 9 females, 21.7 $\pm$ 0.6 years) ranged from 186 $\pm$ 2 beats·min^{-1} to 190 $\pm$ 2 beats·min^{-1} during the Loughborough Intermittent Tennis Test (LITT). The test consisted of bouts of maximal tennis hitting of 4 minutes duration with 40 seconds recovery between bouts until volitional fatigue. The tennis ball serving machine fed balls in a random direction at a frequency of 30 balls per minute. Meanwhile, the highest concentration of blood lactate during the test recorded was 9.6 $\pm$ 0.9 mmol·L^{-1}.

During rest, blood lactate concentration of 1 to 2 mmol·L^{-1} was expected among tennis players (Bergeron et al., 1991; Christmass et al., 1995; Reilly and Palmer, 1993), while during play it is around 3 to 4 mmol·L^{-1} in squash, which represent the aerobic nature of racket sports (Sharp, 1998). However, the highest blood lactate concentration observed was fairly higher than in badminton but no more than 5 mmol·L^{-1} (Hughes, 1995). In general, lactate concentrations remain low (1.8 to 2.8 mmol·L^{-1}) during tennis match play (Bergeron et al., 1991; Konig et al., 2001; Fernandez et al., 2006). In addition, mean lactate levels of well-trained players during singles tennis seldom exceed 3 mmol·L^{-1} (Elliot et al., 1985; Bergeron et al., 1991; Groppel and Roetert, 1992). This suggestion was supported by a study by Smekal et al. (2001) as they found the mean lactate concentration was 2.07 $\pm$ 0.9 mmol·L^{-1} during tennis match play.

However, during long and intense rallies, lactate levels can increase up to 8 mmol·L^{-1} (Christmass et al., 1998), which in turn suggest increased involvement of anaerobic glycolytic processes to supply energy (Bergeron et al., 1991). Furthermore, during intense play and towards the end of the match, blood lactate concentration can exceed 10 mmol·L^{-1} in tennis (Bergeron et al., 1991) and in squash (Sharp, 1998). In other studies, researchers found that plasma lactate concentration remain low or increase moderately throughout the simulated tennis match (Bergeron et al., 1991; Therminarias et al., 1991).

Previous studies revealed that the VO_2 during singles tennis play vary between 24 ml·kg^{-1}min^{-1} to 40 ml·kg^{-1}min^{-1}. The oxygen consumption measured in male competitive tennis players during on-court play ranged from 24 ml·kg^{-1}min^{-1} to 28 ml·kg^{-1}min^{-1} (Elliot et al., 1985). A study by Smekal et al. (2001) found that, in a simulated match, the highest oxygen uptake (VO_2) in male national level tennis players (N=20, 26.0 $\pm$ 3.7 years) was 47.8 ml·kg^{1}min^{-1} even though the average

VO_2 throughout the match was only 29.1 ± 5.6 ml·kg^{-1}min^{-1}. Another study by Ferrauti et al. (2001a), twelve nationally ranked senior tennis players (6 females and 6 males; 47.2 ± 6.6 years and 47.0 ± 5.4 years old, respectively), completed a 2 hours singles tennis match. Mean VO_2 during the 2 hours match were 23.1 ± 3.1 ml·kg^{-1}min^{-1} for females and 25 .6 ± 2.8 ml·kg^{-1}min^{-1} for males. Fernandez et al. (2006) summarised from previous studies that average VO_2 during tennis match were between 23.1 ml·kg^{-1}min^{-1} and 40.3 ml·kg^{-1}min^{-1}.

2.4 Groundstrokes Performance

A good technique appears to be a good predictor of performance, and biomechanics plays an important role in stroke production as all strokes have a fundamental mechanical structure (Elliot, 2006). Research showed that internal rotation of the upper arm at the shoulder joint plays an important role in service and groundstrokes, particularly the forehand strokes (Elliot et al., 1995; Elliot et al., 1997). Elliot (2006) also added that, when the leg movements were ignored during execution of groundstrokes, the internal rotator musculature must accelerate the upper arm in the swing impact, before the external rotators eccentrically contract to decelerate this rotation during the follow through phase of the action.

During a rally, the activity may involve quick burst of running, with sudden changes in direction, often at top speed and the body should always be in good balance during execution of groundstroke (Therminarias et al., 1991; Chandler, 1995; Fernandez et al., 2006). The execution of groundstroke needs specific changes in body position of body segments organised in particular time and space sequence (Therminarias et al., 1991). Researchers also suggested, to perform a rally, players must address that the fitness components such as flexibility, strength and endurance, agility and speed, body composition, and aerobic and anaerobic fitness to improve their tennis games (USTA, 1998; Chandler, 2000)

The ability to perform good groundstrokes during a match is very important in tennis. As the groundstrokes are very important in tennis, Vergauwen et al. (1998) and Davey et al. (2002) carried out studies which were related to stroke performance. The Leuven Tennis Performance Test (LTPT) was carried out on 27 well-trained male Belgian tennis players (7 international level, 10 national level and 10 amateurs) by Vergauwen et al. (1998). The test was conducted in three different rally situations; which were performance in neutral rallies, defensive rallies and offensive rallies among international and national level players. For performance in neutral rallies, compared to national level players, the internationals scored better for nearly all stroke quality parameters studied. The internationals made 10% fewer ($P<0.05$) errors than national level players. Ball placement to the sideline was better ($P<0.05$) in internationals when compared to the national players. Performance in defensive rallies also showed that the international level players made fewer errors ($P<0.05$) compared to national level players. The percentages of errors for the international and national level players are 27 $\pm$ 2% and 36 $\pm$ 2% respectively. Performance in offensive rallies was studied by evaluating the quality of volleys. Compared with the national players, international players made fewer

(P<0.05) errors (36 ± 4 vs. 22 ± 4%), both in forehand (31 ± 4 vs. 21 ± 4%) and backhand volleys (40 ± 5 vs. 24 ± 7%).

In general, fatigue develops as the duration and intensity of physical exertion increase as the match progresses and is affected by environmental temperature, hydration status, as well as initial core temperature and degree of acclimatisation (Kay and Marino, 2000). Davey et al. (2002) examined the effect of fatigue from maximal tennis hitting on skilled tennis performance in 18 senior country tennis players (9 males, 20.7 ± 0.9 years; 9 females, 21.7 ± 0.6 years). Subjects undertook two performance tests, both against tennis ball serving machine; (1) a pre- and post-skill test of groundstrokes and service; (2) the Loughborough Intermittent Tennis Test (LITT). The LITT consisted of bouts of maximal tennis hitting of 4 minutes duration with 40 seconds recovery between bouts until volitional fatigue. The tennis ball serving machine fed balls in a random direction at a frequency of 30 balls per minute. Results of groundstroke hitting accuracy showed no significant differences between the first and the second skill tests for crosscourt forehand and backhand, and, down-the-line forehand and backhand. However, in the Loughborough Intermittent Tennis Test, groundstroke hitting accuracy decreased by 69% (P<0.01) from start to volitional fatigue (35.4 ± 4.6 min). Another study by Davey et al. (2003) found that hitting accuracy decreased by approximately 81% as the players (10 elite tennis players; 21.7 ± 1.0 years and 21.9 ± 1.3 years for males and females, respectively) became fatigued. In the study, the subjects were fed 30 balls per minute by the tennis ball serving machine and fatigue was considered to have occurred when the hitting frequency for two consecutive ball feeds could no longer be maintained, or when the players stopped voluntarily (Davey et al., 2003).

McCarthy-Davey (2000) indicated that blood lactate concentration in excess of 7-8 mmol·L^{-1} was associated with a decline in technical and tactical performance in tennis. In contrast, Ferrauti et al. (2001b) found that in a 30 shot intermittent tennis speed and accuracy test in elite tennis players, as the duration of recovery decreased from 15 to 10 seconds, blood lactate reached 9.0 mmol·L^{-1} but the number of target hits increased and the number of errors decreased. Thus, the results suggested that players were still able to perform skilfully even though they were under fatigue condition. The physical demands of tennis have been studied on the basis of heart rate, since heart rate bears a linear relationship with oxygen consumption. Hence, the present study was undertaken with a view to investigate the fractional utilisation of maximal oxygen consumption using portable metabolic cart directly during execution of groundstrokes. The findings of this study will provide a baseline data for future studies on energy expenditure of the groundstrokes and tennis match play in Malaysian state-level players.

CHAPTER 3

METHODOLOGY

3.1 Subjects For The Study

Ten tennis players who are physically fit, competitive and being in regular training were recruited for this study. Their age ranged from 14 to 18 years. All the subjects were training at Majlis Sukan Sekolah-Sekolah Kelantan (MSSK) tennis court, Kota Bharu, Kelantan. This study only involved male subjects who have competitive experience for at least 2 years at national level.

Participation of subjects in regular training was ensured in Medical and Health Information questionnaire, which is attached in subject's Personal Details Form (Appendix A). All the subjects were free from any serious injury or health problems.

This study has been approved by the Research and Ethics Committee, School of Medical Sciences, Universiti Sains Malaysia, Health Campus, Kelantan.

3.2 Research Protocol Design

This present study was carried out in the following 3 main phases, which took 14 weeks to be completed:

- Phase I: Laboratory test
- Phase II: On-court test
- Phase III: Simulated match

Before the tests were carried out, the subjects were explained about the exercise protocol and all possible risks and benefits associated to this study. Subjects were asked to complete the Participation Information and Consent Form and Participation Data Collection Form.

3.2.1 Instruction to the subjects

During the laboratory test (Part I), subjects were asked to report at the laboratory before 8.30 a.m. on the day of incremental test. During the on-court test (Part II) and simulated match (Part III), subjects were asked to report at the tennis court at 3.15 p.m. (for Part II) and before 4.15 p.m. (for Part III) as the tests were carried out at 4.00 p.m. and 5.00 p.m., respectively.