AGE RELATED CHANGES USING ALTERNATIVE APPROACHES TO THE POWER RATIO

ALTERNATIVE APPROACHES TO ASSESSING THE ANAEROBIC-AEROBIC POWER RATIO; AGE RELATED CHANGES FROM CHILDHOOD TO EARLY ADULTHOOD

By

TREVOR G. ALLIN, B.KIN

A Thesis
Submitted to the School of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree
Master of Science

McMaster University

© Copyright by Trevor G. Allin, Nov 2007

MASTER OF SCIENCE (2007) McMaster University

(Kinesiology) Hamilton, Ontario

TITLE: Alternative approaches to assessing the anaerobic-aerobic power ratio; age related changes from childhood to early adulthood

AUTHOR: Trevor G. Allin, B.Kin. (Brock University)

SUPERVISOR: Dr. Cameron J.R. Blimkie

NUMBER OF PAGES: ix, 144

ABSTRACT

The anaerobic-to-aerobic power ratio is a useful tool to evaluate the strengths and weaknesses of both the aerobic and anaerobic energy systems. The traditional method of calculation has shown this ratio to increase with age in children and to plateau by late adolescence or early adulthood. However, by using the traditional approach, the aerobic component of the ratio is likely highly influenced by anaerobic sources and therefore, may not demonstrate the true proportional changes observed in the respective physiological capacities comprising this ratio with age through childhood and adolescence. The purpose of this study was to examine the age-related development of the power ratio using two new approaches. The lactate threshold (LT) and ventilatory anaerobic threshold (VAT) were identified in 31 competitive male hockey players ranging from 10 to 21 years of age and compared across three discrete age groups. Peak mechanical anaerobic power was obtained from a Wingate test (WAnT) and incorporated into the numerator of the power ratio, while peak mechanical aerobic power was obtained from a modified McMaster all-out progressive test and included into the denominator of the ratio. Mechanical power at the LT and VAT were also identified and integrated into the denominator of the power ratio and results compared to the traditional approach to identify similarities or differences in developmental trends with age. Furthermore, the reliability of the traditional, LT and VAT approaches was examined with retests of six subjects using intra-class correlation analysis and Method Error analysis. When power ratio approaches were compared among discrete age groups, significant differences ($P \leq 0.05$) were found between the youngest and oldest age groups for each of the three approaches. Notwithstanding the trend for progressive increases with advancing age group for all approaches, significant correlations with age were only found for the traditional approach (r=0.36). Finally, the VAT approach was the most reliable (r=0.95; ME=0.13) while the LT and traditional approaches demonstrated strong but non-significant test-retest correlations. Results of this study suggest that the LT and VAT approaches may theoretically be more accurate methods of measuring the power ratio than the traditional approach, as there is likely less anaerobic contribution to the denominator of the ratio. Each of the new approaches demonstrates expected age-related trends, and notwithstanding methodological and sample limitations, the VAT in particular, appears to be a more reliable and accurate means of assessing the power ratio compared to the traditional or LT approach.

ACKNOWLEDGEMENTS

First, to Dr. Joe Blimkie, thanks for making this process much easier with all your support and guidance, all your hard work is greatly appreciated and I really enjoyed all the comical stories you had to share along the way.

Dr. Digby Sale, Dr. Baraket Falk, thank you so much for all the time and effort you have put into my project. Your advice and guidance is much appreciated and this project could not have been completed without your help.

A thank you to all the friends that I have made in the Kinesiology Department at McMaster, making these two years a lot of fun.

A special thanks to Amanda and Elyse for all their help in the lab. You ladies made testing much easier and a lot of fun. Good luck with all your future endeavors.

Thank you to my parents and two sisters for supporting me throughout this process.

Finally, thank you to my wife Tammy for everything; you will no longer have to tell your friends that your husband is a student!

TABLE OF CONTENTS

List of Appendices

List of Figures

List of Tables

INTRODUCTION

To date, there has been a considerable amount of research investigating the contributions of the energy systems during exercise in adults and youth. The aerobic energy pathway, which provides ample amounts of energy for long periods of time, has been the primary focus of much of this research. Aerobic activities are typically of a low-to-moderate intensity and can be continued for up to several hours. Aerobic energy release has been easily quantified due to the direct relationship between oxygen uptake, measured through expired air, and the adenosine triphosphate (ATP) production of the whole body (Åstrand, 1981b).

Conversely, there is less literature, particularly in children, investigating activities that are anaerobic in nature, which are very intense and can therefore only be sustained for a very short period of time, usually up to a maximum of two minutes. This short duration is mainly due to physiological limitations in anaerobic energy production which makes continuing the activity much more difficult (Rowland, 1996).

Many sporting activities require both short bursts of energy as well as longer sustained periods of energy production, and therefore the ability to exercise at maximal levels depends on the capacities of both the aerobic and the anaerobic systems (MedbØ & Tabata, 1989). To enhance our understanding of how the energy systems function during different types of exercise, it is important to know the physiology involved. Furthermore, since the current research involves children, it is also important to know the current state of the literature with regards to the age-related differences in the development and utilization of these different energy systems during exercise.

Anaerobic Power

The anaerobic system, which provides instant energy in the absence of oxygen for muscle contraction, obtains its immediate source of energy from the hydrolysis of ATP (McArdle, Katch & Katch, 2001). ATP is present in the muscle cell and releases energy when it is broken down to adenosine diphosphate (ADP) and inorganic phosphate (P_i), with the help of the enzyme myosin ATPase. The energy that is released is then used to detach crossbridges that are formed between actin and myosin filaments in the muscle, and ultimately this allows the crossbridge cycle to take place, causing the muscle to contract (McArdle et al., 2001). Also in the muscle fiber is creatine phosphate (CP), a high-energy phosphate. With the help of the creatine kinase enzyme, CP can be split and combined with ADP providing the resynthesis of ATP to provide immediate, non-aerobic energy to power the muscles for a short period of time. This pathway for energy turnover in the muscle has been termed the anaerobic alactic system because it does not require any oxygen and no lactate is generated (McArdle et al., 2001). However, since this process is providing energy at such a fast rate, it will only provide energy for a very short period of time. Therefore, if the muscle is needed to continue working for more than a few seconds, other processes are engaged to resynthesize the ATP for contraction.

A second process, known as anaerobic glycolysis (the anaerobic lactic or glycolytic system) commences shortly after engagement of the alactic system. This process involves the breakdown of carbohydrate, mainly in the form of muscle glycogen to pyruvic acid, and in the absence of oxygen, pyruvate is converted to lactate with the help of the enzyme, lactate dehydrogenase (McArdle et al., 2001). This pathway generates lactate and therefore increases the concentration of hydrogen ions (H^+) in the muscle, which has been thought to play a role in muscle fatigue (McArdle et al., 2001). The glycolytic pathway is able to resynthesize ATP at a very high rate, which is essential for high-intensity short burst activities. Unfortunately, the amount of energy that can be released in a short burst of exercise by glycolysis is also limited, only providing energy lasting 60-90 seconds (McArdle et al., 2001). If exercise continues further, the addition of oxygen is needed to aid in the resynthesis of ATP in a process known as aerobic metabolism, the details of which will be explained later.

Current research has focused on evaluating the capacity of the anaerobic metabolic system, but this has proven to be a very difficult task, as many factors are commonly associated with the regulation of this system (Green & Dawson, 1993). Furthermore, methods for quantifying anaerobic energy have been limited because the production of ATP during anaerobic activity is an intracellular process (Gastin, 2001) which until recently, with the advent of magnetic resonance spectroscopy could not be assessed directly without invasive procedures. Therefore, there is no "gold standard" method to directly measure this physiological capacity, unlike that for assessing maximal aerobic capacity from gas analysis during maximal exercise testing. In addition, the combined contributions of both the aerobic and anaerobic systems during short, intense exercise make it challenging to understand how these systems interact. It was originally believed that the aerobic contribution was slower to respond to energy demands of short-burst activities (Yamamoto & Kanehisa, 1995). However, research has suggested otherwise as both of the energy-producing systems have been shown to contribute during most types of exercise, even those that are short and high in intensity (Yamamoto & Kanehisa, 1995).

Despite these methodological difficulties, numerous investigations into the contributions of the energy systems during exercise in young children have been conducted (Bar-Or, 1987; MedbØ & Tabata, 1989; Rivera-Brown, Alvarez, Rodriguez-Santana & Benetti, 2001). The majority of studies have focused mainly on aerobic, rather than anaerobic energy contribution in children, since as mentioned previously, direct measurement of anaerobic performance is not readily available (De Ste Croix, Armstrong, Chia, Welsman, Parsons & Sharpe, 2001). To further complicate matters, the growth and maturation that occurs during childhood and adolescence must be considered. Furthermore, when studying children, ethical constraints which limit methodological approaches (e.g. the use of muscle biopsies), have also contributed to the relative dearth of information about the development and contribution of these energy systems during exercise in children (Van Praagh & Doré, 2002). For these reasons, there is less known about the metabolic physiology of the anaerobic system in children, and it has been difficult to attempt to understand any underlying mechanisms with regards to the developmental aspects of anaerobic power in this population.

In contrast to the aerobic energy system, much less is known and understood about a child's ability to generate maximal amounts of energy anaerobically, in a brief period of time. Anaerobic power can be defined as "the production of anaerobic energy when the demand for ATP is greater than that which can be provided aerobically" (Williams, 1997, p.228). Numerous approaches have been used with children to assess their anaerobic capacities. Typically, anaerobic characteristics have been examined with the use of both the Margaria step test (Margaria, Aghemo & Rovelli, 1966) and the Wingate Anaerobic Test (WAnT) (Bar-Or, 1983) to obtain peak mechanical power, overall mechanical work, as well as the rate of power decline.

The most common current laboratory method to measure anaerobic power output on either an arm-crank or leg-cycle ergometer has been the WAnT. This is a 30-s all-out test which purportedly is capable of determining the maximal and average rates of work production over 30 s, the work rate being dependent on alactic and lactic ATP and CP breakdown, (Bar-Or, 1987). Body mass determines resistance to pedaling with the resistive load being applied within three seconds after overcoming the initial inertia on a cycle ergometer. Peak power (PP) expressed in absolute (W) represents the highest mechanical power generated during any three to five second period, while the mean power (MP) represents the average local muscle endurance throughout the test. A fatigue index (FI) is also measured, which corresponds to the percentage drop in power from the peak to the lowest power output (Bar-Or, 1987). The WAnT has been shown to be highly reliable with test-retest correlation coefficients of 0.95-0.98 (Inbar & Bar-Or, 1986), as well, it is not invasive and minimal laboratory equipment is needed. Because of its high reliability, and ease of application, the WAnT is the most commonly used method of testing anaerobic power in children, and was the method of choice used to determine anaerobic characteristics in the current study.

However, there are some potential limitations to using the WAnT as a pure index of anaerobic energy production, as there is evidence at least in adults, of a substantial contribution of aerobic energy sources contributing to power output during a maximal anaerobic test. In a recent study by Beneke, Pollman, Bleif, Leithäuse and Hütler (2002), the amount of aerobic contribution to the Wingate test was examined in young adult males. Oxygen uptake was used to examine aerobic metabolism while the lactic and alactic anaerobic energy systems were calculated from the net lactate production to estimate relative energy contributions. Results demonstrated that approximately 50% of energy during a 30 s test was derived from glycolysis, 30% from PCr breakdown and the remaining portion (20%) from aerobic contributions. These findings suggest that the 30 s Wingate test is highly anaerobic with only a 20% aerobic contribution. Others have estimated similar aerobic contributions of 13 – 28% confirming the mostly anaerobic nature of the WAnT, with increasing contributions, the longer the duration of the test (Bar-Or et al., 1980). The actual relative contribution may, however, vary by age, maturity and even level of training of the respective anaerobic and aerobic energy systems, but there are little specific data on these potential influences on relative energy contributions for children. Regardless, the aerobic contribution to the numerator of the power ratio in the current study is probably negligible, since peak power (PP) which occurs in the initial 10 sec of the WAnT was used as the criterion measure of anaerobic energy contribution in our power ratio calculations, thus precluding a major influence of aerobic metabolism.

Developmental Aspects of Anaerobic Power

As children grow and develop, so do their anaerobic capacities. Both peak and mean powers appear to increase with age, whether data are presented in absolute or relative values (Bar-Or, 1983; Inbar & Bar-Or, 1986; Williams, 1997). Anaerobic tests using the WAnT have shown that absolute values of both mean and peak anaerobic power increase significantly between the ages of 8 and 14 years (Bar-Or, 1983). Bar-Or (1983) reported increases in relative values of mean anaerobic power from 5.6 to 8.0 W/kg in boys and from 5.5 to 6.5 W/kg in girls across this age span (Bar-Or, 1983). Likewise, Inbar and Bar-Or (1986) examined cross-sectional data of non-athletic males between the ages of 8-45 that were divided into separate age groups. They established that both PP and MP of the legs and arms increased with age, with the lowest values obtained by children, whether expressed as an absolute value or relative to body weight. Relative PP values increased from 6.8 W/kg in boys <10yrs to approximately 8.0 W/kg in boys 10.0 to 11.9yrs, with the latter values not being much different from the young adult group (Inbar & Bar-Or, 1986).

Other investigators have found somewhat different results for age related changes in peak and mean anaerobic power. Naughton, Carlson and Fairweather (1992) examined anaerobic power using the WAnT in children aged 6 to 12yrs. No significant peak power differences relative to body weight were found between children 6 to 10 years old (6.2 W/kg, and 7.1 W/kg), suggesting that absolute growth in this capacity in the pre-pubertal years was affected mostly by body size. However, peak power was significantly increased by 12 years of age (8.3 W/kg), corresponding to the onset of puberty (Naughton et al., 1992), suggesting that factors besides body size may influence the development of this system with advancing maturity.

The age-related development of anaerobic power has also been examined in relation to pubertal status in a longitudinal study by Falk and Bar-Or (1993). A total of 36 subjects were divided into three groups that were based on Tanner pubertal assessment. Prepubertal, midpubertal and late pubertal subjects were tested four times over an 18 month period. Absolute peak power increased with age and maturity as there were significant differences between adjacent maturity groups. However, when peak power relative to body weight was calculated, there was no significant age difference. Although there were a couple limitations to the study, peak and mean anaerobic power did demonstrate an increase with advancing sexual maturity, with a trend towards an increase with age (Falk & Bar-Or, 1993).

A similar investigation into the development of anaerobic power in children has been done using the WAnT during arm cranking (Blimkie, Roache, Hay & Bar-Or, 1988). A total of 50 boys and 50 girls between the ages of 14 and 19 completed a 30 second all-out arm cranking test in a sitting position. Furthermore, lean arm volume was calculated using anthropometric measurements as well as a water displacement technique to assess correlations with arm lean tissue mass. Results demonstrated that absolute PP and MP increased significantly with age for boys but not for the girls. Similarly, when anaerobic power was corrected for lean arm volume, higher values occurred in the oldest group of boys, where girls showed no significant differences with age (Blimkie et al., 1988). This study demonstrates that body weight is not the only determinant of anaerobic power, as this study displays that lean tissue mass, in particular arm volume, is closely related to the development of anaerobic power.

There has been considerable debate about the best method of accounting for size and growth effects on the development of anaerobic power during the formative growth years. As already discussed many studies have simply measured anaerobic power with respect to body weight. Van Praagh (1997) acknowledged that peak and mean anaerobic power should not be related solely to body size, but rather to muscle size, particularly when testing occurs on a non-weight-bearing device such as a cycle ergometer. Several studies have been conducted that have examined the relationship between leg muscle volume and anaerobic measures using anthropometric techniques. Docherty and Gaul (1991) reported positive correlations between PP and MP (r=0.62 and r=0.72, respectively) with anthropometric estimates of thigh volume in boys. Slightly stronger positive correlations were also reported between PP and MP (r=0.79 and r=0.88 respectively) with thigh volume for girls.

More recently, magnetic resonance imaging (MRI) has been used to more accurately measure leg muscle volume and its relationship to anaerobic power development in children. De Ste Croix et al. (2001) examined boys and girls twice, once at age 10, and again at approximately age 12. A multilevel modeling approach was used to study the development of anaerobic power. Each subject completed the WAnT, and thigh muscle volume was determined by MRI. One benefit of MRI is that volume can include the muscles of the hip, specifically, the gluteus maximus which is often not taken into account using anthropometric techniques. Results demonstrated that there was an age effect, as values of PP from test two were higher than test one values for both girls and boys. As well, the estimated thigh volume significantly contributed to both peak and mean power development, suggesting that thigh muscle volume has a considerable influence on anaerobic power development, using the WAnT on children in this particular age range (De Ste Croix et al., 2001).

However, not all examiners are in agreement, as Doré, Bedu, França and Van Praagh (2001) suggest that the ease of relating anaerobic power to body mass, which can be simply and accurately measured, makes mass the most suitable factor for normalizing for growth effects on the development of anaerobic power in children. Overall, it would appear that regardless of the method of scaling (e.g. by body mass or lean tissue involved), anaerobic power increases throughout the developing years in children. Furthermore, particularly in males, it has been shown that even if anaerobic performance is principally related to body dimensions, improvements of anaerobic power are greater than can be explained solely by an increase in body mass or muscle quantity, and therefore, other factors such as hormonal or neural influences are implicated as potential important modifiers of the development of the anaerobic energy system in the transition from childhood to adulthood (Van Praagh, 1997). These qualitative factors may also be important in explaining gender differences in anaerobic power, particularly during and after puberty.

Gender-Related Differences in Anaerobic Power

Gender differences in the development of anaerobic power during childhood have also been investigated (Armstrong & Welsman, 2000; Blimkie et al., 1988; Docherty & Gaul, 1991). Data on girls is slightly more limited and the results appear to be more inconsistent compared with developmental trends in boys. Docherty and Gaul (1991) investigated 52 boys and girls aged 11 on several laboratory measures, including the WAnT. Although the boys and girls were very similar anthropometrically, relative peak anaerobic power values were greater for boys (8.4 W/kg) compared with girls (7.7 W/kg), whereas absolutely, no peak power differences were revealed. Therefore, it would appear from this study that at this young age, when children are similar anthropometrically, relatively, boys appear to have greater anaerobic power. Blimkie et al. (1988) examined peak anaerobic power of the arms in boys and girls aged 14 to 19. This age group represents a significant time of developmental changes occurring in both sexes. Results demonstrated that both PP and MP in boys increased significantly with age, but did not for girls, as boys showed significantly higher absolute PP values at all ages. However, when values were normalized for lean arm volume, gender differences were almost eliminated for the three youngest groups, suggesting that "gender differences in early adolescence (14-16 years) are closely associated with quantitative differences in lean tissue mass" (Blimkie et al., 1988, p. 681).

More recently, Armstrong, Welsman and Chia (2001) examined longitudinal changes in peak and mean anaerobic power in boys and girls to explore age and gender influences. A fairly large sample of boys and girls were tested at ages 12, 13 and 17 on the WAnT. Other measurements such as skinfold thickness and body mass were included as additional possible determinants of power development. Significant differences for absolute PP were only found in the oldest age group with mean values of 707 watts for boys compared to 553 watts for the girls. Furthermore, even when PP and MP were related to body composition, a significant difference between boys and girls was still demonstrated in the oldest age group. The authors concluded that with the positive influences of body mass on anaerobic power, and a negative influence found from skinfold measurements (subcutaneous fat) for boys and girls, the sex-related changes in power are most likely a product of changes in muscle mass (Armstrong et al., 2001). On the contrary, Carlson and Naughton (1994) examined the anaerobic power of children aged 6 to 12 exercising against varying braking forces using the WAnT. Results demonstrated that absolute peak and mean power of the children increased with age, with girls actually displaying higher PP and MP values than boys (Carlson & Naughton, 1994).

Clearly, there is still some controversy regarding gender differences in the development of anaerobic capacity in children. The effects of physical factors such as body mass and body composition in explaining gender differences remains equivocal, and there is little good evidence to suggest any underlying physiological differences in the energy pathways underlying anaerobic energy production between the sexes during childhood. Furthermore the most appropriate method of adjustment for body dimensions is still disputed and different methods of testing and a lack of longitudinal studies make it difficult to interpret and compare studies. However, most of these studies have consistently supported the concepts that anaerobic power improves during the developing years with a larger increase observed in boys than in girls, and that something besides body mass or muscle size accounts for the improvements.

Possibilities for Increased Anaerobic Power

As discussed above, it is fairly clear that both absolute and relative anaerobic power increase with growth during childhood, albeit the reasons for this developmental change are not fully understood. Although towards the end of adolescence, anaerobic power is similar to that of adults; younger children show evidence of lower values. In a comparison of anaerobic measures between prepubertal boys aged 11 to 12 and men, Gaul, Docherty and Cicchini (1995) reported that men had significantly higher absolute maximal anaerobic power of approximately 33% in comparison to the boys. Even when values were related to body weight, and thigh volume, the men still displayed higher values. This age related difference has been attributed to a greater relative muscle mass and strength of adults (Bar-Or, 1987). However, other aspects such as biochemical characteristics have also been considered in explaining this lower power output in children (Eriksson & Saltin, 1974; Eriksson, 1980). Unfortunately, only a couple of studies have been able to obtain muscle biopsy samples from children, and therefore it is difficult to accurately account for potential growth and development differences in muscle cellular metabolic and biochemical activity that might explain age related differences in anaerobic capacity. Eriksson and Saltin (1974) examined boys separated into four age groups from 11.6 to 13.5 years of age, with the oldest group examined again two years later at 15.5 years of age. Muscle biopsy samples from the vastus lateralis muscle were obtained at rest and after each work period including at maximal exercise. Muscle samples were analyzed for glycogen, lactate, ATP, CP and glucose concentrations. Findings demonstrated that resting ATP and CP were similar to adult values, suggesting that the alactacid energy system of boys is similar to adults. However, both muscle and blood lactate values at maximal exercise were low compared to adult values, and progressively increased with age, suggesting that the lactacid energy system may be somewhat deficient in youth (Eriksson & Saltin, 1974). When compared to adults from another study (Gollnick, Armstrong, Sanbert, Piehl & Saltin 1972), levels of phosphofructokinase (PFK), a rate-limiting step in glycolytic metabolism, were found to be 30 % lower in 11-year-old boys (Eriksson, 1980). This is thought to perhaps be a factor limiting the accumulation of lactate during intense exercise in children (Gollnick et al., 1972). In a review of muscle metabolism, Eriksson (1980) surmised that overall, children possess lower intra-muscular glycogen than adults, as well as slightly lower CP concentration, whereas ATP concentration is the same as adults (Eriksson, 1980). Therefore, as energy during short, intense exercise is mainly provided by the glycolytic pathway, the significantly lower concentration of muscle glycogen is perhaps the central difference in children, which results in a difference in the utilization of glycogen during glycolysis and thus the reduced mechanical anaerobic power (Eriksson, 1980).

To support the idea of a diminished glycolytic capability in children, Eriksson and Saltin (1974) had demonstrated that the rate of lactate appearance during a standardized exercise test is lower in adolescents than in adults, therefore suggesting a lowered anaerobic capability in children (Eriksson & Saltin, 1974). Other researchers have shown similar findings of lower lactate concentrations in both boys and girls, compared to adults (Åstrand, 1952, Eriksson & Saltin, 1974, Falgairette, Bedu, Fellman, Van-Praagh & Coudert, 1991, Williams & Armstrong, 1991). Eriksson & Saltin (1974) examined four groups of boys aged 11.6 to 15.5 years of age. Both muscle lactate and blood lactate was obtained at maximal exercise. Results demonstrated that blood lactate concentrations were similar to muscle lactate for each of the age groups. The youngest age group had a maximal blood lactate concentration of 7.9 ± 0.5 mmol $\cdot$ l^{-1} whereas the oldest group had a value of 10.5 ± 0.9 mmol $\cdot$ l^{-1}, demonstrating an increase with age (Eriksson & Saltin, 1974). Additionally, lactate values of children have been compared to adult values to examine age-related differences. Hebestreit, Meyer, Heigenhauser and Bar-Or (1996) tested five young boys (9.6 years of age) and five men (24.9 years of age) and their lactate responses, specifically post-exercise, using the WAnT. The boys had significantly lower lactate levels at three minutes post-exercise as well as ten minutes post-exercise with values for the boys being 5.7 mmol $\cdot$ l^{-1} compared to 14.2 mmol $\cdot$ l^{-1} for the men. These findings therefore suggest that children and adults differ with regards to contributions from the lactic energy pathway which may limit their reliance on the glycolytic pathways during this type of intense exercise.

However, there has been some controversy surrounding the validity of using blood lactate samples as a means for assessing glycolysis, as blood lactate levels reflect both the production and clearance from the blood (Rowland, 1996). As well, difficulties comparing studies in children due to variations in exercise testing methods have further complicated this area of study. Methodological concerns include the modality of the testing, be it a cycle ergometer or a running treadmill, the site of blood sampling, the length and variation in study exercise protocols, as well as the method of blood assay (Armstrong and Welsman, 1994). However, the accumulated data support the concept of lactate values increasing throughout development in children, similar to findings of increasing anaerobic power.

More recently, newer, non-invasive technology has allowed researchers to study the intracellular processes that are occurring in the skeletal muscle during exercise, without the need for a muscle biopsy. This will help in the understanding of how children function metabolically, compared to adults. Phosphorus nuclear magnetic resonance spectroscopy (^{31}PNMR) examines the changes in molecular dynamics through the use of a magnetic coil, in which the subject is placed (Rowland, 2005). Estimations of changes in CP, P_i as well as hydrogen ion concentration (pH) during exercise can be applied to children. Metabolic adaptations associated with aerobic energy production can be assessed by examining changes in the P_i to CP ratio. This ratio increases linearly with progressive intensity exercise, and is considered an accurate and reliable measure of aerobic metabolism. A second steeper phase with an increased slope during progressively increasing exercise intensity is thought to reflect anaerobic glycolysis (Cooper & Barstow, 1996).

Kuno et al. (1995) used ^{31}PNMR spectroscopy to examine muscle metabolism in adolescents aged 12 to 15 years and compared these findings to adult values during a maximal ankle dorsi flexion exercise test. Subject's performed 40 contractions per minute with the intensity increasing 1 kg each minute, until exhaustion. The ratio of P_i to CP for the second linear slope was calculated and found to be lower in the children compared to the adults, suggesting that children have less glycolytic engagement than adults during this type of exercise (Kuno et al., 1995). Similarly, Zanconato, Buchthal, Barstow and Cooper (1993) performed a study involving younger children aged 7 to 10 and compared them to adult subjects using ^{31}PNMR spectroscopy. Full plantar flexion calf exercises were completed at a frequency of one contraction per second. The intensity of the exercise was achieved by progressively increasing the external resistance by a pneumatic device, until the subject could no longer sustain the instructed contraction rate. Again, pH, CP and P_i were estimated and similar results to those of Kuno et al. (1995) were found, where the second linear aspect of the relationship between P_i and CP was lower in children. This led the authors to conclude that during high intensity exercise, children seem to "rely less on anaerobic glycolytic metabolism than adults" (Zanconato et al., 1993, pg. 218).

Although there are some discrepancies in the literature, and the underlying mechanisms are still not fully elucidated, in general, it appears that the anaerobic energy system, in particular, the anaerobic glycolytic pathway continues to develop and mature with advancing age throughout growth in childhood. This has been examined in both girls and boys from early childhood into adolescence and results typically show young children to have lower values of anaerobic power than both adolescents and adults, with adolescent values approaching those of adults. This increase has been consistent across varying methods for assessing anaerobic capacity, including peak mechanical anaerobic power derived from the WAnT, maximal lactate levels obtained from blood and muscle sampling, as well as changes in the muscle intracellular biochemical properties using ^{31}PNMR spectroscopy.

Aerobic Power

As discussed previously, the development of anaerobic power in children appears to increase with age based on mainly cross-sectional studies involving exercise that is short, and of high intensity. Likewise, aspects of maximal aerobic power assessed during exhaustive endurance-type exercise that challenges the cardiorespiratory system, have also been examined in children and results appear to be slightly different compared to development of the anaerobic system. Aerobic exercise involves any type of activity that uses large muscle groups continuously, for a prolonged period that stimulates the heart and lungs to work harder than they would at rest (McArdle et al., 2001). Aerobic exercise requires several physiological components interacting in order to transport oxygen quickly and efficiently to the muscles. The pulmonary, cardiovascular and haematological systems play a major role in the transport of oxygen to the muscles (Armstrong, Kirby, McManus & Welsman, 1995). This type of exercise is typical of many different sports and activities in which children participate, e.g. running, cycling and cross-county skiing. Energy production during these types of activities is derived from aerobic metabolism via the Krebs cycle and oxidative phosphorylation, with the muscles obtaining energy primarily from carbohydrates and an increased reliance on fat the longer the duration of exercise (McArdle et al., 2001).

The aerobic system is capable of generating much more energy, albeit at a slower rate in response to exercise than is the anaerobic system (McArdle et al., 2001). This type of metabolism is limited by the capacities of oxygen delivery and by the rates of oxidative phosphorylation and the electron transport chain that produce ATP. When comparing the amount of ATP that can be produced via aerobic metabolism versus anaerobic metabolism, 38-39 mol of ATP is produced from 1 mole of glucose in the former, compared with 2-3 mol provided by anaerobic metabolism (McArdle et al., 2001). Similar to anaerobic metabolism, glycolysis is also important for aerobic metabolism as it is the precursor pathway for both energy systems with its activation and importance depending on the presence of oxygen. If oxygen is available, pyruvate will not be converted to lactate, rather it will enter into the Krebs cycle to further produce ATP (McArdle et al., 2001).

Given that oxygen is essential for all aerobic energy producing reactions in the body, it is possible to estimate the production of energy through the measurement of oxygen consumption. The most common method of measuring oxygen consumption is via a maximal aerobic power test, or $\dot{V}0_2$max test, that requires an individual to exercise to their maximal capacity. Maximal aerobic power ($\dot{V}0_2$max) is "the highest rate of oxygen consumption by the body in a given period of time during exercise involving a significant portion of the muscle mass" (Krahenbuhl, Skinner & Kohrt, 1985, pg. 503), with the measure reflecting the ability to transport and utilize oxygen.

There are several different laboratory protocols used to assess an individual's $\dot{V}0_2$max, but cycling and running protocols on an ergometer and treadmill, respectively, are the most common approaches used to measure this capacity in children and adults. These tests usually consist of incremental, graded exercise to a point at which the subject can no longer continue. $\dot{V}O_2$max is recognized as the point during the exercise test where further increases in work are accompanied by a plateau in the oxygen consumption (McArdle et al., 2001). This test is generally conducted in laboratories using gas analyzers and is a highly accurate and reproducible test. Field tests have also been performed with the use of portable gas analyzers to obtain sport-specific measurements of oxygen consumption (Rowland, 1993). $\dot{V}O_2$max is most commonly expressed as either an absolute value ($L \cdot min^{-1}$) or relative to a measure of body size, most commonly body mass ($ml \cdot kg^{-1} \cdot min^{-1}$). Therefore, to measure one's maximal aerobic power output, the $\dot{V}O_2$max test has been used extensively in the field of exercise physiology, most commonly with adults, but examined in children as well.

When assessing maximal oxygen uptake in children and adolescents, several factors must be considered that are not necessarily a problem when testing adults. Åstrand (1952) found that many children and adolescents have difficulty obtaining a true $\dot{V}O_2$max as they do not show a leveling off of oxygen consumption near the end of the test, commonly observed with an adult population. Therefore, $\dot{V}O_2$ peak, identified as the highest $\dot{V}O_2$ value obtained in an exercise test to exhaustion, is a more appropriate term to describe the maximal oxygen consumption in children, regardless of whether a plateau is evident or not (Paterson, Cunningham & Donner, 1981). Lack of motivation or low levels of anaerobic capacity have been suggested as potential explanations for the relative failure of children to achieve a plateau in oxygen consumption, compared to adults

(Krahenbuhl, et al., 1985, Rowland, 1989). Rowland (1989) has also suggested it is possible that a child with an underdeveloped anaerobic energy system would be less likely to perform exercise at very high levels of intensity, such as during the final stages of a $\dot{V}O_2$max test. Cunningham, van Waterschoot, Paterson, Lefcoe, & Sangal (1977) reported that RERmax and lactate levels after maximal aerobic tests tended to be higher in children who reached a plateau than those that did not, supporting the theory children have a diminished anaerobic ability.

It is also unlikely that children who do not achieve a plateau during this type of testing are less motivated than those who do. Armstrong et al. (1995) tested approximately 150 pre-pubescent children and found no evidence to suggest that children who displayed a $\dot{V}O_2$ plateau were any different than those who did not demonstrate a plateau. There were no significant differences in $\dot{V}O_2$ peak, HRmax, RERmax or peak lactate measurements between children who did with those who did not display a plateau in $\dot{V}O_2$. Based on these findings, it appears that children who do not achieve a plateau are equally as motivated as those that do, and there appears to be little if any difference in maximal anaerobic capacity compared to those with a plateau. Further, Rivera-Brown et al. (2001) compared the ability to achieve a $\dot{V}O_2$ plateau in pre-pubertal boys with regards to their anaerobic ability. The participants completed the McMaster aerobic protocol to exhaustion as well as a 30s WAnT and results demonstrated that only 33% of the boys reached a $\dot{V}O_2$ plateau. Results also indicated that no differences in PP or MP were found between the boys that achieved a plateau with those that did not. Based on these findings, it appears unlikely that a child's level of motivation and anaerobic characteristics limit their achievement of a plateau during a maximal aerobic test. Consequently, it appears that in children, a leveling of $\dot{V}O_2$ is not critical and other criteria such as a plateau of peak heart rate or blood lactate levels of 6-7mmol·l^{-1} can be employed to distinguish a maximal effort in children (Armstrong & Welsman, 1994). As a result of the lack of attainment of a plateau in children, $\dot{V}O_2$ peak has more commonly been used to assess the aerobic development of children and is used as a marker of maximal aerobic capacity in the current study.

Developmental Aspects of Aerobic Power

Both longitudinal and cross-sectional studies have examined the development of maximal aerobic power of children, most commonly expressing values relative to the child's body mass, height or fat-free mass. These normalization approaches have been used extensively as they are convenient and relatively easy to measure. However, as with anaerobic power, comparison of studies among children becomes difficult, as different protocols and other methodological issues become apparent. For absolute measures, the pattern of maximal aerobic power development is somewhat similar to anaerobic power, with levels increasing progressively with advancing age. Unlike anaerobic power however, there appears to be little if any change in relative $\dot{V}O_2$max with increasing age during childhood.

The most valid measures of developmental trends in girls and boys, is derived from longitudinal studies of the same child retested over a number of years. Mirwald and Bailey (1986) conducted a longitudinal examination of boys and girls to describe the development of maximal aerobic power from age 8 to 16 years. Over this period, boys showed an increase of 164% in absolute $\dot{V}O_2$ peak, while girls demonstrated an overall increase of approximately 73%. The largest increases occurred between 13 and 15 years of age for boys with average peak annual increases of 0.31 $L \cdot min^{-1}$ and 0.32 $L \cdot min^{-1}$, respectively. These large increases appear to coincide with the onset of puberty when several physiological changes are occurring in the body. Similarly, the girls demonstrated their largest yearly absolute increases between 11 and 12 years of age (0.25 $L \cdot min^{-1}$) and 12 to 13 years (0.23 $L \cdot min^{-1}$). These large increases also occur at the age when girls are pubertal, which occurs approximately two years ahead of boys. Similar findings from other longitudinal studies have shown these large increases in maximal aerobic power for the same age ranges for girls (Armstrong & Van Mechelen, 1998; Kemper, Verschuur & de Mey, 1989).

When results from longitudinal studies of aerobic power are expressed relative to body weight, a different developmental pattern emerges in children. Kemper et al. (1989) studied the development of aerobic power of 102 boys and 133 girls over a five-year period using a standard treadmill test to bring the subjects to exhaustion. Absolute values increased for both boys and girls with higher values at age 17 than at age 12, albeit the values for the boys were consistently higher than those of the girls at all ages. For boys, values relative to body weight remained constant (59 $ml \cdot kg^{-1} \cdot min^{-1}$) over the given age period, while the relative values for the girls actually decreased from 50 $ml \cdot kg^{-1} \cdot min^{-1}$ at age 12 to 45 $ml \cdot kg^{-1} \cdot min^{-1}$ at age 17, most likely due to an increase in body fat during this period of development (Kemper et al., 1989).

There have also been several reviews that have examined the plethora of data on the developmental aspects of aerobic power in children (Armstrong & Welsman, 1994; Armstrong & Welsman, 2000; Krahenbuhl et al., 1985). Each of these reviews examines both cross-sectional and longitudinal data of thousands of $\dot{V}0_2$ peak data sets of children ranging in age from 6 to 17 years. Krahenbuhl et al. (1985) reported that with the exception of only a few studies, the majority of cross-sectional studies demonstrate year-to-year increases in absolute values of untrained males. Conversely, the year-to-year data from studies of females displayed many more reductions in maximal aerobic power, particularly through the ages of 12 to 17 years (Krahenbuhl et al., 1985). When examining the $\dot{V}0_2$max data relative to body weight, there appears to be a trend in boys of only slightly increasing levels of maximal aerobic power with age, while females actually show a reduction in maximal relative aerobic power from the pre-pubertal years to late adolescence (Krahenbuhl et al., 1985). These trends are consistent with a more recent review by Armstrong and Welsman (2000) who concluded that male children and adolescents do exhibit a steady increase in relative $\dot{V}0_2$ peak with age, while longitudinal data for girls display a leveling off at the age of 14 years (Armstrong & Welsman, 2000).

Most of these findings have used the simple ratio scaling approach, controlling for body size by simply dividing by mass and expressing values as a ratio of $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. However, the most appropriate means of normalizing for body size in children is unresolved and there are conflicting opinions in the literature about the most appropriate scaling approach to use in these analyses (Welsman, Armstrong, Nevill, Winter & Kirby, 1996). More recently, allometric scaling, using log-linear analysis of covariance has been used to challenge the traditional simple ratio scaling approach to investigate growth and development of $\dot{V}0_2$ peak. Welsman et al. (1996) compared the simple ratio method with allometric scaling to remove the effects of body size from peak $\dot{V}0_2$ in both genders, separated into three groups: prepubertal and circumpubertal children and young adults. Different patterns emerged between methods, with the allometric analysis indicating significant developmental increases in $\dot{V}0_2$ peak within all groups of males when adjusted for body mass while the youngest group of girls showed the lowest values compared to the older girls. When peak $\dot{V}0_2$ values for girls were adjusted, there appeared to be an upward trend from prepuberty to circumpuberty. Furthermore, these values remained consistent into adulthood in comparison to the mass related ratio scaled values which usually decrease in females with advancing age into adulthood. Conversely, the ratio method displayed no significant differences for weight adjusted peak aerobic power among the three groups of males, and significant differences were found only between the circumpubertal and young female adults, with the former having lower values than the latter group. These data therefore challenge the traditional methods of scaling as they demonstrate progressive increases in aerobic fitness independent of any influences from body size for both males and females (Welsman et al., 1996).

Although there has been some controversy over methods of partitioning out body size, the majority of the data demonstrate that absolute values of peak $\dot{V}0_2$ increase through childhood and adolescence and into early adulthood for both sexes, whereas the developmental trend for relative $\dot{V}0_2$ peak appears to be dependent on the method of accounting for, or normalizing for the effects of size, during the remaining formative years of somatic growth.

Gender-Related Differences in Aerobic Power

Another aspect that has been thoroughly investigated in children is the gender difference at various chronological ages with regards to $\dot{V}0_2$ peak. Several studies have examined the developmental aspects of maximal aerobic power from prepuberty to early adulthood in both sexes. Although there appears to be a clear gender difference, only speculations as to why this difference exists have been proposed. A review by Krahenbuhl et al. (1985) of cross-sectional data demonstrates that differences in relative $\dot{V}0_2$max widen progressively between sexes throughout childhood, with boys exhibiting greater values as they age. The data demonstrate that even eight year old boys show a marked difference compared to their female counterpart, with a 6% greater maximum $\dot{V}0_2$, with the difference increasing to approximately 18% by age 12 (Krahenbuhl et al., 1985).

Armstrong et al. (1995) examined peak $\dot{V}0_2$ values of 111 boys and 53 girls aged 11, classified as Tanner stage 1 from pubertal assessments. Each child performed a discontinuous, incremental treadmill test until voluntary exhaustion. Results demonstrated that both absolute and relative values of peak $\dot{V}0_2$ were higher among boys (1.78 $L{\cdot}min^{-1}$ in comparison to 1.46 $L{\cdot}min^{-1}$ and 51 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ compared to 45 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ respectively). Even when body mass was removed using a log-linear adjustment, boys had values approximately 16% higher than girls. One interesting aspect of this study is that both skinfold thicknesses and hemoglobin concentrations were measured in boys and girls. Each of these variables has been considered a possibility for explaining sex differences for aerobic power in children. However, despite there being no sex differences in the skinfold thicknesses or hemoglobin concentrations, the boys still demonstrated higher values than the girls (Armstrong et al., 1995).

As discussed previously, a couple of hypotheses have been proposed to help explain these gender differences in aerobic power. Differences in body composition, amount of physical activity, as well as hemoglobin concentrations have all been examined as possibilities. However, Kemper and Verschuur (1981) suggested that changes in body composition such as fat-free mass (FFM) and blood hemoglobin concentration are more likely to contribute to these differences than habitual activity.

The greater the amount of muscle mass in boys and increased adiposity levels with age in girls may contribute to sex differences. This is observed even before puberty as Rowland (1996) established that eight year old boys have a percent body fat of approximately 15% while females the same age have approximately 23% body fat. This greater FFM in boys has been suggested to contribute to a higher peak $\dot{V}O_2$, as greater muscle mass will more readily facilitate the use of oxygen during exercise, as well as augment venous return to the heart. Girls however have increased levels of adiposity contributing to decreasing $\dot{V}O_2$max values relative to body mass (Rowland, 1996).

A higher peak $\dot{V}O_2$ in boys is further shown when it is expressed relative to FFM. Kemper et al. (1989) in a longitudinal examination of boys and girls ages 12 to 23 found that gender differences remained as boys still demonstrated a 6% higher peak $\dot{V}O_2$ even when values were related to FFM. A more recent study by Welsman, Armstrong, Kirby, Winsley, Parsons and Sharpe (1997), however, that used MRI technology rather than skinfolds to estimate thigh muscle volume came to a different conclusion. In this study, a total of 32 children approximately 10 years old and classified as Tanner stage 1, completed a discontinuous treadmill test to exhaustion. Results demonstrated that there were no significant differences in thigh volume between the boys and the girls with values of 2.39 L and 2.18 L respectively. The boys, however, demonstrated significantly higher values of absolute and body mass relative peak $\dot{V}O_2$ compared to their female counterparts (1.95 L·min^{-1} in comparison to 1.81 L·min^{-1} and 62 ml·kg^{-1}·min^{-1} versus 51 ml·kg^{-1}·min^{-1}). However, when peak $\dot{V}O_2$ was expressed relative to thigh muscle volume, there were no significant differences between genders (0.82 L · L^{-1}· min^{-1} for boys and 0.84 L · L^{-1}· min^{-1} for girls), suggesting no significant gender differences for peak $\dot{V}O_2$ expressed relative to muscle mass.

In summary, gender differences are apparent regardless of method of body size normalization, with boys generally having higher values than girls at all ages and the difference becoming even more pronounced as boys reach puberty. However, it is still not fully understood why these gender differences exist even when influences such as FFM are considered. Therefore, further investigation is needed to clarify the mechanisms underlying these physiological differences between boys and girls in the development of maximal aerobic power.

Anaerobic Threshold

The term anaerobic threshold (AT) has been used to identify a particular point during an incremental test at which aerobic metabolic processes can no longer keep up with the energy demands from the muscle (Wasserman, Van Kessel & Burton, 1967). This point describes a particular peak work rate or oxygen uptake recognized by a disproportionate increase of either ventilation ($\dot{V}_E$) or lactate concentration relative to $\dot{V}0_2$. During a progressive exercise test where the intensity continues to increase, lactate levels are fairly stable until approximately 50 to 60% of an individuals' $\dot{V}0_2$max (Rowland, 1996). Lactate progresses in a linear fashion with respect to power output and oxygen consumption until lactate begins to accumulate in a non-linear fashion. This particular breakpoint has been termed the lactate threshold or anaerobic threshold (Brooks, 1985). The term lactate threshold (LT) and AT are used somewhat interchangeably, but have traditionally been thought to denote the onset of anaerobic metabolism as a backup source of energy to continue exercising (Rowland, 1996).

At rest, lactic acid is formed throughout the body in red blood cells, skeletal muscle and the intestines, and seems to be the result of glucose breakdown (Washington, 1989). Low levels of lactic acid can be measured in the blood at rest where values are similar to those found during low-intensity exercise. When the intensity of exercise increases to a point when anaerobic metabolism is thought to aid in energy production, lactic acid concentration increases, as it is a by-product of anaerobic metabolism. This sharp increase in the concentration of lactic acid has also been termed the onset of blood lactate accumulation (OBLA) (McArdle et al., 2001). This accumulation of lactic acid causes an increase in H^+ and therefore, an increase in the acidity in the muscle cells. For this reason, it is necessary for the lactic acid to be buffered to reduce the acidity in the muscle cell. This occurs predominantly by the bicarbonate system. Sodium bicarbonate is an alkalizing agent which prevents the blood from becoming too acidic (McArdle et al., 2001). The result of the buffering of lactic acid generates an excess of carbon dioxide ($C0_2$), causing the partial pressure of $C0_2$ in the venous capillary blood to increase, leading to an increase in ventilation (Rowland, 1993).

As previously discussed, blood lactate levels during exercise have been examined in children and results appear to suggest a progressive increase with age during childhood and adolescence, similar to anaerobic power. Eriksson, Karlsson and Saltin (1971) examined circumpubertal boys during a progressive cycle test to exhaustion. Muscle lactate was analyzed through biopsies taken from the quadriceps, while blood lactate was also measured to compare values. Both of these measures corresponded to each other and were found at approximately 50% of the child's $\dot{V}0_2$max. Lactate values increased in a curvilinear fashion up to a mean maximal value of 11.3 $\text{mmol} \cdot \text{kg}^{-1}$. When lactate values were compared to adults, the curvilinear trend was similar; however, values were consistently lower in the children (Eriksson et al., 1971). Similar findings have been reported by others. Falgairette et al. (1991) found similar results in boys aged 6 to 15 years. $\dot{V}0_2$max was measured on a cycle ergometer and peak lactate levels were measured two minutes after voluntary exhaustion. The youngest group showed significantly lower lactate concentrations than the older group, with peak lactate values of 5.5 $\text{mmol} \cdot \text{l}^{-1}$ compared to 7.9 $\text{mmol} \cdot \text{l}^{-1}$. Longitudinal studies have further demonstrated the same trend of increasing lactate with chronological age. Paterson, Cunningham and Bumstead (1986) found that peak lactate values increased on average 0.9 mmol · l^{-1} per year in children aged 11 to 15 years.

Further investigations have demonstrated that the point of inflection of lactate concentration during progressive intensity exercise occurs at a lower concentration in children compared to adults. Williams and Armstrong (1991) examined prepubertal and pubertal boys who performed a maximal aerobic test to exhaustion. Results indicated that the lactate breakpoint occurred at an approximate concentration of 2.5 mmol · l^{-1} in the boys which is significantly lower that the threshold of adults which has been found to occur at approximately 4 mmol · l^{-1} (Maćek & Vavra, 1980). Therefore, children reach the AT at a lower concentration of lactate than do adults. These findings are in agreement with Mocellin, Heusgen and Gildein (1991) who examined the AT and blood lactate concentration relative to maximal aerobic power in 12-year-old boys. A steep increase in lactate concentration marked the AT, which was found to occur on average at a concentration of 2.6 mmol · l^{-1}. Furthermore, at this threshold, the percentage of $\dot{V}0_2$max was found to be 78% in the boys (Mocellin et al., 1991). In comparison, Farrell, Wilmore, Coyle, Billing and Costill (1979) examined the onset of plasma lactate accumulation in young adult runners and established that the AT occurred at 69.9% of their $\dot{V}0_2$max, somewhat lower than that of children. Therefore, it would appear that the AT occurs at a much lower lactate concentration in children and at a higher oxygen uptake than that of adults, reflecting the reduced capability and maturation of children's anaerobic energy system.

Interpretation of these apparent developmental differences in lactate responses during exercise, however, must be made cautiously and with a full appreciation of methodological considerations. Blood lactate sampling in children is an invasive measure and if it is not necessary, then it should not be done. Establishing a threshold requires multiple samples and ethical constraints have limited the application of this procedure in children. Consequently, there are fewer studies examining the LT in children compared to adults, leaving age- and child-adult comparisons largely unresolved. Furthermore, the physiological interpretation of the AT determined by the inflection point of lactate during an exercise test has been challenged in the literature (Armstrong & Welsman, 1994; Rowland, 1993). It has been suggested that the AT may not mark the point when anaerobic metabolism becomes the primary energy source, as the increase in lactate at the breakpoint appears to depend on a balance between lactate accumulation and elimination (Armstrong & Welsman, 1994). Therefore, the AT has also been examined with the use of non-invasive approaches that are preferable with children as there is no need to draw blood from the participant for lactate analysis.

As mentioned above, the buffering of lactic acid generates an excess of CO_2, leading to an increase in ventilatory drive due to an attempt to maintain homeostasis (Rowland, 1993). Wasserman and McIlroy (1964) observed that $\dot{V}_E$ initially increases with exercise intensity and begins to diverge from its normal linear trend with oxygen uptake in the transition to higher exercise intensity. This breakpoint where $\dot{V}_E$ begins to diverge from linearity has been termed the ventilatory anaerobic threshold (VAT) and this approach has been used in the pediatric research to examine developmental changes in anaerobic metabolism during progressive exercise testing.

This VAT approach is non-invasive and does not require a maximal effort, making it more feasible than repeated blood lactate sampling for pediatric populations. Furthermore, it has been shown in children that there is a good correlation between the lactate anaerobic threshold and the ventilatory threshold, suggesting that VAT is an accurate marker of the AT. Ohuchi, Nakajima, Kawade, Matsuda and Kamiya (1996) examined children aged 8 to 21 years to determine the feasibility of the VAT as a reflection of anaerobic threshold in children. A progressive exercise test was completed on a treadmill and both VAT and LT were determined. The VAT was established as an increase in the change of ventilatory equivalent for $\dot{V}0_2$ and $\dot{V}C0_2$, whereas the LT was determined from lactate concentrations obtained from arterial blood samples from indwelling angiocath at rest and throughout the protocol. Results demonstrated a strong correlation between the VAT and the LT (r=0.91), suggesting VAT to be an accurate marker of the lactate anaerobic threshold for this age range.

Several pediatric studies have been conducted examining the VAT as it is fairly easy to determine, and multiple methods of determination are available. Commonly used methods for determining VAT involve breath-by-breath gas analysis and a ramp or one minute increment in work rate protocols. It has been suggested that breath-by-breath ventilatory parameters should be averaged over 15-s intervals as this has been shown to improve the detection of the VAT (Washington, 1989). The VAT is determined as the exercise intensity at which $\dot{V}_E$ stops to increase linearly with increasing $\dot{V}0_2$ and a continual increase in $\dot{V}_E$ is observed above the initial threshold (Rowland, 1996). The method described by Wasserman and McIlroy (1964) that has been used to determine this threshold involves the ventilatory equivalent for CO_2 ($\dot{V}_E/\dot{V}CO_2$) and ventilatory equivalent for O_2 ($\dot{V}_E/\dot{V}O_2$). When plotted against time, there is a deflection point where $\dot{V}_E/\dot{V}O_2$ increases without a change in $\dot{V}_E/\dot{V}CO_2$. Further methods have used an excess rise of the respiratory gas exchange ratio (RER) to detect the VAT (Reybrouck, Ghesquiere, Cattaert, Fagard & Amery, 1983), as well as a method described by Conconi, Ferrari, Ziglio, Droghetti and Codeca (1982) which describes a deflection point in HR displayed at the time when the slope of HR decreases, coinciding with the OBLA.

Several of these methods have been used with children to examine the development of the ventilatory threshold with age. Most studies examining the development of VAT with age evaluate it either as a percentage of the individual's $\dot{V}O_2$ peak, or relative to their sub-maximal oxygen uptake in $ml \cdot kg^{-1} \cdot min^{-1}$. The data appear to display a trend of decreasing VAT with age regardless of whether it is expressed as a percentage of $\dot{V}O_2max$ or in $ml \cdot kg^{-1} \cdot min^{-1}$. Cooper, Weiler-Ravell, Whipp and Wasserman (1984) examined a large number of girls and boys aged 6 to 17 years. Each child performed a maximal test on a cycle ergometer while gas exchange parameters were collected. Results indicated that both the older girls and boys reached their ventilatory threshold at a lower value of $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) than the younger age groups. As well, a lower percentage of $\dot{V}O_2max$ was shown as the oldest group reached their threshold at 55% of their $\dot{V}O_2max$ compared to 64% in the younger boys with similar findings observed in girls (Cooper et al., 1984).

Further studies have examined both age and gender differences with respect to the VAT. Reybrouck, Weymans, Stijns, Knops and van der Hauwaert (1985) tested a total of 257 children on a treadmill to investigate the changes of VAT with age and gender. Results were again displayed as a percentage of $\dot{V}0_2$max and expressed as ml·kg^{-1}·min^{-1} for all subjects. Girls and boys from ages 5 to 18 were divided into separate groups and VAT was determined as the exercise intensity when $\dot{V}_E$ began to increase in a non-linear fashion with increasing oxygen uptake. Results displayed significant age differences with the youngest achieving their VAT at a much higher percentage of their $\dot{V}0_2$max (74.4%) compared to the oldest age group (50.5%). The authors suggested that this decrease with age is due to an increase in the lactacid anaerobic capacity, and as mentioned previously, this may be explained by the differences in the properties of the muscle and the lower capacity for glycolytic metabolism in children. Furthermore, values of VAT expressed as ml·kg^{-1}·min^{-1} significantly decreased with age from 32.3 ml·kg^{-1}·min^{-1} in the youngest boys to 26.5 ml·kg^{-1}·min^{-1} in the oldest group, with similar drops in the females, demonstrating that the breakpoint occurred at a lower oxygen uptake. Reybrouck et al. (1985) also found that the VAT values for girls were significantly lower at all ages compared to boys, suggesting that girls reach a point when they are in need of anaerobic energy at a lower intensity of exercise than do boys.

Therefore, the anaerobic threshold measured either directly by examining lactate concentrations or indirectly by observing ventilatory parameters at the VAT are capable of being determined in children. It appears that children display lower levels of lactate compared to adults at their threshold, while the VAT occurs at a higher percentage of their $\dot{V}0_2$max. These observations suggest a decreased anaerobic ability in children compared to adolescents and adults.

Both the lactate and VAT thresholds have been thought to describe the transition from essentially aerobic energy to exercise that requires greater involvement of anaerobic metabolism (MacDougall, Wenger and Green, 1991). At this breakpoint, when exercise intensity continues to increase, it becomes more difficult to continue exercising as the muscles begin to starve for oxygen. Therefore, it represents an important transition stage of energy supply and allows researchers to estimate a precise point, be it a particular power output or a specific oxygen uptake when anaerobic sources become increasingly important for contributing to energy output and the continuance of mechanical power output. This was of particular interest for the current study, as the mechanical power output at the VAT or LT can be considered to represent the point where exercise is being fuelled almost entirely by aerobic metabolism. Comparison of mechanical power output at this point with peak power achieved during a mostly anaerobic test such as the WAnT facilitates calculation of the anaerobic to aerobic power ratio, a potential indicator of the relative engagement of the two major energy systems during an exercise bout. Traditionally, investigators have used the mechanical power output at exhaustive exercise during a progressive intensity test as the criterion for aerobic power in the calculation of this power ratio. At this point in time, however, mechanical power output is being supported not only by aerobic energy production, but also by contributions from the anaerobic energy pathways. Conceptually, the mechanical power output at the LA and VAT is relatively less dependent on anaerobic energy sources than at exhaustive exercise, and power output at these break points may therefore prove a conceptually more valid and better denominator in the calculation of the anaerobic-to-aerobic power ratio than peak power attained at exhaustion. If proven valid, these new metabolic ratios based on aerobic power at the LA and VAT thresholds may facilitate our understanding of the coordination of age- and sex-related development of these energy systems during growth and in the transition from childhood to adulthood.

Power Ratio

It is evident that there is plenty of valuable information on the separate development of both the aerobic and anaerobic aspects of children's exercise, and although some aspects of the development with age are not clear, it appears that there are particular trends with increasing age. Anaerobic power appears to increase with age whether data are presented in absolute or relative terms. Similarly, absolute maximal aerobic power demonstrates an increase with age, whereas relative to body weight, this value appears to be steady in boys, and decreases somewhat in females. (Åstrand, 1981a; Bar-Or, 1983; Inbar & Bar-Or, 1986; Krahenbuhl et al., 1985). However, there is a paucity of studies investigating the development of these systems in relation to each other within the same individual. Bar-Or (1986) introduced the concept of the anaerobic-to-aerobic power ratio as an index to assess a subject's physiological function, in particular with regards to sick children. It is defined as the ratio between peak mechanical anaerobic power and peak mechanical aerobic power. The index in a healthy child is approximately 2.5 to 3.0, whereas sick children display a much lower value suggesting deficiencies of both aerobic and anaerobic power (Bar-Or, 1986). Peak anaerobic power is typically measured using the WAnT, while, peak aerobic power has been measured using the McMaster Progressive Cycle Test (Bar-Or, 1983). When considered in conjunction with traditional absolute or relative measures of peak aerobic and anaerobic power, the ratio allows for the assessment of relative deficiencies or enhancements of these systems associated with disease or specialized training, respectively.

Blimkie, Roche & Bar-Or (1986) investigated the developmental aspects of the power ratio in boys and girls aged 8 to 14 years. The power ratio was based on calculations of peak mechanical power at $\dot{V}0_2$max (Cumming, 1977) where mechanical aerobic power was calculated as the prorated power during the final stage of a progressive test when the subject could no longer sustain a particular cadence on the cycle ergometer, and peak anaerobic power from the WAnT. Based on these independent measures of aerobic and anaerobic power, it was hypothesized that the power ratio would increase with age in both boys and girls up to a certain point where it would then plateau. Results from Blimkie et al. (1986) demonstrated that this did in fact occur, and that the increase in the ratio in girls was due to a relative continuous increase in anaerobic power and a small decrease in aerobic power, whereas the ratio increased during the same period in boys due to their continued increase in anaerobic power with unchanging aerobic power. This ratio therefore gives an understanding of how short-term power output and aerobic power develop during the growing years, particularly outlining that the anaerobic power continues to increase up to a certain developmental age (Blimkie et al., 1986).

Falgairette et al. (1991) examined changes in aerobic and anaerobic power of 144 boys aged 6 to 15 years. Mechanical power was measured at $\dot{V}O_2max$ using a method assuming a mechanical efficiency of 22.5%, while maximal anaerobic power was obtained during a force-velocity test. It was observed that $\dot{V}O_2max$ remained constant from 6 to 15 years of age, while anaerobic power increased significantly. Therefore, similar to the work of Blimkie et al. (1986), the power ratio increased consistently with growth, which can be attributed to an increase in anaerobic metabolism with age. This has been further researched in a longitudinal study by Falk and Bar-Or (1993), the results of which also support the findings of Blimkie et al. (1986). Three groups of boys, prepubertal, midpubertal and late pubertal were studied over an 18-month period. Anaerobic power was determined using the WAnT, while aerobic power was determined using a progressive, continuous test to exhaustion on a cycle ergometer. Results demonstrated no significant differences for peak mechanical aerobic power relative to body weight among the three groups. However, when examining peak anaerobic power relative to body weight, there was a significant difference among groups classified by pubertal status, but not by age. When the power ratio was calculated, results demonstrated a significant increase with age for the prepubertal and midpubertal group, but not the late pubertal group.

Another use for this ratio other than to assess functional capacities in pediatric clinical populations, has been to assess any deficiencies in either energy system in young athletes. A coach is able to enhance a certain physiological capacity depending on if the ratio demonstrated a weakness in either the aerobic or anaerobic components. For example, if a hockey player appeared to have a lower ratio displaying a superior aerobic power, the coach could strengthen the anaerobic component to ensure a good balance between the two energy system capacities, as hockey requires both good aerobic and anaerobic capacities. The use of the power ratio has been investigated with adult male off-road cyclists in an attempt to determine an optimal ratio of aerobic power to anaerobic power for this sport (Baron, 2001). Results from this study demonstrated the usefulness of the power ratio in evaluating which physiological aspect, be it endurance or power needs to be improved. The anaerobic-to-aerobic power ratio has also been evaluated during arm-crank exercise to investigate whether it was related to specialization of swimming events when comparing middle-distance swimmers to sprint event swimmers (Mercier, Granier, Mercier, Trouquet & Préfaut, 1993). Male swimmers aged 16 to 23 performed an incremental aerobic test as well as a force-velocity test to obtain peak aerobic and peak anaerobic power. Results demonstrated slightly higher power ratio values for the sprint group; however, these ratios were not significantly different from the middle-distance swimmers. Although no significant differences were found between the two groups, the authors concluded that the power ratio is a useful means of evaluating the anaerobic and aerobic proportions involved in the supply of energy in male swimmers (Mercier et al., 1993). Therefore, the power ratio appears to be a very useful tool for coaches and trainers to be able to optimize the energy contributions for specific sporting events.

Although the ratio is a useful means of evaluating the proportions of energy components in particular sports, the original method of Blimkie et al. (1986) that demonstrated an increase with age may be somewhat flawed in the method of measurement. The difficulty with the anaerobic to aerobic power ratio is the way it is currently assessed, as the denominator of the ratio (mechanical aerobic power determined at maximal exhaustion) is likely highly influenced by anaerobic sources, and thus this ratio does not accurately reflect the independent contributions of the capacities of the two energy systems to the ratio. It is highly likely that the peak aerobic power used in the original approach by Blimkie et al. (1986) was achieved with significant contributions from the anaerobic energy system, questioning the validity of using this variable as a marker of pure aerobic power in calculation of the power ratio. Therefore, the primary focus of this thesis is to investigate the possibility of using the mechanical power output at the LT or VAT as a more valid indicator of aerobic capacity in the calculation of a new power ratio. If proven valid, age-related trends using this new approach can be compared to the original approach to better our understanding of the development of the aerobic and anaerobic energy systems during the course of growth and development, and in relation to disease and specialized training.

Purpose

The purpose of my Master's thesis is two-fold. First, we compared two new approaches to calculating the anaerobic-to-aerobic power ratio to the traditional approach that incorporated peak mechanical power at exhaustive exercise. The first new approach used for calculating the power ratio was to identify the LT and incorporate the mechanical power at the LT as a substitute for the peak aerobic mechanical power output in the denominator of the power ratio calculation. The second new approach was to identify the VAT, and determine the mechanical power output at the VAT for inclusion in the denominator of the power ratio. These two new approaches were then compared to the traditional method of calculating the power ratio to determine whether there were any age-related differences in the developmental trends for this ratio from childhood into early adulthood. The second purpose was to assess the reliability of the two new approaches to calculating the power ratio, compared to the traditional method.

Hypotheses

1. The new power ratio calculated using the LT and VAT approaches will demonstrate the same age-related patterns as the traditional approach.
2. The new approaches to calculating the power ratio will be moderately to strongly-correlated with the traditional power ratio approach.
3. The new approaches to calculating the power ratios will be more reliable than the traditional approach.

METHODOLOGY

Subjects and Methods

This research project received ethical approval from the Hamilton Health Sciences/McMaster University Research Ethics Board. All participants were informed of testing procedures, and consent was obtained from all participants (Appendix E), as well as from a legal guardian for those under the age of 18 years (Appendix C). An assent form (Appendix D) written in a style that an eight-year old child could understand was provided to each participant under the age of 18, and signed by them prior to their participation in the study. Subjects that were 18 and older were also asked to complete a medical history questionnaire (Appendix B) to ensure that nothing would hinder them from performing the exercise. Similarly, parents of the young children were asked to complete a children's medical questionnaire (Appendix A) for any child under the age of 18. The medical questionnaire ensured that each participant was free from any chronic or acute diseases, illnesses or any condition or disability that could negatively impact their general physical activity levels or their ability to perform the exercise testing.

Young male ice hockey players (n=31) were recruited from local rep hockey teams located in Hamilton and the surrounding area, ranging in age from ten to twenty one. Subjects were recruited and classified by discrete age groups rather than by maturational status, as the latter was not evaluated in the current study. Age groups were comprised of 10 – 12 years olds, 13 – 15 year olds, and 16 – 21 year olds, serving as surrogate measures for the pre-pubertal, mid-pubertal and adolescent stages of development, respectively. Data were analyzed in two ways: one with age as a continuous variable to investigate age related changes in the key dependent variables and secondly, with age group as a discrete categorical variable to enable inference of developmental changes. Competitive hockey levels ranged from Single A to Junior A to minimize variability of different training backgrounds. Recruitment was restricted to hockey players, as this sport relies equally on aerobic and anaerobic physiological systems, thus minimizing the effect of specialized conditioning that might favour development of either the anaerobic or aerobic physiological systems. Testing occurred towards the end of the hockey season to ensure that participants were in peak physical condition.

All testing took place in the exercise physiology laboratory in the Department of Kinesiology in the Ivor Wynne Centre at McMaster University. Each session lasted approximately one and a half hours and consisted of two tests that were conducted on the same visit to the laboratory. Anthropometric measurements including height and weight, and circumference measurements of the leg and skinfolds to estimate muscle mass were taken prior to exercise testing. The aerobic test was conducted first, using a modified McMaster All-Out Cycling test (Bar-Or, 1983) while the WAnT according to Inbar and Bar-Or (1986) was conducted last to obtain anaerobic power. Details of the two testing conditions were thoroughly explained to ensure the subject felt comfortable with the testing conditions and any questions or concerns were answered prior to commencing.

PRIMARY MEASUREMENTS

Peak Aerobic Power - Modified McMaster Protocol

To establish a new approach for assessing the aerobic metabolic contribution to the denominator of the power ratio, a modified discontinuous McMaster All-Out Test was completed. From this test, three different approaches were used to determine the "criterion" mechanical aerobic power to be used in the denominator of the ratio: the traditional (Trad), lactate threshold (LT) and ventilatory threshold (VAT) approaches– detailed methods described below. The criterion mechanical aerobic power is different from peak aerobic power which is defined as the highest obtained oxygen uptake at exhaustion. The new approaches can be examined by sampling oxygen consumption, ventilatory measures and lactate during the modified McMaster protocol. Prior to testing, the subjects were made familiar with the equipment. The aerobic test began using the McMaster All-Out Cycling Protocol on a Lode cycle ergometer. Seat height was adjusted for the subject's stature to ensure that the legs were capable of generating optimal power. Gas analysis was determined using a Medi-soft Ergocard $QTC0_2$ using the Medi-soft Exp'air software program (version 1.28) to analyze the data. Subjects breathed through a mouthpiece with a saliva trap and a light-weight, low dead-space pneumotach throughout the test (Pneumotach, Medi-soft). Ventilatory and respiratory parameters were determined using breath-by-breath analysis with the Ergocard, which was calibrated prior to testing with gases of known concentrations. Subjects also wore a Polar A1 HR Monitor with a T31 transmitter throughout the test to monitor heart rate. To acquire high-quality heart rate data in the younger children, it was necessary to strap the heart rate monitor very securely to the child using medical tape so the electrodes would stay in place. Additionally, a small amount of water was placed on the electrodes to ensure a good connection.

According to the McMaster All-Out cycle protocol, the stature of the subject determined the initial load of the test. Table 1 summarizes how the stature of the subject was used to determine the appropriate initial load as well as the load increments as recommended by Bar-Or (1983). The subject was instructed to pedal at a cadence between 45 and 55 rpm throughout the entire test, which was on the display panel of the bike for the subject to see. The modified cycle ergometer protocol for a subject ≥160cm used in this study is illustrated in Figure 1.

Prior to beginning the test, one capillary blood lactate sample was taken from the figertip as a baseline measurement. No warm-up was needed prior to testing as the protocol allowed for four minutes of light pedaling with minimal load. To begin the protocol, the load was increased every two minutes for the first two increments, and then the modified McMaster protocol began. The modified discontinuous version of the protocol consisted of load increments that were half the load of the McMaster protocol increments, and the time intervals between increases in load were extended to three minutes rather than two minutes to allow for attainment of steady state.

At the end of this first three minutes of exercise, a one minute rest with continued cycling and no load occurred. During the second one minute rest period, fingertip blood samples were taken during the first 15-20 s. This process continued until four sub-maximal lactate samples were obtained, at which time the protocol returned to the original McMaster all-out test consisting of two-minute increments until exhaustion. If the investigator felt that the lactate threshold had not been obtained after the first four samples, one subsequent sample was taken at the end of the first two-minute interval following the final rest period. The two minute increments continued until the subject could no longer sustain a cadence of 45 rpm. At this point, the test was completed and the peak mechanical power and time of completion were recorded for later analysis. One final maximal fingertip lactate measurement was taken at the very end of the protocol, approximately two and a half minutes after completion. A cool-down period was also provided until the participant felt comfortable getting off of the cycle ergometer.

Table 1. The McMaster All-Out Progressive Cycling Protocol *(Bar-Or, 1983)*

Body Height (cm)	Initial Load (Watts)	Increments (Watts)	Duration of Each Load (min)
≤ 119.9	12.5	12.5	2
120 – 139.9	12.5	12.5	2
140 – 159.9	25	25	2
≤ 160	25	50	2

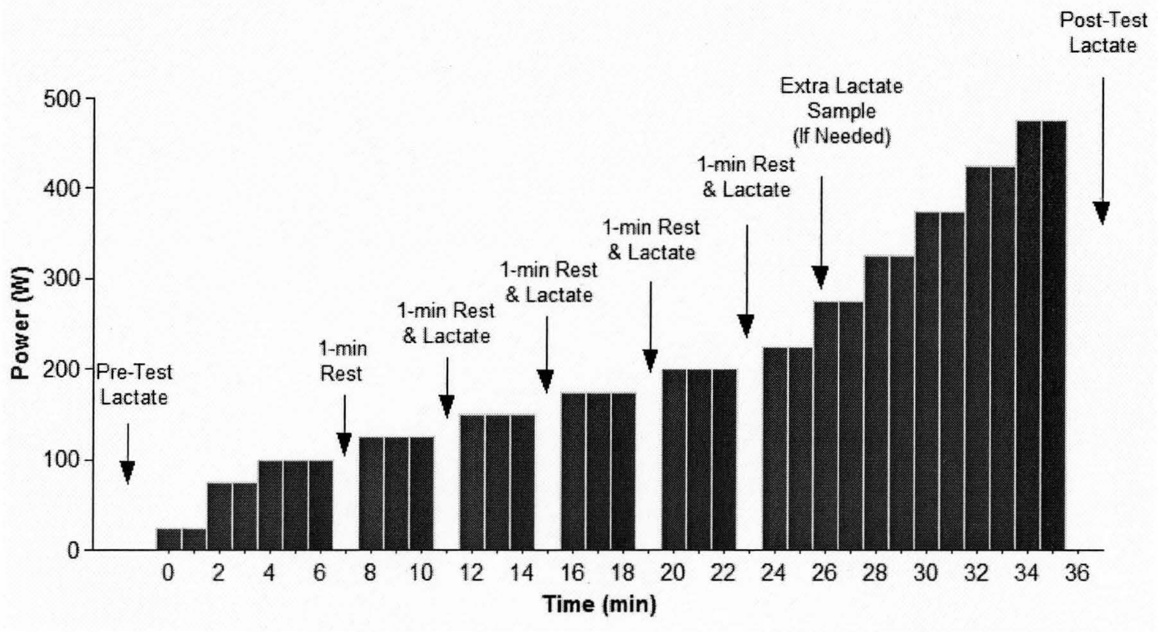

Figure 1: Sample modified McMaster aerobic protocol for a subject ≥160cm.

Lactate Measurements

During the aerobic protocol, up to seven fingertip lactate samples were obtained from each subject to determine the lactate threshold. Capillary blood sampling is the simplest and least traumatic method of sampling blood lactate and since children were being tested, it was felt that this was the most effective manner of obtaining a blood sample in this study. It has been shown that capillary blood lactate levels from fingertip sample sites will accurately reflect arterial levels with good blood flow (Williams, Armstrong, & Kirby, 1992). Blood lactate was measured using a portable lactate analyzer (Accutrend). While the subject continued to cycle, one finger was cleaned with an alcohol swab to remove any sweat or dirt that could affect measurements. Using a sterile lancet, a small prick was applied to the finger and a small amount of blood was obtained using a sterile pipette (approximately 32μl). Once the sample was acquired, sterile gauze was held in place on the finger with pressure applied to stop any bleeding, and band aids were applied if necessary. The blood was immediately placed on the blood lactate strip (BM Lactate Test Strips) to be analyzed. The resulting value in millimoles/L (mmol/L) was recorded for later analysis. Individual regression analysis was used for each subject to find the lactate threshold, as well as its corresponding mechanical aerobic power output (Beaver, Wasserman & Whipp, 1985). All bio-hazardous materials were disposed of accordingly once the procedure was complete.

$\dot{V}0_2$ Peak Criteria

Because children are less likely than adults to achieve an oxygen uptake plateau, it is necessary to have some criteria to ensure maximal effort was given (Rowland, 1996). There are several criteria that have been established to determine whether a true $\dot{V}0_2$max was likely achieved. A peak heart rate (HRmax) value of approximately 195 beats per minute (bpm) on a cycle ergometer can be used as an indicator of maximal effort; however, this value varies significantly among children and may be difficult to achieve during a cycling test (Rowland, 1993). Alternatively, maximal respiratory exchange ratio (RERmax) can also be used as a criteria, even though it appears to be slightly lower in prepubertal children than typical values in adults during cycling (Hansen, Froberg, Hyldebrandt & Nielsen, 1991). Therefore, for the purposes of this study, the maximal amount of oxygen consumption will be described as $\dot{V}0_2$ peak. A maximal effort for the child was assumed when the appearance suggested an exhaustive effort, and one of the following two criteria were met at peak exercise: HRmax $\geq$195 bpm or RERmax $\geq$1.05 (Rowland, 1993).

Peak Anaerobic Power - The Wingate Anaerobic Test

All subjects performed a WAnT conducted using a Monark (Ergomedic 814E) cycle ergometer to determine the peak mechanical anaerobic power for the numerator of the power ratio. Peak power is usually achieved within the first 5s, and this was recorded for further analysis (Bar-Or, 1987). Furthermore, the MP and FI were obtained and recorded. A warm-up period preceded the test as this has been shown to improve performance (Inbar & Bar-Or, 1975). The warm-up consisted of four all-out sprints, each

5 s in duration, with the load equal to that used during the test. This type of warm-up is done to familiarize the subjects with the intensity of the test (Inbar & Bar-Or, 1975).

The optimal braking force depends on the child's body weight to ensure the force yields the highest mean power (Bar-Or, 1993). For each of the all-out sprints, the predetermined load, according to Bar-Or's (1993) optimal braking force, was used for each child, unless the subject's body weight was 70 kg, at which point the standard 0.075 g per kilogram of body mass was used as the resistance. A two minute rest period then separated the warm-up from the actual test.

To begin the test, the examiner clarified the test requirements, particularly, emphasizing that the test would require a maximal effort throughout the entire 30 s, and that the subject must stay seated throughout the test. The examiners then counted down from three and yelled "Go" to prompt the subject to begin pedaling. Once the subject pedaled to a maximal effort against zero resistance (approximately 2-3 s), the prescribed load was applied to the cycle ergometer. The subject was encouraged by the examiners throughout the test to ensure subject motivation. After 30 s, the test was complete and a short two-minute cool-down period of low-resistance pedaling followed until the subject felt comfortable dismounting the ergometer. The examiner made sure the subject continued to move around and observed the subject to ensure full recovery before leaving the laboratory.

SECONDARY MEASUREMENTS

Height and Weight

The stature of each participant was measured while standing in socked feet using a standard stadiometer. Subjects were instructed to keep their heels together and arms hanging to the side. Shoulders and head were in contact with the vertical wall and subjects were instructed to look straight ahead and take a deep breath. The researcher then instructed the participant to step away from the wall and the measurement was taken to the closest 0.1 cm. To measure weight, participants stood on a balance scale (Healthometer) in shorts, a t-shirt and socked feet. Measurements were taken to the closest 0.1 kg.

Muscle Mass Estimates

To estimate lean tissue volume in the dominant leg, circumferences as well as skinfold measurements were taken at specific sites (Figure 2) according to the method of Jones and Pearson (1969). Segmental limb measurements allow for estimates of muscle and bone volume, subcutaneous fat volume and total leg volume (Jones & Pearson, 1969). With the subject standing in socked feet, both the height above the floor and circumferences at the following seven levels on the dominant leg were taken: 1) the gluteal furrow, 2) one third of the subischial height up from the tibial-femoral joint space, 3) the minimum circumference above the knee, 4) the maximum circumference around the knee joint space, 5) the minimum circumference below the knee, 6) the maximum calf circumference, and 7) the minimum ankle circumference. Each of these sites was marked with an erasable pen for an accurate measurement. The circumferences and height above the floor were measured using a flexible measuring tape (Creative Health Products). Skinfold measurements were taken using a Lange Skinfold Caliper (Cambridge Scientific Industries) at four specific sites: 1) the anterior thigh in the mid line at the one third subischial height level, 2) the posterior thigh in the mid line at the one third subischial height level, 3) the medial calf at the maximum circumference level, and 4) the lateral calf at the maximum circumference level (Jones & Pearson, 1969). All data were recorded for further analysis. As the calipers squeeze a double layer of skin-fold, measurements were halved to determine the thickness of the underlying fat, which was corrected prior to data analysis. In order to calculate the volume of the leg, the seven circumference sites were divided by the thigh and calf into six separate truncated cones. The formula to calculate the volume of a single truncated cone was $\frac{1}{3}h(a+\sqrt{(ab)}+b)$, where a and b are the area of two parallel surfaces derived from circumference measurements (Jones & Pearson, 1969). To estimate the volume of the muscle and bone, the halved fat caliper values for the thigh and calf were summed and the results subtracted from their respective diameters. This mathematical method, using anthropometric measurements to estimate lean muscle mass, has been shown to be highly correlated with water displacement measures as well as x-ray measures (Jones & Pearson, 1969).

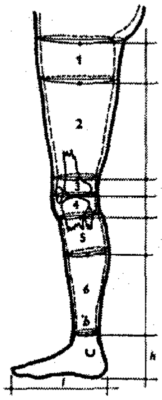

Figure 2: Illustration of the six truncated segments of the leg and the sites from which the anthropometric measurements were taken (Jones & Pearson, 1969).

Power Ratio Reliability

To test the reliability of the various approaches used to calculate the power ratio in this thesis, a total of six subjects, two from each age category, returned to the laboratory for repeat measures. Height and weight were recorded and the subjects were given a brief review of the aerobic and anaerobic test protocols. Both aerobic and anaerobic measurements were recorded exactly as they were for the first test, and data was recorded for further analysis.

Power Ratio Calculations

Peak mechanical anaerobic power obtained from the WAnT was used in the numerator of each of the three approaches of calculating the power ratio (Trad approach, LT approach and the VAT approach). To obtain the criterion mechanical aerobic power using the traditional power ratio approach, gas collection data was averaged every minute at the end of each exercise stage until exhaustion and plotted against mechanical power (watts). Both the absolute and relative mechanical aerobic power was calculated to be used in the denominator of the ratio. Similarly, to calculate criterion mechanical aerobic power at the LT, gas analysis was averaged every minute, plotted against power while lactate values were plotted at each particular load where the sample was taken. A visual inspection of the plotted lactate values was done first, and then the lactate data points were divided into two segments. Using regression analysis on both segments, a division point could be found which could then be aligned with a particular mechanical power output at the breakpoint (Beaver et al., 1985). Both absolute and relative power at the LT could then be obtained to be used in the denominator of the calculation of the new power ratio at the LT. Finally, one minute averages of $\dot{V}_E/\dot{V}0_2$, $\dot{V}_E/\dot{V}C0_2$, $\dot{V}C0_2$, $\dot{V}0_2$ and $\dot{V}_E$ were calculated at the end of each exercise stage and were plotted against the power of that particular stage on the x-axis. The point at which there was a systematic increase of ventilatory equivalent of oxygen ($\dot{V}_E/\dot{V}0_2$) without an associated increase in the ventilatory equivalent of $C0_2$ ($\dot{V}_E/\dot{V}C0_2$), was used as the VAT (Davis, 1985), and measures of absolute and relative power at this breakpoint were calculated and used in the denominator of the new power ratio, referred to as the VAT approach.

Statistical Analysis

Pearson product moment correlation analysis was used to examine the relationship between decimal age of all subjects pooled and the power ratio determined by the Trad, LT and VAT approaches, as well as the interrelations between our new approaches and the traditional approach to assess concurrent validity. Likewise, correlation analysis was used to investigate relationships between age and measures of both peak aerobic and anaerobic power components. When examining age as a discrete variable with subjects separated into specific age groups, one-way ANOVA was used to determine differences for descriptive and physical characteristics and to compare assessment approaches including aerobic and anaerobic measures and power ratio calculations. Intra-class correlation analysis (ICC) and method-error (ME) comparisons were used to determine the reliability of the repeated measures for peak anaerobic power, peak aerobic power, LT aerobic power, VAT aerobic power, Trad power ratio, LT power ratio and VAT power ratio. The method-error technique was used to calculate a coefficient of variation (CV) for the repeated measures on six subjects, two subjects representing ach of the three distinct age groups. STATISTICA analysis software (version 7) was used for the Pearson-product moment correlation analyses and ANOVA. Method-error was calculated using Microsoft Excel (version 2007), while SPSS (version 13) was used for intra-class correlation analysis.

RESULTS

Descriptive and Physical Characteristics

Table 2, 3 and 4 summarize the descriptive and physical characteristics for age, height, weight, BMI, leg muscle plus bone volume and number of years of hockey experience for each discrete age group. Table 5 summarizes the significant differences for age, height, weight and leg muscle plus bone volume with subjects separated into discrete age groups.

Table 2: Descriptive and physical characteristics of age group 1 (n=10).

Measure	Mean
Age (years)	11.6 ± 0.8
Height (cm)	153.3 ± 7.3
Weight (kg)	44.4 ± 8.4
BMI (%ile)	50th – 75th
Leg Muscle plus bone volume (L)	3.2 ± 0.7
Hockey Experience (years)	7.4 ± 1.3

All values are mean ± SD

Table 3: Descriptive and physical characteristics of age group 2 (n=12).

Measure	Mean
Age (years)	13.7 ± 0.8
Height (cm)	168.5 ± 9.1
Weight (kg)	59.7 ± 9.7
BMI (%ile)	50th – 75th
Leg Muscle plus bone volume (L)	4.4 ± 1.1
Hockey Experience (years)	8.3 ± 1.4

All values are mean ± SD

Table 4: Descriptive and physical characteristics of age group 3 (n=9).

Measure	Mean
Age (years)	18.2 ± 1.9
Height (cm)	177.4 ± 3.6
Weight (kg)	73.3 ± 10.6
BMI (%ile)	50th – 75th
Leg Muscle plus bone volume (L)	6.1 ± 1.4
Hockey Experience (years)	12.3 ± 2.7

All values are mean ± SD

Table 5: Significant differences of descriptive and physical characteristics of hockey groups between age groups.

Age Group	Age (yrs)	Height (cm)	Weight (kg)	Leg Muscle + bone Volume (L)
10 – 12 years^{1} (n=10)	11.6 ± 0.8^{2,3}	153.3 ± 7.3^{2,3}	44.4 ± 8.4^{2,3}	3.2 ± 0.7^{2,3}
13 – 15 years^{2} (n=12)	13.7 ± 0.8^{1,3}	168.5 ± 9.1^{1,3}	59.7 ± 9.7^{1,3}	4.4 ± 1.1^{1,3}
16 – 21 years^{3} (n=9)	18.2 ± 1.9^{1,2}	177.4 ± 3.6^{1,2}	73.3 ± 10.6^{1,2}	6.1 ± 1.4^{1,2}

All values are mean ± SD, group differences are distinguished by superscript numbers (^{1,2,3}), significant at $P<0.05$

Physiological Variables for Anaerobic Power

Mean values of absolute and relative anaerobic power for each discrete age group are displayed in Table 6, 7 and 8. Significant differences for measures of anaerobic power between discrete age groups are summarized in Table 9. Absolute PP and relative PP demonstrated a significant, positive correlation with age for all subjects (Figure 3 and 4). Significant correlations (Table 10) were found between age and absolute peak power (r=0.81), relative peak power (r=0.53) and absolute average power (r=0.74). Likewise, there was a significant correlation between absolute peak power and body weight, as well as absolute peak power and total muscle plus bone volume (Table 10). Furthermore, age was significantly positively correlated with body weight and muscle plus bone volume (Table 10).

Table 6: Anaerobic Power measures for age group 1 (Absolute and relative PP, MP and FI). n=10

MEASURE	Mean
Peak Power (W)	422.7 ± 84.0
Average Power (W)	327.0 ± 73.3
Peak Power (W/kg)	9.6 ± 0.9
Average Power (W/kg)	7.4 ± 0.8
Fatigue Index (%)	39.3 ± 8.7

All values are mean ± SD

Table 7: Anaerobic Power measures for age group 2 (Absolute and relative PP, MP and FI). n=12

MEASURE	Mean
Peak Power (W)	630.3 ± 109.3
Average Power (W)	469.2 ± 87.3
Peak Power (W/kg)	10.5 ± 0.6
Average Power (W/kg)	7.9 ± 0.8
Fatigue Index (%)	44.3 ± 8.1

All values are mean ± SD

Table 8: Anaerobic Power measures for age group 3 (Absolute and relative PP, MP and FI). n=9

MEASURE	Mean
Peak Power (W)	799.3 ± 122.1
Average Power (W)	585.7 ± 88.1
Peak Power (W/kg)	10.9 ± 0.7
Average Power (W/kg)	8.0 ± 1.1
Fatigue Index (%)	46.5 ± 11.2

All values are mean ± SD

Table 9: Significant differences between age groups for measures of anaerobic power.

Age Group	Peak Power (W)	Avg. Power (W)	Rel. Peak Power (W/kg)	Avg. Rel. Power (W/kg)	Fatigue Index (%)
10 – 12 years^{1} (n=10)	422.7 ± 83.9^{2,3}	327.0 ± 77.3^{2,3}	9.6 ± 0.9^{2,3}	7.4 ± 0.8	39.3 ± 8.7
13 – 15 years^{2} (n=12)	630.3 ± 109.3^{1,3}	469.2 ± 87.3^{1,3}	10.5 ± 0.6^{1}	7.9 ± 0.8	44.3 ± 8.1
16 – 21 years^{3} (n=9)	799.3 ± 122.1^{1,2}	585.7 ± 88.1^{1,2}	10.9 ± 0.6^{1}	8.0 ± 1.1	46.5 ± 11.2

All values are mean ± SD, group differences are distinguished by superscript numbers (^{1,2,3}), significant at $P<0.05$

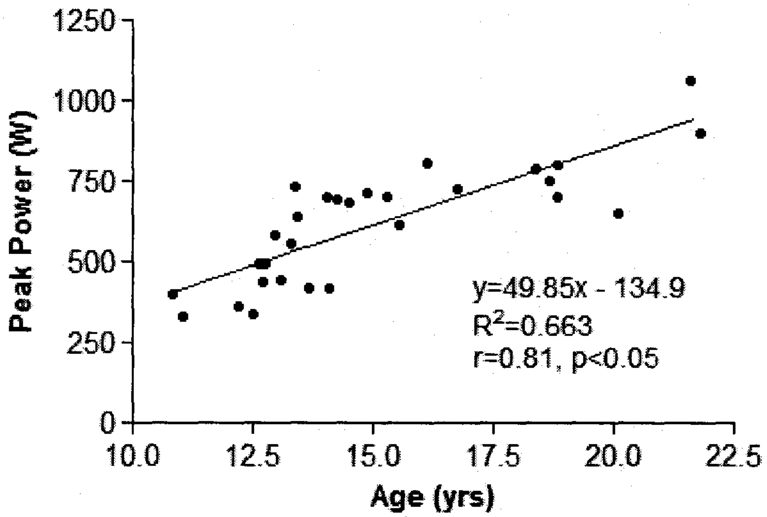

Figure 3: Absolute peak anaerobic power vs. age for all subjects.

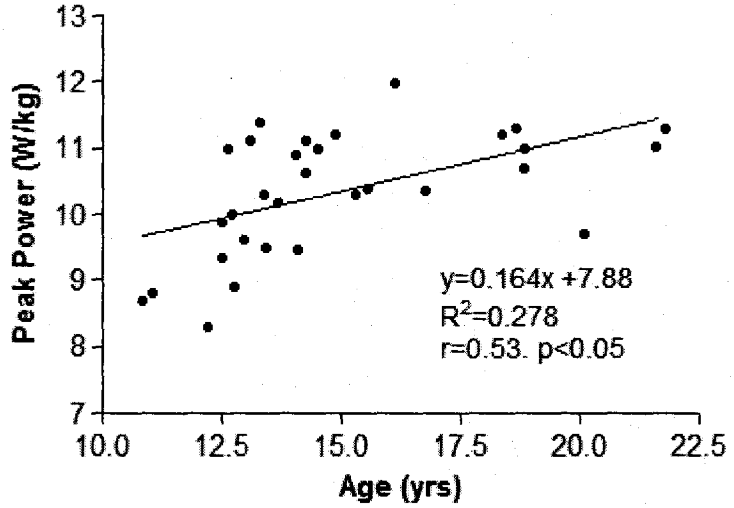

Figure 4: Relative peak anaerobic power vs. age for all subjects.

Table 10. Correlation matrix of all subjects' anaerobic power measures with relation to decimal age, body weight and muscle plus bone volume.

	Age	Abs. Peak Power	Abs. Avg. Power	Rel. Peak Power	Rel. Avg Power	Body Weight	Leg Muscle + Bone Volume
Age	—	0.81*	0.74*	0.53*	0.18	0.79*	0.75*
Abs. Peak Power		—	0.93*	0.68*	0.28	0.97*	0.86*
Abs. Avg. Power			—	0.66*	0.54*	0.90*	0.77*
Rel. Peak Power				—	0.63*	0.49*	0.41*
Rel. Avg. Power					—	0.13	0.04
Body Weight						—	0.90*
Muscle + Bone Volume							—

*Denotes significant relationship at P<0.05

Physiological Variables for Aerobic Power

Aerobic parameters for each age group including HRmax, RER, absolute and relative $\dot{V}0_2$ peak are shown in Table 11, 12 and 13. Significant differences between age groups are summarized in Table 14 with no significant differences found for relative $\dot{V}0_2$ peak across the three groups. RER was only significantly different between the age group 1 and age group 3 (Table 14). Significant correlations for all subjects were found between age and absolute $\dot{V}0_2$ peak (r=0.77), whereas $\dot{V}0_2$ peak relative to age did not change with age (Figure 5 and 6 respectively).

Table 11: Aerobic Measures for age group 1(n=10)

MEASURE	Mean
Absolute $\dot{V}0_2$ peak ($L \cdot min^{-1}$)	2.2 ± 0.3
Relative $\dot{V}0_2$ peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.4 ± 6.8
HRmax (bpm)	191.3 ± 9.0
RER	1.1 ± 0.1

All values are mean ± SD

Table 12: Aerobic Measures for age group 2 (n=12)

MEASURE	Mean
Absolute $\dot{V}0_2$ peak ($L \cdot min^{-1}$)	3.0 ± 0.5
Relative $\dot{V}0_2$ peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.6 ± 9.4
HRmax (bpm)	196.2 ± 7.0
RER	1.1 ± 0.1

All values are mean ± SD

Table 13: Aerobic Measures for age group 3 (n=9)

MEASURE	Mean
Absolute $\dot{V}0_2$ peak ($L \cdot min^{-1}$)	3.8 ± 0.4
Relative $\dot{V}0_2$ peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.9 ± 5.2
HRmax (bpm)	190.9 ± 11.9
RER	1.2 ± 0.1

All values are mean ± SD

Table 14: Significant differences between age groups for aerobic measures.

Age Group (n=31)	Abs. $\dot{V}O_2$peak (L/min)	Rel. $\dot{V}O_2$peak (mL/kg/min)	HRmax (bpm)	RER
10 – 12 years^1 (n=10)	$2.2 \pm 0.3^{2,3}$	50.4 ± 68	191.3 ± 8.9	1.1 ± 0.1^{3}
13 – 15 years^2 (n=12)	$3.0 \pm 0.5^{1,3}$	51.5 ± 9.4	196.2 ± 7.0	1.1 ± 0.1^{3}
16 – 21 years^3 (n=9)	$3.8 \pm 0.4^{1,2}$	51.9 ± 5.2	190.1 ± 11.8	1.2 ± 0.1

All values are mean ± SD, group differences are distinguished by superscript numbers (^{1,2,3}), significant at $P<0.05$

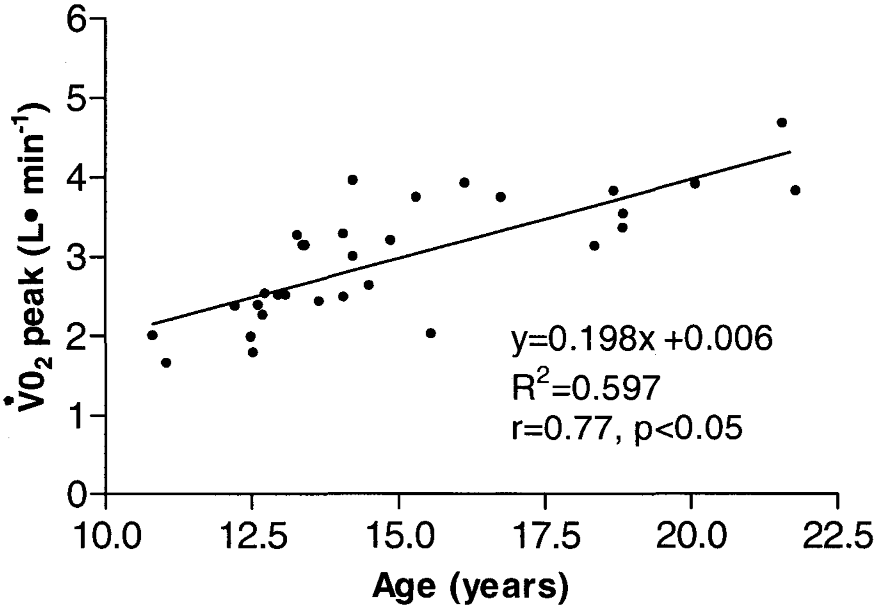

Figure 5: Correlation between age and absolute V̇0₂ peak for all subjects.

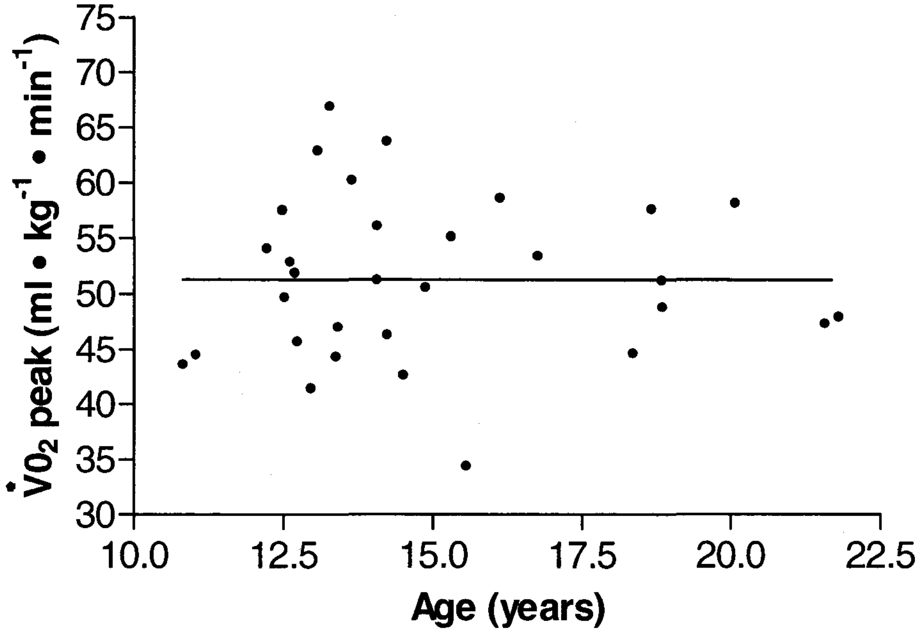

Figure 6: Correlation between age and relative V̇0₂ peak for all subjects. No significant difference.

Criterion Mechanical Aerobic Power

Mean values of the criterion absolute and relative mechanical aerobic power for all three methods for each age group are displayed in Table 15, 16 and 17. Significant correlations (Table 18) were found between age and absolute traditional mechanical power (r=0.74), absolute LT power (r=0.77) and absolute VAT power (r=0.79), whereas there were no significant correlations with age for any of the relative criterion aerobic power measures.

Table 15: Criterion mechanical aerobic power for Trad, LT and VAT methods for age group 1 (n=10).

MEASURE	Mean
Absolute Trad Mechanical Power (W)	183.8 ± 31.2
Relative Trad Mechanical Power (W/kg)	4.5 ± 0.6
Absolute LT Mechanical Power (W)	120 ± 23.7
Relative LT Mechanical Power (W/kg)	2.7 ± 0.3
Absolute VAT Mechanical Power (W)	138.8 ± 24.6
Relative VAT Mechanical Power (W/kg)	3.2 ± 0.4

All values are mean ± SD

Table 16: Criterion mechanical aerobic power for Trad, LT and VAT methods for age group 2 (n=12)

MEASURE	Mean
Absolute Trad Mechanical Power (W)	264.6 ± 47.6
Relative Trad Mechanical Power (W/kg)	4.5 ± 0.6
Absolute LT Mechanical Power (W)	172.9 ± 25.5
Relative LT Mechanical Power (W/kg)	3.0 ± 0.7
Absolute VAT Mechanical Power (W)	191.7 ± 43.4
Relative VAT Mechanical Power (W/kg)	3.2 ± 0.7

All values are mean ± SD

Table 17: Criterion mechanical aerobic power for Trad, LT and VAT methods for age group 3. (n=9)

MEASURE	Mean
Absolute Trad Mechanical Power (W)	319.4 ± 39.1
Relative Trad Mechanical Power (W/kg)	4.4 ± 0.5
Absolute LT Mechanical Power (W)	216.7 ± 35.4
Relative LT Mechanical Power (W/kg)	3.0 ± 0.3
Absolute VAT Mechanical Power (W)	255.6 ± 16.7
Relative VAT Mechanical Power (W/kg)	3.5 ± 0.3

All values are mean ± SD

Table 18. Correlation matrix of all subjects' criterion aerobic power measures with relation to decimal age.

	Age	Rel. $\dot{V}0_2$ peak	Abs. $\dot{V}0_2$ peak	Abs. Trad Power	Rel. Trad Power	Abs. LT Power	Rel. LT Power	Abs. VAT Power	Rel. VAT Power
Age	—	0.00	0.77*	0.74*	0.02	0.77*	0.09	0.79*	0.21
Rel. $\dot{V}0_2$ peak		—	0.29	0.05	0.64	0.00	0.39	0.03	0.48*
Abs. $\dot{V}0_2$ peak			—	0.90*	0.24	0.84*	0.07	0.87*	0.25
Abs. Trad Power				—	0.35	0.85*	0.05	0.92*	0.28
Rel. Trad Power					—	0.14	0.45*	0.24	0.66*
Abs. LT Power						—	0.41*	0.84*	0.23
Rel. LT Power							—	0.09	0.46*
Abs. VAT Power								—	0.49*
Rel. VAT Power									—

*Denotes significant relationships at $P<0.05$

AGE-GROUP ANALYSES

Absolute Power

When analyzing the data using three separate age groups, peak anaerobic power increased significantly with increasing age (Figure 7A). For the criterion aerobic power measures (Figure 7B), there was a significant increase with increasing age for the traditional aerobic power measures (indicated by asterisk), and the traditional aerobic power measure was also significantly higher than either the LT or VAT aerobic power measures within each age group (indicated by superscript +,++ and +++). There were no significant differences between the LT and VAT aerobic power measures at any age (Figure 7B).

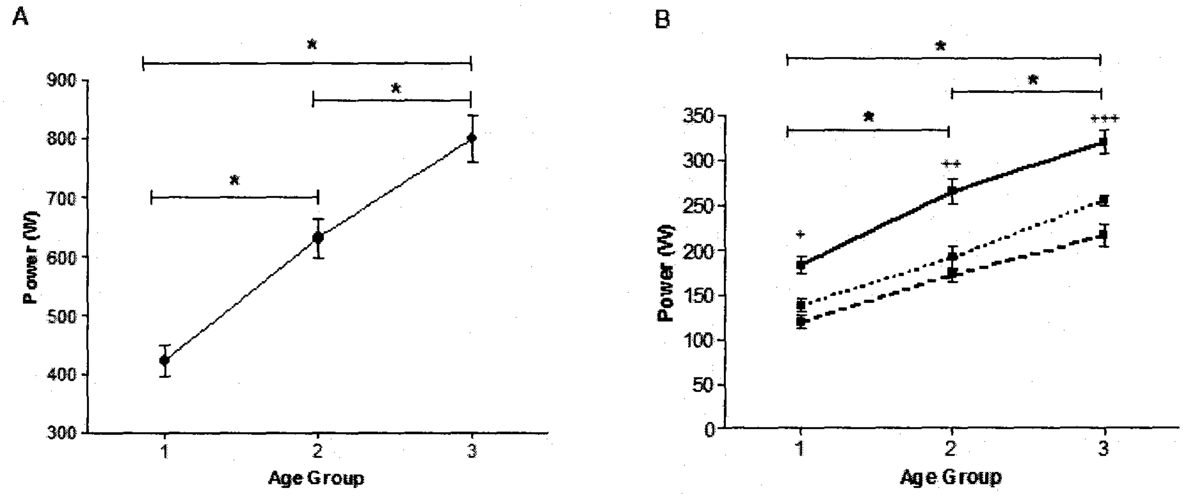

Figure 7: A: Age related differences of absolute anaerobic power between the three age groups (* significantly different at $P<0.05$). B: Age and method differences of criterion aerobic power including peak traditional power (solid line), VAT aerobic power (dotted line) and LT aerobic power (dashed line). ($^{+}$,$^{++}$,$^{+++}$) significant differences between methods within each age group)

Relative Power

Relative anaerobic power increased with age, with each of the age groups being significantly different from one another, and the oldest group having the highest values (Figure 8A). Significant differences were also evident among the criterion measures of relative aerobic power with the traditional relative aerobic power being significantly higher than either the LT or VAT measures at each age (Figure 8B). There were no differences across ages for any of the criterion measures of relative aerobic power, and no age related differences between the LT and VAT aerobic power measures.

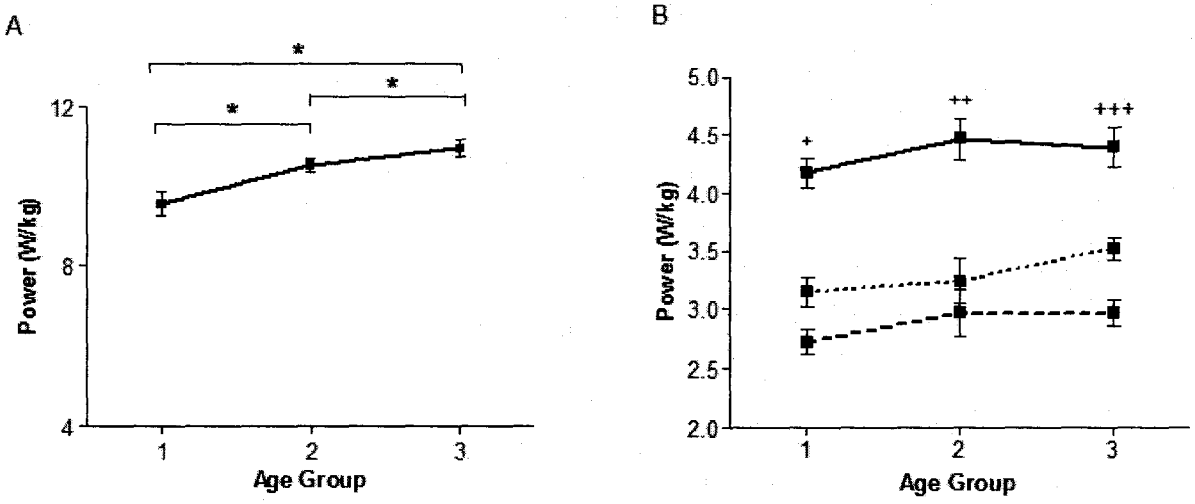

Figure 8: A: Age-related differences of relative anaerobic power (* significantly different at P<0.05). B: Age and method differences of criterion relative aerobic power including peak traditional power (solid line), VAT aerobic power (dotted line) and LT aerobic power (dashed line). ($^{+}$,$^{++}$,$^{+++}$ significant differences between methods within each age group).

Power Ratio

Power ratio values from each of the three methods of calculation are shown in Figure 9. The LT approach resulted in the highest ratio, followed by the VAT and traditional approaches respectively. One way ANOVA demonstrated that the power ratio calculated by the three approaches were significantly different from each other. When the power ratio approaches were compared among discrete age groups, significant differences were found between the youngest and oldest group for each of the three methods (Figure 10). There was a significant correlation between age and the traditional relative power ratio (r=0.36), but not with either of the two new approaches (Figure 11). Furthermore, moderate to strong correlations were found within each discrete age group between the two new ratio approaches (LT and VAT) and the traditional ratio calculations. The VAT approach showed significant correlations with the traditional method for each age group (Table 19,20 and 21), while the LT approach displayed a significant relationship only in the youngest age group (Table 19).

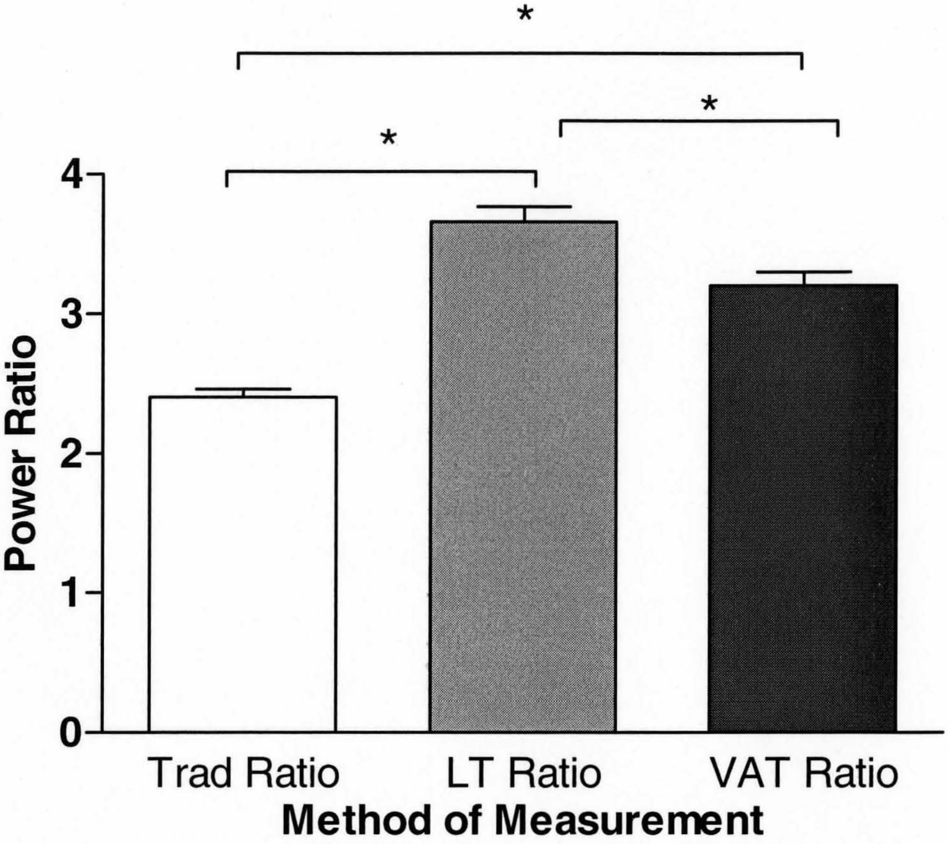

Figure 9: Power ratio values from each of the three approaches: Trad method, LT method and VAT method for all subjects. *Denotes significance at $P<0.05$

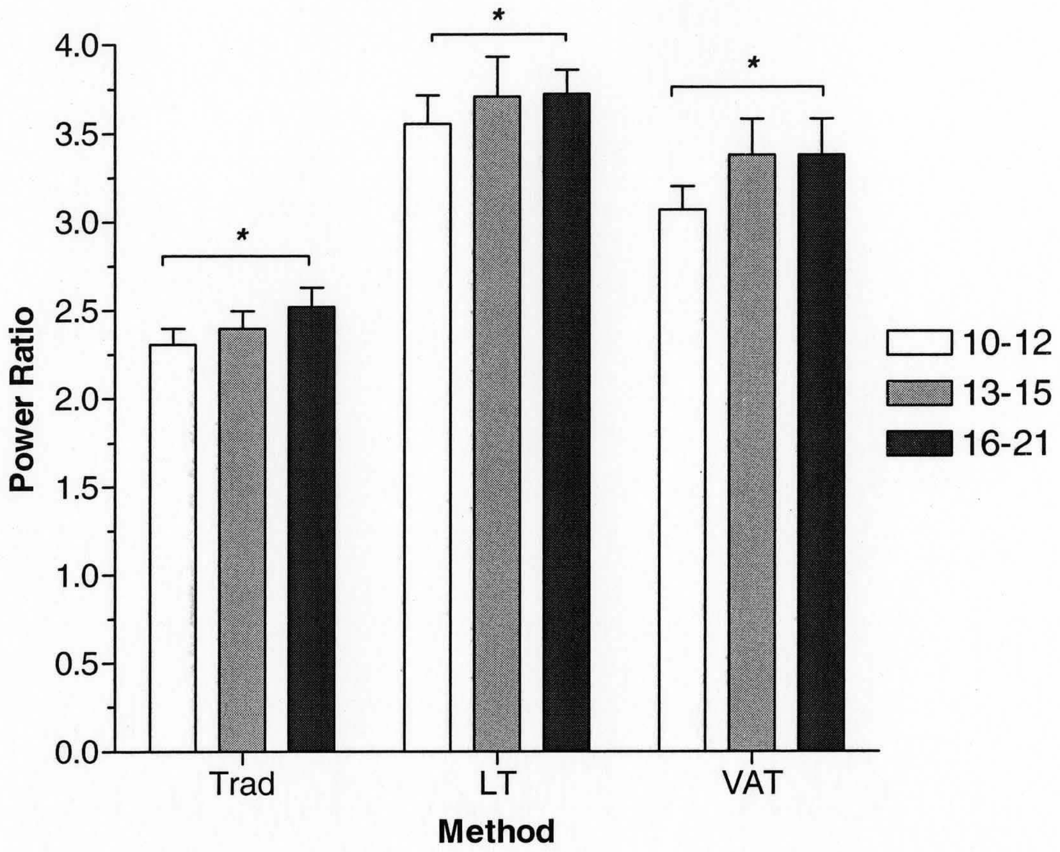

Figure 10: Age group comparisons between three power ratio approaches. *Denotes significance at P<0.05

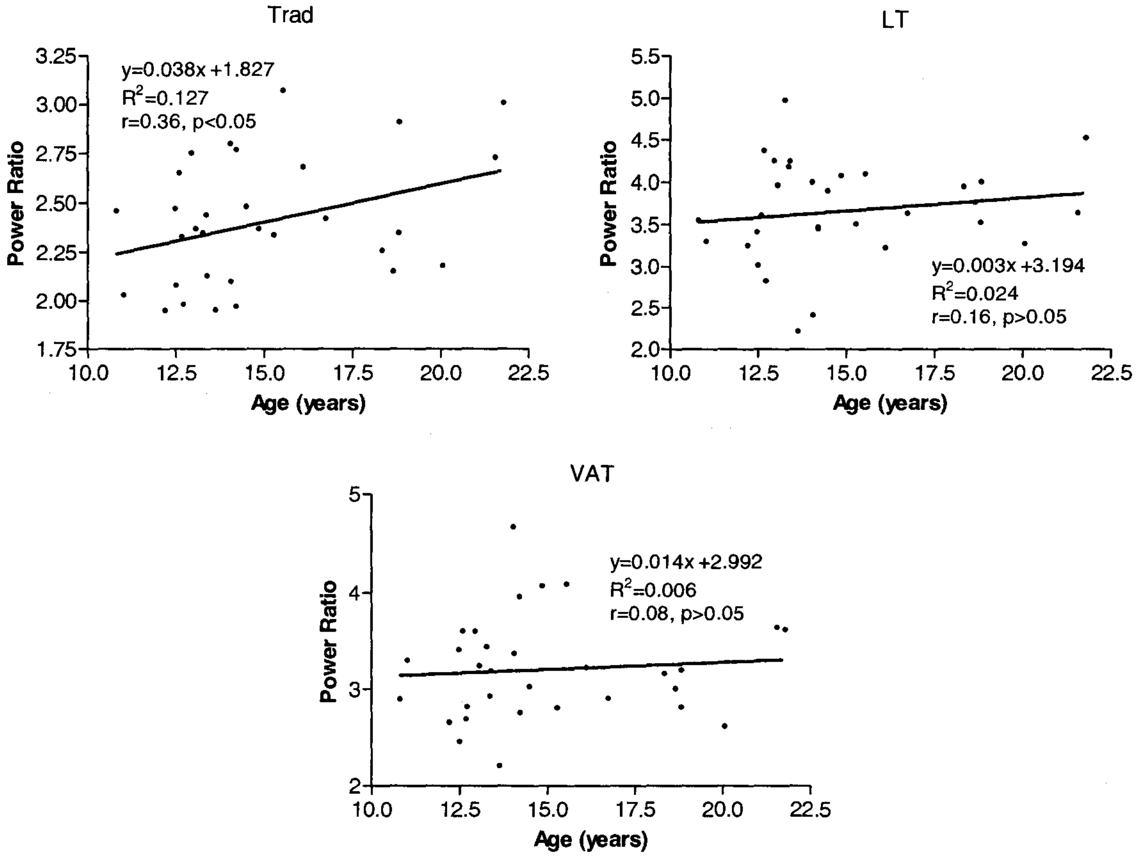

Figure 11: Age vs. Trad power ratio approach, Age vs. LT power ratio approach, Age vs. VAT power ratio approach.

Table 19: Correlations between power ratio approaches for age group 1. (n=10)

10 – 12 Years	Trad Ratio	LT Ratio	VAT Ratio
Trad Ratio	—	0.69*	0.71*
LT Ratio		—	0.36
VAT Ratio			—

*Denotes significance at P<0.05

Table 20: Correlations between power ratio approaches for age group 2. (n=12)

10 – 12 Years	Trad Ratio	LT Ratio	VAT Ratio
Trad Ratio	—	0.44	0.76*
LT Ratio		—	0.42
VAT Ratio			—

*Denotes significance at P<0.05

Table 21: Correlations between power ratio approaches for age group 3. (n=9)

10 – 12 Years	Trad Ratio	LT Ratio	VAT Ratio
Trad Ratio	—	0.51	0.77*
LT Ratio		—	0.58
VAT Ratio			—

*Denotes significance at P<0.05

Reliability

Table 22 summarizes the means, correlations and variability for the measures of anaerobic and aerobic power and derived ratios for test 1 and test 2 conditions. A significant correlation was found for the VAT power ratio from test 1 to test 2, whereas repeat measures for peak anaerobic power, peak aerobic power, VAT aerobic power, Trad power ratio and LT power ratio were positively but non-significantly correlated. The method error and CV were relatively small for peak anaerobic power, the VAT aerobic power and the VAT power ratio. The variability in repeat measures was somewhat higher for the traditional aerobic power, the LT aerobic power and the traditional and LT power ratios, than for respective VAT measures.

Table 22: Reliability of measures from Test 1 (n=6) to Test 2 (n=6). Measures of relative anaerobic power, relative peak aerobic power, relative LT aerobic power, relative VAT aerobic power, Trad power ratio, LT power ratio and VAT power ratio. Correlation, method error and coefficient of variation values for six subjects.

Variable	Test 1	Test 2	ICC	Method Error	CV
Peak Anaerobic Power (W/kg)	10.6±0.8	10.3±1.1	0.72	0.26	2.5%
Peak Aerobic Power (Trad) (W/kg)	4.4±0.4	4.5±0.4	0.52	0.48	10.7%
LT Aerobic Power (W/kg)	3.0±0.2	2.8±0.3	0.51	0.19	6.6%
VAT Aerobic Power (W/kg)	3.4±0.3	3.2±0.3	0.75	0.16	4.7%
Traditional Power Ratio	2.4±0.3	2.3±0.3	0.34	0.28	11.9%
LT Power Ratio	3.6±0.8	3.4±0.3	0.37	0.19	5.5%
VAT Power Ratio	3.1±0.4	3.2±0.3	0.95*	0.13	4.2%

Mean ± SD *Denotes significance at $P<0.05$

DISCUSSION

Numerous studies have been conducted examining the influence of growth on anaerobic power (Bar-Or, 1983; Blimkie et al., 1986; Blimkie et al., 1988; Falk & Bar-Or, 1993; Inbar & Bar-Or, 1986) as well the development of maximal aerobic power (Åstrand, 1952; Bar-Or, 1983; Krahenbuhl, 1985; Kemper et al., 1989; Mirwald & Bailey, 1986). Further, these measures have been described in relation to one another within the same individual using the anaerobic-to-aerobic power ratio (Blimkie et al., 1986; Falk & Bar-Or, 1993). However, the power ratio appears to be somewhat flawed as the traditional method of calculating the aerobic component in the denominator of the ratio is likely highly influenced by contributions from the anaerobic energy system. Therefore, the traditionally calculated ratio does not provide an accurate measurement of the metabolic index and ultimately may misrepresent the true age-related development of this ratio during the formative growth years. For this reason, aerobic power at the LT and VAT were determined in the current study to provide a truer measure of the denominator in the power ratio, as these breakpoints have been described to reflect the point at which there is a transition from reliance on aerobic sources of energy to anaerobic energy. As the mechanical aerobic power was measured in the current study at each of these breakpoints and inserted into the denominator of the power ratio, it is believed that each of these approaches will reflect a more accurate contribution of the aerobic component to the power ratio, and thus a more valid measure of the development of the anaerobic-aerobic energy ratio during growth, than currently used approaches.

One of the main findings from the current study was that the power ratios calculated using the LT and VAT approaches, in contrast to the traditional approach, did not display a significant increase with chronological age between pre-puberty and later adolescence. However, there was an age-related trend towards increasing values with increasing age, and when results were analyzed between discrete age groups, significant differences were found between the youngest and oldest group using the LT and VAT approaches. These trends help validate our new approaches, and test-retest correlations, although limited by sample size, demonstrate the reliability of these approaches, thus resulting in a new, more accurate and useful means of calculating the anaerobic-to-aerobic power ratio in children and adolescent hockey players.

Descriptive and Physical Characteristics

The descriptive and physical characteristics of the subjects in the current study fit the profile of young elite minor hockey players (Cunningham, 1979; Maingourd, Libert, Bach, Jullien, Tanguy & Freville, 1994; Montgomery, 1988; Rhodes, Mosher & Potts, 1985). The distribution of individual BMI's were all within the age-appropriate healthy weight percentile range, between the 50th and 75th percentiles (Malina, Bouchard & Bar-Or, 2004). When compared to normal active children and adolescents in the same age range, height and weight in the current study were slightly higher than some previous reports, most likely due to a greater amount of muscle mass development obtained from the subjects' hockey training (Doré, Martin, Ratel, Duché, Bedu, Van Praagh, 2005). On the contrary, muscle plus bone volume in the current study was slightly lower than previous reports with values of 4.3 L ± 1.5 in comparison to 4.77 L in normal active children and adolescents (Doré et al., 2005). As the current study used the same anthropometric techniques of estimating muscle mass, this difference may be explained by the larger number of subjects and greater variability in sports background among subjects studied by Doré et al. (2005). When compared to thigh muscle volume using MRI technology, the youngest age group in the current study demonstrated slightly higher values than that found by Welsman et al. (1997). Average muscle plus bone volumes for the youngest group aged 10 to 12 years in the current study were 3.2 L ± 0.7 which were higher than the 10 year old subjects in the study by Welsman et al. (1997) who had on average 2.39 L of thigh muscle volume. However, the subjects from Welsman et al. (1997) were slightly younger and untrained, and the anthropometric technique used in the current study also includes the bone volume, whereas using MRI, the bone is sectioned out, further accounting for our higher values.

In summary, subjects in the current study have similar anthropometric and physical characteristics to young hockey players in other studies, and therefore, the results from this study can be considered representative of young hockey players in general.

Anaerobic Measures

Several studies have used the WAnT to measure PP and MP in children and adolescents, and this test remains the most popular non-invasive means of assessing anaerobic characteristics in these populations (Bar-Or, 1983; Blimkie et al., 1986; Falk &

Bar-Or, 1993). The popular Wingate protocol was used in the current study for the purposes of obtaining peak mechanical anaerobic power for insertion into the numerator of the anaerobic-to-aerobic power ratio. In the current study only the peak power from the WAnT was used as the criterion measure of anaerobic power for inclusion in the numerator of the power ratio. Although there is likely some aerobic energy contribution to the generation of peak power even at 5-10 sec of this test, the contribution is likely relatively small, and this was accepted as an inevitable and unquantifiable methodological limitation of the current study. In agreement with previous reports, the results in the current study demonstrate that absolute and relative PP, as well as absolute MP increases with chronological age. These findings confirm the increase in anaerobic capabilities throughout development as seen in several other studies (Bar-Or, 1983; Blimkie et al., 1986; Inbar & Bar-Or, 1986; Falk & Bar-Or, 1993). Relative anaerobic values were expressed in relation to body weight and the average value of 10.3 W/kg in the current study is similar to and consistent with findings for similar age ranges in other reports (Bar-Or, 1983; Blimkie et al., 1986; Inbar & Bar-Or, 1986). However, in comparison to the longitudinal study of Falk and Bar-Or (1993), relative anaerobic values in the current study are somewhat lower. This may be due to fatigue associated with the shorter recovery time between the aerobic and anaerobic protocols in the current study. Subjects completed the WAnT approximately 10-15 minutes after the aerobic protocol in the current study, whereas in the study by Falk and Bar-Or (1993), subjects were allowed 30 minutes recovery between protocols, possibly contributing to their higher reported anaerobic power values.

The increase observed in peak anaerobic power with age during childhood and adolescence has been suggested to be partially due to increases in body size as well as muscle mass (Blimkie et al., 1988). Docherty and Gaul (1991) demonstrated a correlation of r=0.65 between weight and peak power in young boys. Higher correlations (r=0.92) between peak power obtained from a force velocity test and body weight were found in boys aged 11 to 19 in a study by Mercier, Mercier, Granier, Le Gallais and Préfaut (1992). In the current study a correlation of r=0.97 was found between body weight and peak anaerobic power for all subjects, demonstrating consistent findings with the literature.

With exercise that involves physically moving the body, such as on a treadmill, it is appropriate to relate measures to body mass. However, when exercise is performed on a cycle ergometer, it may be more appropriate to relate measures to thigh volume, as thigh muscle volume has been shown to be related to the production of power during a WAnT (Chia, Armstrong, Welsman & Winsley, 1997). This observation is confirmed in several studies, as peak and mean anaerobic power consistently correlate highly with thigh muscle mass in boys (Davies, Barnes & Godfrey, 1972; De Ste. Croix et al., 2001; Docherty & Gaul, 1991). As previously mentioned, the amount of estimated lower limb muscle mass in the current study is fairly similar to that found in children of the same age range using anthropometric and MRI techniques. Although MRI would be the preferred method of quantifying the amount of muscle in the lower limb, the anthropometric techniques according to Jones and Pearson (1969) used in the current study have been validated in children (Davies et al., 1972). When absolute anaerobic PP values and muscle plus bone volume were related in the current study, significant correlations were found (*r*=0.86), suggesting that an increase in lean tissue volume in the leg was associated with an increase in the amount of absolute power generated. Further, each of these measures were highly correlated with age, demonstrating that development of anaerobic power in children and adolescents is closely linked to concurrent development of regional muscle mass and likely strength (Bar-Or, 1983; Blimkie et al., 1986; Blimkie et al., 1988; Davies et al., 1972; Falk & Bar-Or, 1993).

The developmental aspects of mechanical anaerobic power were also examined using discrete age groups as a proxy for relative maturational status. Results demonstrated significant differences for absolute peak anaerobic power between each of the three age groups, with the oldest group having the highest values. Similarly, relative (per kg body weight) anaerobic power was significantly higher with successive age increases, with the highest values obtained again by the oldest group. These results further suggest an increased capability to generate anaerobic power with age and increasing maturity, which is consistent with the literature (Blimkie et al., 1986; Blimkie et al., 1988; Falk & Bar-Or, 1993).

Aerobic Measures

In agreement with previous reports of young hockey players, HRmax in the current study reached similar levels to those found by Maingourd et al. (1994), suggesting a near maximal effort for young subjects in assessment of their aerobic capacity. Similarly, peak heart rate values of the youngest group in the current study are comparable to those obtained on a cycle ergometer from the same age group in a study by Washington, van Gundy, Cohen, Sondheimer and Wolfe (1988). However, HRmax values are somewhat lower than those found by other investigators who used treadmill protocols and obtained average values of approximately 200 bpm (Armstrong et al., 1995; Rowland, 1997; Welsman et al., 1996). This discrepancy in maximal heart rate is not uncommon as peak values are known to be dependent on the testing modality (Rowland, 1996). Although the subjects in the current study were very fit, peak heart rate values were most likely lower compared to other findings due to the testing being performed on the cycle ergometer rather than the treadmill; the latter typically resulting in higher peak heart rates in children (Rowland, 1996). The RER has also been used to define a maximal effort in children as it reflects the ratio between the volume of $C0_2$ being produced compared to the volume of 0_2 being consumed. Findings from the current study were consistent with other reports in children and adolescents regardless of the modality of testing, and further suggest a maximal effort from the subjects (Armstrong et al., 1995; Rowland, Vanderburgh & Cunningham, 1997; Washington et al., 1988; Welsman et al., 1996).

The peak $\dot{V}0_2$ values observed for subjects in the present study are fairly similar to those reported in both longitudinal (Falk & Bar-Or, 1993; Kemper et al., 1989; Rowland, 1997) and cross-sectional studies (Armstrong, Welsman & Kirby, 1998; Bar-Or, 1983; Cunningham, 1979; Krahenbuhl et al., 1985; Maingourd et al., 1994; Washington et al., 1988; Welsman et al., 1996) of young children and adolescents. Compared to young elite hockey players, relative $\dot{V}0_2$ peak values are fairly consistent with other reports that utilized cycle ergometer (Maingourd et al., 1994) and treadmill testing (Cunningham et al., 1979). Relative values in the current study are slightly lower (51 ml · kg^{-1} · min^{-1}) in comparison to values found by Maingourd et al. (1994) (54 ml · kg^{-1} · min^{-1}). However, the current study tested a wider age range including young adults who perhaps had surpassed their peak $\dot{V}O_2$ values achieved in earlier years, therefore lowering the average values in this study. Similarly, Cunningham et al. (1979) demonstrated $\dot{V}O_2$ values of approximately 56 ml · kg^{-1} · min^{-1} in hockey players ranging in age from 8 to 16 years, although testing occurred on a running treadmill likely producing higher values. Welsman et al. (1996) tested untrained children and adolescents of the same age range as the current study on a treadmill and average relative values were similar to the current findings. Other longitudinal examinations show somewhat higher values than in the current study regardless of the modality of testing (Falk & Bar-Or, 1993; Kemper et al., 1989; Rowland, 1997).

Falk and Bar-Or (1993) examined physically active subjects longitudinally on a cycle ergometer, with age varying from 10.7 years at the onset of the study up to 17.6 years. Peak $\dot{V}O_2$ values obtained were somewhat higher than those found in the current study. Perhaps some subjects in the current study did not truly reach their $\dot{V}O_2$ peak whereas others exceeded expected values, as the standard deviation of $\dot{V}O_2$ peak values were fairly large (6.8, 9.4 and 5.2 ml/kg/min from the youngest to oldest groups respectively). This variation in individual response may perhaps explain why average values are slightly lower in the current study compared to those reported by Falk and Bar-Or (1993). Kemper et al., (1989) are also reported higher $\dot{V}O_2$ peak values for young athletes compared to the current study, however, subjects were tested on a treadmill, most likely explaining the discrepancy between their values and those in the present study (Rowland, 1996).

Based on these maximal exercise responses, it appears that the majority of subjects in this study provided a true exhaustive performance during the modified McMaster Cycle protocol. Comparisons of the traditional power ratio between the present study and the literature, therefore, are likely valid and not biased by different methodologies or subject motivation to perform maximal exhaustive exercise.

The significant age-related increase for absolute $\dot{V}0_2$ peak and the constant age-related relative $\dot{V}0_2$ peak values observed in the present study are similar to what has been observed by previous investigators (Blimkie et al., 1986; Falk & Bar-Or, 1993; Kemper et al., 1989; Krahenbuhl et al., 1985; Welsman et al., 1996). As would be expected, absolute $\dot{V}0_2$ peak increased with age with a correlation of r=0.77, largely reflecting age-related increases in body and lean tissue mass in our subjects. Welsman et al., (1996) examined children and adolescents in the same age range as the current study and found similar results with significant differences between age groups for absolute $\dot{V}0_2$ peak, whereas no significant differences were found for $\dot{V}0_2$ peak relative to body weight. Similarly, in an extensive review of aerobic power examining children and adolescents, Krahenbuhl et al., (1985) observed similar patterns from both absolute and relative measures reflecting growth in body size.

Mechanical Aerobic Power

Values of both absolute and relative mechanical aerobic power using the traditional method at the point when exercise could not be continued are in agreement with previous reports within similar age ranges (Blimkie et al., 1986; Falk & Bar-Or, 1993). The average absolute peak mechanical aerobic power (254.4 W) in the present study for all subjects closely matches values in 14 to 19 years-olds (258 W) from Blimkie et al., (1986) although they are somewhat higher than the 209.4 W reported by Falk and Bar-Or (1993) in their longitudinal study of 10.9 to 16.2 year-olds. Average values for relative peak mechanical aerobic power were slightly higher in the current study, compared to values from Falk and Bar-Or (1993). However, the subjects in the present study were older and therefore more capable of generating a greater maximal power output.

To the author's knowledge, there are no studies that have examined the mechanical aerobic power at the LT in children and only one study examining the power output at the VAT (Mahon, Gay & Stolen, 1998). However, a small number of investigators have examined mechanical power output at the LT and the ventilatory breakpoint in adult populations. Helel, Guezennec and Goubel (1987) examined adult elite cyclists and reported power outputs of 250 W and 275 W at the LT and VAT, respectively. In the current study, the average power output for all subjects at the LT was 168.5 W and 193.1 W at the VAT. It is not valid to compare results from the present study with those of Helel et al. (1987) due to differences in sport specialization and testing methodology. However, one similarity in the two studies is that the VAT occurred at a higher power output than at the LT. Mahon et al. (1998) examined the VAT of 11 year-old children using a cycle ergometer protocol and found that power output at the VAT was 55.8% of their peak power output. By comparison, in the present study, the youngest age group of 10 to 12 years achieved their VAT of 33% of their peak power, which is considerably lower than in the study of Mahon et al. (1998). The discrepancy between this finding and those of the previous study may be attributed to different exercise protocols and methods of break point detection and analysis. However, it is again difficult to compare studies with different protocols; as well, subjects in the current study were very fit hockey players capable of generating higher maximal power outputs than normal active children.

Furthermore, significant positive correlations with age were found for absolute peak mechanical aerobic power, as well as the mechanical aerobic power at both the LT and the VAT. Absolute peak mechanical aerobic power measured using the traditional approach was similar to that of previous reports demonstrating an increase with age throughout childhood and adolescence (Blimkie et al., 1986; Falk & Bar-Or, 1993). In the longitudinal examination of Falk and Bar-Or (1993), significant differences for absolute peak mechanical aerobic power were found with age, and between pubertal groups, with the late pubertal group demonstrating the highest values. Similar higher absolute values were obtained in the oldest group of boys in the study by Blimkie et al., (1986), consistent with results in the present study. On the contrary, when expressed relative to body weight in the present study, no significant correlations were found between age and any of the criterion mechanical aerobic power measures, reflecting a stable pattern of development from late childhood throughout adolescence. This is in agreement with previous reports that demonstrate no apparent change with age for the peak mechanical aerobic power measured using the traditional approach (Falk & Bar-Or, 1993).

Power Ratio

The anaerobic-to-aerobic power ratio has been used as a metabolic index to assess coordination of development of the anaerobic and aerobic energy systems. A higher power ratio indicates a relatively higher capability of the anaerobic system compared to the aerobic system and vice versa. The results obtained in the current study generally agree with previous reports from children and adolescents of a wide age range. The average traditional power ratio for all subjects in the present study (2.4 ± 0.3) is slightly lower than values obtained by others (Blimkie et al., 1986; Falk & Bar-Or, 1993). Blimkie et al. (1986) reported values that ranged between approximately 2.8 and 3.1 for boys aged 14 to 18 years, while values from Falk & Bar-Or (1993) ranged from approximately 2.4 in the pre-pubertal group up to 3.1 in the late pubertal group. In the latter study, subjects were active, but not competitive athletes, and therefore values may have been slightly higher as the subjects' anaerobic capabilities were superior to their aerobic ability. In the current study, however, very competitive hockey players were examined and the slightly lower observed power ratio potentially reflects their higher peak aerobic power resulting from intensive endurance training. In a similar study using peak anaerobic power from a force-velocity test in calculation of the power ratio, Falgairette et al. (1991) found an average power ratio value of 2.2 for active boys aged 6 to 15 years. This average is somewhat lower than values in the current study most likely because it includes values from younger aged children.

When calculating the power ratio using the LT and VAT approaches, values were found to be higher than those of the traditional method of calculation. This was to be expected as the mechanical aerobic power measures occur at sub-maximal levels, thus increasing the value of the power ratio. The LT approach yielded a higher power ratio compared to the VAT approach, which would be expected as the LT occurred on average at an aerobic power output of 25 W lower than the VAT. This may be explained by developmental changes in lactate buffering which would result in the LT occurring at a lower mechanical power output than the VAT. To the author's knowledge, there are no other studies that have examined the power ratio using either of these approaches and therefore these values cannot be compared to the literature.

The anaerobic-to-aerobic power ratio has been shown to increase with age in males until late adolescence where it begins to plateau (Blimkie et al., 1986). This has been suggested to reflect the increase in anaerobic power with age shown with children, while aerobic power remains somewhat constant. The results from the current study demonstrate an increase in the power ratio using the traditional approach which is in agreement with other findings (Blimkie et al., 1986; Falgairette et al., 1991; Falk & Bar-Or, 1993). Blimkie et al. (1986) compared measured power ratios in adolescents 14 to 18 years of age and compared these to estimated power ratios derived from population studies of aerobic and anaerobic power data from Cumming (1977) and Bar-Or (1983), respectively. These results demonstrated a plateau in the power ratio that became evident at the onset of adolescence and that persisted into early adulthood. In the current study, an age-related increase in the power ratio using the traditional approach was observed; however, there was no evidence of a plateau between the two older age groups. Using the LT and VAT approaches, very similar power ratio values were found for the middle and oldest age groups, perhaps reflecting a leveling or plateau as reported in previous studies. Falk and Bar-Or's (1993) longitudinal study confirmed the findings of Blimkie et al. (1986), as significant increases in the power ratio were evident between the pre-pubertal and mid-pubertal groups, with a leveling off of the ratio in the late-pubertal group.

Similar to the traditional approach, the two new approaches of calculating the power ratio demonstrated an increasing trend with age, although, no significant correlations with age were found for either of the new approaches. However, when results were examined between discrete age groups, there was a significant difference between the youngest and oldest group for all three approaches, suggesting that the new LT and VAT power ratio approaches demonstrated the same age-related patterns as the traditional method of calculation. Furthermore, moderate to strong correlations were found between our new methods and the traditional method for each age group, and in particular, significant correlations were found between the VAT and Trad approach for each age group. These results therefore provide a level of concurrent validity to our new approaches for assessing the power ratio, which are theoretically more accurate in representing the independent contributions of the anaerobic and aerobic energy systems in a growing population of active youth.

Figure 10 demonstrates the slight increases with age for each of the three power ratio approaches. Results from the middle age group demonstrate similar values to the oldest group. This higher than expected value for the middle group may be influenced by their more intensive training, as both aerobic and anaerobic components were elevated in this group. The traditional approach demonstrated a much more pronounced linear relationship with age compared to our new approaches (Figure 11). This difference may indicate that the traditional method fails to account for specific training influences on the breakpoints of aerobic and anaerobic performance and therefore the new approaches may more accurately reflect specificity of aerobic and anaerobic training effects than the traditional method.

The AT has been examined in the pediatric population. The reliability and reproducibility of the AT has been assessed and strong test-retest correlations varying from $r = 0.74$ to $r = 0.98$ have been found that are comparable to correlations in adults (Reybrouck, 1989). Therefore, we can assume that the age-related trends with our new approaches are valid and comparable to the traditional method of measurement, albeit perhaps providing a theoretically more justifiable basis of assessing the anaerobic-to-aerobic power ratio.

To assess the reliability of our new approaches, a second test was completed with six subjects, two from each age group, and intra-class correlations for the power ratio were found to be significant only for the VAT approach ($r = 0.95$). However, strong positive, but non-significant correlations were also found for the traditional power ratio and the LT power ratio approaches (Table 22). As only six subjects were re-tested, it was felt that the coefficient of variation (CV) derived using the method-error technique might provide a more meaningful measure of reliability than that based solely on intra-class correlation analysis. The CV was small for both the VAT power ratio (4.2%) and the LT power ratio (5.5%) suggesting that each method was reproducible and reliable. Conversely, a higher variation of approximately 12 % was found using the traditional approach to calculating the power ratio, perhaps demonstrating the subjective nature of measuring the aerobic component with this approach. Therefore, it appears that the VAT approach for calculating the power ratio is the most reliable in the present study and these findings provide partial validation for using this approach in examining age-related trends in the power ratio in future studies.

Given their better reliability, the finding in the present study suggest that the LT and VAT approaches of assessing the power ratio may be just as appropriate, if not better than the traditional method. As each of these new methods provide a more physiologically valid aerobic component to the denominator of the ratio (less influenced by anaerobic metabolism), the new approaches may present a more accurate means of examining the concurrent development and relative contributions of the anaerobic and aerobic energy systems within an individual during growth. The age-related trends observed with the new approaches are consistent with previous reports, further giving some validity to these newer methods of calculation. However, with the limited sample size for our reliability study, and the methodological limitations in the assessment of the

LT and VAT break points, further investigation is warranted.

A more thorough validation of the LT and VAT methods of calculating the power ratio should be pursued using ^{31}PNMR spectroscopy. This would allow for the assessment of muscle oxidative metabolism and intramuscular glycolytic activity in a safe, non-invasive procedure. The WAnT could be used to calculate the numerator of the power ratio, whereas a progressive exercise test to maximal effort using a treadle ergometer simultaneous with ^{31}PNMR spectroscopy could determine the anaerobic threshold at a more purely, cellular level, and the mechanical power at that break point could then be incorporated as the aerobic component of the power ratio. As the data obtained from the cellular level may be an even more purely aerobic, our approaches could be compared, and age-related developments in the power ratio could be examined. Furthermore, the LT and VAT approaches could be examined with athletes specializing in sports that require greater amounts of anaerobic energy such as sprinting, or endurance athletes who have a more highly developed aerobic system. Sport specific ratio profiles that reflect specialized training would lend further support to the utility and validity of these new measurement approaches. This may aid in furthering our understanding of the developmental coordination of the anaerobic and aerobic energy systems during growth and the influence of specialized training during childhood and adolescence.

The findings in the current study demonstrate that the VAT approach to calculating the power ratio is more reliable than the LT and Trad approaches; however, this must be interpreted with caution as our sample size was relatively small and the detection of the break points using the LT and VAT approaches is likely highly influenced by our testing protocol (the VAT being a continuous measure and the LT being a discontinuous measure) and our specific method of data analysis. Further, the VAT approach is less invasive than the LT approach as blood samples are not required and it is considered to be a valid and reliable measure in a pediatric population (Hebestreit, Staschen & Hebestreit, 2000). Lastly, the VAT approach does not require maximal exhaustive performance, which may be limiting for some children, especially non-athletes and children with chronic disease. Therefore, for the purposes of measuring the anaerobic-to-aerobic power ratio, notwithstanding the need for further validation, the VAT approach used in the present study is proposed as perhaps a more valid and reliable means of calculating the power ratio in children than the traditional method. The VAT approach provided the most reliable and valid measures of the power ratio in highly active hockey players in the current study and now needs further validation in other non-athlete and athlete groups and children with chronic pediatric diseases.

Limitations

There are several limitations in the current study. It would have been appropriate to measure body fat percentage, as this has been shown to have an influence on peak aerobic and anaerobic power (Rowland, 1996). In the current study, BMI was considered as a measurement of body fatness. However, the weakness associated with BMI as an index of fatness is that it does not consider the possibility that muscle tissue, rather than fat may contribute to a greater body weight. This may be particularly relevant with the hockey players examined as they would have a greater amount of muscle mass due to their training. Notwithstanding these considerations, all testing was conducted on cycle ergometers and body fat would be expected to have less influence on performance outcomes with this mode of testing than with weight-bearing modalities.

Another limitation of the current study is the sample size. A total of 31 subjects were recruited, approximately ten for each distinct age group. We may have observed more of a clear, distinct trend with age if the sample size had been larger. The sample size of the reliability data is very small with only six subjects returning, and therefore, it is difficult to be certain of findings as this is a very small retest sample size. Furthermore, the hockey players that were tested were among the elite for their age, particularly the middle group (13-15 years). The high fitness of this middle group may have skewed our findings, precluding detection of the expected age related increase in the power ratio. Moreover, the results of this study are not representative of the general population due to the high level of physical fitness of the participants; findings therefore can only be generalized to high-level hockey players.

Another limitation of the current study is the protocol used to assess the LT in the young children. The greater the number of successive samples, the more precise the detection of the lactate breakpoint. However, for practical and ethical considerations, lactate sampling at the lower initial levels of exercise intensity was not performed. However, after further analysis, it was felt that the LT would have been missed in some instances as these low level exercise intensities may have produced lactate values that may have been crucial in detecting the LT. This, as well as incorporating the resting value into the regression analysis, may be a reason why the LT values were low with respect to $\dot{V}0_2$ peak. Furthermore, samples were drawn from the fingertip and analyzed using a portable lactate analyzer. Although results from this device have been shown to correlate well with other assay methods (von Duvillard et al., 2005), and the analyzer was cleaned and calibrated regularly, in a couple of instances, questionable lactate values were obtained that could not be used for analysis. As well, it may have been more appropriate to measure the LT and VAT using two entirely different protocols, as the methodology for assessing these breakpoints may have contributed to confounding the results.

The cross-sectional study design used in this study also limited our ability to detect true developmental changes in the power ratio within the same individual as they grew. The best method for such a study would be to use a repeated measures longitudinal design where baseline measures could be obtained and the same tests conducted over a couple of years with the same individual. However, this type of study is expensive and labor intensive and very difficult to conduct as it requires participants to return several times to the laboratory over a span of a couple of years. Further, in the current study, we did not account for the amount of training the participants were doing and perhaps a physical activity questionnaire would have been beneficial to quantify the number of hours of specific hockey training, as this may have affected our results.

CONCLUSION

In summary, the main finding from the current study demonstrates that each of the two new approaches of calculating the anaerobic-to-aerobic power ratio illustrate an age-related trend, similar to that found using the traditional method of calculation. Although there were no significant correlations with age for the new approaches, significant differences were found between the youngest and oldest age groups suggesting an increase in the power ratio with age. Our new methods demonstrated moderate to strong positive correlations with the traditional approach, in particular the VAT ratio, providing a level of concurrent validity to our new approaches. As the new approaches provide a more reliable and accurate means of assessing this ratio in comparison to the old approach, they may provide a more useful method of demonstrating this ratio with age. The results also support the usefulness of employing the VAT as a non-invasive technique of determining the AT in young children and adolescents. The VAT approach to calculating the power ratio appears to be an accurate means of providing a reliable measure of calculating the power ratio within the limitations of the study. With minimal invasiveness compared to the LT approach, and a stronger physiological justification than the traditional approach for isolating the true aerobic contribution to this power ratio, the VAT needs to be further investigated as an alternative means of calculating the anaerobic to aerobic power ratio in children.

Reference List

1. **Armstrong N and Welsman JR**. Assessment and interpretation of aerobic fitness in children and adolescents. *Exerc Sport Sci Rev* 22: 435-476, 1994.

2. **Armstrong N, Kirby BJ, McManus AM and Welsman JR**. Aerobic fitness of prepubescent children. *Annals of Human Biology* 22: 427-441, 1995.

3. **Armstrong N, Welsman JR and Kirby BJ**. Peak oxygen uptake and maturation in 12-yr olds. *Med Sci Sports Exerc* 30: 165-169, 1998.

4. **Armstrong N and Welsman JR**. Development of aerobic fitness during childhood and adolescence. *Pediatr Exerc Sci* 12: 128-149, 2000.

5. **Armstrong N, Welsman JR and Chia M**. Short term power output in relation to growth and maturation. *Br Journal Sports Med* 35: 118-124, 2001.

6. **Åstrand PO**. Aerobic and anaerobic energy sources in exercise. *Med Sci Sports* 13: 22-37, 1981.

7. **Åstrand PO**. *Experimental studies of physical working capacity in relation to age and sex*. Copenhagen: Ejnar Munksgaard, 1952.

8.**Åstrand PO**. Exercise and sports for all: our biological heritage. In: *Future directions in exercise and sport science research XV-XXIII,* Champaign, IL: Human Kinetics, 1981.

9.**Bar-Or O**. *Pediatric Sports Medicine for the Practitioner: From Physiologic Principles to Clinical Applications*. New York: Springer-Verlag, 1983.

10. **Bar-Or O**. Pathophysiological factors which limit the exercise capacity of the sick child. *Med Sci Sports Exerc* 18: 276-282, 1986.

11. **Bar-Or O**. The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Med* 4: 381-394, 1987.

12. **Bar-Or O**. Noncardiopulmonary pediatric exercise tests. In: *Pediatric Laboratory Exercise Testing: Clinical Guidelines*, edited by Rowland TW. Champaign, IL: Human Kinetics, 1993, p. 165-185.

13. **Bar-Or, O., Dotan, R., Inbar, O., Rothstein, A, Karlsson, J and Tesch, P.** Anaerobic capacity and muscle fibre type distribution in man. *Int J Sports Med.* 1: 82-85, 1980

14. **Baron R**. Aerobic and anaerobic power characteristics of off-road cyclists. *Med Sci Sports Exerc* 33: 1387-1393, 2001.

15. **Beaver WL, Wasserman K and Whipp BJ**. Improved detection of lactate threshold during exercise using a log-log transformation. *J Appl Physiol* 59: 1936-1940, 1985.

16. **Beneke, R., Pollmann, C., Bleif, I., Leithäuser, R.M., Hütler, M.** How anaerobic is the Wingate test for humans? *Eur J Appl Phys* 87: 388-392, 2002.

17. **Blimkie CJ, Roche P and Bar-Or O**. Concept of anaerobic to aerobic power ratio in pediatric health and disease. In: *Children and Exercise XII,* Champaign, IL: Human Kinetics, 1986, p. 31-37.

18. **Blimkie CJR, Roache P, Hay JT and Bar-Or O**. Anaerobic power of arms in teenage boys and girls: relationship to lean tissue. *Eur J Appl Physiol* 57: 677-683, 1988.

19. **Brooks GA**. Anaerobic threshold: review of the concept and directions for future research – Directions. *Med Sci Sports Exerc* 17: 22-31, 1985.

20. **Carlson J and Naughton G**. Performance characteristics of children using various braking resistances on the wingate anaerobic test. *J Sports Med Phys Fitness* 34: 362-369, 1994.

21. **Chia M, Armstrong N, Welsman JR and Winsley RJ**. Wingate anaerobic test performance in relation to thigh muscle volume. *Children and exercise* 19: 297-300, 1997.

22. **Conconi F, Ferrari M, Ziglio PG, Droghetti P and Codeca L**. Determination of the anaerobic threshold by a noninvasive field test in runners. *J Appl Physiol* 52: 869-873, 1982.

23. **Cooper DM, Weiler-Ravell D, Whipp BJ and Wasserman K**. Aerobic parameters of exercise as a function of body size during growth in children. *J Appl Physiol* 56: 628-634, 1984.

24. **Cumming GR**. Exercise studies in clinical pediatric cardiology. In: *Frontiers of activity and child health.* Quebec, PQ: Pelican, 1977, p. 17-45.

25. **Cunningham DA, van Waterschoot BM, Paterson DH, Lefcoe M and Sangal SP**. Reliability and reproducibility of maximal oxygen uptake measurement in children. *Med Sci Sports* 9: 104-108, 1977.

26. **Cunningham DA**. Characteristics of the elite minor hockey player. *Can J Appl Sport Sci* 4: 123-125, 1979.

27. **Davies CT, Barnes C and Godfrey S**. Body composition and maximal exercise performance in children. *Hum Biol* 44: 195-214, 1972.

28. **Davis, JA.** Anaerobic threshold: review of the concept and directions for future research. *Med Sci Sports Exerc* 17: 6-21, 1985.

29. **De Ste Croix MBA, Armstrong N, Chia MYH, Welsman JR, Parsons G and Sharpe P**. Changes in short-term power output in 10-to 12-year-olds. *J Sports Sci* 19: 141-148, 2001.

30. **Docherty D and Gaul CA**. Relationship of body size, physique, and composition to physical performance in young boys and girls. *Int J Sports Med* 12: 525-532, 1991.

31. **Doré E, Bedu M, França NM and Van Praagh E**. Anaerobic cycling performance characteristics in prepubescent, adolescent and young adult females. *Eur J Appl Physiol* 84: 476-481, 2001.

32. **Doré E, Martin R, Ratel S, Duché P, Bedu M and Van Praagh E**. Gender Differences in Peak Muscle Performance During Growth. *Int J Sports Med* 26: 274-280, 2005.

33. **Eriksson BO, Karlsson J and Saltin B**. Muscle metabolites during exercise in pubertal boys. *Acta Paediatr Scand Suppl* 217: 154-157, 1971.

34. **Eriksson BO**. Muscle metabolism in children-A Review. *Acta Paediatr Scand Suppl* 283: 20-28, 1980.

35. **Eriksson O and Saltin B**. Muscle metabolism during exercise in boys aged 11 to 16 years compared to adults. *Acta Paediatr Belg* 28: 257-265, 1974.

36. **Falgairette G, Bedu M, Fellmann N, Van-Praagh E and Coudert J**. Bio-energetic profile in 144 boys aged from 6 to 15 years with special reference to sexual maturation. *Eur J Appl Physiol* 62: 151-156, 1991.

37. **Falk B and Bar-Or O**. Longitudinal changes in peak aerobic and anaerobic mechanical power of circumpubertal boys. *Pediatr Exerc Sci* 5: 318-331, 1993.

38. **Farrell PA, Wilmore JH, Coyle EF, Billing JE and Costill DL**. Plasma lactate accumulation and distance running performance. *Med Sci Sports* 11: 338-344, 1979.

39. **Gastin PB**. Energy system interaction and relative contribution during maximal exercise. *Sports Med* 31: 725-741, 2001.

40. **Gaul CA, Docherty D and Cicchini R**. Differences in anaerobic performance between boys and men. *Int J Sports Med* 16: 451-455, 1995.

41. **Gollnick PD, Armstrong RB, Saubert CW, Piehl K and Saltin B**. Enzyme activity and fiber composition in skeletal muscle of untrained and trained men. *J Appl Physiol* 33: 312-319, 1972.

42. **Green S and Dawson B**. Measurement of anaerobic capacities in humans. Definitions, limitations and unsolved problems. *Sports Med* 15: 312-327, 1993.

43. **Hansen H, Froberg K, Hyldebrandt N and Nielsen J**. A controlled study of eight months of physical training and reduction of blood pressure in children: the Odense schoolchild study. *BMJ* 303: 682-685, 1991.

44. **Hebestreit H, Meyer F, Heigenhauser GJF and Bar-Or O**. Plasma metabolites, volume and electrolytes following 30-s high-intensity exercise in boys and men. *Eur J Appl Physiol* 72: 563-569, 1996.

45. **Hebestreit H, Staschen B and Hebestreit A**. Ventilatory threshold: a useful method to determine aerobic fitness in children. *Med Sci Sports Exerc* 32: 1964-1969, 2000.

46. **Helal JN, Guezennec CY and Goubel F**. The aerobic-anaerobic transition: re-examination of the threshold concept including an electromyographic approach. *Eur J Appl Physiol* 56: 643-649, 1987.

47. **Inbar O and Bar-Or O**. The effects of intermittent warm-up on 7 to 9 year-old boys. *Eur J Appl Physiol* 34: 81-89, 1975.

48. **Inbar O and Bar-Or O**. Anaerobic characteristics in male children and adolescents. *Med Sci Sports Exerc* 18: 264-269, 1986.

49. **Jones PR and Pearson J**. Anthropometric determination of leg fat and muscle plus bone volumes in young male and female adults. *J Physiol* 204: 63P-66P, 1969.

50. **Kemper HC and Verschuur R**. Maximal aerobic power in 13-and 14-year-old teenagers in relation to biologic age. *Int J Sports Med* 2: 97-100, 1981.

51. **Kemper HCG, Verschuur R and de Mey L**. Longitudinal changes of aerobic fitness in youth ages 12 to 23. *Pediatr Exerc Sci* 1: 257-270, 1989.

52. **Krahenbuhl GS, Skinner JS and Kohrt WM**. Developmental aspects of maximal aerobic power in children. *Exerc Sport Sci Rev* 13: 503-538, 1985.

53. **Kuno S, Takahashi H, Fujimoto K, Akima H, Miyamura M, Nemoto I, Itai Y and Katsuta S**. Muscle metabolism during exercise using phosphorus-^{31} nuclear magnetic resonance spectroscopy in adolescents. *Eur J Appl Physiol* 70: 301-304, 1995.

54. **MacDougall JD, Wenger HA and Green HJ**. *Physiological testing of the high-performance athlete.* (pp. 107 – 173) Champaign, IL: Human Kinetics , 1991.

55. **Macek M and Vavra J**. The adjustment of oxygen uptake at the onset of exercise: a comparison between prepubertal boys and young adults. *Int J Sports Med* 1: 70-72, 1980.

56. **Mahon AD, Gay JA and Stolen KQ**. Differentiated ratings of perceived exertion at ventilatory threshold in children and adults. *Eur J Appl Physiol Occup Physiol* 78: 115-120, 1998.

57. **Maingourd Y, Libert JP, Bach V, Jullien H, Tanguy C and Freville M**. Aerobic capacity of competitive ice hockey players 10-15 years old. *Jpn J Physiol* 44: 255-270, 1994.

58. **Malina, R, Bouchard, C and Bar-Or, O.** *Growth, Maturation, and Physical Activity* (2nd edition). Champaign, IL: Human Kinetics, 2004.

59. **Margaria R, Aghemo P and Rovelli E**. Measurement of muscular power (anaerobic) in man. *J Appl Physiol* 21: 1662-1664, 1966.

60. **McArdle WD, Katch FI and Katch VL**. *Exercise Physiology: Energy, Nutrition. & Human Performance* (5th ed) (pp. 108 – 290) Boston: Lippincott Williams & Wilkins, 2001.

61. **MedbØ JI and Tabata I**. Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *J Appl Physiol* 67: 1881-1886, 1989.

62. **Mercier B, Mercier J, Granier P, Le Gallais D and Préfaut C**. Maximal anaerobic power: relationship to anthropometric characteristics during growth. *Int J Sports Med* 13: 21-26, 1992.

63. **Mercier B, Granier P, Mercier J, Trouquet J and PrΘfaut C**. Anaerobic and aerobic components during arm-crank exercise in sprint and middle-distance swimmers. *Eur J Appl Physiol* 66: 461-466, 1993.

64. **Mirwald RL and Bailey DA**. *Maximal Aerobic Power: A Longitudinal Analysis.* London, Ontario: Sports Dynamics, 1986.

65. **Mocellin R, Heusgen M and Gildein HP**. Anaerobic threshold and maximal steady-state blood lactate in prepubertal boys. *Eur J Appl Physiol Occup Physiol* 62: 56-60, 1991.

66. **Montgomery DL**. Physiology of ice hockey. *Sports Med* 5: 99-126, 1988.

67. **Naughton G, Carlson J and Fairweather I**. Determining the variability of performance on Wingate anaerobic tests in children aged 6-12 years. *Int J Sports Med* 13: 512-517, 1992.

68. **Ohuchi H, Nakajima T, Kawade M, Matsuda M and Kamiya T**. Measurement and validity of the ventilatory threshold in patients with congenital heart disease. *Pediatr Cardiol* 17: 7-14, 1996.

69. **Paterson DH, Cunningham DA and Donner A**. The effect of different treadmill speeds on the variability of $\dot{V}0_2$ in children. *Eur J Appl Physiol* 47: 113-122, 1981.

70. **Paterson DH, Cunningham DA and Bumstead LA**. Recovery O_2 and blood lactic acid: longitudinal analysis in boys aged 11 to 15 years. *Eur J Appl Physiol* 55: 93-99, 1986.

71. **Reybrouck T, Ghesquiere J, Cattaert A, Fagard R and Amery A**. Ventilatory thresholds during short-and long-term exercise. *J Appl Physiol* 55: 1694-1700, 1983.

72. **Reybrouck T, Weymans M, Stijns H, Knops J and Van der HL**. Ventilatory anaerobic threshold in healthy children. Age and sex differences. *Eur J Appl Physiol Occup Physiol* 54: 278-284, 1985.

73. **Reybrouck T**. The Use of the Anaerobic Threshold in Pediatric Exercise Testing. In: *Advances in Pediatric Sports Sciences*, edited by Bar-Or. 1989, p. 131-149.

74. **Rhodes EC, Mosher RC and Potts JE**. Anaerobic capacity of elite pre-pubertal ice-hockey players. *Med Sci Sport Exer* 17: S265, 1985.

75. **Rivera-Brown AM, Alvarez M, Rodriguez-Santana JR and Benetti PJ**. Anaerobic Power and Achievement of VO2 Plateau in Pre-Pubertal Boys. *Int J Sports Med* 22: 111-115, 2001.

76. **Rowland T, Vanderburgh P and Cunningham L**. Body size and the growth of maximal aerobic power in children: a longitudinal analysis. *Pediatr Exerc Sci* 9: 262-274, 1997.

77. **Rowland TW**. Oxygen uptake and endurance fitness in children: a developmental perspective. *Pediatr Exerc Sci* 1: 313-328, 1989.

78. **Rowland TW**. Aerobic exercise testing protocols. In: *Pediatric Laboratory Exercise Testing: Clinical Guidelines*. Champaign, IL: Human Kinetics, 1993, p. 19-42.

79. **Rowland TW**. *Developmental exercise physiology*. Champaign, IL: Human Kinetics, 1996.

80. **Rowland TW**. The Development of Aerobic Fitness. In: *Children and Exercise XIX*. Champaign, IL, Human Kinetics, 1997, p. 179-190.

81. **Rowland TW**. *Children's Exercise Physiology*. Champaign, IL: Human Kinetics, 2005.

82. **Van Praagh E**. Developmental aspects of anaerobic function. In: *Children and Exercise XIX*. Champaign, IL, Human Kinetics, 1997, p. 267-290.

83. **Van Praagh E and Doré E**. Short-term muscle power during growth and maturation. *Sports Med* 32: 701-728, 2002.

84. **von Duvillard SPF, Pokan RF, Hofmann P, Wonisch M, Smekal G, Alkhatib A, Beneke RF and Leithauser R**. Comparing Blood Lactate Values Of Three Different Handheld Lactate Analyzers To YSI 1500 Lactate Analyzer: 154 Board# 61 9: 30 AM-11: 00 AM. *Med Sci Sports Exerc* 37: S25, 2005.

85. **Washington RL, van Gundy JC, Cohen C, Sondheimer HM and Wolfe RR**. Normal aerobic and anaerobic exercise data for North American school-age children. *J Pediatr* 112: 223-233, 1988.

86. **Washington RL**. Anaerobic threshold in children. *Pediatr Exer Sci* 1: 244-256, 1989.

87. **Wasserman K and McIlroy MB**. Detecting the threshold of anaerobic metabolism. *Am J Cardiol* 14: 844-852, 1964.

88. **Wasserman K, Van Kessel AL and Burton GG**. Interaction of physiological mechanisms during exercise. *J Appl Physiol* 22: 71-85, 1967.

89. **Welsman JR, Armstrong N, Nevill AM, Winter EM and Kirby BJ**. Scaling peak $\dot{V}0_2$for differences in body size. *Med Sci Sports Exerc* 28: 259-265, 1996.

90. **Welsman JR, Armstrong N, Kirby BJ, Winsley RJ, Parsons G and Sharpe P**. Exercise performance and magnetic resonance imaging-determined thigh muscle volume in children. *Eur J Appl Physiol* 76: 92-97, 1997.

91. **Williams CA**. Children's and adolescents' anaerobic performance during cycle ergometry. *Sports Med* 24: 227-240, 1997.

92. **Williams JR and Armstrong N** . The influence of age and sexual maturation on children's blood lactate responses to exercise. *Pediatr Exerc Sci* 3: 111-120, 1991.

93. **Williams JR, Armstrong N and Kirby BJ**. The influence of the site of sampling and assay medium upon the measurement and interpretation of blood lactate responses to exercise. *J Sports Sci* 10: 95-107, 1992.

94. **Yamamoto M and Kanehisa H**. Dynamics of anaerobic and aerobic energy supplies during sustained high intensity exercise on cycle ergometer. *European J Appl Physiol* 71: 320-325, 1995.

95. **Zanconato S, Buchthal S, Barstow TJ and Cooper DM**. ^{31}P-magnetic resonance spectroscopy of leg muscle metabolism during exercise in children and adults. *J Appl Physiol* 74: 2214-2218, 1993.

Appendix A – Children's Medical Questionnaire

McMaster
University

Department of Kinesiology

1280 Main Street West
Phone 905.525.9140
Hamilton, Ontario, Canada
Fax 905.523.6011
L8S 4K1
http://kinlabserver.mcmaster.ca

DEPARTMENT OF KINESIOLOGY - MCMASTER UNIVERSITY
Medical Questionnaire for Participation in Scientific Research

Name of the child: ____

Date of Birth: ____ **(mm/day/yr)**

Address: ____

City: ___________________________ **Postal Code:** ___________________

Phone number: _____________________________

HEALTH HISTORY

*** Has your child ever had or are they experiencing any of the following?**

	YES	NO	If YES, please describe
Asthma			
Dizziness			
Muscle/Joint Pain			
Poor Motor Skills			
Broken Bones			
Epilepsy			
Constipation			
Digestion Difficulties			
Excessive Thirst			
Frequent Urination (night)			
Heart Disease			
Thyroid Disease			
Poor Vision			
Poor Hearing			
Skin Infections			
Contagious Diseases			
EXERCISE COMPLAINTS			
	YES	NO	If YES, please describe
Shortness of Breath			
Coughing			
Chest Pain			
Fatigue			
Dizziness			

Weakness			
Muscle/Joint Pain			
Specific Physical Limitations			

III. Hospitalization:
Date: ____________________
Reason: ____

IV. Medications
Type: __________________________________
Frequency of use: ____

Has your physician ever suggested that your child be restricted from physical activity? YES / NO

Do you know of any medical reasons that would prevent your child from participating in physical activity? ____

How long has your child maintained his current weight? _________________________

Parent/Guardian Statement: I have read and understand the Medical Questionnaire for my child's participation in Scientific Research, as administered by McMaster University's Department of Kinesiology. I have freely filled out the document to the best of my knowledge, and I have sought medical advice where appropriate to determine my child's risk for participation in scientific research.

Participant's Name: _______________________
Parent/Guardian Signature: _______________________ **Date:** ____________

Thank-you for your cooperation.

Appendix B – Participant Medical Questionnaire

McMaster
University

Department of Kinesiology
1280 Main Street West Phone 905.525.9140
Hamilton, Ontario, Canada Fax 905.523.6011
L8S 4K1
http://kinlabserver.mcmaster.ca

DEPARTMENT OF KINESIOLOGY - MCMASTER UNIVERSITY
Medical Questionnaire for Participation in Scientific Research

You are being invited to participate in a research study being conducted by the Department of Kinesiology. Prior to taking part in a laboratory session, all participants are required to fill out a medical questionnaire. This procedure is necessary for the safety of participants, because it screens for conditions that may place a person at risk if they choose to participate in an experiment.

Please indicate your selection by checking the boxes that most accurately describe yourself, and sign and date the bottom of the form on the lines provided. If you have any uncertainty regarding whether a condition might put yourself at risk when participating in an experiment, please consult the advice of your family physician prior to signing and submitting this questionnaire. A statement of the details of the procedure and its inherent risks can be provided to better inform your physician.

Note that this questionnaire will remain on record with the Department of Kinesiology, and will be kept in the strictest confidence.

	YES	NO
Have you had or are you at risk for a heart attack?	☐	☐
Have you had or are you at risk for a stroke?	☐	☐
Have you had or are you at risk for a seizure?	☐	☐
Do you have a history of fainting?	☐	☐
Have you recently sustained any injuries? - ex. fracture, muscle tear, sprain, concussion, etc. - please list: ______________________________ ______________________________	☐	☐
Have you recently undergone any medical procedures? - orthopaedic surgery, knee surgery, hernia repair, etc. - please list: ______________________________ ______________________________	☐	☐

	YES	NO
Do you have any allergies? - ex. to electrode gel, latex, pain medication, etc. - please list: ______________________________ ______________________________	☐	☐
Are you taking any medication that would preclude participation? - ex. to blood pressure, seizures, diabetes, etc. - please list: ______________________________ ______________________________	☐	☐

Please list and describe any other conditions that may put yourself at risk in the space below:

____

____

____

Emergency Contact Information: please provide the contact information for two people who may be contacted in the event of an emergency.

Contact Name:	______________	**Contact Name:**	______________
Relationship to Signee:	______________	**Relationship to Signee:**	______________
Contact Number Home:	______________	**Contact Number Home:**	______________
Contact Number Work:	______________	**Contact Number Work:**	______________

Participant's Statement: I have read and understand the *Medical Questionnaire for Participation in Scientific Research*, as administered by McMaster University's Department of Kinesiology. I have freely filled out the document to the best of my knowledge, and I have sought medical advice where appropriate to determine my risk for participation in scientific research.

Participant's Name: ________________________

Participant's Signature: ________________________ **Date:** ______________

Thank-you for your cooperation.

Appendix C – Parent/Guardian Consent Form

McMaster
University

INFORMATION & CONSENT TO PARTICIPATE IN RESEARCH

AGE RELATED CHANGES IN THE ANAEROBIC-TO-AEROBIC POWER RATIO: A COMPARISON OF TWO APPROACHES

You are being invited to permit your son to participate in a research study being conducted by the investigators listed below. Prior to your child's participation in this study you are asked to read this form, which outlines the purpose of the study and the testing procedures. Unless otherwise stated, all testing and experimental procedures will be conducted in the Exercise Physiology Laboratory, Rm. AB101, the Ivor Wynne Centre, McMaster University.

Principal Investigator:	Dr. Cameron Joe Blimkie Department of Kinesiology, McMaster University Hamilton, Ontario, Canada **(905) 525-9140 ext. 24702**
Student / Co-Investigator	Trevor Allin M.Sc Candidate Department of Kinesiology, McMaster University Hamilton, Ontario, Canada **(905) 525-9140 ext. 27384**

Your child has indicated an interest in being, and qualifies as a participant in this study, as he meets the age requirement and is free from any chronic or acute disease/illness that might negatively impact on his general physical activity levels or his ability to perform the proposed exercise testing. In order to decide whether or not you want your child to be a part of this research study, you should understand what is involved and the potential risks and benefits. This form provides detailed information about the proposed research, and once you understand the study, you will be asked to sign this form as the parent/guardian of the child who is participating. Please take your time to make your decision.

Purpose of the Study

We wish to investigate the contributions and independence of the two major systems that contribute energy during exercise in growing children and adolescents; the one system known as the aerobic metabolic pathway provides energy for relatively long bouts of activity like endurance running, whereas the other system known as the anaerobic metabolic pathway provides energy for short, intense types of activity such as sprinting. Comparisons will be made of the capacity and efficiency of these two energy systems within the same individual. We are hoping that through a new testing approach, we will be able to develop a more accurate means of comparing relative deficiencies in one system verses the other so we can develop activity programs to improve the capacity of the underdeveloped system. This study will help us to understand better the development of the energy systems in growing children and adolescents, and perhaps provide a better means of evaluating training needs for the enhancement of these systems in young athletes.

Procedures involved in the Research

Your child will be asked to come in to the lab at McMaster University once for approximately 2 hours to complete two separate tests. One 20 – 30 minute test on a cycle ergometer and one 30 second test on a different bicycle. Before starting testing, height and weight, as well as skinfold measurements will be taken, the latter to help estimate leg muscle volume. Skinfold measurements will involve the investigator using a special device to pinch fat at four sites on the body.

The first test procedure is known as a modified McMaster All-Out Cycle test, using a special cycle ergometer. This will be the longer of the two tests, lasting approximately 20 – 30. During the test, your child will be asked to cycle at a particular tempo while the instructor increases the resistance or load on the cycle every couple of minutes. Six rest periods of one minute duration will be given during the test, at which time blood will be drawn from a fingertip prick to measure blood lactate concentration. Furthermore, throughout the test, your child will be asked to breathe into a mouthpiece that will assess the amount of oxygen being consumed during the exercise. The test will conclude when your son is no longer able to sustain a pedal rate of between 45-50 rpm.

The second test is known as the Wingate Anaerobic Test, that measures power generated by the leg muscles during all out exercise. This is a 30 s sprint on a cycle against a specific resistance according to your child's body weight. The test will involve a brief warm-up, consisting of four, 5s sprints that will occur before the test. This will be followed by 3 minutes of rest, and then performance of the 30 s test. A brief 2-3 min cool down will conclude the test.

Potential Harms, Risks or Discomforts

Every effort will be made to conduct the exercise test in such a way as to minimize any discomfort or risks. However, your child may feel a slight discomfort in their muscles during each of the tests, similar to the burning feeling felt in the muscles when competing hard in any sport. This discomfort will go away within a few minutes. Some other risks associated with each test may include light-headedness, chest discomfort, leg cramps and in the rarest of instances (extremely low and improbable risk) heart attacks. Each of the tests will be somewhat tiring and therefore your child may feel like simply relaxing for the rest of the day. There may also be some discomfort from wearing a mouthpiece during the first test, but this is quite tolerable and is usually not a problem with children during this test. Finally, the fingertip prick to measure lactate concentration may sting for a second or so, but no longer than this, and there will be minimal blood loss.

Potential Benefits

As a participant in the study, your child will acquire an understanding of the state of their level of fitness. Furthermore, you will both gain some knowledge about the energy systems (aerobic and anaerobic) with regards to hockey, which may be of value to you and your child. The information may also be valuable if your child is training for hockey and wishes to know which aspect they need to improve, be it the short, intense performance (anaerobic pathways) or the longer duration performance capacities (endurance pathways). Your child's participation will also advance the understanding within the scientific community of the development of the aerobic and anaerobic energy systems and how they interact in growing children and adolescents and will hopefully help us to further understand any age differences.

Confidentiality

All of the data from the study will be kept confidential and stored in offices and on computers that only the investigators have access to. The results of the study may be published in a scientific journal, however, no reference of you or your child's name will be made public. At the end of the study, if you are interested, you will be provided with your child's results as well as those of the group, once the analysis is complete.

Participation and Withdrawal

It is your choice whether or not you would like your son to participate in this study and if they do volunteer and later wish to withdraw from the study, there will be no consequences of any kind. As a participant, you may also request the removal of your child's data from the study. If circumstances arise which warrant your child to be removed from the study, the investigators reserve the right to request this.

Rights of Research Participants

As a parent/guardian, you may withdraw your consent and discontinue your child's participation at any point during the study. As a participant your child is not waiving any legal claims, right or remedies by participating in this research study. This study has been reviewed by and has received ethical clearance from the McMaster University

Research Ethics Board (MREB). If you have concerns or questions about your child's rights as a participant or about the way the study is conducted, you may contact:

Hamilton Health Sciences Patient Relations Specialist
Telephone: (905) 521-2100 ext. 75240

INFORMATION

If you have any further questions or concerns about the study or participation, please contact Trevor Allin at (905) 525-9140 x 27384, allintg@mcmaster.ca, or Dr. Blimkie at (905) 525-9140 x 24702.

I HAVE READ AND UNDERSTOOD THE INFORMATION PROVIDED FOR THIS STUDY AS DESCRIBED HEREIN. MY QUESTIONS HAVE BEEN ANSWERED TO MY SATISFACTION ABOUT MY CHILD'S INVOLVEMENT IN THE STUDY. I UNDERSTAND THAT I MAY WITHDRAW MY CHILD FROM THE STUDY AT ANY TIME, IF I CHOOSE TO DO SO, AND I AGREE TO PERMIT MY SON/DAUGHTER TO PARTICIPATE IN THIS STUDY. I HAVE RECEIVED A SIGNED COPY OF THIS FORM.

Name of Participant	Signature of Participant	Date
Name of Parent/Guardian	Signature of Parent/Guardian	Date

INVESTIGATOR

In my opinion, the parent/guardian of the participant has voluntarily and knowingly given informed consent and possesses the legal capacity to give informed consent and participate in this research study.

Signature of Researcher	Date

Appendix D – Children's Assent Form

McMaster
University

INFORMATION & ASSENT TO PARTICIPATE IN RESEARCH

AGE RELATED CHANGES IN THE ANAEROBIC-TO-AEROBIC POWER RATIO: A COMPARISON OF TWO APPROACHES

I am being invited to be part of a research study. It is up to me if I want to be in this study. No one will make me be part of the study. Even if I agree now to be part of the study, I can change my mind later. No one will be mad at me if I choose not to be part of this study.

Who Is Doing This Study?

Dr. Joe Blimkie is the principal investigator for the study and **Trevor Allin,** a Master's student in the Department of Kinesiology at McMaster University is the Student that will be conducting the study. They will answer any questions I have about the study. I can call Trevor at **905-525-9140 x27384**, if I am having any problems or if there is an emergency and I cannot talk to my parents.

Why Are We Doing This Study?

This study is trying to find out the best way to compare the relationship between the two major systems in your body that produce energy during exercise. The main goal of this study is to come up with the best way to identify if one of these systems is more developed than the other in children, so that exercise programs may be recommended to improve the weaker system.

What Will Happen in This Study?

If I agree to be in this study, I will go to a laboratory at McMaster University once lasting about 2 Hours. I will complete two exercise tests that will be exhausting, similar to being tired after playing hockey or running in track and field. During my visit, I will be weighed and my height will be taken and I will have the width of my leg measured with a tape measure. I will also have my skin squeezed (doesn't hurt) with a small testing device which will test the amount of fat on my body.

Test 1: For the first exercise test, I will be seated on a bicycle and asked to pedal at a certain speed while the pedaling becomes harder and harder, similar to biking up a big hill. I will be on the bike for around 20-30 minute. I will have something that looks like a helmet on my head which is attached to a mouthpiece that will be in my mouth during the entire test. Also, my finger will be pricked a total of seven (7) times with a tiny needle and a little bit of blood will be taken to measure the lactate concentration that is in my blood during exercise. Once I am no longer able to pedal at the speed I am told to, the test will be finished and one more sample of blood will be taken from my finger one (1) minute after I am finished the test. I will feel very tired and short of breath immediately after this test, but I will be fully recovered in 5-10 minutes.

Test 2: The second test will be on a different bicycle and will measure how powerful my muscles are. I will be on the bike for a total of 8 minutes warming up and cooling down, but the test itself will only last 30 seconds. The test will again feel like I am pedaling up a very big hill. My legs may feel very warm and weak immediately after this test, but I will be fully recovered within 5-10 minutes.

Can Anything Bad Happen to Me?

Sometimes, hard exercise makes people feel a little light-headed or sick to the stomach, but this does not happen to everybody. I may also feel some soreness in my muscles once I've finished, which is similar to the feeling I get after competing hard in hockey or any other sports that I play, or when I run around all recess. I know that this discomfort is only temporary and it will go away after a few minutes. I am aware that once I have completed the tests, I may feel like resting for the remainder of the day by the television and going to bed early because I will most likely be tired. It is possible that the mouthpiece I have to wear during the first test may be uncomfortable in my mouth, but it will not cause any pain. As well, I know that the fingertip prick in order to get a sample of my blood will sting for a second or two, but it will not be very painful and I can put a band-aid on it if it won't stop bleeding.

What Should I Do If I Am Not Feeling Well?

If during any of the two tests, I feel like I may be sick or light-headed, I will tell one of the testers by saying how I am feeling, or by waving my hands to get their attention. I know that the people conducting the study are aware of signs and symptoms that will show if I am not feeling very good. If there is any other problem, the investigators will know the proper safety procedures in order to make sure that I will be all right.

Who Will Know I Am in the Study?

Only my parents and people who are involved in the study will know I am in it. When the study is finished, the researchers will write a report about what was learned. This report will not say my name or that I was in the study. My parents and I do not have to tell anyone I am in the study if we don't want to.

When Do I Have To Decide?

I have as much time as I want to decide to be part of the study. I have also been asked to discuss my decision with my parents.

IF YOU WANT TO BE IN THE STUDY, SIGN YOUR NAME ON THE LINE BELOW. I HAVE RECEIVED A SIGNED COPY OF THIS FORM.

Child's name, printed:

____

Date: __________________________

Signature of the Professor/Student: __________________________

Date: __________________________

Appendix E – Participant Consent Form

McMaster
University

INFORMATION & CONSENT TO PARTICIPATE IN RESEARCH

AGE RELATED CHANGES IN THE ANAEROBIC-TO-AEROBIC POWER RATIO: A COMPARISON OF TWO APPROACHES

You are being invited to participate in a research study being conducted by the investigators listed below. Prior to your participation in this study you are asked to read this form, which outlines the purpose of the study and the testing procedures. Unless otherwise stated, all testing and experimental procedures will be conducted in the Exercise Physiology Laboratory, Rm. **AB101**, the Ivor Wynne Centre, McMaster University.

Principal Investigator:
Dr. Cameron Joe Blimkie
Department of Kinesiology, McMaster University
Hamilton, Ontario, Canada
(905) 525-9140 ext. 24702

Student / Co-Investigator
Trevor Allin M.Sc Candidate
Department of Kinesiology, McMaster University
Hamilton, Ontario, Canada
(905) 525-9140 ext. 27384

As a hockey player, you have indicated an interest, and qualify to be a participant in this study as you meet the age requirement and are free from any chronic or acute disease/illness that might negatively impact on your general physical activity levels or your ability to perform the proposed exercise testing. In order to decide whether or not you want to be a part of this research study, you should understand what is involved and the potential risks and benefits. This form provides detailed information about the proposed research, and once you understand the study, you will be asked to sign this form to indicate that you are interested in being a subject. Please take your time to make your decision.

Purpose of the Study

We wish to investigate the contributions and independence of the two major systems that contribute energy during exercise in growing children and adolescents; the one system known as the aerobic metabolic pathway provides energy for relatively long bouts of activity like endurance running, whereas the other system known as the anaerobic metabolic pathway provides energy for short, intense types of activity such as sprinting. Comparisons will be made of the capacity and efficiency of these two energy systems within the same individual. We are hoping that through a new testing approach, we will be able to develop a more accurate means of comparing relative deficiencies in one system verses the other so we can develop activity programs to improve the capacity of the underdeveloped system. This study will help us to understand better the development of the energy systems in growing children and adolescents, and perhaps provide a better means of evaluating training needs for the enhancement of these systems in young athletes, in particular, hockey players.

Procedures involved in the Research

You will be asked to come in to the lab at McMaster University once for approximately 1 hour to complete two separate tests. One 20-30 minute test on a cycle ergometer and one 30 second test on a different bicycle will be completed. Before starting testing, height and weight, as well as skinfold measurements will be taken, the latter to help estimate leg muscle volume. Skinfold measurements will involve the investigator using a special device to pinch fat at several sites on the body.

The first procedure is known as a modified McMaster All-Out Cycle test, using a special cycle ergometer. This will be the longer of the two tests, lasting approximately 20-30 minutes. During the test, you will be asked to cycle at a particular tempo while the instructor increases the resistance or load on the cycle every couple of minutes. Six rest periods of one minute duration will be given during the test, at which time blood will be drawn from a fingertip prick to measure blood lactate concentration. Furthermore, throughout the test, you will be asked to breathe into a mouthpiece that will assess the amount of oxygen being consumed during the exercise. The test will conclude when you are no longer able to sustain a pedal rate of between 45-50 rpm.

The second test is known as the Wingate Anaerobic Test, that measures power generated by the leg muscles during all out exercise. This is a 30 s sprint on a cycle against a specific resistance according to your body weight. The test will involve a brief warm-up, consisting of four, 5s sprints that will occur before the test. This will be followed by 3 minutes of rest, and then performance of the 30 s test. A brief 2-3 min cool down will conclude the test.

Potential Harms, Risks or Discomforts

Every effort will be made to conduct the exercise test in such a way as to minimize any discomfort or risks. However, you may feel a slight discomfort in your muscles in each of the tests, similar to the burning feeling felt in the muscles when competing hard in any sport. This discomfort will go away within a few minutes. Some other risks associated with each test may include light-headedness, chest discomfort, leg cramps and in the rarest of instances (extremely low and improbable risk) heart attacks. Each of the tests will be somewhat tiring and therefore you may feel like simply relaxing for the rest of the day. There may also be some discomfort from wearing a mouthpiece during the first test, but this is quite tolerable and is usually not a problem. Finally, the fingertip prick to measure lactate concentration may sting for a second or so, but no longer than this, and there will be minimal blood loss.

Potential Benefits

As a participant in the study, you will acquire an understanding of the state of your level of fitness. Furthermore, you will gain some knowledge about the energy systems (aerobic and anaerobic) with regards to hockey, which may be of value to you. The information may also be valuable if you are training for hockey and wish to know which aspect you need to improve, be it the short, intense performance (anaerobic pathways) or the longer duration performance capacities (endurance pathways). Your participation will also advance the understanding within the scientific community of the development of the aerobic and anaerobic energy systems and how they interact in growing children and adolescents and will hopefully help us to further understand any age differences.

Confidentiality

All of the data from the study will be kept confidential and stored in offices and on computers that only the investigators have access to. The results of the study may be published in a scientific journal; however, no reference of you will be made public. At the end of the study, if you are interested, you will be provided with your results as well as those of the group, once the analysis is complete.

Participation and Withdrawal

It is your choice whether or not you would like to participate in this study and if you do volunteer and wish to withdraw at a later date, there will be no consequences of any kind. If circumstances arise which warrant you to be removed from the study, the investigators reserve the right to request this.

Rights of Research Participants

As a subject, you may withdraw your consent and discontinue participation at any point during the study. As a participant you are not waiving any legal claims, right or remedies by participating in this research study. This study has been reviewed by and has received ethical clearance from the McMaster University Research Ethics Board (MREB). If you have concerns or questions your rights as a participant or about the way the study is conducted, you may contact:

Hamilton Health Sciences Patient Relations Specialist
Telephone: (905) 521-2100 ext. 75240

INFORMATION

If you have any further questions or concerns about the study or participation, please contact Trevor Allin at (905) 525-9140 x 27384, allintg@mcmaster.ca, or Dr. Blimkie at (905) 525-9140 x 24702.

I HAVE READ AND UNDERSTOOD THE INFORMATION PROVIDED FOR THIS STUDY AS DESCRIBED HEREIN. MY QUESTIONS HAVE BEEN ANSWERED TO MY SATISFACTION. I UNDERSTAND THAT I MAY WITHDRAW FROM THE STUDY AT ANY TIME IF I CHOOSE TO DO SO, AND I AGREE TO PARTICIPATE IN THIS STUDY. I HAVE RECEIVED A SIGNED COPY OF THIS FORM.

______________________ ______________________ ____________

Name of Participant Signature of Participant Date

INVESTIGATOR

In my opinion, the parent/guardian of the participant has voluntarily and knowingly given informed consent and possesses the legal capacity to give informed consent and participate in this research study.

______________________________________ ____________

Signature of Researcher Date

Appendix F – Raw Data for All Measures Analyzed

DESCRIPTIVE DATA

Subject	**Age Category**	**#YearsHockey (Years)**	**#CompYears (Years)**	**CompLevel**
1	3	8	4	A
2	1	7	5	A
3	2	7	4	A
4	2	7	5	AA
5	2	6	4	AA
6	2	8	4	AA
7	1	9	4	A
8	1	9	5	A
9	1	7	4	A
10	3	15	6	Junior C
11	3	13	8	Junior A
12	3	15	13	Junior C
13	2	9	6	AAA
14	3	10	7	Junior C
15	2	9	1	A
16	1	6	5	AA
17	3	15	6	Junior C
18	2	10	6	A
19	1	8	6	AAA
20	3	14	8	Junior C
21	2	10	6	AAA
22	1	8	5	AAA
23	1	7	7	AAA
24	2	7	4	AAA
25	1	5	3	A
26	2	8	7	AA
27	3	12	3	AA
28	2	10	3	AA
29	1	8	1	A
30	3	9	7	AAA
31	2	9	7	AAA
Average		**9.2**	**5.3**	
SD		**2.7**	**2.3**	

DESCRIPTIVE DATA

Decimal Age (Years)	Height (cm)	Weight (kg)	BMI (%)	TotalLeg Vol (L)	Muscle (L)	Fat (L)
18.85	181	72.7	22.20	10.05	7.06	2.99
12.69	154.5	43.7	18.31	4.79	3.37	1.54
13.28	157.1	49.0	19.85	5.64	3.81	1.83
13.65	149.5	40.6	18.17	4.28	2.88	1.4
14.5	165	62.0	22.77	7.88	5.02	2.86
13.38	176.8	71.0	22.71	8.95	6.06	2.89
12.73	167	55.5	19.90	5.87	3.59	2.28
12.96	159.2	60.9	24.03	6.84	4.04	2.8
13.08	149.2	40.1	18.01	5.16	3.58	1.58
21.57	183	99.0	29.56	11.39	9.01	2.38
18.84	176.5	65.8	21.12	7.23	4.84	2.39
21.8	170	80.0	27.68	8.11	5.58	2.53
13.41	163.5	67.0	25.06	8.36	5.26	3.1
18.36	178	70.5	22.25	9.38	6.63	2.75
15.56	169.1	59.0	20.63	7.34	4.81	2.53
11.04	145	37.5	17.84	4.12	2.7	1.42
18.68	176.5	66.5	21.35	7.2	4.99	2.21
15.3	179.6	68.1	21.11	8.52	5.95	2.57
12.22	152.3	44.0	18.97	5.9	4.05	1.85
20.08	178	67.4	21.27	7.85	5.45	2.4
14.23	170.3	62.1	21.41	6.53	4.86	1.67
12.61	157.2	45.1	18.25	5.5	3.71	1.79
10.82	157.9	46.0	18.45	4.93	3.29	1.64
14.06	173.7	64.2	21.28	6.58	4.33	2.25
12.52	147.5	36.2	16.64	3.36	2.2	1.16
14.07	164	44.4	16.51	4.6	3.09	1.51
16.13	175.9	67.2	21.72	6.02	4.58	1.44
14.23	176	65.2	21.05	4.78	3.27	1.51
12.49	143.4	34.6	16.83	3.42	1.89	1.53
16.75	178.1	70.2	22.13	9.18	6.39	2.79
14.87	177.3	63.6	20.23	5.98	3.92	2.06
14.99	**166.2**	**58.7**	**20.9**	**6.6**	**4.5**	**2.1**
3.0	**12.0**	**14.8**	**3.0**	**2.0**	**1.5**	**0.6**

ANAEROBIC DATA

PeakPower (W)	PeakPower (W/kg)	AvgPower (W)	AvgPower (W/kg)	Fatigue (%)
801	11	579	7.9	56.2
439	10	320	7.3	44.2
558	11.4	467	9.5	42.1
419	10.2	342	8.3	29.4
681	11.0	431	7.0	47.2
733	10.3	610	8.6	34.7
494	8.9	440	7.9	19.2
583	9.6	451	7.4	37.7
444	11.1	332	8.3	39.9
1063	11.02	652	6.6	59.3
704	10.7	481	7.3	51.1
904	11.3	694	8.7	39.3
638	9.5	487	7.3	43.8
788	11.2	713	10.1	21.8
615	10.4	447	7.6	57.1
330	8.8	277	7.4	33.9
751	11.3	573	8.6	42.1
700	10.3	510	7.5	47.7
363	8.3	249.2	5.7	49.9
651	9.7	469	7	52.1
692	11.1	431	6.9	37.7
496	11	378	8.4	46.2
399	8.7	294	6.4	46.4
699	10.9	505	7.9	47.1
338	9.34	268	7.4	36.1
421	9.48	302	6.8	54.2
805	11.98	594	8.84	46.8
694	10.64	563	8.63	39.9
341	9.9	261	7.5	39.6
727	10.35	516	7.35	49.7
713	11.2	536	8.4	50.8
612.4	**10.3**	**457.2**	**7.8**	**43.3**
181.9	**0.9**	**130.9**	**0.9**	**9.4**

AEROBIC DATA

Abs AerPow (L/min)	Rel AerPow (ml/kg/min)	Test Time (min)	Pre Lact (mMol/L)	Post Lact (mMol/L)	HRmax (bpm)	RERMax
3.55	48.80	26:18	2.3	11.2	191	1.1
2.27	51.9	28:08	2.3	5.2	182	1.04
3.28	66.9	32:20	2.2	10.1	203	1.11
2.44	60.2	31:04	2.7	7.7	194	0.98
2.64	42.6	24:08	2.3	10.7	188	1.07
3.15	44.3	26:48	2.8	5.2	182	1.02
2.54	45.7	25:40	4.5	12.4	184	1.07
2.52	41.4	30:15	2.8	13.2	195	1.18
2.52	62.9	29:17	2.3	8.1	191	1.07
4.68	47.3	30.13	3	15.2	184	1.15
3.37	51.2	27.40	3	17.7	194	1.21
3.83	47.9	28:10	3	16.8	163	1.09
3.15	47	26:15	3.1	8.7	198	1.06
3.14	44.6	28:01	3	11.2	191	1.31
2.03	34.4	21.58	3.5	12	203	1.07
1.67	44.5	26:35	3.2	10.7	185	1.06
3.83	57.6	28:35	3.1	13	199	1.23
3.75	55.1	27.23	3.2	11.4	194	1.18
2.38	54.1	29:40	2.8	6.5	200	0.96
3.92	58.1	27:38	2.7	13.2	194	1.29
3.96	63.74	28:02	2.3	9.7	203	1.22
2.39	52.90	29:30	2.4	11.2	206	1.14
2.01	43.6	26:40	2.4	8.7	181	1.11
3.29	51.3	26:00	2.7	14	201	0.97
1.80	49.7	27:30	2.3	14.2	202	1.3
2.49	56.1	21:15	1.9	10.7	191	1.01
3.93	58.6	28:12	5.2	15.7	203	1.27
3.01	46.3	26:13	2.3	8.2	193	1.03
1.99	57.5	25:31	4.4	10.5	187	1.05
3.75	53.4	27:32	3.1	11.7	199	1.23
3.21	50.6	27:02	2.1	17.6	204	1.33
3.0	**51.3**	**27:19**	**2.9**	**11.4**	**193.1**	**1.1**
0.8	**7.3**	**2:19**	**0.7**	**3.3**	**9.3**	**0.1**

CRITERION MECHANICAL AEROBIC POWER

TradAe PPow (W)	**Power@ LT (W)**	**Power@ VAT (W)**	**TradAe PPow (W/kg)**	**Power@ LT (W/kg)**	**Power@ VAT (W/kg)**
275	200.0	250.0	3.78	2.75	3.44
187.5	100.0	162.5	4.29	2.29	3.72
237.5	112.5	162.5	4.85	2.30	3.32
212.5	187.5	187.5	5.23	4.62	4.62
275	175.0	225.0	4.44	2.82	3.63
300	175.0	250.0	4.23	2.46	3.52
250	175.0	175.0	4.50	3.15	3.15
212.5	137.5	162.5	3.49	2.26	2.67
187.5	112.5	137.5	4.68	2.81	3.43
400	300.0	300.0	4.04	3.03	3.03
300	200.0	250.0	4.56	3.04	3.80
300	200.0	250.0	3.75	2.50	3.13
300	150.0	200.0	4.48	2.24	2.99
350	200.0	250.0	4.96	2.84	3.55
200	150.0	150.0	3.39	2.54	2.54
162.5	100.0	100.0	4.33	2.67	2.67
350	200.0	250.0	5.26	3.01	3.76
300	200.0	250.0	4.41	2.94	3.67
187.5	112.5	137.5	4.26	2.56	3.13
300	200.0	250.0	4.45	2.97	3.71
350	200.0	250.0	5.64	3.22	4.03
187.5	137.5	137.5	4.16	3.05	3.05
162.5	112.5	137.5	3.53	2.45	2.99
250	175.0	150.0	3.89	2.73	2.34
162.5	112.5	137.5	4.49	3.11	3.80
200	175.0	125.0	4.50	3.94	2.82
300	250.0	250.0	4.46	3.72	3.72
250	200.0	175.0	3.83	3.07	2.68
137.5	100.0	100.0	3.99	2.89	2.89
300	200.0	250.0	4.27	2.85	3.56
300	175.0	175.0	4.72	2.75	2.75
254.4	**168.5**	**193.1**	**4.4**	**2.9**	**3.3**
67.0	**47.2**	**55.7**	**0.5**	**0.5**	**0.5**

POWER RATIO CALCULATIONS

TradRatio	**LTRatio**	**VATRatio**
2.91	4.00	3.20
2.33	4.37	2.69
2.35	4.97	3.44
1.95	2.21	2.21
2.48	3.89	3.03
2.44	4.18	2.93
1.98	2.82	2.82
2.75	4.25	3.60
2.37	3.96	3.24
2.73	3.64	3.64
2.35	3.52	2.82
3.01	4.52	3.62
2.13	4.25	3.19
2.26	3.95	3.16
3.07	4.09	4.09
2.03	3.30	3.30
2.15	3.76	3.01
2.34	3.51	2.81
1.95	3.25	2.66
2.18	3.27	2.62
1.97	3.45	2.76
2.65	3.61	3.61
2.46	3.55	2.90
2.80	4.00	4.67
2.08	3.01	2.46
2.10	2.41	3.37
2.68	3.22	3.22
2.77	3.47	3.96
2.47	3.41	3.41
2.42	3.63	2.91
2.37	4.07	4.07
2.4	**3.7**	**3.2**
0.3	**0.6**	**0.5**

RELIABILITY DATA

TEST 1

Subject	HeightT1 (cm)	WeightT1 (kg)	Rel AerPowT1 (ml/kg/min)	PreLactT1 (mMol/L)	PostLactT1 (mMol/L)
1	167.0	55.5	45.7	4.5	12.4
2	157.2	45.1	52.9	2.4	11.2
3	179.6	68.1	55.1	3.2	11.4
4	157.1	49.0	66.9	2.2	10.1
5	176.5	65.8	51.2	3.0	17.7
6	181.0	72.7	48.8	2.3	11.2
Mean	169.7	59.4	53.4	2.9	12.3
SD	10.9	11.2	7.4	0.9	2.7

TEST 2

Subject	HeightT1 (cm)	WeightT1 (kg)	Rel AerPowT1 (ml/kg/min)	PreLactT1 (mMol/L)	PostLactT1 (mMol/L)
1	169.2	58.8	49.3	4.4	15.1
2	157.4	45.1	54.3	2.0	8.7
3	180.3	69.0	54.2	3.1	12.1
4	157.5	50.0	56.2	2.4	11.4
5	176.5	66.5	57.6	3.1	13.0
6	181.1	69.0	43.5	2.5	9.4
Mean	170.3	59.7	52.5	2.9	11.6
SD	10.8	10.3	5.2	0.8	2.4

RELIABILITY DATA

TEST 1

Subject	PeakPowerT1 (W)	PeakPowerT1 (W/kg)	TradAePPowT1 (W)	TradAePPowT1 (W/kg)
1	494.0	8.9	250.0	4.5
2	496.0	11.0	187.5	4.2
3	700.0	10.3	300.0	4.4
4	558.0	11.4	237.5	4.9
5	704.0	10.7	300.0	4.6
6	801.0	11.0	275.0	3.8
Mean	625.5	10.6	258.3	4.4
SD	127.4	0.9	43.1	0.4

TEST 2

Subject	PeakPowerT2 (W)	PeakPowerT2 (W/kg))	TradAePPowT2 (W)	TradAePPowT2 (W/kg)
1	508.0	8.6	250.0	4.3
2	514.0	11.4	187.5	4.2
3	704.0	10.2	300.0	4.3
4	573.0	11.5	237.5	4.8
5	712.0	10.7	350.0	5.3
6	635.0	9.2	300.0	4.3
Mean	607.7	10.3	270.8	4.5
SD	90.4	1.2	57.4	0.4

RELIABILITY DATA

TEST 1

Subject	**Power@LTT1 (W)**	**Power@LTT1 (W/kg)**	**Power@VATT1 (W)**	**Power@VATT1 (W/kg)**
1	175.0	3.2	175.0	3.2
2	137.5	3.0	137.5	3.1
3	200.0	2.9	250.0	3.7
4	137.5	2.8	162.5	3.3
5	200.0	3.0	250.0	3.8
6	200.0	2.8	250.0	3.4
Mean	175.0	3.0	204.2	3.4
SD	30.6	0.2	51.6	0.3

TEST 2

Subject	**Power@LTT2 (W)**	**Power@LTT2 (W/kg)**	**Power@VATT2 (W)**	**Power@VATT2 (W/kg)**
1	175.0	3.0	175.0	3.0
2	137.5	3.0	137.5	3.0
3	200.0	2.9	225.0	3.3
4	162.5	3.3	162.5	3.3
5	200.0	3.0	250.0	3.8
6	200.0	2.9	200.0	2.9
Mean	170.8	2.8	191.7	3.2
SD	37.6	0.3	41.6	0.3

RELIABILITY DATA

TEST 1

Subject	TradRatioT1	LTRatioT1	VATRatioT1
1	2.0	2.8	2.8
2	2.7	3.6	3.6
3	2.3	3.5	2.8
4	2.4	5.0	3.4
5	2.4	3.5	2.8
6	2.9	2.9	3.2
Mean	2.4	3.6	3.1
SD	0.3	0.8	0.4

TEST 2

Subject	TradRatioT2	LTRatioT2	VATRatioT2
1	2.0	2.9	2.9
2	2.7	3.7	3.7
3	2.3	3.5	3.1
4	2.4	3.5	3.5
5	2.0	3.6	2.8
6	2.1	3.2	3.2
Mean	2.3	3.4	3.2
SD	0.3	0.3	0.3