CORRELATION BETWEEN AEROBIC CAPACITY AND ANAEROBIC CAPACITY IN ELITE JUNIOR TENNIS PLAYERS.

A DESCRIPTIVE STUDY

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Summary

The aerobic and anaerobic capacities are two fundamental pieces of the elite tennis player. The importance of knowing the aerobic capacity and its correlation to the anaerobic capacity may provide useful information about the player’s abilities. Besides from having the ability to play matches that can last up to several hours, players should also be explosive in every rally and this demonstrates the complexity of tennis as a sport.

The aim with this study was to investigate the correlation between aerobic and anaerobic capacity in elite junior tennis players. Our main hypotheses are: 1). There is a correlation between aerobic capacity and anaerobic capacity in elite junior tennis players and; 2). There are gender and age differences in anaerobic and aerobic capacity in this population.

Thirty-nine elite tennis junior players were included in the study, 21 males and 18 females. The subjects were 15-23 years of age. Each player completed a VO$_2$ max test, and a modified Wingate test.

The results of this study indicate that there is a correlation between aerobic and anaerobic capacity in this group of elite junior tennis players (P<0.05) in absolute values and values corrected for body mass. This correlation persisted when the groups were divided according to age in absolute values 15-16 (n=16) (P<0.05), however, when corrected for body mass the correlation did not persist (P>0.05); and 17-23 (n=23): the correlation persisted in absolute values and when corrected for body mass (P<0.05). However, when divided into gender, the males (n=21) showed a significant correlation (P<0.05) in absolute values, but not when corrected for body mass (P>0.05) whereas the females (n=18) did not show any significance (P>0.05).

To summarize, the results of this study could be a useful tool when further developing the exercise programs in a more sport specific fashion to enhance performance in elite tennis junior players.

Keywords: Aerobic and anaerobic capacity, VO$_2$ max, Wingate test, Adolescent athletes, Adolescent physiology, tennis players.
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Abbreviation

HR - Heart rate
mWAnT - Modified Wingate Test (Test for anaerobic capacity)
PCr - ATP- phosphocreatine system
PHV - Peak height velocity (A measure of the real puberty)
Q - Cardiac output
r - Correlation coefficient (statistical measure)
95% CI - Confidence interval (statistical measure)
RER - Respiratory exchange ratio
SvTF - Swedish Tennis Federation
SV - Stroke volume
VO₂ max - Maximum oxygen uptake
W - Watt (derived unit for power)
Foreword

This project thesis is a part of the examination of Scandinavian college of Naprapathic Manual Medicine. Our mentor for this thesis is Doctor of Naprapathy Fredrik Johansson who is the head of strength and conditioning in the Swedish Tennis Federation (SvTF).

During our time at school we have encountered sports physiology and have become very interested in this topic. The balance between aerobic and anaerobic energy systems and their influence in different types of sports caught our attention especially. We thought adolescents would be interesting to have as subjects because of the effects of growth and maturation. We got in contact with Fredrik Johansson who works professionally with elite junior tennis players and discussed this subject. We finally decided to write about the correlation between anaerobic and aerobic capacity in tennis junior players.

We would like to give our greatest gratitude to: Fredrik Johansson, our mentor, for being very enthusiastic and helpful whenever needed and giving us good advice along the way; William Strømsvold for helping us with figures and layout and useful tips and; our friends, family and opponents for their support and proofreading.
1 Introduction

Physiological measurements, and the ability to tell a person's physiologic capacity in an objective way, are important for trainers who are focussed on the development of athletes. What happens in the body when you exercise in different ways? Wilmore at al. (2008), says that resistance training in combination with endurance training does not appear to restrict improvement in aerobic power and may increase short-term endurance, but endurance training can limit improvements in strength and power when compared with gains from resistance training alone. Thus, it appears that, aerobic training is unaffected by the anaerobic strength training, but the aerobic training can negatively affect anaerobic capacity [1]. König et al. (2001), stated that there is a consensus that a high VO$_2$ max value (above 55 ml·kg$^{-1}$·min$^{-1}$ in young females, 65 ml·kg$^{-1}$·min$^{-1}$ in young males) is not desirable in tennis. The implication from this statement is that these high values of aerobic capacity could only be achieved by focusing mainly on endurance training. This training specificity would likely lead to a change of muscle fibre types that would subsequently reduce strength, power, speed and explosiveness of the player [2]. In a sport like tennis, the players must possess explosive speed to sprint and reach the ball, but also have a large endurance capacity as games can last for several hours. Therefore, it would be an advantage to develop both the aerobic and anaerobic energy systems concurrently.

1.1 Aerobic Capacity

The adaptations that occur during aerobic exercise can be divided into central and peripheral components (see Figure 1). Central adaptations occur in the cardiovascular and respiratory system whereas peripheral adaptations occur within the muscles [1]. The cardiovascular systems ability to transport and utilize oxygen improves as a result of aerobic training, so that a bigger part of the total energy contribution to intensive training occurs via aerobic processes. The muscles ability to process oxygen improves, as well as the ability to utilize fat as a fuel source, and therefore is able to exercise for a longer period of time. Maximum oxygen uptake represents the highest rate at which oxygen can be utilized for oxidative metabolism during whole body exercise [3]. It is measured in litres of oxygen per minute, and is referred to as VO$_2$ max, which is considered to be the best single measure of aerobic capacity [4].

The cardiovascular adaptations during aerobic training will lead to hypertrophy of the heart muscle, which will be able to hold more blood and consequently increase stroke volume (SV). Increasing SV and blood volume are the most important factors for cardiac output (Q) after aerobic training. The maximum heart frequency remains unchanged or decreases after a training period [5]. The result of increased blood volume will lead to an increase of total haemoglobin amount, which is a measure of the oxygen capacity of the blood [5]. One function of the respiratory system is to adapt to supply adequate oxygen to the working muscles during exercise. Major adaptations occur mainly during maximal exercise, when all systemic functions are being maximally stressed. Peripherally, the increase in blood flow to the muscles, and the capillary supply, helps to deliver more oxygen to the active muscle. Aerobic training will also enhance myoglobin content and increase mitochondria size and numbers, which will lead to an increase in capacity for oxidative metabolism. How long an athlete can keep up a given pace depends on their glycogen stores and how effective
energy in the form of carbohydrates and fat can be utilized. The ability to exercise at a high intensity without accumulating lactate is beneficial to the athlete because the lactate accumulation contributes to fatigue [1]. Lactate threshold, when expressed as a percentage of VO2max is one of the best determinants of an athlete’s optimal pace in endurance events[1]. Consequently, a higher lactate threshold reflects a greater aerobic capacity [1].

Figure 1: Illustration of the adaptations that occur after aerobic exercise [1, 5].
The body’s capability to recover after a hard work out will also improve with aerobic training and thereby, the athletes will be prepared for subsequent training more rapidly. Aerobic exercise is commonly divided into low intensity, moderate intensity and high intensity [5]. Low intensity is usually implemented the day after a hard workout, at an intensity level of 65% of maximum HR. Moderate intensity is normally 80% of maximum HR and implemented as continuous work over longer periods. It can be implemented for a shorter amount of time in conjunction with higher intensity within area training session. High intensity is an average of 90% of maximum HR and the work should not last until exhaustion. It can be implemented as interval training, with either short or long intervals, and has been proposed to be one of the best ways to develop the maximum oxygen uptake [5].

1.2 Anaerobic Capacity

The overall reason for training anaerobically is to improve or maintain the body’s capability to respond quickly to changes in energy requirements. Anaerobic training will also, together with aerobic training, develop the athletes’ ability to recover after hard training. Anaerobic training is usually divided in two main groups [5]: Speed endurance and speed training. Training for speed endurance can be further divided in two groups: Tolerance training and production training. The purpose of tolerance training is to improve the capability to work continuously at a high intensity. By improving the capability of the muscles to tolerate factors associated with muscle fatigue, fatigue during intense exercise is attenuated and the recovery phase after exercise will be shortened. For tolerance training, the workout periods are somewhat longer, the periods of recovery shorter, and the intensity is slightly lower than for production training.

Production training targets the athlete’s ability to exercise at a maximum intensity during a relatively short amount of time. In other words, to improve the body’s capability to quickly develop as much energy as possible using anaerobic processes. Production training is normally targeted with shorter workout periods and longer recovery periods than in tolerance training [5].

Speed training should be implemented with maximum intensity. The major adaptations occur in the nervous system and the interaction between nerve and muscle. This interaction should be trained in sport-specific situations. It is important to develop coordination patterns, so that the rapid muscle fibre activation will occur in the appropriate order. To summarize, speed training increases the ability to move as quick as possible with the right technique [5].

With anaerobic exercise the concentration of the enzymes dealing with the anaerobic energy-production increases. The glycolytic enzymes contribute to a faster degradation of ATP-phosphocreatine (PCr) and a higher lactic acid production during maximum work. Enhancement of this process provides an advantage when producing more energy with the anaerobic breakdown of muscle glycogen (glycolysis). As a result, anaerobic- together with aerobic processes lead to a faster replenishment of PCr, and this contributes to enhanced recovery capability after an intensive workout. In conclusion, a lack of fatigue will lead to better decision-making and skill execution [1, 5].
\textbf{1.3 Adolescent Physiology and Gender Differences}

\subsection*{1.3.1 Biological maturity}

One important consideration when dealing with adolescent athletes is the consequences of maturation. Biological maturation does not change linearly with chronological age, but can vary dramatically and reflects the variation between individuals in timing and development \cite{3}. Peak height velocity (PHV) is a commonly used indicator of maturity in studies of adolescence and is a measure of the time of maximum velocity of growth in stature during adolescence. In a study from 2002 by Mirwald and colleagues, the timing of PHV was measured in three different ways on a sample of 113 males and 115 females. These researchers measured leg length, sitting height and height when standing and concluded that males age of PHV ranged from 13.4-14.2 and females from 11.9-12.5 years \cite{5}.

\subsection*{1.3.2 Long-term athletic development}

For the athlete, an appropriate and sport-specific physique is an advantage for reaching an elite level. An expert group in the Canadian Sport Centre have studied and developed a model to optimize performance longitudinally throughout childhood and adolescence. The model is divided into four stages of training development: FUNdamental phase, training to train phase, training to compete phase, and training to win phase. This model is called Long Term Athletic Development. This model was designed to help identify the sensitive periods of accelerated adaption for youth and adolescents in relation to biologic maturation, which they termed "windows of opportunity"\cite{7}. This model is well known worldwide, and has been advanced and applied to badminton in England 2006, British gymnastics in 2006, England and Wales cricket in 2005, as well as lawn tennis in England \cite{8}. However, this model lacks empirical evidence. Ford et al. (2010) said the data is based on questionable assumptions and erroneous methodologies. It is therefore of more advantageous to use this model as a generic model rather than an individualized plan for athletes \cite{7}.

According to Balyi I. et al. (2004) it takes between 8 and 12 years of training for a talented athlete to reach elite level. This assertion has been termed the 10 year or 10,000-hour rule. The U.S. Olympic committee (2001) surveyed American Olympic athletes from 1988-1996 and concluded that it took between 10-13 years of practice or training to make the Olympic team and between 13-15 years for these athletes to win a medal \cite{8}.

Stamina, strength, speed, skill and suppleness cover the basics of the well-trained athlete \cite{9}. The optimal window of trainability for stamina (endurance) occurs at the onset of PHV but training to improve aerobic capacity has been recommended even earlier \cite{9}. Strength can be trained immediately after PHV for young female athletes or at the onset of menarche; however, it has been reported that young males should delay weight training 12-18 months after PHV \cite{9}. The best development of speed for young males is between seven and nine years of age \cite{9}. The second window of trainability for speed occurs between 13 and 16 years of age. The first trainability window for young females in speed is between six and eight, and the second between 11-13 years of age \cite{9}. Trainability for skills for young males is between 9-12 years and 8-11 for young females. Suppleness (flexibility) is best trained for both genders between the ages 6-10. Special attention should be paid to flexibility during PHV \cite{8}. However, there appears to be no published evidence that failure to exploit these "windows of opportunity" will result in inhibited development or performance plateaus \cite{9}. 
1.3.3 Psychological differences

Psychological differences in gender and age also exist in high-level athletes. Women have a significant higher risk to suffer from psychopathological disorders such as generalized anxiety or eating disorders than men, regardless of the sport they participate in. Younger athletes are also more susceptible to psychopathological disorders [10].

1.3.4 Development of aerobic capacity

An improvement in endurance occurs in both adults and adolescents through various adaptations in the body's organ system such as the cardio-respiratory system, referred to earlier in this dissertation. In young athletes however, there is a substantial change in body composition that occurs during puberty that will affect their aerobic capacity. At this time the difference in sex begin to appear and is maintained into adulthood. Aerobic capacity is commonly assessed by determining the peak oxygen consumption of an athlete and is reported as an absolute value (ml oxygen/min) and also as a value corrected for bodyweight (ml·kg⁻¹·min⁻¹) in this text [1].

VO₂max expressed in ml/min increases approximately 150% from 8 to 16 years and peaks in the period between 17-25 in males [11]. The increase for females in VO₂max is about 80% during the same years and peaks at 15-17 years of age. If corrected to body weight, VO₂max will plateau between the age of 6 to 25 and stay at a relatively steady level in males; however in young females it will start to decline at about 13 years of age [1, 11]. Young females generally have about 10% lower VO₂max than boys in childhood and at 16 years of age; the sex difference often increases to approximately 35% [11]. No differences have been seen in maximal heart rate, but there is evidence that suggests that maximal stroke volume in males could be higher than in females [12, 13]. Physiologically, the sex differences in VO₂max during adolescence are explained by the dramatic change of body composition. Males increase their relative muscle mass from 42 to 54 % of body mass, compared to females; who increase their muscle mass from 40 to 42% during this development phase. As a result, females’ relative muscle mass is declining due to an increase in body fat after about 13 years of age. The greater muscle mass of males makes it easier to utilize oxygen and will also assist the venous return to the heart and thereby intensifying stroke volume through the peripheral muscle pump [11].

1.3.5 Development of anaerobic capacity

It is also important to consider maturation when assessing anaerobic capacity in young athletes [14]. Peak power will be discussed further in the text and is a measure of the highest power output that the athlete can produce [15]. Peak power will be mentioned as an absolute value (W) and as a value corrected for body weight (W/kg).

As in aerobic capacity, there are age related differences and differences between gender in anaerobic capacity. It has been shown that females have about 35-40% lower peak power values in the Wingate test, than males even when corrected for body mass [14, 16]. A young male of 9 years only has 70-80% of what is generated by a 30-year-old man (corrected for body mass), which demonstrates a positive relationship between anaerobic capacity and age. The similar relationship has been reported in females [16].
The ability to perform maximal anaerobic power peaks during adolescence in females, but continues to rise into adulthood in males (for lower limbs) [16]. These differences can partly be described by both qualitative and quantitative factors. Quantitative factors include the development in muscle mass and muscle fibre diameter as males reach their peak muscle mass at about 30 years of age compared to females who peak at approximately 20 [16]. As the capability to produce force depends of the length and the cross-sectional area of the muscle, and mechanical power is the product of force and velocity, these factors can explain the gender- and age-related differences in anaerobic power [14]. The rate of increase in muscle volume is similar to the rate of increase in anaerobic power during adolescence, when correcting for body size [16].

Qualitative factors, such as genetics, have been reported to affect the ability to produce anaerobic power although data is scarce on the direct influence [16]. Given all of the areas were heredity is stated to affect muscle size, proportions of muscle fibre types and the trainability of high-intensity muscle performance, it is likely that genetics will have an impact on the individuals’ anaerobic power producing capabilities. Other qualitative factors that are likely to influence anaerobic power production include muscle metabolism, neural, and hormonal factors. Neuromuscular performance that is required to perform maximal bursts of speed, as in sprint cycling, undergoes development during puberty [16]. The neural components, for instance the myelinations of the nerve fibres and the ability to recruit motor units, are not fully developed in adolescent subjects [14]. In a relatively short period of time, both genders undergo substantial hormonal changes that can influence the response to exercise. One hypothesis is that the ability to produce lactate or generate anaerobic power is affected by circulating levels of testosterone in the blood [14]. These hormonal factors could help to explain the age-related differences and the differences in sex when it comes to anaerobic capacity [14, 16, 17].

1.4 Physiological Requirements of Tennis

Tennis as a sport is based on unpredictability. Influences from match duration, point length and weather will affect the complex physiological demands on tennis players [18]. Reid et al. (2008) describe tennis as an intermittent, non-cyclical anaerobic sport with an aerobic recovery phase. Furthermore, these researchers state that the contribution of anaerobic glycolysis in tennis performance has been underestimated. According to the demands of the sport it seems difficult to maximize all of the associated parameters, but a balance of power and endurance capacity will likely benefit the player [19]. König et al. (2001) describe tennis as a complex sport involving strength, power, speed, agility, explosiveness and endurance. They state that the overall intensity in tennis ranges between 60-70% of VO₂ max, thus requiring a good aerobic capacity. There are also frequent periods of high intensity where the muscles rely on anaerobic glycolysis to provide energy [2].

The work to rest ratio in a high level match can range between 1:2-1:5, which means that for every second of play, there can be 2-5 seconds of rest. Average length of points depends on the surface and on the individual playing style of each player and their opponent [2]. A whole court player will generally have a longer point time (about 15.7 seconds) than an attacking player (about 4.8 seconds) who tries to reach the net more often and hit more attacking shots. Thus, the individual style of a tennis player will impact the total playing time in a match. The VO₂ max of tennis players have been reported to range between 44-69 ml·kg⁻¹·min⁻¹ with the majority above 50 ml/kg/min. Even here it differs between playing styles with a lower VO₂ max often seen in the attacking players [18].

A method of describing the intensity of an activity is to measure heart rate. This measurement was performed on a group of college student tennis players during 85 minutes of playing time and mean values of 144 beats/min were observed [17]. Despite the varying intensity in the game, the heart rate remains significantly increased compared to levels pre-exercise. However, the large variability in heart rate should also be taken into account during a match due to the explosive nature of the sport, so a mean value may not be reliable [18]. Blood lactate values are also used as a measure of the intensity in competitions and could help to get information about the energy provided by the glycolytic system (anaerobic processes) [20-22]. A mean value of 2 mmol/l was measured in a study of junior female tennis players during a singles tournament [23] and in males, the values ranged from 1.8-2.8 mmol/l [24]. These elevations in blood lactate suggest that glycolytic processes are responsible for a low to moderate part of the fuel to movements in tennis matches [24].

Although Kovac states in his review from 2006 that it might be better to classify tennis as an “anaerobic predominant activity” that requires a good aerobic capacity to aid recovery between points and avoid fatigue, rather than a consistently aerobic activity. He also concluded that there is still an on-going debate regarding the relative importance of the aerobic and anaerobic energy systems in tennis [18].

1.5 Review of Similar Research
To the best of the authors’ knowledge, there are no studies investigating the specific correlation between aerobic and anaerobic capacity in elite junior tennis players. Although there are no studies investigating the correlation between aerobic and anaerobic capacity in tennis players, there are a few in the same area in other sports and environments.

Buccheit (2011) examined the association between aerobic fitness and repeated sprint performance in 61 team sport players (soccer, handball, basketball and futsal.) The study concludes that the mean time of the repeated sprints were largely correlated with the best sprint time and moderately correlated with VO_{2}max [25]. Carey et al. (2007) found no correlation between the ability to recover from high-intensity intermittent work and aerobic capacity in 11 female hockey players [26]. In a study from 2011, Thibault et al. (2011) showed that there was a correlation between repeated sprint ability-fatigue indices and two different aerobic field tests. The subjects were 19 well-trained soldiers. He stated that subjects with higher maximal aerobic speed were able to maintain almost constant level of speed throughout series of repeated sprints and achieved better recovery between series [27].

1.6 Aims
The aim of this study was to investigate the correlation between aerobic capacity and anaerobic capacity in elite junior tennis players. The results of this study could be a useful tool for trainers and assist in the further development of exercise programs in a more sport-specific fashion. Specifically, two hypotheses were addressed: 1). There is a correlation between aerobic capacity and anaerobic capacity in elite junior tennis players and; 2). There are gender and age differences in anaerobic and aerobic capacity in this population.
2 Materials and Methods

2.1 Subjects

The subjects in this study were elite junior tennis players (15-23 years of age). The players were tested in different regions but our focus was on aerobic and anaerobic capacity. In total, data from 172 elite junior tennis players were collected. When assessing VO\textsubscript{2}max and modified Wingate test performed within one week, data for 40 subjects was included. One subject was excluded from the VO\textsubscript{2}max test because of asthma. Thus, the final population of the study was 39 players, 21 males and 18 female.

The players were in the top five of their age group in Sweden and 10 of 39 were ranked top 100 on the junior world ranking from 2009-2012 [25]. The SvTF and sports scientists have determined a training schedule appropriate to the players’ age groups. Fifteen to sixteen year olds have 13-15 hours of tennis training as well as 7-9 hours strength and conditioning training every week. These players have about 110 matches per year and 15 of these are international matches. From 17 years of age and above, they have 16-17 hours of tennis training and seven hours of strength and conditioning training. They have 110 matches per year and 20-22 of these is likely to be international matches (see Appendix A).

Table I: Demographic characteristics of the participants

<table>
<thead>
<tr>
<th></th>
<th>AGE</th>
<th>HEIGHT (cm)</th>
<th>BODY MASS (kg)</th>
<th>VO\textsubscript{2}max (ml/min)</th>
<th>VO\textsubscript{2}max(ml/min/kg)</th>
<th>PEAK POWER (W)</th>
<th>PEAK POWER (W/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MEAN TOTAL</strong> (n=39):</td>
<td>17 (15-23)</td>
<td>176 (160.0-198.5)</td>
<td>69 (53.0-88.3)</td>
<td>4049 (2354.0-5524.0)</td>
<td>58 (44.4-70.6)</td>
<td>947 (610-1359)</td>
<td>14 (10.1-17.3)</td>
</tr>
<tr>
<td><strong>MEAN MALES</strong> (n=21):</td>
<td>18 (15-23)</td>
<td>183 (173.5-198.5)</td>
<td>75 (62.7-88.3)</td>
<td>4724 (3450.0-5524.0)</td>
<td>63 (49.3-70.6)</td>
<td>1112 (841-1359)</td>
<td>15 (11.7-17.3)</td>
</tr>
<tr>
<td><strong>MEAN FEMALES</strong> (n=18):</td>
<td>17 (15-20)</td>
<td>169 (160.0-182.0)</td>
<td>63 (53.0-69.0)</td>
<td>3262 (2354.0-3809.0)</td>
<td>52 (44.4-58.7)</td>
<td>754 (610-981)</td>
<td>12 (10.1-15.6)</td>
</tr>
<tr>
<td><strong>MEAN 15-16</strong> (n=16):</td>
<td>15 (15-16)</td>
<td>172 (161.0-186.0)</td>
<td>64 (53.0-85.5)</td>
<td>3646 (2354.0-5384.0)</td>
<td>57 (44.4-68.3)</td>
<td>804 (610-981)</td>
<td>13 (10.1-15.6)</td>
</tr>
<tr>
<td><strong>MEAN 17-23</strong> (n=23):</td>
<td>19 (17-23)</td>
<td>179 (160.0-198.5)</td>
<td>73 (59.1-88.3)</td>
<td>4330 (2971.5-5524.0)</td>
<td>59 (44.4-70.6)</td>
<td>1046 (703-1359)</td>
<td>14 (10.8-17.3)</td>
</tr>
</tbody>
</table>

The SvTF has specific goals for their junior players. In aerobic capacity, the target for males is 65 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} (4940 ml) and female 58 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} (3712 ml) in VO\textsubscript{2}max. In terms of anaerobic capacity, peak power targets are 1160 W for males (76 kg) and 760 W (64 kg) for female. These targets were selected by collecting values for one year and taking the mean value of the top 25% players in both genders (see Appendix B & C).
Inclusion criteria:

- The top five junior tennis players in their age group in Sweden.
- Measured VO2max and modified Wingate test within the same week.
- Weight and height had to be documented when performing the tests.
- Respiratory Exchange Ratio (RER) minimum 1.0 (described under Intervention)

Exclusion criteria:

- Injury that occurred during test performance, for example muscle rupture.

2.2 Intervention

A medical team have supervised these tests, and the subjects could quit the tests whenever they wanted. VO2 max is regarded by most as the gold standard measurement for cardiorespiratory endurance [1]. The test was performed on a treadmill, where the subjects performed a physical effort of sufficient duration and intensity to fully tax the aerobic energy system. The intensity was increased gradually while measuring ventilation, oxygen, and carbon dioxide concentrations of the inhaled and exhaled air. VO2 max was assessed as the point at which the oxygen consumption remained at a steady despite an increase in workload. At this point the test person had reached their maximum aerobic capacity and the test was stopped. VO2 max is measured in millilitres of oxygen consumed per minute. VO2 max (ml·kg⁻¹·min⁻¹) is a measure of maximum oxygen uptake considering bodyweight. This relative measure was calculated by taking the four highest ml/min consistent values and dividing by four to get a mean value. The mean value was thereafter divided by the person’s bodyweight.

RER, is the ratio of the volume of carbon dioxide exhaled versus the volume of oxygen consumed at a given exercise intensity. It is necessary to know which type of energy substrate (combination carbohydrates, fat, protein) is being oxidized because this depends on the amount of oxygen used during metabolism. RER of 0.85 means burning approximately 50% fat and 50% carbohydrate [1]; whereas an RER over 1.00 means that carbohydrates are primarily used as fuel. RER is also used to assess maximum effort during the VO2 max test [1].

The Wingate test is the most widely used test for measuring anaerobic power and is highly reliable [3]. In our study a modified version was used, termed the Modified Wingate Test (mWAnT). Here, the subjects pedal a cycle ergometer at maximal speed for 30 seconds against a high breaking force, which is determined by the person’s weight, sex, age and level of training. In this case, 10% of the subjects weight was used. The test starts once the subject starts to pedal. Power output can be determined instantaneously throughout the 30 seconds but is generally measured in 5 seconds intervals. Peak power is the highest mechanical power achieved in the test (generally during the first 5-10 seconds) [15]. If the individual is able to reach their peak power in a short amount of time, this indicates a good level of anaerobic capacity [1].

The results from the VO2 max and mWAnT tests were entered and processed in Microsoft Excel spreadsheets. The main group contained all of the subjects (n=39), thereafter subjects were divided into subgroups according to their gender (males n=21/female n=18) and age; 15
to 16 (n=16), 17 to 23 (n=23). The age groups were based on the amount of training. This was to keep the groups as equal as possible. If a subject was measured on several occasions within a year, or in different many years, the average test result of one year was used. The specific year was selected according to the most appropriate group for that subject.

2.3 Statistical Analysis

The collected data is organized as a ratio scale and has been categorized in the five groups mentioned above. Pearson product-moment was the statistical method used to assess relationships between aerobic and anaerobic measures within each group. The result of the calculation was summarized as a correlation coefficient, which is a measure of the strength of an association between two variables (X and Y). A value of 1.0 shows a perfect linear correlation. Negative values show an increase of X and a decrease of Y (anti-correlation). Positive values show an increase of both X and Y. P-values of <0.05 were considered statistical significant.

2.4 Ethical Considerations

Applications of ethical considerations are in progress for Doctor of Naprapathy, Fredrik Johansson and all of his test results. If this study is to be published it will fall under his ethical consideration application. All data was classified. When the junior tennis players agreed to be a part of the National Swedish Tennis team, that involved them being tested under several occasions. They had been informed about this study and agreed to be a part of it. As the tests were maximal in nature, there are always some risks (e.g. falling of the bike or treadmill, fainting caused by exhaustion). Therefore, trained medical personnel always supervised the tests, and the subjects were informed that they could stop the test at any time if they felt unwell.
3 Results

3.1.1 Absolute values

Correlations between VO\textsubscript{2} max and Peak power on the entire study population demonstrated a positive significance ($r=0.86$, CI=0.74 to 0.92, $P<0.05$) See Figure 2. The results are summarized in Table II.

![Figure 2: Scatter plot of the correlation between aerobic and anaerobic capacity in the group of tennis junior players. Y-axis= Peak power (W), X-axis= VO\textsubscript{2} max (ml·kg\textsuperscript{-1}·min\textsuperscript{-1}). Each marker reflects the correlation between aerobic and anaerobic capacity in one player.](image)

The correlation between VO\textsubscript{2} max and Peak power in the group of males demonstrated a positive significance ($r=0.60$, CI=0.23 to 0.82, $P<0.05$). See Figure 3.
The correlation between \( \text{VO}_2 \text{max} \) and Peak power in the group of females demonstrated a negative significance (\( r = 0.39 \), CI= -0.091 to 0.73, \( P > 0.05 \)) See Figure 4.
The correlation between VO$_2$ max and Peak power in the age group of 15-16 year olds demonstrated a positive significance ($r = 0.74$, CI=0.38 to 0.90, $P <0.05$) See Figure 5.

Figure 5: Scatter plot of the correlation between aerobic and anaerobic capacity in the age group 15-16. Y-axis= Peak Power (W), X-axis= VO$_2$ max (ml·kg$^{-1}$·min$^{-1}$). Each marker reflects the correlation between aerobic and anaerobic capacity in one player.

The correlation between VO$_2$ max and Peak power in the age group of 17-23 year olds demonstrated a positive significance ($r = 0.88$, CI= 0.74 to 0.95, $P <0.05$) See Figure 6.
Figure 6: Scatter plot of the correlation between aerobic and anaerobic capacity in the age group 17-23. Y-axis= Peak power (W), X-axis= VO₂ max (ml·kg⁻¹·min⁻¹). Each marker reflects the correlation between aerobic and anaerobic capacity in one player.

Table II: Statistical analysis- Absolute values

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<th></th>
<th>r</th>
<th>CI 95%</th>
<th>P-value</th>
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<td>0.74-0.92</td>
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<td>Young males (n=21)</td>
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<td>17-23 (n=23)</td>
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3.1.2 Values corrected for body mass

Correlations between VO₂ max (ml·kg⁻¹·min⁻¹) and Peak power (W/kg) on the entire study population demonstrated a positive significance (r= 0.64, CI= 0.40 to 0.79, P <0.05) See Figure 7. The results are summarized in Table III.
Figure 7: Scatter plot of the correlation between aerobic capacity and anaerobic capacity in the group of tennis junior players, corrected for body mass. Y-axis= Peak power (W/kg), X-axis= VO₂ max (ml·kg⁻¹·min⁻¹).

Correlations between VO₂ max (ml·kg⁻¹·min⁻¹) and Peak power (W/kg) on the group of young males demonstrated a negative significance (r= 0.27, CI= -0.19 to 0.62, P >0.05) See Figure 8. The results are summarized in Table III.

Figure 8: Scatter plot of the correlation between aerobic and anaerobic capacity in the group of young males, corrected for body mass. Y-axis= Peak power (W/kg), X-axis= VO₂ max (ml·kg⁻¹·min⁻¹).
Correlations between VO₂ max (ml·kg⁻¹·min⁻¹) and Peak power (W/kg) on the group of young females demonstrated a negative significance (r= 0.16, CI= -0.33 to 0.58, P >0.05) See Figure 9. The results are summarized in Table III.

Figure 9: Scatter plot of the correlation between aerobic and anaerobic capacity in the group of young females, corrected for body mass. Y-axis= Peak power, X-axis VO₂ max (ml·kg⁻¹·min⁻¹).

Correlations between VO₂ max (ml·kg⁻¹·min⁻¹) and Peak power (W/kg) on the age group 15-16 demonstrated a negative significance (r= 0.44, CI= -0.75 to 0.77, P >0.05) See Figure 10. The results are summarized in Table III.
Figure 10: Scatter plot of the correlation between aerobic and anaerobic capacity in the age group 15-16, corrected for body mass. Y-axis= Peak power (W/kg), X-axis= VO$_2$max (ml·kg$^{-1}$·min$^{-1}$).

Correlations between VO$_2$ max (ml·kg$^{-1}$·min$^{-1}$) and Peak power (W/kg) on the group of 17-23 demonstrated positive significance ($r=0.74$, CI= 0.48 to 0.88, $P<0.05$) See Figure 11. The results are summarized in Table III.

Figure 11: Scatter plot of the correlation between aerobic and anaerobic capacity in the age group 17-23, corrected for body mass. Y-axis= Peak power (W/kg), X-axis= VO$_2$ max (ml·kg$^{-1}$·min$^{-1}$).
### Table III: Statistical analysis- Corrected for bodymass (kg)

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<td>Young males (n=21)</td>
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<td>Young females (n=18)</td>
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<td>15-16 (n=16)</td>
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<td>-0.75-0.77</td>
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<td>17-23 (n=23)</td>
<td>0.74</td>
<td>0.48-0.88</td>
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3.2 Threshold Values

A threshold value was calculated multiplying the average weight by the peak target values for each gender, resulting in VO$_2$ max 4940 ml for males (65 ml·kg$^{-1}$·min$^{-1}$), and 3712 ml for females (58 ml·kg$^{-1}$·min$^{-1}$). Anaerobic capacity was 1160 W for males (76 kg) (15.3 W/kg), 760 W for females (64 kg) (11.9 W/kg). These thresholds represent the marked lines that divide the Figures 12, 13, 14 and 15 into four quadrants.

The population was divided into 4 quadrants. (See Figures 12, 13, 14 and 15):

- Quadrant I top left: Results above peak power threshold but below VO$_2$ max threshold.
- Quadrant II top right: Results above peak power and VO$_2$ max threshold.
- Quadrant III bottom left: Results below peak power and VO$_2$ max threshold.
- Quadrant IV bottom right: Results below peak power threshold but above VO$_2$ max threshold.

![Figure 12: Scatter plot of the threshold values for young males](image-url)
Figure 13: Scatter plot of the threshold values for young males. Values corrected for body mass (kg).

Table IV: Young males threshold values for each quadrant. Absolute values & corrected for body mass

<table>
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<th>Quadrant</th>
<th>Number of subjects (n=21). Absolute values</th>
<th>Percentage [%] of total subject. Absolute values</th>
<th>Number of subjects (n=21). Absolute values corrected for body mass (kg)</th>
<th>Percentage [%] of total subject. Absolute values corrected for body mass (kg)</th>
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Figure 14: Scatter plot of the threshold values for young females.

Figure 15: Scatter plot of the threshold values for young females. Values corrected for body mass (kg).
Table V: Young females threshold values for each quadrant. Absolute values & corrected for body mass

<table>
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<tr>
<th>Quadrant</th>
<th>Number of subjects (n=18). Absolute values</th>
<th>Percentage [%] of total subject. Absolute values</th>
<th>Number of subjects (n=18). Absolute values corrected for body mass (kg)</th>
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</table>

The results according to the absolute values demonstrated that only 18% (n=7) of the athletes exceeded the threshold values for peak power and VO_2 max. A total of 44% (n=17) did not reach either of the threshold values. On the contrary, results according to absolute values corrected for body mass (kg) demonstrated that 15% (n=6) reached the threshold values. Whereas 28% (n=11) did not reach either of the goals set by SvTF.
4 Discussion

4.1 Discussion of the Results

Our data indicates that there is a strong correlation between aerobic and anaerobic capacity in this group of elite junior tennis players. The correlation exist when using the absolute values and the values corrected for body mass. The results when dividing the groups according to age 15-16 and 17-23 still show correlations in the absolute values but when corrected for body mass, only 17-23 a correlation persisted. When divided into gender there was only a significant correlation in the group of males when using the absolute values and no correlation at all when corrected for body mass.

We think the strong correlation in this group is an effect of the intermittent, high-intensive nature of the sport. The aerobic contribution in the first 6 seconds of a 30 seconds maximal sprint is 9% and both PCr resynthesis and the removal of accumulated intracellular inorganic phosphates (anaerobic power) are oxygen-dependent processes [29]. By developing the aerobic and anaerobic energy systems one can assume it should be beneficial to enhance both performance and recovery. Players with a strong aerobic capacity are more likely to perform repeated sprints with high quality that will develop the anaerobic system [1]. Thereby we can assume that a high VO\textsubscript{2}max value could be advantageous when building the anaerobic capacity.

Based on our data, there seems to be a possibility to have high values of aerobic capacity combined with high values of anaerobic capacity. We thereby prove König et al. (2001) partly wrong when he states that it will be disadvantageously for a tennis player to develop good aerobic capacity. The trend in tennis talking to professionals on the ATP/WTA tour suggests that tennis today is developing into longer rallies and therefore longer matches. The attacking playing style, which was estimated to have a lower VO\textsubscript{2}max, is not as common in tennis today. These changes will also lead to higher aerobic and anaerobic demands on the player in the future.

We have also discussed the periods for optimal adaptations to specific training stimuli during the biological maturity. As we could see, anaerobic capacity continues to evolve a long time past PHV, even into young adulthood in males and that the window for aerobic training occurs at the beginning of PHV, or even earlier. The threshold values in VO\textsubscript{2} max and mWAnT from SvTF, showed that there was only one female that reached both. It appears that the group of females were generally less well trained than the males. During puberty, females face a bigger challenge than the boys to keep their aerobic capacity, due to changes in body composition. However, females do have the same ability to produce power when they don’t have to move their body weight, leading us to think that this disparity may partly explain the non-significant correlation between the energy systems in the group of females.

Interval type of training has been shown to improve measures of VO\textsubscript{2} [30] and could be the aspect that is lacking in the training programs of the young female tennis players. Burgomaster (2008) suggest that high-intensive interval training is a time-efficient strategy to increase skeletal muscle oxidative capacity and induce specific metabolic adaptations to exercise that is comparable to traditional endurance training.
We have chosen to use both absolute values and values that are corrected for body size in our calculations. Based on our data, a higher percentage of the players reached the goals for anaerobic capacity when corrected for body mass (kg). When SvTF set the threshold values, they corrected for bodyweight, which is a disadvantage for lighter players and an advantage for heavier players [1]. When comparing the results it is clear that a larger number of the players get higher results in anaerobic capacity when corrected for bodyweight.

Some authors of studies in the area say that it is important to take the weight into account in all sports were body weight is moved [3]. Armstrong et al. (2011) have stated that the reporting of aerobic capacity relative to body mass has clouded the physiological understanding of VO$_2$ max during growth and maturation [31]. Wilmor et al. (2008) raised the problem with correcting for body weight when testing children and adolescent athletes, and described the failure to get a true value. These authors suggest that the method does not take into account the changes and development of cardio-respiratory system. These changes occur during growth, and in parallel to the adaptations of training [1]. We think it is also important to remove some focus from body weight because of the well-known problems with eating disorders that have been described in some elite athletes [32, 33].

4.2 Method Discussion and Sources of Error

Errors in the test results can be caused by biological and technological sources. Biological sources are attributed to the test persons motivation, drift and daily shape which we have tried to rule out by taking the mean value of a year when choosing the test values. It would be ideally to test all players at the same stage in their training cycle. Technological sources are inherent in the testing protocols and calibration of the instruments used. Mistakes while processing the database is another possible source of error that cannot be excluded since there have been several persons inputting results.

We also acknowledge that the size of the study population was a limit of the study; and that conclusions from a larger and more age-varied group the result would likely be more trustworthy.

4.3 Conclusion

The result of this study indicates that there was a correlation between aerobic and anaerobic capacity in this group of elite junior tennis players both when using absolute values and when using the values corrected for body mass. When dividing the groups according to age 15-16 and 17-23, there seemed to be a correlation in both groups when using the absolute values but only in the older group (17-23) when corrected for body mass. The results when divided into gender showed significant correlation in the group of males when the absolute values were used and no correlation in either gender when corrected for body mass. There appears to be a necessity to improve both the aerobic and anaerobic training practices currently performed by elite junior female tennis players in Sweden.
5 References


## Appendix A: Guidelines Elite Junior Tennis Players

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<th>Age Group</th>
<th>TENNIS (per week)</th>
<th>STRENGTH AND CONDITIONING (per week)</th>
<th>MATCHES (per year)</th>
<th>INTERNATIONAL MATCHES (per year)</th>
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Appendix B: Anaerobic Demands and Capacity Analysis for Elite Junior Tennis Players (Young males)

<table>
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<th>Body mass (kg)</th>
<th>Peak Power Instantaneous (W)</th>
<th>Anaerobic Capacity 0-5 (W)</th>
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Author 1: Måns Tillman, 2011
Appendix C: Anaerobic Demands and Capacity Analysis for Elite Junior Tennis Players (Young females)

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<thead>
<tr>
<th>Body mass (kg)</th>
<th>Peak Power Instantaneous (W)</th>
<th>Anaerobic Capacity 0-5 (W)</th>
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Author: Måns Tillman 2011