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## The Effects of Sprint Interval Training and Maturity Status on Metabolic and Neuromuscular Fatigue Thresholds in Adolescents

Kyle Beyer  
*University of Central Florida*

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THE EFFECTS OF SPRINT INTERVAL TRAINING AND MATURITY STATUS ON METABOLIC AND  
NEUROMUSCULAR FATIGUE THRESHOLDS IN ADOLESCENTS

by

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A dissertation submitted in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy  
in the Department of Educational and Human Sciences  
in the College of Education and Human Performance  
at the University of Central Florida  
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## ABSTRACT

**Purpose:** To examine the maturity-related differences in the adaptations to systemic and localized fatigue thresholds (FTs) in response to sprint interval training (SIT) amongst adolescent male athletes. **Methods:** Twenty-seven adolescent male athletes, 11-17 years of age, completed pre-testing, six weeks of SIT, and post-testing. Participants were grouped according to their number of years from peak height velocity (PHV), an estimation of somatic maturity status, into PRE (<-1.5yr), PERI (between -1.5 to +1.5yr) and POST (>+1.5yr) PHV groups. Each testing session consisted of a ramp exercise protocol on a cycle ergometer. During the protocol, three systemic FTs, gas exchange threshold, ventilatory threshold, and respiratory compensation point were calculated from gas exchange and ventilatory parameters. Also, three localized FTs, neuromuscular fatigue threshold (NFT), deoxyhemoglobin breakpoint (HHbBP), and oxygenation deflection point (OxDp) were calculated from electromyography (NFT) and near-infrared spectroscopy signals (HHbBP and OxDp) from the vastus lateralis of both legs. Data were plotted versus oxygen consumption and 30-second moving averages were calculated. All FTs were determined using the maximal distance method. Localized FTs were averaged between the two legs. The six weeks of SIT consisted of repeated 20-second “all-out” sprints on a cycle ergometer against a load equivalent to 7.5% of body mass with 4-minute rest periods. Maturity-related differences to the adaptations to SIT were assessed with mixed-factorial ANOVA and magnitude-based inferences. **Results:** During training, POST and PERI completed significantly greater relative work ( $p=0.003$  and  $p=0.002$ , respectively) and peak power ( $p=0.025$  and  $p=0.023$ , respectively) per session than PRE. Furthermore, POST achieved significantly greater peak rotations per minute than PRE ( $p=0.001$ ) and PERI ( $p=0.042$ ) during the first training session. No significant group $\times$ time interactions existed for absolute  $\dot{V}O_{2max}$  ( $p=0.386$ ), relative

$\dot{V}O_{2\max}$  ( $p=0.341$ ) or maximum workload ( $p=0.593$ ). However, there was a significant group $\times$ time interaction ( $p=0.030$ ) for FTs, with POST having significantly greater changes than PRE ( $p=0.026$ ) and PERI ( $p=0.023$ ), and was the only group to experience a significant improvement in FTs from training ( $p<0.001$ ). In addition, magnitude based inferences revealed that POST had *Likely* improvements in all measures of maximal aerobic performance, while PERI only had *Likely* improvements in maximum workload and PRE experienced *Trivial* changes. Furthermore, all measured FTs experienced *Likely* or *Very Likely* improvements amongst POST; however, PRE and PERI only had improvements in NFT and HHbBP.

**Conclusion:** SIT improved maximal aerobic performance and FTs in POST, but had limited affects in PRE and PERI. The maturity-related differences in the adaptations to SIT may be due to the differences in performance during the training program or underlying physiological changes that occur with maturation.

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## CHAPTER ONE: INTRODUCTION

Prior to peak height velocity (PHV), prepubescent (PRE) children tend to have a reduced anaerobic capacity and a greater reliance on aerobic metabolism during exercise when compared to adults (Boisseau & Delamarche, 2000). Throughout maturation, a gradual shift occurs as postpubescent (POST) adolescents develop a metabolic response to exercise that is similar to adults, such as greater glycogen depletion and lactate production (Boisseau & Delamarche, 2000). The diminished anaerobic capacity in PRE children is evidenced by lower lactate production during high intensity exercise (Beneke, Hütler, & Leithäuser, 2007; O. Eriksson & Saltin, 1974), which may be due to the greater percentage of type I fibers in PRE muscle when compared to adult muscle (Jansson, 1996; Lexell, Sjöström, Nordlund, & Taylor, 1992; Tambovtseva & Kornienko, 1986). Furthermore, phosphofructokinase activity, as well as liver and muscle glycogen stores, increase from prepubescence through adulthood (B. O. Eriksson, Gollnick, & Saltin, 1973; O. Eriksson & Saltin, 1974). Conversely, children have higher concentrations of the oxidative enzymes succinate dehydrogenase and isocitrate dehydrogenase than adults (Fournier et al., 1981). The increased reliance on aerobic metabolism in PRE children compared to adults is reflected by greater fat oxidation (Rowland & Boyajian, 1995). Moreover, previous studies have reported higher peak fat oxidation rates, and faster velocities at which maximal fat oxidation occurred, in PRE boys when compared to POST boys and young adult males (Riddell, 2008; Stephens, Cole, & Mahon, 2006). However, at maximal exercise there are no differences between maturational groups in regards to oxygen consumption, heart rate, or respiratory exchange ratio (Riddell, 2008; Stephens et al., 2006). Evidence to date suggests that PRE children have underdeveloped anaerobic metabolism and rely more on aerobic metabolism during submaximal exercise.

Previous studies suggest that maturation status has an effect on training-induced adaptations (Behringer, vom Heede, Yue, & Mester, 2010; Lesinski, Prieske, & Granacher, 2016; Lloyd, Radnor, Croix, Cronin, & Oliver, 2016; Meylan, Cronin, Oliver, Hopkins, & Contreras, 2014). For example, Behringer and colleagues (2010) and Meylan and colleagues (2014) have demonstrated greater strength and power adaptations to resistance training in peripubescent (PERI) and POST children when compared to PRE. However, a recent meta-analysis reported no significant effect of maturity on strength, power, sprint, or agility adaptations to resistance training (Lesinski et al., 2016). Furthermore, trivial differences in sprint and squat jump performance have been observed between PRE and POST children during a resistance training or a combined resistance and plyometric training program (Lloyd et al., 2016). Moreover, a plyometric-only training program resulted in very likely greater jumping and sprinting adaptations in PRE children when compared to POST children (Lloyd et al., 2016). While maturity-related differences in response to resistance and plyometric training have been thoroughly researched, limited research has directly compared the effect of maturity status on the adaptations to high-intensity interval training (HIIT).

Sprint interval training (SIT) is a form of HIIT which focuses on supramaximal intensities for very short (~10-30 seconds) durations of time (Buchheit & Laursen, 2013). Previous research has shown that recreationally active adults increase ventilatory threshold (Burke, Thayer, & Belcamino, 1994; Lamboley, Royer, & Dionne, 2007) and respiratory compensation point (Lamboley et al., 2007; Robinson IV et al., 2014) following SIT and HIIT of various designs and duration. From a neuromuscular standpoint, four weeks of HIIT has been shown to increase physical working capacity at fatigue threshold (Miramonti et al., 2016). While no studies have examined the effect of SIT or HIIT on muscle oxygenation thresholds, McKay

and colleagues (McKay, Paterson, & Kowalchuk, 2009) observed faster oxygen uptake by exercising muscle after eight sessions of HIIT. In adolescents, SIT has been shown to improve peak power, gas exchange threshold, muscle thickness, fatigue index,  $\dot{V}O_2\text{max}$ , and time to exhaustion after eight training session over two (Barker, Day, Smith, Bond, & Williams, 2014). However, neither study quantified maturational status amongst the adolescent participants. Only one study has directly compared the maturity-related differences to HIIT and observed improvements in agility and intermittent running performance amongst POST girls, while the PRE and PERI had smaller improvements and some performance decrements (Wright, Hurst, & Taylor, 2016). Wright and colleagues (2016) only examined adolescent female soccer athletes; however, as boys typically experience a greater adolescent growth spurt than girls (Beunen & Malina, 1988), adolescent male athletes may experience a greater maturity-related difference in the adaptation to training. Furthermore, Wright and colleagues (2016) did not assess changes in maximal aerobic performance or fatigue thresholds following HIIT. Maturational status may have an impact on adaptations to training, likely due to differences in the utilization and adaptability of aerobic and anaerobic energy systems and the maturing neuromuscular system.

The purpose of this study was to compare the adaptations in fatigue thresholds following SIT in adolescent males of different maturational statuses. Based on the results of previous studies, it was hypothesized that POST children would see increases in fatigue thresholds following four weeks of SIT. In terms of the PERI children, it was likely that SIT would increase fatigue thresholds, but to a lesser extent than the POST group. As PRE children already rely heavily on aerobic metabolism, and therefore have fatigue thresholds that occur at higher intensities when compared to adults (Anderson & Mahon, 2007; Klentrou, Nishio, Plyley, & University, 2006; Pitt et al., 2015), they may not drastically increase fatigue thresholds after SIT.

### Purpose

1. Do 4-weeks of sprint interval training improve metabolic and neuromuscular fatigue thresholds amongst adolescent males?
2. Are there differences in the changes of metabolic and neuromuscular fatigue thresholds between adolescent males of different maturational groups?

### Hypotheses

1. Sprint interval training will improve all measured fatigue thresholds while also improving peak and mean anaerobic power, as determined from training data.
2. POST will have greater adaptations to the sprint interval training than PRE or PERI.

### Operational Definitions

1. Fatigue Threshold – The inflection or deflection point that occurs in the relationship between a physiological variable and time, power output, or  $\dot{V}O_2$  at increasing exercise intensities.
2. Gas Exchange Threshold – The inflection in the  $\dot{V}CO_2$  vs  $\dot{V}O_2$  relationship during increasing exercise intensities.
3. Ventilatory Threshold – The inflection in the  $\dot{V}E$  vs  $\dot{V}O_2$  relationship during increasing exercise intensities.
4. Respiratory Compensation Point – The inflection in the  $\dot{V}E$  vs  $\dot{V}CO_2$  relationship during increasing exercise intensities.
5. Neuromuscular Fatigue Threshold – The inflection in the EMG RMS vs  $\dot{V}O_2$  relationship during increasing exercise intensities.
6. Deoxyhemoglobin Breakpoint – The deflection in the HHb vs  $\dot{V}O_2$  relationship during increasing exercise intensities.

7. Oxygenation Deflection Point – The deflection in the  $O_2Hb$ - $HHb$  vs  $\dot{V}O_2$  relationship during increasing exercise intensities.
8. Sprint Interval Training – Style of HIIT which utilizes supramaximal loads and “all-out” effort for short periods of time.
9. Maturational Status – Defined as number of years from peak height velocity.

#### Abbreviations

$\dot{V}O_2$  – Oxygen Consumption

$\dot{V}CO_2$  – Carbon Dioxide Production

$\dot{V}E$  - Ventilation

GET – Gas Exchange Threshold

VT – Ventilatory Threshold

RCP – Respiratory Compensation Point

EMG – Electromyography

NFT – Neuromuscular Fatigue Threshold

NIRS – Near Infrared Spectroscopy

$O_2Hb$  – Oxygenated Hemoglobin

OxyDP – Oxygenation Deflection Point

$HHb$  – Deoxygenated Hemoglobin

HHbBP - Deoxyhemoglobin Breakpoint

HIIT – High Intensity Interval Training

SIT – Sprint Interval Training

PHV – Peak Height Velocity

PRE – Prepubescent

PERI – Peripubescent

POST – Postpubescent

### Delimitations

Thirty-three adolescent boys between the ages of 11 and 17 were recruited for this study. All participants completed a Confidential Medical and Activity Questionnaire, provided a verbal assent, and parental written consent prior to participating in the study. Also, all participants had been cleared by a physician to participate in physical activity within the last year. All participants were healthy and free from disease or injury. All participants were free from any nutritional supplements.

### Assumptions

#### *Theoretical Assumptions*

1. Participants accurately and truthfully answered the Confidential Medical and Activity Questionnaire.
2. Participants maintained their outside diet and exercise habits throughout the duration of the study.
3. Participants gave maximal effort during all testing and training sessions.
4. Participants maintained a relatively standard sleep cycle.

#### *Statistical Assumptions*

1. The sample was randomly selected from the population.

### Limitations

1. Dietary consumption data was not recorded.
2. Previous involvement with interval training was not recorded.
3. Maturation status (years from PHV) was predicted using anthropometric data.



## CHAPTER TWO: REVIEW OF LITERATURE

### Effect of age and maturation on the response to exercise

*Eriksson and Saltin, (1974)*

#### **Muscle metabolism during exercise in boys aged 11 to 16 years compared to adults**

This study assessed creatine phosphate (CP), adenosine triphosphate (ATP), glycogen content, and muscle lactate in youth muscle at rest and during exercise. The participants in this study were grouped into average ages of 11.6y, 12.6y, 13.5y, and 15.5y; however, no estimates of maturity status were obtained during this study. Muscle biopsies were obtained from each participant prior to and after completing cycling at increasing exercise intensities. At rest, there was no difference in muscle CP or ATP between the different age groups. However, muscle glycogen concentrations at rest increased with each age group. Furthermore, the depletion of muscle glycogen in response to exercise was attenuated in the youngest age group. In terms of muscle lactate, the youngest boys had blunted response to exercise when compared to older boys. The lowered glycogen utilization and decreased lactate concentration in the muscle may be indicative of an underdeveloped and underutilized anaerobic metabolic energy system.

*Lexell, Sjostrom, Nordlund, and Taylor, (1992)*

#### **Growth and development of human muscle: A quantitative morphological study of whole vastus lateralis from childhood to adult age**

This study measured the muscle size and fiber composition of autopsied muscle from males aged 5-37 years old. All participants suffered a sudden death and had no previous history of neuromuscular disease. The vastus lateralis muscle from each participant was obtained within three days' postmortem, which was then sliced and stained for myofibrillar adenosine triphosphatase to differentiate between type I and type II muscle fibers. There was a significant

inverted-U relationship between age and muscle area with the greatest area occurring at around 25 years of age. There was a significant quadratic relationship between proportion of type I fibers and age, with the greatest proportion found in the youngest participants which gradually decreased into adulthood. The greater relative amount of type I fibers in prepubescent children may factor into the reduced anaerobic capacity that has been associated in this maturational group.

*Tolfrey and Armstrong, (1995)*

### **Child-adult differences in whole blood lactate responses to incremental treadmill exercise**

This study examined the differences lactate production during a graded exercise test between prepubescent boys, teenage boys, and adult men. Maturational status was not quantified, but there was a significant difference in age, height, and body mass between the three groups. The prepubescent boys were  $11.1 \pm 0.4$  y, while the teenage boys were  $14.1 \pm 0.3$  y, and the adults were  $22.4 \pm 2.7$  y. The graded exercise test consisted of 3 min stages with increasing incline at a constant speed. Heart rate and oxygen consumption ( $\dot{V}O_2$ ) were measured continuously throughout the graded exercise test. Blood lactate was sampled at the end of each stage and at the cessation of exercise. Absolute and relative heart rate and  $\dot{V}O_2$  were plotted against blood lactate and values at 2.5 and 4.0  $\text{mmol}\cdot\text{l}^{-1}$  were determined. In terms of maximal performance, absolute  $\dot{V}O_{2\text{peak}}$  was greatest in the adults ( $4.18 \pm 0.50 \text{ L}\cdot\text{min}^{-1}$ ) and lowest in the prepubescent boys ( $1.82 \pm 0.22 \text{ L}\cdot\text{min}^{-1}$ ). However, when made relative to body mass, no differences in  $\dot{V}O_{2\text{peak}}$  were observed. Blood lactate concentrations at peak  $\dot{V}O_2$  were also significantly different between all three groups, with adults having the greatest ( $8.7 \pm 1.9 \text{ mmol}\cdot\text{l}^{-1}$ ) and prepubescent boys having the lowest ( $4.5 \pm 1.5 \text{ mmol}\cdot\text{l}^{-1}$ ). At 2.5  $\text{mmol}\cdot\text{l}^{-1}$  of blood lactate, there was no difference between groups in percent of  $\dot{V}O_{2\text{peak}}$ . However, adults ( $87 \pm 4\%$ ) had a significantly

lower % of peak heart rate than prepubescent ( $95\pm 3\%$ ) and teenage ( $94\pm 4\%$ ) boys. A similar pattern was observed at  $4.0 \text{ mmol}\cdot\text{l}^{-1}$  of blood lactate, with adults having a lower percent  $\dot{V}O_{2\text{peak}}$  and percent of peak heart rate than prepubescent and teenage boys. In summary, prepubescent boys, teenage boys, and adult men were all able to reach similar relative  $\dot{V}O_{2\text{peak}}$ s; however, blood lactate concentration at  $\dot{V}O_{2\text{peak}}$  significantly increased with each age group. Despite reaching exercise intensities that resulted in similar relative  $\dot{V}O_{2\text{peak}}$  values, younger individuals did not reach the same concentrations of blood lactate, which may be indicative of a greater reliance on aerobic metabolism in younger individuals.

*Halin, Germain, Bercier, Kapitaniak, and Buttelli, (2003)*

### **Neuromuscular response of young boys versus men during sustained maximal contraction**

The purpose of this study was to compare the neuromuscular responses to sustained maximal contractions in prepubescent boys ( $10.5\pm 0.9 \text{ y}$ ) and adult men ( $21.5\pm 4.5 \text{ y}$ ). All participants were assessed for right upper arm cross-sectional area using arm circumference and four skinfold measurements on the anterior, posterior, lateral, and medial aspect of the arm. Electromyography electrodes were placed over the muscle belly of the right biceps brachii. Participants were seated in an ergometer with their shoulder joint and elbow joint fixed at  $90^\circ$  and  $100^\circ$ , respectively. After setup, participants completed three 3-second maximal isometric contractions of the biceps brachii, separated by two minutes of rest, to determine maximal force. After three minutes of rest, participants perform a 30-second maximal isometric contraction; however, the last two seconds of data were not included in the analysis. Throughout the 30-second contraction, force measurements and electromyography signals were collected and analyzed in successive 1-second periods, which overlapped by 0.5 seconds, for a total of 56 data points. Force data were averaged and normalized to the arm cross-sectional area.

Electromyography signals were band-pass filtered between 5-500 Hz and mean power frequency and mean fiber conduction velocity were calculated. All data were plotted over time and a linear regression was calculated for each variable. The slope of the regression line was considered the changes during the fatiguing contraction, while the intercept was considered the maximal, unfatigued values for mean power frequency and mean fiber conduction velocity. The change scores were also made relative to the initial values to present percent change values. The percent change in mean fiber conduction velocity was made relative to the percent change in mean power frequency and plotted over time. Independent t-tests revealed that boys had significantly smaller arm cross-sectional area, maximal isometric force, and maximal force relative to cross-sectional area. Adult men had a significantly steeper slope than boys when comparing the change in force relative to cross-sectional area when expressed in absolute terms or as a percent of the initial value. In terms of mean power frequency and mean fiber conduction velocity, adult men had a greater initial value than young boys. Furthermore, adult men had significantly steeper slopes than young boys for mean power frequency and mean fiber conduction velocity when expressed in absolute terms or relative to the initial values. When assessing the ratio of mean fiber conduction velocity to mean power frequency, there was a significantly greater slope in adult men when compared to boys. In summary, there was significantly greater rates of fatigue in adult men when compared to boys. Furthermore, there appears to be a greater amount of Type II motor unit activation during a fatiguing contraction in adult men when compared to boys. This may be to the underdeveloped anaerobic metabolism in prepubescent boys. While this study compared men and prepubescent boys, it would be interesting to compare the neuromuscular response to fatiguing contraction amongst boys of different maturity status.

*Ratel, Williams, Oliver, and Armstrong, (2004)*

### **Effects of age and mode of exercise on power output profiles during repeated sprints**

In this study, 12 boys ( $11.7 \pm 0.5$ y) and 13 men ( $22.1 \pm 2.9$ y) completed 10 repeated 10-s sprints with 15-s rest intervals on a cycle ergometer and non-motorized treadmill. Peak and mean power outputs during each sprint were assessed, along with blood lactate and rating of perceived exertion at the end of the tenth sprint. Peak and mean power data were assessed in absolute values and relative to lean leg volume. In absolute terms, peak and mean power were significantly greater in men when compared to boys regardless of exercise mode. When assessed relative to lean leg volume, peak power was greater in men during the first six cycling sprints, but only the first running sprint. In terms of mean power relative to lean leg volume, men were higher than boys during the first 3 cycling and first 2 running sprints. The declines in peak and mean power over the course of the 10 sprints were greater in adults than children regardless of exercise mode. The change in lactate concentrations from the repeated sprints was significantly greater in men than boys during cycling and running. Furthermore, adults reported higher ratings of perceived exertion after exercise when compared to children. In summary, boys produce significantly less absolute and relative power than men at the beginning of repeated sprint protocols. However, due to the greater decline in power found in men, there is no difference in relative power output between boys and men during the final sprints of a repeated sprint exercise bout. Furthermore, men report greater levels of exertion and higher blood lactate concentrations than boys after completing a repeated sprint exercise bout. Boys may not experience decreased performance during repeated bouts which may be attributed to the blunted lactate response to exercise.

*Brandou, Savy-Pacaux, Marie, Brun, and Mercier, (2006)*

### **Comparison of the type of substrate oxidation during exercise between pre and post pubertal markedly obese boys**

This study assessed the pubertal status, using Tanner stage classification, of 15 boys and classified them as pre pubertal or post pubertal. For each participant, maximal aerobic power was estimated from fat-free mass, which was determined via multifrequency bioelectrical impedance. The exercise test consisted of five six-minute stages at 20, 30, 40, 50 and 60% of each participant's estimated maximal aerobic power. Respiratory exchange ratio (RER) was calculated from  $\dot{V}O_2$  and carbon dioxide production ( $\dot{V}CO_2$ ). From RER, fat and carbohydrate oxidation rates were calculated. Although not significant, RER tended to be higher in post pubertal when compared to pre pubertal at all exercise intensities. In post pubertal, absolute fat oxidation was greater than pre pubertal at 20, 30, and 40% of maximal aerobic power. However, when made relative to fat-free mass, pre pubertal boys had greater fat oxidation rates at 20, 30, and 40% of maximal aerobic power. Furthermore, pre pubertal boys had a significantly greater percent of total energy expenditure from fat oxidation than post pubertal boys at 20 and 30% of estimated maximal aerobic power. Altogether, these findings illustrate a preferential utilization of fat as an energy source in pre pubertal boys, which appears to decrease during puberty.

*Stephens, Cole, and Mahon, (2006)*

### **The influence of biological maturation on fat and carbohydrate metabolism during exercise in males**

The aim of this study was to compare the metabolic response to maximal and submaximal exercise amongst males from the ages of 9-27 years old. Forty-three male participants were classified as early-pubertal (EP), mid-pubertal (MP), late-pubertal (LP), or young adult (YA). Pubertal status was assessed with Tanner staging for pubertal age males,

while YA males were not assessed for maturity status. All participants completed a graded exercise test on a cycle ergometer which increased in work rate every two-minutes until maximal effort was obtained. The work rate throughout the test was determined by the participant's height. Throughout the graded exercise test ventilation,  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , RER, rating of perceived exertion, and heart rate were measured.  $\dot{V}O_{2peak}$  was determined as the participant reached volitional fatigue. After completion of the graded exercise test, participants reported on a separate day to complete five submaximal exercise trials at intensities corresponding to 30, 40, 50, 60, and 70% of  $\dot{V}O_{2peak}$ . Each trial lasted 5-6 minutes with 5-10 minutes of rest between trials. During each trial  $\dot{V}O_2$ , RER, heart rate, and rating of perceived exertion were measured. Furthermore, lactate was measured at the completion of each exercise stage. Contribution of fat and carbohydrate to energy expenditure and oxidation rates were calculated from RER and  $\dot{V}O_2$  during the last minute of the stage. When comparing the maximal physiological responses to exercise, there was no difference in relative  $\dot{V}O_{2peak}$ , heart rate, or rating of perceived exertion. However, EP and MP had significantly lower maximal RER values compared YA. At submaximal exercise, there was no difference between groups for heart rate or rating of perceived exertion at an intensity. At all submaximal intensities, there was no difference in RER, substrate utilization, substrate oxidation, or blood lactate response between EP and MP or LP and YA. However, MP had a significantly lower RER, carbohydrate utilization, and carbohydrate oxidation rate than LP and YA at all submaximal intensities. Furthermore, MP had a significantly greater fat utilization and oxidation rate compared to LP and YA at all submaximal intensities. In the EP group, there was a significantly lower RER when compared to YA at all intensities other than 30% and LP at 50 and 60%. Fat utilization was significantly higher and carbohydrate utilization was significantly lower in EP when compared to YA at 40, 50, and 60%

and LP at 60%. Carbohydrate oxidation in EP was never significantly different than LP or YA, but fat oxidation was significantly higher in EP compared to YA at all intensities other than 70% and compared to LP and 50 and 60%. In conjunction with substrate utilization data, there was a significant interaction for blood lactate response to exercise. MP had significantly lower blood lactate than YA at all intensities and LP at 50, 60, and 70%. EP had significantly lower blood lactate than YA at 50, 60, and 70% and LP at 50 and 70%. In summary, the metabolic response to submaximal exercise varies between males based on pubertal status. EP and MP tend to utilize fat more carbohydrates when compared to LP and YA at submaximal exercise intensities. No differences were observed between EP and MP or LP and YA which may indicate that a metabolic shift occurs between MP and LP.

*Beneke, Hütler, and Leithäuser, (2007)*

### **Anaerobic performance and metabolism in boys and male adolescents**

The purpose of this study was to compare performance on a Wingate anaerobic power test between preadolescent and adolescent boys. Maturation status was not measured in this study, but there was significant difference in age between preadolescent ( $11.8 \pm 0.5$ y) and adolescent ( $16.3 \pm 0.7$ y) boys. The Wingate test was performed with a resistance of 7.5% the participant's body mass and required all-out effort for 30 seconds. Prior to the application of Breath-by-breath  $\dot{V}O_2$  was recorded during the test and 20 minutes of seated recovery following the test. During the 20-min recovery period, blood lactate concentrations were determined. Using the blood lactate and  $\dot{V}O_2$  data, the authors were able to estimate the energy derived from glycolysis, anaerobic lactic systems (PCr), and aerobic energy systems. As body mass was different between the two groups, all power and energy measures were made relative to the participant's body mass. The results of the Wingate test revealed a significantly greater peak



cadence in adolescents ( $153.5 \pm 12.3$  rpm) when compared to preadolescent boys ( $97.3 \pm 13.2$  rpm). Furthermore, adolescents had significantly greater relative peak, mean, minimum power when compared to their younger counterparts; however, there was no difference in power drop or fatigue index between groups. In addition, the adolescent group ( $12.6 \pm 0.7$  mmol $\cdot$ l $^{-1}$ ) had a significantly greater blood lactate concentration after the Wingate test when compared to the preadolescent group ( $10.4 \pm 1.1$  mmol $\cdot$ l $^{-1}$ ). However, no group differences were observed in the total energy produced during the Wingate test; however, the preadolescent boys had a significantly greater percentage of their energy come from aerobic metabolism. This study concluded that anaerobic performance during a Wingate test improves with age and that blood lactate concentrations after a Wingate are significantly higher in adolescents than preadolescents. In terms of relative energy contributions during the Wingate test, this study observed a significantly greater contribution from aerobic metabolism in the preadolescent group ( $21.5 \pm 2.1\%$ ) when compared to the adolescent group ( $19.2 \pm 2.1\%$ ). Overall, this study supports the claims that younger boys have significantly reduced anaerobic ability and rely more on aerobic metabolism than their older counterparts.

*Riddell, Jamnik, Iscoe, Timmons, and Gledhill, (2008)*

### **Fat oxidation rate and the exercise intensity that elicits maximal fat oxidation decreases with pubertal status in young male subjects**

The purpose of this study was to assess the changes in maximal fat oxidation rate and the exercise intensity that elicits maximal fat oxidation rate (Fatmax). Five Tanner stage 1 boys were tested three times over a 3-year period. The second test occurred when all boys were Tanner stage 2 or 3. The third test occurred when all boys were Tanner stage 4. Nine young adult males were measured once as a comparison group. During each testing session, participants completed a staged graded exercise test on a cycle ergometer. During the test  $\dot{V}O_2$  and  $\dot{V}CO_2$  were

measured to determine RER and fat oxidation rates throughout the test. There was no difference between groups when comparing  $\dot{V}O_{2peak}$ , peak heart rate, or peak RER. The maximal fat oxidation rate was significantly greater than Tanner stage 1 boys when compared to adult men. Furthermore, maximal fat oxidation rate did not significantly change from Tanner stage 1 to Tanner stage 2/3, but significantly decreased at Tanner stage 4, which was similar to adult men. All Tanner stages had a significantly higher fatmax when compared to adult men. Furthermore, there was a trend towards a decrease in fatmax with increased maturation. In summary, prepubescent children have increased fat oxidation rates which occur at higher exercise intensities when compared to postpubescent boys and young adult males. Furthermore, the fat oxidation rate and fatmax decrease with maturation, particularly from pre- and peri-pubescence to post-pubescence.

*Bottaro, Brown, Celes, Martorelli, Carregaro, and de Brito Vidal, (2011)*

### **Effect of rest interval on neuromuscular and metabolic responses between children and adolescents**

This study compared different work:rest ratios and isokinetic contraction velocities amongst pre-adolescent and adolescent males. Eighteen boys, classified as Tanner stages 1 or 2, were recruited into the pre-adolescent group, while 19 Tanner stage 4 boys were recruited into the adolescent group. All participants completed four trials on an isokinetic dynamometer over the course of two days. For each trial, participants were required to complete three sets of 10 concentric knee extensions at either 60 or 180 °/sec. The other variable that was manipulated was rest time, which was either one or two minutes between sets for each contraction velocity. During each of the 60 °/sec trials, blood lactate concentration was determined before and after the completion of the trial. Peak torque values were recorded for each repetition and the average peak torque for each set was calculated. The adolescent males had significantly greater peak

torque values when compared to pre-adolescent males regardless of contraction velocity, set, or rest interval. Both groups had significantly greater peak torque during the 60 °/sec trials regardless of set or rest interval. Furthermore, set 1 produced the greatest peak torque in both groups regardless of contraction velocity or rest interval. However, only the adolescent group had a significant decline in peak torque from set 2 to set 3. There was no effect of rest interval on the decline in peak torque amongst pre-adolescent males at either contraction velocity. Amongst adolescent males, there were significantly greater declines in peak torque when 1-minute rest intervals were used when compared to 2-minute rest intervals. When comparing blood lactate concentrations, both groups had significant increases in blood lactate regardless of rest interval. Both groups had similar resting blood lactate concentrations, but the adolescent group had significantly greater concentrations than the pre-adolescent group after each trial. However, there was no effect of rest interval on the change in blood lactate concentration in either group. In conclusion, adolescent boys may need longer rest times to maintain anaerobic performance while pre-adolescent boys are not affected by the duration of the rest interval. Furthermore, adolescent boys have a greater blood lactate response than their pre-adolescent counterparts regardless of rest interval. When training youth athletes, their maturational status may have an impact on their recovery from exercise bouts and therefore must be accounted for when designing a training program.

*Kappenstein, Ferrauti, Runkel, Fernandez-Fernandez, Müller, and Zange, (2013)*

### **Changes in phosphocreatine concentration of skeletal muscle during high-intensity intermittent exercise in children and adults**

This study compared the ATP and phosphocreatine (PCr) concentrations between children ( $9.4 \pm 0.5$ y) versus adults ( $26.1 \pm 0.3$ y) during high-intensity intermittent exercise. Both males and females were utilized in this study, but there were no sex differences amongst the

children. The intermittent exercise consisted of 10 bouts of 30 seconds of plantar flexion at 25% of estimated 1 repetition maximum (1RM), with 20 seconds of rest between bouts. During the exercise test, magnetic resonance spectroscopy (MRS) of the calf was assessed to determine PCr, ATP, and pH in the exercising muscle. The decrease in PCr during the first exercise bout was significantly attenuated in children when compared to adults. No other differences in the PCr depletion rate were noted during subsequent exercise bouts. However, the average PCr at the end of the exercise bout and during recovery periods was significantly greater in children. These findings show that children do not utilize and deplete PCr at the same rate as adults.

*Engel, Hartel, Wagner, Strahler, Bos, and Sperlich, (2014)*

### **Hormonal, metabolic, and cardiorespiratory response of young and adult athletes to a single session of high-intensity cycle exercise**

This study aimed to compare the responses of boys ( $11.5 \pm 0.8$  y) and men ( $29.7 \pm 4.6$  y) to a single high-intensity interval training session. The high-intensity interval training session consisted of four 30-second all-out isokinetic sprints on an electronically braked cycle ergometer. The cadence was set to 120 rpm during each sprint and participants were instructed to pedal at maximum intensity. Between each sprint, there was a 2-minute active recovery period of cycling between 60-90 rpm at a resistance equivalent to  $1.5 \text{ W} \cdot \text{kg}^{-1}$ . During the training session, heart rate, oxygen consumption, and carbon dioxide production were recorded. For each sprint, peak power, mean power, and fatigue index were recorded for each sprint. Peak and mean power were expressed relative to lean body mass assessed with bioelectrical impedance analysis. Before and after the training session, salivary cortisol and blood lactate concentrations were recorded. Also, blood lactate was recorded after each sprint. There was no difference in salivary cortisol concentrations between boys and men before or after the training session. However, blood lactate concentrations were significantly lower in boys than men after sprints 2, 3, and 4, and throughout

recovery. No differences in blood lactate were noted at baseline or after the first sprint. Also, average heart rate during each sprint was greater in boys when compared to men, but no differences were observed when heart rate was expressed relative to max heart rate. Conversely, relative and absolute maximal oxygen consumption were lower in boy than in men. When assessing performance, relative peak and mean power were significantly greater in men than boys. However, no differences were observed in fatigue index for any of the four sprints. In summary, boys had similar oxygen consumption, relative heart rate, and cortisol responses to the training session when compared to men. Conversely, men had greater power outputs during each sprint and a greater blood lactate response to the training session. The differing responses to interval training may result in different training adaptations between boys and men.

*Hatzikotoulas, Patikas, Ratel, Bassa, Kotzamanidis, (2014)*

### **Central and peripheral fatigability in boys and men during maximal contraction**

The purpose of this study was to assess central and peripheral fatigue amongst prepubescent boys ( $10.7 \pm 0.2$ y) and adult men ( $26.4 \pm 0.7$ y). All participants were seated in in an isokinetic dynamometer and testing was conducted on the dominant foot. Participants were situated in a supine position, with hips flexed at  $60^\circ$  and knee at full extension.

Electromyography electrodes were placed on the soleus, medial gastrocnemius, and tibialis anterior. All participants completed a fatigue-inducing protocol consisting of sustained maximal isometric plantarflexion. Participants held this contraction until they were unable to maintain 50% of maximal isometric force. Before and after the fatigue-inducing protocol, a maximal isometric voluntary contraction of the plantar flexors with a supramaximal stimulation at the plateau of force was conducted. Also, a resting twitch torque and M-wave were assessed before and after the fatigue-inducing protocol. The torque and electromyography signals from the

fatigue-inducing protocol were separated into fifths and averages were calculated for each. Pre-fatigue and post-fatigue values were recorded for peak torque, twitch torque, rate of torque development, maximum m-wave, and activation deficit. Activation deficit was calculated as interpolated torque divided by voluntary torque minus 1 and then multiplied by 100. At baseline, men had significantly greater absolute and relative plantarflexion torque, twitch torque, and rate of torque development. All data was assessed as a percentage of the baseline values. When assessing post-fatigue values, men had a significantly greater decline in twitch torque and rate of torque development. However, no differences were observed in activation deficit or M-wave. During the fatigue-inducing protocol, men had a significantly longer time until exhaustion. Furthermore, there was a significantly greater decreases in torque in men when compared to boys in the second and third fifth of the protocol. Similarly, medial gastrocnemius activation has significantly greater decreases in men at the second and third fifth of the protocol. In conclusion, men have higher fatigability than boys in response to a sustained isometric contraction. Furthermore, it appears that men have greater peripheral fatigability, while central fatigability appears to be similar. The blunted fatigue in boys is most likely due to peripheral factors.

*Engel, Sperlich, Stockinger, Haertel, Bos, and Holmberg, (2015)*

### **The kinetics of blood lactate in boys during and following single and repeated all-out sprints of cycling are different than men**

This study examined the performance decrements during repeated all-out sprints and associated lactate concentrations in boy and men. All participants were members of local soccer clubs, under-12 for the boys ( $11.4 \pm 0.8$ y) and adult recreational for the men ( $29.4 \pm 5.0$ y). All participants completed two interval training sessions completed in a random order on separate days. The single sprint session consisted of a 10-minute warm up followed by a 3-minute recovery and then a 30-second all-out Wingate-style sprint. The resistance for the sprint was set

7.5% of participant's body mass. During the repeated sprint session, the same warm and sprint parameters were utilized. In addition, participants were provided with 2-minutes of active recovery between sprints. Before each sprints, in between repeated sprints, and 30 minutes after the last sprint, blood lactate concentrations were measured. In terms of performance, boys had significantly lower relative peak and mean power than men during all springs. Furthermore, men had a significant reduction in relative peak power from the first to fourth sprint, while the boys did not. Peak blood lactate concentrations in the boys were significantly lower than the men during the single and repeated sprint sessions. Furthermore, the men had significantly higher blood lactate concentrations than the boys throughout the recovery the period. In addition, boys had significantly faster rise and clearance of blood lactate during single and repeated sprint protocols. In conclusion, boys produce less power and lower blood lactate concentrations than men; however, boys also are able to maintain their power output and remove lactate faster than men.

#### Effect of age and maturation on fatigue thresholds

*Reybrouck, Weymans, Stijns, Knops, and van der Hauwert, (1985)*

#### **Ventilatory anaerobic threshold in healthy children**

This study examined the  $\dot{V}O_2\text{max}$  and ventilatory threshold in boys from ages 5.7 to 18.5 years old and girls aged 6.0 to 16.5 years old. Maturity status was not assessed in this study, but children were grouped into 2-year age brackets starting with 5-6 and ending with 17-18. Graded exercise tests were performed on a treadmill with a set speed and increasing incline every minute.  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , and ventilation ( $\dot{V}E$ ) were measured throughout the graded exercise test. In this study, ventilatory threshold was defined as the nonlinear increase in the  $\dot{V}E/\dot{V}O_2$  relationship with increasing workloads.  $\dot{V}O_2$  data were expressed relative to body mass and ventilatory

threshold data were expressed as the  $\dot{V}O_2$  value relative to body mass and as a percent of  $\dot{V}O_{2max}$ . Amongst boys,  $\dot{V}O_{2max}$  values were lowest in the youngest age group when compared to all other age groups; however, no other differences were noted. For ventilatory threshold, the oldest boys had the lowest  $\dot{V}O_2$  value and percentage of  $\dot{V}O_{2max}$ , while the youngest boys had the greatest values. The findings of this study indicate that the onset of ventilatory threshold occurs earlier in older males when compared to younger boys. While a decrease in ventilatory threshold with age may be interpreted as a maladaptation, it is likely indicative of greater anaerobic energy system utilization in older males.

*Tanaka and Shindo, (1985)*

### **Running velocity at blood lactate threshold of boys aged 6-15 years compared with untrained and trained young males**

This study assessed the age-related change in running velocity and heart rate at lactate threshold. Eighty-eight males between the ages of 6 and 23 completed a discontinuous incremental running test. The first stage of the running test began between 80 and 100 m/min and increased by 20 m/min per stage. Each stage last 4 minutes with 2 minutes of rest between stages. Heart rate and blood lactate vales were obtained immediately after each stage and at the end of the test. Lactate threshold was determined as the velocity just below accumulation of 2 mmol/L of lactate. Participants were grouped according to age with groups of 6-7 years old, 8-9 years old, 10-11 years old, 12-13 years old, 14-15 years old, 16-18 years old, and 19-23 years old. The 16-18 years old group was actively participating in competitive sports for at least 90 minutes per day, while all other groups were considered untrained. The velocity at which lactate threshold occurred was significantly lower in the 19-23 years old group when compared to all other groups. In terms of heart rate at lactate threshold, the 19-23 years old group was significantly lower than all other groups. Furthermore, the 6-7 years old, 8-9 years old, and 10-11



years old groups had heart rates at lactate threshold that were significantly greater than the 12-13 years old, 14-15 years old, 16-18 years old, and 19-23 years old groups. While the results of this study indicate that lactate threshold occurs at lower running velocities in younger children, this finding was only based on absolute velocity and not relative to maximal running velocity. As with ventilatory thresholds, it is important to assess age and maturity related differences as percentages of maximum to fully understand the differences in the responses to exercise.

*Klentrou, Nishio, and Pyley, (2006)*

### **Ventilatory breakpoints in boys and men**

This study compared the first and second ventilatory breakpoints between boys and adult men. The average age of the boys in the study was  $10.8 \pm 0.3$  years, while the men were  $24.6 \pm 1.1$  years. All of the boys in the study were determined to be prepubescent and were actively competing in soccer or hockey. All adult men were exercising for at least 30 minutes, three times per week. All participants completed three sessions, with the first visit including anthropometric and body composition measurements. The second and third visit consisted of a graded walk-run maximal treadmill test. All participants began at a comfortable walking pace, which increased to a slow jog and then a self-selected running pace. After reaching the self-selected running pace, the grade of the treadmill increased 1% per minute until exhaustion.  $\dot{V}O_{2peak}$  was determined from the highest  $\dot{V}O_2$  value in a 30-second period. The first ventilatory breakpoint (VB1) was determined by averaging by the first inflection in the  $\dot{V}E$  versus  $\dot{V}O_2$  curve and the inflection in the  $\dot{V}CO_2$  versus  $\dot{V}O_2$ . The second ventilatory breakpoint (VB2) was determined by averaging the second inflection in the  $\dot{V}E$  versus  $\dot{V}O_2$  curve and the  $\dot{V}O_2$  value corresponding to the inflection in the  $\dot{V}E$  versus  $\dot{V}CO_2$  curve. While 11 of 12 adult men had a discernable VB2, only six of the boys showed a discernable VB2. No differences in  $\dot{V}O_{2peak}$  were observed between

the boys and adult men when made relative to body mass. Furthermore, no differences were observed in the  $\dot{V}O_2$  value at which VB1 and VB2 occurred when expressed relative to body mass. However, significant differences did exist in VB1 and VB2 when expressed as an absolute  $\dot{V}O_2$  value, with men being greater than boys. Furthermore, VB1 was significantly greater in boys ( $64.9 \pm 7.1\%$ ) than men ( $57.7 \pm 8.0\%$ ) when expressed relative to  $\dot{V}O_{2peak}$ . However, for VB2, no differences were observed between boys ( $82.0 \pm 3.8\%$ ) and men ( $77.3 \pm 5.1\%$ ) when expressed relative to  $\dot{V}O_{2peak}$ . The difference in VB1 between boys and men has been a consistent finding in the literature, usually attributed a greater increase in  $\dot{V}E$  in younger children. The lack of an identifiable VB2 in boys may be due to the lack of anaerobic energy metabolism that would have resulted in increased hydrogen ions and ultimately increased ventilation. The main finding of this study is that despite similar maximal aerobic capacity there is a difference in the onset and detection of ventilatory thresholds in boys and adult men. Therefore, assessing maximal oxygen consumption of adolescent males may not be adequate information to properly prescribe endurance exercise programs.

*Anderson and Mahon, (2007)*

### **The relationship between ventilatory and lactate threshold in boys and men**

This study assessed the difference in ventilatory and lactate thresholds between prepubescent boys ( $11.1 \pm 0.7y$ ) and adult men ( $24.0 \pm 3.3y$ ). Pubertal status was assessed in the boys using Tanner stages. All participants completed a graded exercise test on an electronically braked cycle ergometer, with 2-minute stages. For the boys, the workload started at 30 watts and increased by 15 watts every stage. For the men, the initial workload and workload increments were doubled.  $\dot{V}O_2$ ,  $\dot{V}CO_2$ ,  $\dot{V}E$ , and RER were recorded throughout the graded exercise test. Blood lactate concentration was measured during the last 15 seconds of each stage. Ventilatory

and lactate thresholds were determined by visual inspection from a skilled evaluator. Ventilatory threshold was defined as the  $\dot{V}O_2$  value corresponding to a nonlinear increase in the  $\dot{V}E/\dot{V}O_2$  relationship. Lactate threshold was identified as the  $\dot{V}O_2$  values associated with a nonlinear increase in blood lactate concentrations. The adult men had significantly greater absolute  $\dot{V}O_{2peak}$ , RER, and maximal blood lactate concentrations. Ventilatory and lactate thresholds occurred at a lower absolute  $\dot{V}O_2$ , but greater percent of  $\dot{V}O_{2peak}$  in boys when compared to men. As  $\dot{V}O_{2peak}$  was significantly different between the groups, percent of  $\dot{V}O_{2peak}$  provides a better understanding when comparing males of different ages. The delayed ventilatory and lactate thresholds in boys may be due to their underdeveloped anaerobic system and greater reliance on aerobic metabolism.

*Cunha, Lorenzi, Sapata, Lopes, Gaya, and Oliveira, (2011)*

### **Effect of biological maturation on maximal oxygen uptake and ventilatory thresholds in soccer players: An allometric approach**

This study compared the  $\dot{V}O_{2max}$ , ventilatory threshold, and respiratory compensation point in pubescent and post pubescent male soccer athletes. The study categorized 110 amateur soccer players as either pubescent or post pubescent according to their Tanner stage. Tanner stages 2, 3, and 4 were considered pubescent while Tanner stage 5 was considered post pubescent. All participants completed a graded exercise test on a treadmill which began at 7 km/h and increased 0.5 km/h every 30 seconds. From this graded exercise test, values for  $\dot{V}O_{2max}$ , ventilatory threshold, and respiratory compensation point were determined.  $\dot{V}O_{2max}$ , ventilatory threshold, and respiratory compensation point data were expressed in absolute terms, relative to body mass, and relative to body mass with allometric scaling factors. Three different allometric scaling factors were utilized when expressing the data. Theoretical factors of 0.67 and 0.75 were used for all variables and an experimental factor was calculated based on the linear

regression from the data collected. The experimental factor for  $\dot{V}O_{2\max}$ , ventilatory threshold, and respiratory compensation point were 0.90, 0.94, and 0.95, respectively. When expressed in absolute terms, post pubescent had significantly greater  $\dot{V}O_{2\max}$ , ventilatory threshold, and respiratory compensation point. No differences were observed between groups when assessing all variables relative to body mass. For  $\dot{V}O_{2\max}$  data, post pubescent had significantly greater values than pubescent regardless of allometric scaling factor. However, no differences were observed between post pubescent and pubescent when assessing ventilatory threshold with any of the allometric scaling factors. When assessing respiratory compensation point, post pubescent was significantly greater than pubescent when scaled with 0.67 and 0.75, but no differences were observed with 0.95. In conclusion, absolute  $\dot{V}O_{2\max}$ , ventilatory threshold, and respiratory compensation point are significantly greater in post pubescent boys, compared to pubescent boys. However, this difference is most likely due to differences in body mass, which when taken into account, results in no difference between the groups. The use of allometric scaling, specifically experimentally derived factors, may be the most appropriate means of comparing individuals of different maturational statuses. However, it is important to note that this study did not compare ventilatory threshold and respiratory compensation point relative to the measured  $\dot{V}O_{2\max}$ . While the absolute intensity at which these thresholds occur may be higher in more mature individuals, the relative intensity at which these thresholds occur may be greater in younger, less mature individuals.

*Pitt, Dotan, Millar, Long, Tokuno, O'Brien, and Falk, (2015)*

### **The electromyographic threshold in boys and men**

This study compared the onset of neuromuscular fatigue, via electromyography, between boys ( $11.1 \pm 1.1$ y) and men ( $23.4 \pm 4.1$ y). All participants were actively competing in sports and

there was no difference in body fat percentage between groups. All of the boys we assessed for maturity status, using Tanner staging and years from peak height velocity. On average, the boys were  $-2.30 \pm 0.63$  years from peak height velocity with a range of  $-0.88$  to  $-3.59$ . During their first visit to the lab, all participants completed a staged graded exercise test on a cycle ergometer to determine  $\dot{V}O_{2\text{peak}}$ . For the second visit, participants completed a ramp exercise protocol on the same cycle ergometer with the addition of electromyography on the vastus lateralis muscle throughout the test. The electromyography threshold was determined as the point where the electromyography signal exceeded 3 standard deviations above the regression line for the first 70% of the test. A threshold was determined in 95.2% of adults and 78.3% of boys. In those participants where a threshold was determined, the electromyography threshold occurred at a significantly higher relative workload in boys ( $86.4 \pm 9.6\%$  of peak power) than men ( $79.7 \pm 10.0\%$  of peak power). This finding demonstrates that young boys activate their higher threshold motor units at a greater relative exercise intensity, indicating a lesser utilization of type II motor units. Accordingly, young boys may have a greater reliance on type I motor units, which would provide further evidence of their reliance on oxidative metabolism.

#### Effect of age and maturation on the adaptation to training

*Lillegard, Brown, Wilson, Henderson, and Lewis, (1997)*

#### **Efficacy of strength training in prepubescent to early postpubescent males and females: effects of gender and maturity**

The purpose of this study was to assess the efficacy of a 12-week resistance training program in prepubescent and postpubescent children. Maturity status was determined using Tanner staging, with stages 1-2 considered prepubescent and stages 3-5 considered postpubescent. For each maturity group, there was a male and female training group and a male and female control group. Before and after training, each participant was assessed for a 10-

repetition maximum on a barbell curl, triceps extension, bench press, lat pulldown, leg extension, and leg curl. Also, circumferences were measured at the upper arms, thighs and forearms and skinfold thickness was measured at the subscapular, triceps, and medial calf. Motor performance was also assessed using a bent arm hang, sit and reach, vertical jump, broad jump, shuttle run, and 30-yard dash. The 12-week training program consisted of three 1-hour training sessions per week of progressive resistance training. During each session, participants completed three sets of ten repetitions of their respective 10-repetition-maximum on six different exercises. Change scores for each variable were calculated and used in further assessment. For each assessment, a gender by group by maturity status ANOVA was conducted. For the strength measures, there was no significant 3-way or 2-way interactions. However, there was a significant main effect of group for triceps extension, bench press, lat pulldown, and leg extension, with greater gains in the training group. There was also a main effect of gender for lat pulldown and leg extension with greater gains in the males. For anthropometric measurements, there was no group by maturity interaction, but a main effect of group for the biceps and thigh circumference and all skinfolds. The training group had greater increases in the girth measurements and greater decreases in the skinfold measurements. Similarly, there was a main effect of group for the shuttle run, broad jump, 30-yard dash, and sit and reach, all with greater improvements in the training group. This study illustrated that resistance training is an effective means to improve strength, body composition, and motor performance in adolescent youths. However, this study showed no difference between maturity groups in improvements.

*Behringer, vom Heede, Yue, and Mester, (2010)*

### **Effects of resistance training in children and adolescents: a meta-analysis**

The aim of this meta-analysis was to determine the effects of resistance training on

strength improvements amongst different age groups of children. A total of 42 studies were included in this meta-analysis. Overall effect size was determined, along with the effect of maturity, gender, and program design variables. The overall combined effect size of resistance training on strength amongst children and adolescents was  $1.12 \pm 0.11$ . This overall effect was statistically significantly greater than the control groups in the meta-analysis. The effect of resistance training on strength was significantly affected by maturity, with a larger effect amongst more mature children. However, there was no effect of gender on the effect of resistance training on strength. Program design variables had significant influence on the effect of resistance training on strength. The variables that had significant effects were study duration and number of training sessions per week, while number of sets and average intensity did not have an effect. Furthermore, there was no effect of training type or external resistance type. In conclusion, resistance training does significantly improve strength amongst children and adolescents. Furthermore, that effect appears to be greater in postpubescent children when compared to prepubescent. Also, the most important training program variables for increasing strength from resistance training are training session frequency and total length of training.

*Lloyd, Radnor, De Ste Crois, Cronin, and Oliver, (2016)*

### **Changes in sprint and jump performances after traditional, plyometric, and combined resistance training in male youth pre- and post-peak height velocity**

The purpose of this study was to compare three different training programs amongst prepubescent and postpubescent males. Prior to any testing all participants were assessed for maturity status via years from peak height velocity. All participants completed squat jump and 5-maximal rebound tests. From the two tests, a reactive strength index was calculated for each participant. Also, participants completed a 20-meter sprint test. The first 10 meters were used to determine acceleration. The jump and sprint testing were completed before and after the 6-week

training period. Participants were randomly placed into either a control, traditional strength training, plyometric training, or combined training group. All training groups completed training two days per week. The traditional strength training group completed three sets of ten repetitions on the back squat, lunge, step up, and leg press exercises. The plyometric training group completed multiple sets of four exercises per session with total foot contacts starting at 74 and progressing to 88. The combined training group completed two traditional strength training exercises and two plyometric exercises per session. All data were assessed with a group by time by maturity ANOVA. Regardless of maturity status, no control group made any significant improvements in jumping or sprinting performance. There were significant main effects of maturity for acceleration and sprinting performance, with greater improvements in the postpubescent group. Furthermore, acceleration improved amongst all three training groups within the prepubescent group, but only improved in the traditional and combined groups amongst the postpubescent group. Also, sprinting speed only improved in the plyometric and combined groups in both the prepubescent and postpubescent groups. In terms of jump performance, all training groups amongst the prepubescent group showed significant improvements, while amongst the postpubescent group squat jump improvements only occurred in the traditional and combined groups and reactive strength index only improved in the plyometric and combined groups. When differences between maturity groups were compared with magnitude based inferences, most data revealed trivial differences. However, when examining the plyometric training groups, the prepubescent group had *Very Likely* greater increases in acceleration squat jump performance. In conclusion, prepubescent children appear to have better training adaptations to plyometric training than postpubescent children. The addition of resistance training may be a greater benefit to postpubescent children than prepubescent.



*Moran, Sandercock, Ramirez-Campillo, Todd, Collison, and Parry, (2016)*

### **Maturation-related effect of low-dose plyometric on performance in youth hockey players**

The aim of this study was to investigate the maturity-related differences in the adaptations to plyometric training amongst youth field hockey athletes. This study randomized thirty-eight male athletes into either a plyometric training or control group. Further, participants were assessed for maturity status using the years from peak height velocity equation. Participants were classified as prepubescent (-1.9 to -1.0 years from peak height velocity) and peripubescent (0.0 to 0.9 years past peak height velocity). To assess adaptations to plyometric training, all participants completed a countermovement jump, 10-meter sprint and 30-meter sprint. The plyometric training program consisted of 60 foot contacts per sessions with two sessions per week over a 6-week training period. Within each plyometric training session, no more than ten repetitions per set of each exercise, which included countermovement jumps, bilateral forward hops, and unilateral forward hops. The control group completed low intensity hockey skills work during the time the plyometric training was being conducted. After the intervention period, the peripubescent athletes who completed plyometric training had a small improvement in 10-meter sprint time, while the prepubescent control had a small decrease in countermovement jump height. All other results within each group were considered trivial increases or decreases. When compared to control groups, plyometric training had moderate improvements in countermovement jump height and 30-meter sprint and a small improvement in 10-meter sprint. In summary, plyometric training resulted in small or moderate improvements in jumping and sprinting performance in peripubescent athletes, but only small or trivial effects were observed in the prepubescent athletes.

*Moran, Sandercock, Ramirez-Campillo, Meylan, Collison, and Parry, (2016)*

### **Age-related variation in male youth athletes' countermovement jump following plyometric training: a meta-analysis of controlled trials**

The purpose of this meta-analysis was to assess the trainability of jumping ability from plyometric training amongst children and adolescents. A total of 21 studies were included in this meta-analysis. The overall effect of plyometric training on countermovement jump performance was 0.73, which was significantly greater than control. To investigate the effect of maturity, the studies were grouped according to age of participants into prepubescent (10-12.99y), peripubescent (13-15.99y), and postpubescent (16-18y). The peripubescent group had a significant effect of plyometric training on jump performance, but it was the smallest effect (0.47) of the maturity groups. Both prepubescent and postpubescent had significant moderate sized effects of 0.91 and 1.02, respectively. Furthermore, training program duration and number of training sessions were significant moderators of the effect of plyometric training on countermovement jump performance, with longer training programs and a greater number of sessions having a greater effect, respectively. In conclusion, plyometric training appears to be moderately effective at improving countermovement jump performance in prepubescent and postpubescent children, but has little effectiveness on peripubescent children.

*Moran, Sandercock, Rumpf, and Parry, (2016)*

### **Variation in responses to sprint training in male youth athletes: a meta-analysis**

This meta-analysis aimed to assess the trainability of sprint speed from sprint training amongst adolescents. Further, this study assessed the effect of maturation on the trainability of sprint speed. Fourteen studies were included in this meta-analysis and determined maturity status as prepubescent (10-12.99y), peripubescent (13-15.99y), and postpubescent (16-18y). The overall effect of sprint training on sprint speed amongst youth was 1.01 which was moderate and

significant. Amongst maturity groups, postpubescent had the largest significant effect, which was 1.39. Furthermore, peripubescent had a significant moderate effect of 1.15. However, there was not a significant effect of sprint training on sprint speed amongst prepubescent youth. When assessing training program variables, longer training duration and increased number of training sessions resulted in larger effects. In conclusion, as children progress through puberty the trainability of sprint speed increases. This may be another result of the diminished anaerobic metabolism that exists prior to puberty.

#### Effect of high-intensity interval training on adults

*Burgomaster, Hughes, Heigenhauser, Bradwell, and Gibala, (2005)*

#### **Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans**

The purpose of this study was to examine the effect of six sprint interval training session on aerobic capacity and oxidative potential in recreationally active adults (age: 22±1y) compared to a control group. All participants completed a staged  $\dot{V}O_{2peak}$  test and time to exhaustion test on a cycle ergometer before and after completing a 2-week interval training protocol. Also, resting muscle biopsies were collected from the vastus lateralis of the training group before and after training. The time to exhaustion test was completed at 80% of the previously determined  $\dot{V}O_{2peak}$ . The interval training program consisted of six training sessions over the course of 14 days with at least one day of rest in between sessions. During each session, participants completed 30-s repeated Wingate-style sprints against a load equivalent to 7.5% of the participant's body mass. Throughout the training program, the number of sprints was increased from four to seven, with a taper of four sprints during the last training session. After the completion of training, all participants completed exercise testing and the training group provided a second muscle biopsy. The training group had a significant improvement in cycling

time to exhaustion, but no change in  $\dot{V}O_{2\max}$  when compared to the control group. Furthermore, peak power output was significantly greater during the four sprints of the last training session when compared to the four sprints of the first training session. From the muscle biopsy samples, it was determined that there was a significant increase in citrate synthase activity and muscle glycogen content. However, there were no changes in ATP, phosphocreatine, or creatine. In conclusion, this study observed significant increases in anaerobic power and time to exhaustion from only six sessions of sprint interval training. Furthermore, this study observed significant changes in citrate synthase activity and muscle glycogen stores after short-term sprint interval training in recreationally active males.

*Burgomaster, Heigenhauser, and Gibala, (2006)*

### **Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance**

The purpose of this study was to assess the effectiveness of a short-term sprint interval training program on carbohydrate metabolism. This study utilized 16 health males who were considered recreationally active two to three times per week. Eight of the participants engaged in a 2-week sprint interval training program, while the other eight served as controls. All participants completed a staged test on a cycle ergometer to establish  $\dot{V}O_{2\text{peak}}$ . Before and after training, all participants completed a 10-km time trial and Wingate test. In addition, the training group completed an exercise metabolism test. The exercise metabolism test consisted of muscle biopsies before and after a 10-minute exercise bout at 60% of  $\dot{V}O_{2\text{peak}}$  followed by another 10-minute exercise bout at 90% of  $\dot{V}O_{2\text{peak}}$  and a third muscle biopsy. The muscle samples were analyzed for pyruvate dehydrogenase activity, citrate synthase activity, glycogen content, lactate content, creatine content, phosphocreatine content, and ATP content. The sprint interval training program consisted of six sessions over the course of 14 days. Each training session consisted of

repeated Wingate sprints with four minutes of recovery between sprints. The training group had significant improvements in time trial performance, Wingate mean and peak power, and percent fatigue. Conversely, the control group had no changes in any performance measures. In terms of muscle biopsy samples, there was increased citrate synthase activity, pyruvate dehydrogenase activity, and glycogen content, while lactate, creatine and ATP contents were significantly decreased. In conclusion, six sprint interval training sessions decreased glycogenolysis and lactate accumulation, while also improving sprint and time trial performance. Short-term sprint interval training appears to be a potent stimulus to cause changes in exercise metabolism and performance.

*Gibala, Little, van Essen, Wilkins, Burgomaster, Safdar, Raha, and Tarnopolsky, (2006)*

### **Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance**

This study compared sprint interval training and high volume endurance training in young adult males. All participants completed a ramped  $\dot{V}O_{2peak}$  test on a cycle ergometer, a 2-km time trial, 30-km time trial, and Wingate test. Furthermore, participants provided a resting muscle biopsy before and after training. Muscle samples were analyzed for oxidative capacity (cytochrome c oxidase), muscle buffering capacity and glycogen content. Both training groups completed six training sessions over the course of two weeks. The sprint interval training sessions consisted of 4-6 repeated Wingate-style sprints with four minutes of recovery between sprints. The endurance training sessions consisted of 90-120 minutes of cycling at 65% of  $\dot{V}O_{2peak}$ . After training, both groups improved 2-km and 30-km time trials, with no differences between groups. Similarly, both groups increased muscle oxidative capacity, muscle buffering capacity, and muscle glycogen content, without any significant differences between groups. In summary, sprint interval training and high volume endurance training resulted in similar

performance and metabolic improvements. In addition, the sprint interval training volume was 10% of the endurance training volume. Sprint interval training appears to be a time efficient alternative to high volume endurance training.

*Burgomaster, Howarth, Phillips, Rakobowchuk, MacDonald, McGee, and Gibala, (2008)*

### **Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans**

The purpose of this study was to compare the metabolic adaptations to sprint interval training and traditional endurance training. This study utilized recreationally active young adult men and women in both the sprint interval training and traditional endurance training groups. To assess  $\dot{V}O_{2peak}$ , all participants completed a ramp exercise protocol on a cycle ergometer. Before and training participants provided muscle biopsies prior to and immediately after a one hour cycling bout at 65% of  $\dot{V}O_{2peak}$ . Muscle samples were assessed for citrate synthase activity, 3-hydroxyacyl CoA dehydrogenase activity, and pyruvate dehydrogenase activity. Furthermore, these samples were assessed for proliferator activated receptor gamma coactivator 1 alpha, creatine, phosphocreatine, ATP, and lactate concentrations. Both training protocols were six weeks in length, with the endurance training occurring five days per week and the sprint interval training occurring only three days per week. The endurance training consisted of 40-60 minutes of continuous cycling at 65% of  $\dot{V}O_{2peak}$ . The sprint interval training consisted of 4-6 repeated Wingate-style sprints. After training, both groups increased  $\dot{V}O_{2peak}$  and peak anaerobic power, with no differences between groups. However, sprint interval training resulted in significant increases in mean anaerobic power, while there was no change in the endurance training group. Also, mean respiratory exchange ratio and heart rate during submaximal exercise was decreased after training in both groups. Also, fat oxidation increased while carbohydrate oxidation decreased after training, with no differences between groups. Similarly, activities of

citrate synthase and 3-hydroxyacyl CoA dehydrogenase and proliferator activated receptor gamma coactivator 1 alpha content were increased after training, with no differences between groups. Furthermore, there was no difference between groups in terms of glycogenolysis during exercise, but both groups exhibited significant decreases. In summary, both sprint interval training and endurance training improved aerobic and anaerobic performance while also altering fat and carbohydrate metabolism, despite sprint interval training had a 90% lower training volume than endurance training. This study contributes to the support of sprint interval training as a time efficient training strategy to increase performance and cause adaptation in substrate utilization.

*Bailey, Wilkerson, DiMenna, and Jones, (2009)*

### **Influence of repeated sprint training on pulmonary O<sub>2</sub> uptake and muscle deoxygenation kinetics in humans**

The purpose of this study was to compare sprint interval training and traditional endurance training on oxygen uptake and muscle oxygenation when the total work completed in the two training programs was equal. This study recruited recreationally active men and women who were randomized into either a sprint interval training group, endurance training group, or a control group. All participants completed a  $\dot{V}O_{2peak}$  test and two exercise bouts at moderate and severe intensity before and after the intervention period. The moderate exercise bout was set at 90% of gas exchange threshold, while the severe intensity bout was set at 70% of the difference between GET and  $\dot{V}O_{2peak}$ . During all tests, oxygen consumption, carbon dioxide production, ventilation, heart rate, and oxygenation status of the right vastus lateralis were recorded. Further, blood lactate was recorded at the end of each exercise bout. Both training groups completed six training sessions during a 14-day period. The sprint interval training sessions consisted of 4-7 repeated Wingate-style sprints with four minutes of recovery between sprints. The endurance

training sessions included continuous cycling at 90% of gas exchange threshold for a duration that would equate to the total work completed by the sprint interval training group. The sprint interval training had a significant increase in peak work rate, absolute  $\dot{V}O_{2\text{peak}}$ , and relative  $\dot{V}O_{2\text{peak}}$ , while none of these parameters had significant changes in the endurance training or control groups. Furthermore, blood lactate in response to moderate and severe intensity exercise was significantly reduced in the sprint interval training group only. Also, sprint interval training resulted in more rapid oxygen consumption kinetics, greater oxygen extraction, and a blunted lactate response to severe exercise. As work was equal between the two training groups, the adaptations in the sprint interval training group may be due to the increased intensity of exercise.

*Hazell, MacPherson, Gravelle, and Lemon, (2010)*

### **10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance**

The purpose of this study was to compare how different work to rest ratios of sprint interval training effected the adaptations to aerobic and anaerobic performance. The different training programs were 30-second sprints with 4-minute rest periods, 10-second sprints with 4-minute rest periods, or 10-second sprints with 2-minute rest periods. Forty-eight men and women were randomized into of the training groups or a control group. All training groups completed three training sessions per week and all sprints were “all-out” Wingate-style sprints. The number of sprints started at four and increased by one every two sessions. Before and after training, all participants completed a ramp  $\dot{V}O_{2\text{max}}$  test, a 5-km time trial, a Wingate test, and body composition test via BodPod. All three groups improve 5-km time trial performance and relative peak power when compared to baseline and control, but no differences were noted between training groups. In terms of  $\dot{V}O_{2\text{max}}$  and relative average power, only the training groups who had 4-minute rest periods between sprints had significant increases while the 10-second sprint



with 2-minute rest period and control groups did not change. However, there were no changes in body composition in any of the groups. In summary, sprint interval training with 10- or 30-second sprints improved anaerobic and aerobic performance, as long as the rest interval was 4 minutes. The longer rest interval would allow for greater power output during training, which may stimulate greater adaptations.

*Naimo, de Souza, Wilson, Carpenter, Gilchrist, Lowery, Averbuch, White, and Joy, (2015)*

### **High-intensity interval training has positive effects on performance in ice hockey players**

The aim of this study was to compare the adaptations to continuous endurance training and sprint interval training in ice hockey players. All participants had at least 3 years of ice hockey experience and were members of the same university ice hockey team. Participants were counterbalanced according to anaerobic peak power and then randomly assigned to either continuous endurance training or sprint interval training. Each training group completed two training sessions per week of their respective training program over the course a 4-week period. The sprint interval training sessions included 4-10 repeated “all-out” intensity sprints at an intensity equivalent to 7.5-10% of the participants’ body mass. The duration of each sprint was between 10 and 30 seconds with rest intervals primarily set at four minutes, with the exception of the ten sprint training day, where the rest intervals were only two minutes. The continuous endurance training sessions consisted of 45-60 minutes of continuous cycling at an intensity equivalent to 65% of heart rate reserve. Total training time for the sprint interval training group was 109.2 minutes, while the continuous endurance training group completed 420 minutes of exercise. Before and after training, all participants were assessed for body composition via dual x-ray absorptiometry, muscle thickness of the quadriceps via ultrasonography, anaerobic power and fatigue via a Wingate anaerobic test, and on-ice speed and agility. No significant changes or

differences between groups occurred for lean body mass, or body fat percentage. However, the sprint interval training group had a significantly greater increase in muscle thickness when compared to the continuous endurance group. In terms of anaerobic power, the sprint interval training group had significantly greater improvements in peak and mean power than the continuous endurance group; however, no differences were noted for changes in minimum power or fatigue index. In addition, there were no effects of either training program on on-ice agility or endurance, but the sprint interval training group had significantly greater improvements than continuous endurance training in on-ice sprint performance. In conclusion, sprint interval training resulted in significantly greater adaptations in muscle size, anaerobic power, and on-ice sprinting performance than continuous endurance training in male ice hockey athletes, despite a 26% lower training time.

*Robinson IV, Stout, Miramonti, Fukuda, Wang, Townsend, Mangine, Fragala, and Hoffman, (2014)*

### **High-intensity interval training and $\beta$ -hydroxy- $\beta$ -methylbutyric free acid improves aerobic power and metabolic thresholds**

This study investigated the individual and combined effects of high-intensity interval training (HIIT) and  $\beta$ -hydroxy- $\beta$ -methylbutyric free acid (HMBFA) on  $\dot{V}O_{2\text{peak}}$ , ventilatory threshold, respiratory compensation point, and time to exhaustion in healthy adult men and women. Thirty-four moderately active individuals were grouped into either control (CON) or HIIT. Within the HIIT group, half of the participants received placebo (PLAB-HIIT) while the other half received HMBFA (HMBFA-HIIT). The HIIT consisted of 12 training sessions over a 4-week period, each consisting of five 2-minute exercise bouts on a cycle ergometer with varying intensities ranging from 85% to 120% of  $\dot{V}O_{2\text{peak}}$  with 1-minute rest periods between bouts. To determine  $\dot{V}O_{2\text{peak}}$ , VT, and RCP before and after training, all participants completed

a staged graded exercise test on a cycle ergometer that started at 75W and increased 25W every 2 minutes. VT was determined as the nonlinear increase in the  $\dot{V}E/\dot{V}O_2$  versus  $\dot{V}O_2$  curve while the  $\dot{V}E/\dot{V}CO_2$  versus  $\dot{V}O_2$  curve remained constant. RCP was determined as the nonlinear increase in the  $\dot{V}E$  versus  $\dot{V}CO_2$  curve. VT and RCP were expressed as the corresponding  $\dot{V}O_2$  and workload at which they occurred. The groups were compared with all data being analyzed using the baseline values as a covariate. Following the four weeks of HIIT,  $\dot{V}O_{2peak}$ , VT, and power at VT were significantly greater in the HMBFA-HIIT group when compared to CON and PLA-HIIT. There was a trend for PLA-HIIT having a greater  $\dot{V}O_{2peak}$  than CON after HIIT. HMBFA-HIIT and PLA-HIIT had significantly greater peak power, time to exhaustion, RCP, and power at RCP when compared to CON. In summary, HIIT was shown to increase maximal aerobic exercise performance and improve RCP. VT only increased in the HMBFA group; however, VT and RCP were not assessed using relative to maximal values, which may have revealed more improvements in the PLA-HIIT group. Also, it is possible the HIIT protocol utilized in this study was not a potent enough stimulus to cause changes in VT in the PLA-HIIT group.

*Zelt, Hankinson, Foster, Williams, Reynolds, Garneys, Tschakovsky, and Gurd, (2014)*

### **Reducing the volume of sprint interval training does not diminish maximal and submaximal performance gains in healthy men**

This study aimed to assess the effect of sprint duration during sprint interval training on maximal and submaximal exercise performance. Thirty-six recreationally active men were randomized into endurance training, 30-second sprint training, or 15-second sprint training. All training programs consisted of three sessions per week for four weeks. The endurance training consisted of 60-75 minutes of continuous cycling at 65% of  $\dot{V}O_{2peak}$ . Both sprint interval training groups complete 4-6 sprints per sessions at a resistance of 7.5% of body mass. Before

and after training, all participants completed a staged  $\dot{V}O_2$  peak test, Wingate test, and critical power test. All groups had significant improvements in  $\dot{V}O_2$  peak, peak power, average power, and critical power, with no differences between groups. However, only endurance training had a significant improvement in lactate threshold. In summary, both sprint interval training programs were as effective as endurance training at improving aerobic and anaerobic performance.

*Granata, Oliveira, Little, Renner, and Bishop, (2016)*

**Training intensity modulates changes in PGC-1 $\alpha$  and p53 protein content and mitochondrial respiration, but not markers of mitochondrial content in human skeletal muscle**

The purpose of this study was to assess the effect of different exercise intensities on mitochondrial biogenesis and respiration. Thirty-one healthy, moderately trained men were matched according to power at lactate threshold and then randomly assigned to sprint interval training (SIT), high-intensity interval training (HIIT), or sub-lactate threshold continuous training (STCT). The SIT consisted of repeated Wingate-style 30-second sprints against a resistance of 7.5% of body mass with 4-minute rest periods. The HIIT consisted of 4-minute cycling intervals at an intensity above lactate threshold with 2-minute rest periods. The STCT consisted of 20-35 minutes of continuous cycling against resistance just below lactate threshold. All training programs consisted of 12 training sessions over the course of 4 weeks. All participants provided a resting muscle biopsy and completed a cycling 20k time trial and a cycling discontinuous graded exercise test (GXT) before and after the training programs. The cycling GXT consisted of 4-minute stages with 30-second rest periods at increasing workloads of 30W. During training, SIT had completed approximately 35% less work than HIIT and STCT. All three groups increased lactate threshold, while peak workload only increased after SIT and HIIT. Furthermore, 20km time trial performance improved only after STCT and HIIT, but not

SIT. Within the muscle, mitochondrial respiration increased only after SIT, but not HIIT or STCT. Furthermore, PGC-1 $\alpha$  increased only after 4 weeks of SIT, with no changes in the other groups. In summary, the intensity of the training program seems to determine the magnitude of the changes in mitochondrial respiration. The increased training volume of SIT appears to offset the greater training volume associated with HIIT and STCT to cause adaptation, making SIT a time-efficient option to increase aerobic exercise capacity.

*Miramonti, Stout, Fukuda, Robinson IV, Wang, La Monica, and Hoffman, (2016)*

### **Effects of 4 weeks of high-intensity interval training and $\beta$ -hydroxy- $\beta$ -methylbutyric free acid supplementation on the onset of neuromuscular fatigue**

This manuscript utilized participants and data from the previously mentioned study by Robinson et al. The aim of this analysis was to investigate the effects of high-intensity interval training (HIIT) and  $\beta$ -hydroxy- $\beta$ -methylbutyric free acid (HMBFA) on physical working capacity at fatigue threshold (PWCft). As previously reported by Robinson et al, all participants were moderately active men and women, who were grouped into control (CON), placebo and HIIT (PLA-HIIT), and HMBFA and HIIT (HMBFA-HIIT). To assess PWCft, all participants were equipped with surface electrodes on the vastus lateralis muscle during a cycling graded exercise test (GXT). The GXT began at 75W and increase by 25W every 2 minutes until volitional fatigue. Throughout the GXT, electromyographic (EMG) signals were collected from the vastus lateralis at 1,000 Hz. All EMG signals were band pass filtered and the root mean square was calculated for each 10-second epoch. From this data, a 30-second moving average was conducted and the resulting data was plotted versus workload. The onset of the PWCft was determined using the maximal distance method. Following the 4-week training protocol, both PLA-HIIT and HMBFA-HIIT had significant increases in PWCft which were significantly greater than CON. Furthermore, HMBFA-HIIT had significantly greater changes in PWCft than PLA-HIIT. In

summary, HIIT regardless of HMBFA supplementation does appear to increase PWCft in moderately trained individuals. The addition of HMBFA may result in greater improvements in PWCft than without supplementation.

*Gillen, Martin, MacInnis, Skelly, Tarnopolsky, and Gibala, (2016)*

**Twelve weeks of sprint interval training improves indices of cardiometabolic health similar to traditional endurance training despite a five-fold lower exercise volume and time commitment**

The purpose of this study was to compare the cardiorespiratory benefits of sprint interval training and moderate intensity continuous training to a control group. The training programs in this study were 12 weeks in length with three training sessions per week. All participants in the study were sedentary men with an average age of  $27 \pm 8$  years. All participants completed a ramp exercise test on a cycle ergometer, an intravenous glucose tolerance test, and a resting muscle biopsy before and after training. The ramp exercise test increased at a rate of 1 watt every 2 seconds. During the ramp exercise test, oxygen consumption was collected and peak oxygen consumption was recorded. Participants were matched for age, body mass index, and baseline  $\dot{V}O_{2peak}$ . From the glucose tolerance test, glucose area under the curve, insulin area under the curve, and insulin sensitivity index were determined. From the muscle biopsy samples, maximal citrate synthase activity was determined. The sprint interval training program consisted of three 20-second all out sprints against a resistance of 5% of a body mass. Each sprint was separated with 2 minutes of active recovery at 50 watts. The total length of each sprint interval training session was 10 minutes. The moderate intensity continuous training consisted of 45 minutes of cycling exercise at  $\sim 70\%$  of maximum heart rate. The total length of each moderate intensity continuous training session was 50 minutes. The control group did not engage in any exercise during the 12-week intervention period. Average total work per session was  $\sim 60$  kJ and  $\sim 310$  kJ

for the sprint interval and moderate intensity continuous training, respectively. After training, both training groups increases  $\dot{V}O_{2\text{peak}}$  by 19%, while the control group had no significant changes. Furthermore, both training groups had significant improvements in body fat percentage, glucose area under the curve, insulin sensitivity index, and citrate synthase activity, with little to no changes in the control group. No differences were observed between the two training groups after the 12-week training programs. In summary, 12 weeks of sprint interval training improved cardiorespiratory fitness, body fat percentage, insulin sensitivity, and mitochondrial content to the same extent as moderate intensity continuous training, but with less total work and time per session.

#### Effect of training on fatigue thresholds in youth

*Rotstein, Dotan, Bar-Or, and Tenenbaum, (1986)*

#### **Effect of training on anaerobic threshold, maximal aerobic power and anaerobic performance of preadolescent boys**

This study analyzed the effectiveness of a 9-week interval training program in preadolescent boys. While the age of the participants was between 10 and 12, no assessment of maturational status was measured. All participants performed the Wingate anaerobic test,  $\dot{V}O_{2\text{max}}$  test, and anaerobic threshold test. The  $\dot{V}O_{2\text{max}}$  test was a graded exercise test on a treadmill with 2-minute stages.  $\dot{V}O_2$  and  $\dot{V}CO_2$  were measured throughout the  $\dot{V}O_{2\text{max}}$  test. The anaerobic threshold test was performed on a treadmill set at a 1% grade. The initial velocity was  $8 \text{ km}\cdot\text{h}^{-1}$ , which was increased by 1 or  $0.5 \text{ km}\cdot\text{h}^{-1}$  every 5 minutes. Between each velocity increase, there was a 2-3-minute rest period. After each 5-minute run,  $\dot{V}O_2$  and blood lactate concentration was recorded. Anaerobic threshold was determined as either the velocity at which the blood lactate concentration reach 4 mM or the running velocity that resulted in a nonlinear increase in blood lactate concentration. Furthermore, the percent of  $\dot{V}O_{2\text{max}}$  at which these two

points occurred was recorded. The 9-week interval training program was completed by 16 of the participants and consisted of three weekly 45-minute training sessions. During each session, the participants three 600-meter runs with 2.5-minute rest intervals, five 400-meter runs with 2-minute rest intervals, and six 150-meter runs with 1.5-minute rest intervals. No quantifiable measure of running intensity was provided by the authors, but it was reported that intensity progressively increased throughout the training program. In the training group, significant increases were observed in peak power, mean power,  $\dot{V}O_{2max}$ , and the running velocity at which a positive inflection in blood lactate concentration occurred. Furthermore, there was a significant decrease in the percent of  $\dot{V}O_{2max}$  values associated with the 4 mM concentration of blood lactate and the inflection in blood lactate concentration after training. It does appear that a 9-week interval training program improved anaerobic power and aerobic capacity in preadolescent males. In terms of anaerobic threshold, a significant increase occurred in terms of absolute exercise intensity; however, there was a significant decrease in the onset of anaerobic threshold when assessed as a percent of  $\dot{V}O_{2max}$ . This disparity is likely due to the increased  $\dot{V}O_{2max}$  that occurred after training. In summary, the inclusion of both absolute and relative measures of anaerobic threshold is necessary when an improvement in  $\dot{V}O_{2max}$  is anticipated.

*Mahon and Vaccaro, (1989)*

### **Ventilatory threshold and $\dot{V}O_{2max}$ changes in children following endurance training**

The purpose of this study was to investigate the changes in  $\dot{V}O_{2max}$  and ventilatory threshold in children (10-14 years old) after an 8-week endurance training program. Eight children completed the endurance training program, while eight others served as controls. The incremental exercise test to determine  $\dot{V}O_{2max}$  and ventilatory threshold began with participants running at a comfortable speed that was determined during familiarization. Throughout the test,



the speed remained constant, with a subsequent 2% grade increase every minute until volitional fatigue. To determine ventilatory threshold, investigators determined the point where there were systematic increases in  $\dot{V}E/\dot{V}O_2$  and end-tidal oxygen tension without increases in  $\dot{V}E/\dot{V}CO_2$  or end-tidal carbon dioxide tension. The endurance training group had significant increases in absolute and relative  $\dot{V}O_{2max}$ . In terms of ventilatory threshold, the endurance training group had significant increases in absolute ventilatory threshold, ventilatory threshold relative to body mass, and ventilatory threshold when expressed as a percentage of  $\dot{V}O_{2max}$ . The control group had no changes in  $\dot{V}O_{2max}$  or ventilatory threshold. In conclusion, this study demonstrates the trainability of  $\dot{V}O_{2max}$  and ventilatory threshold amongst typically prepubescent children.

*Sperlich, Zinner, Heilemann, Kjendlie, Holmberg, and Mester, (2010)*

### **High-intensity interval training improves $VO_2$ peak, maximal lactate accumulation, time trial and competition performance in 9-11-year-old swimmers**

The purpose of this study was to compare high volume interval training and high-intensity interval training programs on measures of aerobic performance in youth swimmers. Twenty-six boys and girls (9-11 years old) completed this crossover training study. Prior to beginning the study, all participants underwent a two and a half week inactivity (Easter break). Then, half of the participants were randomly allocated to complete high volume interval training first, while the other half were assigned to complete high-intensity interval training first. After a 6-week inactivity period (summer break), the participants switched training groups. Prior to beginning each training block, all participants completed a 2-week pre-conditioning program to ensure similar baseline fitness levels. Pre-testing sessions were completed after each pre-conditioning phase, while post-testing was completed after each 5-week training block. Both training programs completed five sessions per week in a 5-week period for a total of 25 training sessions. As all participants were competitive swimmers, all training was completed in a 50-

meter outdoor pool. All training sessions included a 10-minute warm up, ten minutes of technical drills, the specific high volume or high-intensity intervals, and a 10-minute cool down. High volume intervals included of 60 minutes of swimming bouts at distances ranging from 100-800 meters at intensities equivalent to 85% of each participant's personal best. High-intensity intervals included 30 minutes of swimming bouts at distances ranging from 50-300 meters at intensities equivalent to 92% of each participant's personal best. Before and after each 5-week training block, participants completed a ramp exercise protocol on a cycle ergometer to assess  $\dot{V}O_2$ peak and ventilatory threshold. In addition, all participants completed a 2,000-meter and 100-meter swim test to determine changes in swimming performance. Blood lactate concentration was measured before and for up to 10 minutes after the 100-m swim to determine maximal rate of lactate accumulation. To evaluate competition performance, all participants completed a 100-m freestyle and 50-m breast stroke at a regional competition. Performance in these events was determined using the European Governing Body point system (LEN points) for swimming performance. During training sessions, ratings of perceived exertion and blood lactate were monitored after each interval was completed. The high volume interval training completed more than double the distance completed by the high-intensity interval training during the 5-week period. Also, high-intensity interval training resulted in significantly greater ratings of perceived exertion and blood lactate concentrations than high volume interval training. Both training groups had significant increases in  $\dot{V}O_2$ peak, but no changes in ventilatory threshold, which was expressed as a percentage of  $\dot{V}O_2$ peak. Furthermore, 2000-meter swim performance was significantly improved after high-intensity interval training only, but neither training program had an effect on 100-meter swim performance. Maximal rate of lactate accumulation was significantly increased following high-intensity interval training, but was significantly decreased

after high volume interval training. In terms of competition performance, only high-intensity interval had improvements in LEN points. In summary, while both forms of training improved  $\dot{V}O_2$ peak, only high-intensity interval training had significant improvements in swimming and competition performance. Furthermore, the high-intensity interval training was completed in less time per sessions and covered less total distance than the high volume training. The increases in  $\dot{V}O_2$ peak from high volume interval training did not result in sport-specific improvements, which would be the most important factor when training youth athletes.

*McNarry, Welsman, and Jones, (2011)*

### **Influence of training and maturity status on the cardiopulmonary responses to ramp incremental cycle and upper body exercise in girls**

The purpose of this study was to compare the effect of training status and maturity on the response to ramp exercise in girls. All participants were grouped into prepubescent, peripubescent, and postpubescent maturity groups according to Tanner staging. The trained girls were engaged in competitive swim training, while the untrained girls reported low levels of sport participation and physical activity. All girls were assessed for standing height, seated height, body mass, and percent body fat via five skinfolds (bicep, triceps, subscapular, suprailliac, and thigh). All participants completed a ramp exercise protocol on a lower body cycle ergometer and an upper body ergometer. The rate at which resistance increased for the prepubescent, peripubescent, and postpubescent groups was 15, 20, or 25 W/min, respectively, for the lower body test, and 6, 10, or 14 W/min, respectively for the upper body test. Throughout each test oxygen consumption, carbon dioxide production, ventilation, and heart rate were recorded. From the oxygen consumption and carbon dioxide production data, gas exchange threshold and mean response time were determined. Also, cardiac output and stroke volume were measured using a thoracic bioelectrical impedance device. From  $\dot{V}O_2$ peak and peak cardiac output, peak a- $\dot{V}O_2$

difference was calculated using the Fick equation. Furthermore, near-infrared spectroscopy was utilized to measure the oxygenation status of the vastus lateralis during the lower body test and triceps brachii during the upper body test. All data were assessed with allometric scaling to account for body size and surface area differences between maturity groups. There were no significant differences between trained and untrained girls for anthropometric or body composition data; however, there was an effect of maturity, with postpubescent being taller and having more mass than pre- and peripubescent, while peripubescent was taller and had more mass than the prepubescent girls. There was no effect of training or maturity status on test duration for the upper or lower body tests. However,  $\dot{V}O_{2peak}$  was significantly greater in the trained girls in all three maturity groups. Similarly, gas exchange threshold, when expressed as an absolute  $\dot{V}O_2$  value, was significantly greater in the trained girls than the untrained regardless of maturity group. However, when expressed as a percentage of  $\dot{V}O_{2peak}$ , gas exchange threshold was only different between trained and untrained in the prepubescent maturity group. Also, mean response time of  $\dot{V}O_2$  was significantly greater in the trained group when compared to the untrained group regardless of maturity status. Furthermore, peak cardiac output was greater in trained girls when compared to untrained girls in the peripubescent and postpubescent maturity groups. However, peak heart rate was not influenced by training status; therefore, the differences in cardiac output must be attributed to stroke volume. In support of this finding, peak stroke volume was affected by training status in prepubescent and postpubescent girls only with greater values in the trained girls. However, peak a- $\dot{V}O_2$  difference was not affected by training status in any of the maturity groups. In terms of muscle oxygenation, trained girls demonstrated an oxygenation curve that was shifted to the right, indicating a delayed increase in deoxygenated hemoglobin during exercise. There was only one interaction found between training and maturity

status, which was for peak work rate during upper and lower body tests. This interaction revealed greater differences between trained and untrained girls in the peripubescent and postpubescent groups when compared to the prepubescent group differences. In conclusion, training status has an effect on aerobic performance and the physiological responses to maximal exercise tests in youth girls regardless of maturity status. Furthermore, greater differences between trained and untrained youth girls may be observed in the peripubescent or postpubescent maturity groups. This may be due greater to training as older girls will have accumulated more years of training than younger girls.

*Barker, Day, Smith, Bond, and Williams, (2014)*

### **The influence of 2 weeks of low-volume high-intensity interval training on health outcomes in adolescent boys**

This study investigated the effect of a 2-week sprint interval training program on body mass index, aerobic fitness, fat oxidation, and blood pressure in adolescent males. Years from peak height velocity were estimated for all participants in the study. The average years from peak height velocity was  $+1.3 \pm 0.2$  years indicating that these males were postpubescent. All participants were actively involved in some form of organized sports.  $\dot{V}O_{2\max}$  and gas exchange threshold were determined using a ramped incremental exercise test, with workload increases of  $21 \text{ W} \cdot \text{min}^{-1}$  until volitional exhaustion. Gas exchange threshold was defined as  $\dot{V}O_2$  value associated with a nonlinear increase in the  $\dot{V}CO_2/\dot{V}O_2$  relationship. To confirm this  $\dot{V}O_{2\max}$  reading, a supramaximal test (105% of power reached during the ramp exercise test) 15 minutes after completion of the ramp test. If a higher  $\dot{V}O_2$  value was achieved, it was considered the  $\dot{V}O_{2\max}$  for that participant. The second testing day was completed 48 hours after the first and consisted of blood pressure testing and a stage submaximal exercise test. All participants completed six sprint interval training sessions over the course of two weeks. The first training

session consisted of four repeated Wingate-style sprints on a cycle ergometer. The load and duration for each sprint was 7.5% of body mass and 30 seconds, respectively, with a recovery time of 4 minutes. The training program progressed to include up to seven sprints in the final training session. When comparing the first four sprints of the first and last training sessions, there was a significant improvement in peak power in all sprints and fatigue index in the first and third sprints; however, no changes were observed in mean power during any sprints. After training, no changes were seen in body mass, body mass index, or resting blood pressure. In terms of maximal aerobic fitness, there were significant improvements in absolute and relative  $\dot{V}O_{2max}$ , time to exhaustion, peak power achieved, and absolute gas exchange threshold after two weeks of sprint interval training. When assessing submaximal exercise performance, there were significant decreases in absolute  $\dot{V}O_2$ , percent of  $\dot{V}O_{2max}$ , RER, energy expenditure, and carbohydrate oxidation. Conversely, there were significant increases in fat oxidation during submaximal exercise. In conclusion, this study showed that adolescent males significantly increased repeated anaerobic exercise performance, while also improving maximal and submaximal aerobic exercise performance from two weeks of sprint interval training.

*Faude, Schnitker, Schulte-Zurhausen, Muller, and Meyer, (2013)*

### **High intensity interval training vs. high-volume running training during pre-season conditioning in high-level youth football: a cross-over trial**

The purpose of this study was to compare the adaptations to high-intensity interval training and high volume running training in youth male soccer athletes (15.9±0.8 years old). This crossover designed study had half the participants complete high-intensity interval training in the summer and high volume running training in the winter, while the other half completed the training programs in the opposite order. Each training program lasted five and a half weeks, with 2-3 training sessions per week. Throughout the training periods, all participants wore a heart rate

monitor to assess training intensity. The high-intensity interval training sessions included two sets of 21-15 sprints that lasted 10-30 seconds at intensities ranging from 125-140% of individual anaerobic threshold. The high volume running training 30-60 minute continuous or fartlek runs at intensities ranging from 80-95% of individual anaerobic threshold. Average training time for high-intensity interval training was 33 minutes per session, while high volume running training was 47 minutes per session. Prior to and after each training period, all participants were assessed for vertical and drop jump height, 30-meter sprint time with 10-meter split time, and a staged endurance running test. The endurance running test began at 10 km/h and increased by 2 km/h every three minutes until participants were unable to maintain speed. During the endurance running test, peak heart rate was recorded and blood lactate concentrations were measured in between stages and after exercise to determine individual anaerobic threshold. Both training programs resulted in a significant increase in individual anaerobic threshold and significant decreases in maximum heart rate and countermovement and drop jump heights. Also, there was a trend for a significant increase in maximum aerobic velocity. In addition, changes in individual anaerobic threshold from high-intensity interval training were significantly correlated to baseline 30-meter sprint times, indicating that faster participants had greater adaptations to high-intensity interval training. Furthermore, participants who had at least a 2% improvement in individual anaerobic threshold (responders) in response to high-intensity interval training were significantly faster than those who did not exceed a 2% change in individual anaerobic threshold. In conclusion, adaptations to fatigue thresholds from high-intensity interval training may be limited by the speed of the individuals engaged in the high-intensity interval training.

*Mucci, Baquet, Nourry, Deruelle, Berthoin, and Fabre, (2013)*

### **Exercise testing in children: comparison in ventilatory thresholds changes with interval training**

This study aimed to assess the effectiveness of high-intensity interval training on  $\dot{V}O_2$ peak, gas exchange threshold, and respiratory compensation point in prepubescent children. Eighteen prepubescent boys and girls completed this study with nine engaged in high-intensity interval training and the other nine serving as controls. All participants completed a staged exercise test on a cycle ergometer until volitional fatigue. The exercise test began at a workload of 10W, which was increased by 10W every minute. During the exercise test, oxygen consumption, carbon dioxide production, end-tidal oxygen pressure, end-tidal carbon dioxide pressure, ventilation, and heart rate were measured. Also, at the point of volitional fatigue, blood lactate concentration was measured. Gas exchange threshold was determined from the nonlinear increase in the carbon dioxide production versus oxygen consumption relationship. Respiratory compensation point was determined as the point where all gas exchange variables increased while a decreased in end-tidal carbon dioxide pressure occurred. Also, participants in the training group completed a progressive 20-meter shuttle test to determine maximal aerobic velocity, which was utilized to prescribe training intensities. The training program consisted of two training sessions per week for a total of eight weeks. Each training session consisted of four sets of either ten 10-second sprints or five 20-second sprints at intensities ranging from 110-130% of maximal aerobic velocity. Rest periods between sets were three minutes, while rest periods between sprints were equivalent to the duration of the sprints for the respective exercise session. After training, the training group had significantly greater  $\dot{V}O_2$ peak values, but no differences in peak heart rate or lactate response. In terms of fatigue thresholds, both gas exchange threshold and respiratory compensation point were greater in the training group than the control group after



training when expressed as an absolute  $\dot{V}O_2$  value. However, when expressed as a percentage of  $\dot{V}O_{2peak}$ , there were no significant differences between groups for either fatigue threshold. In conclusion, an 8-week high-intensity interval training program can increase  $\dot{V}O_{2peak}$  and fatigue thresholds in prepubescent children.

*Faude, Steffen, Kellmann, and Meyer, (2014)*

### **The effect of short-term interval training during the competitive season on physical fitness and signs of fatigue: a cross-over trial in high-level youth football players**

The aim of this study was to compare the adaptations to in-season high-intensity interval training and small-sided games in adolescent soccer athletes. Sixty-two participants were recruited from four German professional U19 and U17 soccer teams. Half of the participants completed high-intensity interval training during the first half of the season, while the other half completed small-sided games training. After completing the 4-week training period, all participants had a wash-out period of 3-5 months before transitioning to the other training program. Before and after each training period, participants provided capillary blood samples to assess creatine kinase and urea and completed a Recovery-Stress Questionnaire for Athletes, a vertical and drop jump test, a 30-meter sprint test with 10-meter split time, a change of direction agility test, and an endurance test to establish peak running velocity. During the endurance test, capillary blood samples were obtained to determine blood lactate concentrations, which were used to determine individual anaerobic threshold. All training sessions were completed during the competitive season with 4-5 soccer practices per week, weekend matches, and two sessions of the prescribed intervention per week, for a total of eight training sessions period training block. The high-intensity interval training sessions included two sets of twelve to fifteen 15-second sprints with 15-second rest periods between sprints and 10-minute rest periods between sets. The intensity for these sprints was set at 140% of each participant's individual anaerobic

threshold. The small-sided game sessions consisted of four 4-minute games of 3-v-3 or 4-v-4. Throughout both types of training, heart rate and total training time were assessed. The high-intensity interval training sessions were significantly shorter than the small-sided game sessions. In addition, maximum heart rate achieved during training was significantly greater during high-intensity interval training than small sided games, but there was no difference in average heart rate during the sessions. In response to intervention, both training programs had significant increases in individual anaerobic threshold, but decreases in peak heart rate and countermovement jump height. Also, both training programs had significant increases in urea concentration and decreases in total recovery score. Only one interaction was observed, which was found for peak velocity, where high-intensity interval training resulted in a decrease, while small-sided games resulted in a slight increase. In summary, both training programs resulted in increased individual anaerobic threshold, but decreased jump height and total recovery. While interval training may be an effective means to improve performance in the offseason, it may not be appropriate during a competitive season due to the decreases in recovery.

#### Effect of high-intensity interval training in youth

*Massicotte and Macnab, (1974)*

#### **Cardiorespiratory adaptations to training at specified intensities in children**

The aim of this study was to assess the effect of endurance training in children at different relative intensities. Thirty-six boys aged 11-13 years old were assessed for  $\dot{V}O_{2\max}$  and heart rate max on a cycle ergometer. Then, participants were grouped according to their  $\dot{V}O_{2\max}$  and randomly assigned to a control group or one of three training groups. All three training groups completed three 12-minute training sessions per week over a 6-week training period. The three different training groups completed their training at 130-140, 150-160, and 170-180 beats

per minute. All three training groups had significant decreases in heart rate at submaximal exercise, while only the highest intensity group had a reduction in lactate production in response to submaximal exercise. At maximal exercise, all three training groups improved maximum workload, while only the group that trained at the highest intensity had an increase in  $\dot{V}O_2\text{max}$ . In conclusion, children between the ages of 11 and 13 years old have significantly greater responses to training that requires a heart rate of 170-180 beats per minute.

*Fournier, Ricci, Taylor, Ferguson, Montpetit, and Chaitman, (1981)*

### **Skeletal muscle adaptation in adolescent boys: sprint and endurance training and detraining**

The purpose of this study was to assess the effects of sprint and endurance training on intramuscular glycolytic and oxidative enzyme activity in adolescent boys. Furthermore, this study examined changes in muscle fiber area and distribution. Twelve boys between the ages of 16 and 17 were randomized into either an endurance training or sprint training group. Both training groups consisted of four training sessions per week for three months. The endurance training sessions included two jogging bouts that lasted either 10 or 30 minutes. The intensity for the jogging bouts started at 60-70% of maximal heart rate and progressed to 80-90% by the end of the training period. The sprint training sessions included a series of interval runs that spanned 50-250 meters. Before and after training, all participants completed body composition testing via skinfold thickness,  $\dot{V}O_2\text{max}$  testing on a treadmill, and a resting muscle biopsy. All muscle samples were assessed for fiber type area and distribution, as well as phosphofructokinase and succinate dehydrogenase activity. Both groups had significant increases in absolute  $\dot{V}O_2\text{max}$ , but only endurance training had a significant increase in relative  $\dot{V}O_2\text{max}$ . Furthermore, heart rate during submaximal exercise was significantly reduced in both groups after training. In terms of muscle fiber type area, only the endurance training group had significant increases, specifically

slow twitch fibers, fast twitch-a, and fast twitch-c fibers had increases in area. However, there were no changes in fiber type distribution for either the endurance or sprint training groups. When assessing muscle enzyme activity, phosphofructokinase was increased from sprint training, while succinate dehydrogenase was increased following endurance training. While no direct comparison was made between training groups, it is clear that endurance training and sprint training will increase aerobic performance in adolescent males, but muscle metabolism adaptations are specific to the type of training that is employed.

*Williams, Armstrong, and Powell, (2000)*

### **Aerobic responses of prepubertal boys to two modes of training**

The purpose of this study was to compare the adaptations in aerobic exercise performance from sprint interval running and continuous cycle training in prepubescent boys. Thirty-nine prepubescent (Tanner stage one) boys were randomized into either a sprint interval running group, continuous cycle training group, or control group. Prior to beginning their respective training program, all participants completed a staged graded exercise test to determine  $\dot{V}O_{2peak}$ , blood lactate at  $\dot{V}O_{2peak}$ , and oxygen consumption, heart rate, and ventilation at submaximal exercise intensities. Both training groups completed three training sessions per week over an 8-week intervention period. The sprint interval running sessions consisted of three 10-second and three 30-second “all-out” sprints with 30 and 90 seconds of rest between sprints, respectively. The number of total sprints increased by two (one sprint per sprint type) every two weeks. The continuous cycle training sessions consisted of 20 minutes of cycling at an intensity equivalent to 80-85% of maximum heart rate. No differences were noted between any of the groups in terms of absolute  $\dot{V}O_{2peak}$ , relative  $\dot{V}O_{2peak}$ , maximum heart rate, or blood lactate at  $\dot{V}O_{2peak}$ . Furthermore, no differences were observed between groups for any of the measures at

submaximal exercise intensities. In conclusion, this study observed no significant differences between either sprint interval running or continuous cycle training when compared to a control group for any of the aerobic performance measures. It is possible that prepubescent boys may have a blunted adaptation to training. There was a wide variability of change within each group, which may indicate that some participants may have been further along in their maturity than others, and thus had better adaptations to training. Maturity status in this study was assessed with Tanner staging, which provides a marker of sexual maturity, but not may not be indicative of overall biological maturity status.

*Baquet, Berthoin, Dupont, Blondel, Fabre, and van Praagh, (2002)*

### **Effects of high intensity intermittent training on peak $\dot{V}O_2$ in prepubertal children**

This study assessed the effectiveness of a 7-week running-based high-intensity interval training program in prepubescent boys and girls. All participants were classified as prepubescent according to Tanner stages. All testing and training was performed two days per week for 30 minutes per day. The experimental and control groups completed their normal physical education classes throughout the study. Before and after training, maximal aerobic performance was assessed during a progressive shuttle run test. The shuttle run began at a speed of  $7.0 \text{ km}\cdot\text{h}^{-1}$  for 3 minutes, then increased to  $8.5 \text{ km}\cdot\text{h}^{-1}$ , with subsequent increases of  $0.5 \text{ km}\cdot\text{h}^{-1}$  every minute until the participant could not maintain the speed. The speed of the last completed stage was recorded as the participant's maximal speed. During the shuttle run test,  $\dot{V}O_2$  was measured during each stage and the peak  $\dot{V}O_2$  value was recorded. The high-intensity interval training program consisted of repeated sprints of either 10 or 20 seconds at velocities ranging from 110-130% of maximal speed.  $\dot{V}O_{2\text{peak}}$  and maximal speed significantly improved in the interval training group, but remained unchanged in the control group. Furthermore, the interval training group had

a significant decrease in the percent of  $\dot{V}O_2$ peak and percent of maximum heart rate achieved when running at  $7.0 \text{ km}\cdot\text{h}^{-1}$ . In summary, this study observed significant improvements in maximal and submaximal aerobic performance from a 7-week interval training program in prepubescent children.

*Baquet, Gamelin, Mucci, Thevenet, van Praagh, and Berthoin, (2010)*

### **Continuous vs. interval aerobic training in 8- to 11-year-old children**

This study compared the training adaptations to interval and continuous training in prepubescent children. Boys and girls were utilized in this study, the majority of which were Tanner classified as stage 1. All children were matched according to gender, chronological age, and maturity status. Participants were then divided into an interval training, continuous training, or control group. All participants completed regular physical education classes twice per week. The interval and continuous training groups completed three additional sessions per week. All participants completed a staged graded exercise test on a treadmill to determine maximal speed and  $\dot{V}O_2$ peak. The test began at  $6 \text{ km}\cdot\text{h}^{-1}$  and increased by  $0.5 \text{ km}\cdot\text{h}^{-1}$  every minute. The speed of the last stage was recorded as maximal speed. Throughout the test,  $\dot{V}O_2$ ,  $\dot{V}CO_2$ ,  $\dot{V}E$ , RER, and heart rate were recorded. The interval training program consisted of repeated sprints ranging from 5-30 seconds at intensities of 100-130% of maximal speed. The continuous training program consisted of 6-20-minute running at 80-85% of maximal speed.  $\dot{V}O_2$ peak and maximal speed improved in the interval and continuous training groups, but no changes occurred in the control group. Furthermore, there were no differences between the interval and continuous training groups. The lack of difference between training groups may be due to the work completed during the training programs, which was not significantly different. In prepubescent children, the type of training program did not have an affect the adaptation to training.

*Buchan, Ollis, Young, Thomas, Cooper, Tong, Nie, Malina, and Baker, (2011)*

### **The effects of time and intensity of exercise on novel and establish markers of CVD in adolescent youth**

The purpose of this study was to compare the effects of high-intensity interval training and moderate continuous training on markers of cardiovascular disease in boys and girls (16.4±0.7 years old). Fifty-seven participants were randomized into control, high-intensity interval training, and moderate continuous training groups, with equal distribution of boys and girls. Both training groups completed three weekly training sessions over a 7-week intervention period. The high-intensity interval training sessions consisted of repeated 30-second maximal effort shuttles on a 20-meter course, with 30-second rest periods between shuttles. The number of shuttles per session started at four and progressed to six by the final week of training. The moderate continuous training sessions included 20 minutes of continuous running at approximately 70% of  $\dot{V}O_2\text{max}$ . Throughout each training program, heart rate and distance covered were recorded. Before and after the intervention period, all participants were assessed for height, body mass, and body mass index. Body composition was assessed using waist to hip ratio and by calculating body fat percentage from skinfold thickness at the triceps and calf. Also, systolic and diastolic blood pressure was assessed in a seated position at rest. Cardiorespiratory fitness was determined utilizing a 20-meter multistage fitness test. In addition, all participants provided a resting blood sample which was analyzed for adiponectin, C-reactive protein, total cholesterol, insulin, high-density lipoprotein, low-density lipoprotein, glucose, fibrinogen, interleukin-6, triglycerides, and plasminogen activator inhibitor-1. Heart rate response to each of the training program was similar, but the moderate continuous training group completed more distance throughout the intervention period. There was no change in body mass for any of the three groups, but height increased while body mass index significantly decreased, with no

differences between groups for any of the anthropometric measures. Waist to hip ratio significantly increased in the control group, but was maintained in both training groups. In addition, percent body fat decreased only in the moderate continuous training group, while no changes were observed in the control of high-intensity interval training groups. In terms of blood pressure, the high-intensity interval training group had a significant decrease in systolic blood pressure, while the control and moderate continuous training group had no changes in systolic blood pressure. Conversely, only the control group had a significant decrease in diastolic blood pressure, with no changes in the training groups. However, both training groups significantly improved cardiorespiratory fitness, while the control group had no significant change during the intervention period. When assessing the blood markers, the control group had a significant decrease in adiponectin and plasminogen activator inhibitor-1 with an increase in C-reactive protein. For the moderate continuous training group, there was a significant decrease in fibrinogen, plasminogen activator inhibitor-1, and insulin, while there was a significant increase in triglycerides. For the high-intensity interval training group, adiponectin significantly decreased, while triglycerides significantly increased after the intervention period. In summary, moderate continuous and high-intensity interval training both had significant effects on markers of cardiovascular disease in adolescents. While this study demonstrated little difference between moderate continuous training and high-intensity interval training, it is important to note that the two training programs may not have elicited different physiological responses as heart rate response was similar.

*Sperlich, de Marees, Koehler, Linville, Holmberg, and Mester, (2011)*

### **Effects of 5 weeks of high-intensity interval training vs. volume training in 14-year-old soccer players**

The aim of this study was to compare high-intensity interval training and high volume



training amongst adolescent soccer athletes. Nineteen boys, who were actively competing on a U14 German soccer team, were randomly assigned to either a high-intensity interval or high volume training group. Both training groups completed 13 training sessions during a 5-week intervention period. Both training sessions included a 10-minute warm up, 20 minutes of soccer-specific drills, either high-intensity intervals or high volume training, and a 10-minute cool down. The high-intensity intervals included approximately 30 minutes of short distance running at 90-95% of maximum heart rate. The high volume training consisted of 45-60 minutes of Fartlek style running at 50-70% of maximal heart rate. At the end of training sessions 2, 7, and 13, all participants were assessed for ratings of perceived exertion and blood lactate concentration. Furthermore, heart rate was recorded throughout each training sessions. Before and after training, all participants completed body composition testing via bioelectrical impedance analysis, jumping ability via drop, squat, and countermovement jumps, a treadmill-based  $\dot{V}O_2\text{max}$  test, sprint speed at 20, 30, and 40 meters, and a 1000-m run test. In terms of training intensity, high-intensity interval training spent a significantly greater percentage of time at exercise intensities of 80-100% of maximum heart rate, while high volume training spent a significantly greater percentage of time at intensities less than 80% of maximum heart rate. In addition, high-intensity interval training resulted in significantly greater ratings of perceived exertion and blood lactate concentrations. Neither training group had changes in body composition or jumping performance. However, both groups improved sprinting performance at 20, 30, and 40 meters. Furthermore, the high-intensity interval training group improved 1000-m run time and  $\dot{V}O_2\text{max}$ , while there were no significant changes in the high volume training group. In conclusion, high-intensity interval training was more effective and time efficient than high volume training at improving aerobic ability and sprint performance in youth soccer

athletes.

*Buchan, Young, Simpson, Thomas, Cooper, and Baker, (2012)*

**The effects of a novel high intensity exercise intervention on established markers of cardiovascular disease and health in Scottish adolescent youth**

This study aimed to assess the effect of high-intensity interval training on cardiorespiratory fitness, muscular power, speed, and agility amongst adolescent youth. Forty-one boys and girls, between the ages of 15 and 17, were randomized into either a control or high-intensity interval training group. The high-intensity interval training protocol consisted of three training sessions per week over a 7-week period with 4-6 repeated 30-second, maximal effort shuttle runs with 30-second rest periods per session. During the intervention period, the control maintained their current activity level. Before and after the intervention period, were assessed for cardiorespiratory fitness, countermovement jump height, 10-meter sprint speed, and agility via the 505 test. Group×time interactions were noted for countermovement jump height, cardiorespiratory fitness, and agility, with greater improvements observed in the high-intensity interval training group. In summary, high-intensity interval training was significantly improvement aerobic fitness, muscular power, and agility in adolescent boys and girls.

*Buchan, Ollis, Young, Cooper, Shield, and Barker, (2013)*

**High-intensity interval running enhances measure of physical fitness but not metabolic measure of cardiovascular disease risk in healthy adolescents**

The purpose of this study was to examine the effectiveness of high-intensity interval training at reducing cardiovascular disease risk amongst adolescent boys and girls. Eighty-nine participants (16.7±0.6 years old) were assigned to either a high-intensity interval training or control group throughout the intervention period. The high-intensity interval training group completed three weekly training sessions during the 7-week intervention period, with each

session consisting of 4-6 repeated 30-second, maximal effort shuttle runs with 30-second rest period. During one training session per week, the participants were assessed for average heart rate response to the training program. Throughout the intervention period, the control group was asked to maintain their normal daily activities. Before and after the intervention period, all participants were assessed for height, body mass, systolic and diastolic blood pressure, cardiorespiratory fitness via a 20-meter multistage fitness test, countermovement jump height, 10-meter sprint time, and agility via a 505 test. Furthermore, all participants provided a resting blood sample before and after the intervention period. All blood samples were assessed for adiponectin, C-reactive protein, total cholesterol, insulin, high-density lipoprotein, low-density lipoprotein, glucose, fibrinogen, interleukin-6, and triglycerides. After completing the training program, five focus groups, four with participants and one with instructors, were conducted to receive feedback on the training program. After the intervention period, there was significant difference between high-intensity interval training and control groups for countermovement jump height and 10-meter sprint times, with the training group being significantly better than control. Furthermore, the high intensity interval training group had significant improvements in systolic blood pressure, countermovement jump height, and 10-meter sprint speed; whereas, the control group had significant increases in body mass and waist circumference with significant decrements in jump height and agility performance. In terms of biochemical analyses, none of the measures were different between the two groups post-intervention. The focus groups revealed that all the participants and instructors enjoyed the training program and constant encouragement from the researchers. In summary, this high-intensity interval training program improved measures of fitness, but did not have an effect on any of the biochemical analyses.

*Koubaa, Trabelsi, Masmoudi, Elloumi, Sahnoun, Zeghal, and Hakim, (2013)*

**Effect of intermittent and continuous training on body composition cardiorespiratory fitness and lipid profile in obese adolescents**

This study compared the effectiveness of high-intensity interval training and moderate continuous training at improving cardiorespiratory fitness and lipid profile in obese adolescents. Twenty-nine male adolescents ( $13 \pm 0.8$  years old) were randomized into either the high-intensity interval training group or moderate continuous training group. Both training groups completed three weekly training sessions during the 12-week training period. The high-intensity interval training program completed repeated 2-minute runs with 1-minute rest periods at intensities starting at 80% of  $\dot{V}O_2\text{max}$ . The intensity of the runs increased by 5% every four weeks. The continuous training sessions consisted of 30-40 minutes of running at 60-70% of  $\dot{V}O_2\text{max}$ . Before and after the training periods, all participants were assessed for body mass, height, body mass index, body fat percentage via skinfold thickness, and  $\dot{V}O_2\text{max}$  on a treadmill. Furthermore, all participants provided a resting blood sample which was assessed for total cholesterol, triglycerides, high-density lipoproteins, low-density lipoproteins, and glucose. Both training groups had significant decreases in body mass, body mass index, fat mass, and waist circumference, with greater decreases seen in the moderate continuous training group. Furthermore, both groups decreased resting heart rate, systolic blood pressure, and diastolic blood pressure, with greater changes in blood pressure observed in the high-intensity interval training group. Also, there were significant increases in  $\dot{V}O_2\text{max}$  and maximal aerobic speed for both groups. In terms of lipid profile, the moderate continuous groups had significant reductions in triglycerides, low-density lipoproteins, and total cholesterol, while the high-intensity interval training group only had a significant decrease in triglycerides. In summary, both training groups improved body composition and cardiorespiratory fitness, but the moderate continuous training

also resulted in an improved lipid profile.

*Costigan, Eather, Plotnikoff, Taffe, and Lubans, (2015)*

### **High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis**

The purpose of this meta-analysis was to assess the effectiveness of high-intensity interval training on improving cardiorespiratory fitness, muscular power, and body composition amongst adolescents. Criteria for study inclusion into this meta-analysis was that the study included 13-18 year olds, examined at least one of the outcome variables, had an intervention of at least four weeks, and included a control or moderate intensity group to compare to the high-intensity interval training group. In total, 20 studies were included in this meta-analysis, with eight included in the  $\dot{V}O_{2\max}$  analysis, five in the muscular power analysis, eight in the body mass index analysis, seven in the body fat percentage analysis, and six in the waist circumference analysis. There was a significant effect on  $\dot{V}O_{2\max}$ , muscular power, body mass index, and percent body fat from high-intensity interval training, but waist circumference was not significantly affected by high-intensity interval training. Furthermore, the largest effect was for  $\dot{V}O_{2\max}$  ( $d=1.05$ ), with moderated effects for body mass index ( $d=-0.37$ ) and percent body fat ( $d=-0.67$ ) and a small effect for muscular power ( $d=0.21$ ). Study duration was a significant moderator of high-intensity interval training's effect on body fat percentage with greater effects for studies lasting at least eight weeks; however, study duration was not a significant moderator for any of the other measures. In summary, high-intensity interval training has a significant effect on cardiorespiratory fitness, muscular power, and body composition amongst adolescents. However, this meta-analysis did not examine maturity as a moderator variable, which may have an effect on an adolescent's adaptation to high-intensity interval training.

*Martin, Buchan, Barker, Young, Sculthorpe, and Grace, (2015)*

**Sprint interval training (SIT) is an effective method to maintain cardiorespiratory fitness (CRF) and glucose homeostasis in Scottish adolescents**

The aim of this study was to assess the effectiveness of school-based sprint interval training as a method to improve cardiorespiratory fitness and glucose homeostasis in adolescents. Forty-nine healthy adolescent participants who were enrolled in a physical education class were recruited to participate in this study. Half of the participants were enrolled in a 7-week sprint interval training intervention, while the other half maintained participation in their standard 1-hour physical education. Both training groups completed their respective training sessions three times per week. The sprint interval training sessions consisted of 4-6 sets of 30-second sprints with 30 seconds of recovery between sprints. Before and after the 7-week training period, all participants were assessed for body mass, height, daily physical activity via self-reported questionnaire, glucose homeostasis via resting plasma glucose and insulin, and  $\dot{V}O_2\text{max}$  via a multistage running test. After training, body mass and body mass index were unchanged in either training group. Self-reported physical activity increased in the sprint interval training group, but remained unchanged in the physical education group. In terms of  $\dot{V}O_2\text{max}$ , the physical education group had a significant decrease during the seven weeks, while the sprint interval training group had a trend towards an increase, which resulted in significant difference between the two groups after training. Furthermore, the physical education group had significant increases in fasting plasma glucose, insulin and insulin resistance. In summary, sprint interval training significantly cardiorespiratory fitness while concurrently improvement glucose homeostasis when compared to a standard physical education class.

*Harris, Dulson, Logan, Warbrick, Merien, Lubans, (2016)*

### **Acute responses to resistance and high intensity interval training in adolescents**

The purpose of this study to compare the acute responses to a resistance exercise bout and a high-intensity interval exercise bout amongst adolescent boys and girls (12-13 years old). Seventeen total participants, eight males and 9 females, completed all trials within the study. All participants were assessed for years from peak height velocity to establish maturity. Male participants were  $-0.8 \pm 0.6$  years from peak height velocity, while female participants were  $0.9 \pm 0.45$  years past peak height velocity. Half of the participants completed their resistance exercise trial first and then completed their high-intensity interval trial at least three days later, while the other half of the participants completed the trials in the opposite order. The resistance exercise trial consisted of three 30-second sets of squat, push up, and supine pull with 30-second rest periods between sets. The load of the exercises was set so that participants completed 10-15 repetitions per set. The high-intensity interval trial included six 30-second bouts of cycling and boxing with 30 seconds of rest between bouts. The intensity of the sets was set so that participants maintained 90% of their age predicted maximum heart rate. Throughout each trial, heart rate and oxygen consumption were measured at the end of each set and during each rest period, while ratings of perceived exertion were recorded for each set and session. Prior to and ten minutes after each trial, saliva samples were collected and analyzed for cortisol and alpha amylase. Also, blood lactate concentrations were determined at baseline and five minutes after each trial. The high-intensity interval trial produced significantly greater oxygen consumption and heart rate than the resistance exercise trial. Furthermore, total energy expenditure was greater during the high-intensity interval trial than the resistance exercise trial. Similarly, blood lactate concentration was significantly greater after the high-intensity interval exercise trial than

the resistance exercise trial; however, no differences were noted for salivary cortisol or alpha amylase. In summary, high-intensity interval training sessions may result in significantly greater oxygen consumption, heart rate, and blood lactate than resistance training in adolescents. However, this study did not assess the long-term adaptations to these training programs.

*Logan, Harris, Duncan, Plank, Merien, Schofield, (2016)*

### **Low-active male adolescents: a dose response to high-intensity interval training**

The purpose of this study was to establish the effect of different doses of high-intensity interval training on untrained adolescent males ( $16.0 \pm 1.0$  years). All participants were untrained and were not engaged in physical education class or a structured sport team. Twenty-six participants were placed into high-intensity interval training groups, each with a different number of sets per session. All groups completed that same training program, with the only difference being the number of sets completed per high-intensity interval training session. The training program consisted of two high-intensity interval training sessions and one resistance training session per week for eight weeks. Each set of high-intensity interval training included four bouts of 20-second bouts of exercise with 10-second rest intervals between bouts. The intensity of the bouts was set between 90-100% of maximum heart rate. In the groups that performed multiple sets, a 2-minute rest period was provided between sets. The modality of exercise for each set was left to the discretion of each participant, but included rowing ergometer, cycle ergometer, treadmill, cross-trainer, shuttle-runs, box-jumps, or noncontact boxing. The resistance training sessions included three sets of 8-12 repetitions on squat, bench press, and seated row with an intensity equivalent to 70% of pre-testing 1RM. Before and after training, all participants provided a resting blood sample which was assessed for glucose, insulin, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and



interleukin-6. Also, an incremental ramp exercise protocol on a cycle ergometer was completed to determine  $\dot{V}O_2$ max and heart rate maximum. To assess changes in body composition a whole-body dual x-ray absorptiometry test was conducted. In response to high-intensity interval training, there was an overall increase in  $\dot{V}O_2$ peak with concurrent decreases in percent body fat, visceral fat, lean body mass and waist circumference to height ratio. However, only groups who completed four or five sets of high-intensity interval training had improvements in  $\dot{V}O_2$ peak in all participants. In conclusion, high-intensity interval training improved body composition and markers of cardiorespiratory fitness, but there was no clear effect of additional sets of high-intensity interval training for any of the measured markers. While this study demonstrated little difference between one and five sets of high-intensity interval training, the inclusion of resistance training, which was consistent amongst all groups, may have masked the differences that were caused by additional sets of high-intensity interval training.

*Wright, Hurst, and Taylor, (2016)*

### **Contrasting effects of a mixed-methods high-intensity interval training intervention in girl football players**

The purpose of this study was to compare the maturity-related differences to a mixed-methods running-based high-intensity interval training amongst girl football athletes. Thirty-seven female football athletes completed pre-testing, an 8-week training program, and post-testing. The thirty-seven girls were separated according to their number of years from peak height velocity into before-PHV (<-0.5 years), at-PHV (-0.51 to 0.5 years), and after-PHV (>0.5 years). Testing consisted of a 20-meter sprint, a t-test, a yo-yo intermittent running test, and a repeated sprint ability test. The 8-week running-based interval training program consisted of four weeks of long duration intervals and four weeks of sprint intervals. Overall, the high-intensity interval training program elicited *Possibly Small* improvements in t-test time and *Possibly Small*

decrements in repeated sprint ability. Furthermore, there were *Very Likely Moderate* improvements in yo-yo intermittent running performance, with *Likely Trivial* changes in 20-meter sprint time. Amongst the Before-PHV group, there was a *Most Likely Very Large* decrement in repeated sprint performance, with all other variables exhibiting *Unclear* results. For the At-PHV group, there were *Possibly Small* and *Very Likely Moderate* improvements in sprint time and yo-yo intermittent running performance, respectively. However, there were *Likely Moderate* and *Very Likely Moderate* decrements in repeated sprint ability and t-test performance, respectively, amongst At-PHV. In the After-PHV group, there were *Very Likely Moderate* improvements in t-test and yo-yo intermittent running performance with no overserved decrements. In conclusion, this study showed that high-intensity interval training improves agility and intermittent running performance amongst adolescent girls. However, during and prior to puberty, there may be decrements in performance that occur following high-intensity interval training. The girls after puberty had improvements in agility and intermittent running performance with no observed performance decrements. High-intensity interval may only be an effective training intervention for adolescents who have gone through puberty. However, it is important to note that all measures in this study were field-based and did not observe maximal aerobic performance or fatigue thresholds.

## CHAPTER THREE: METHODOLOGY

### Participants

Thirty-three adolescent male athletes were recruited for this study. All participants were between the ages of 11 and 17 years old and were actively engaged in a competitive sport. Prior to enrolling in the study, all participants, with the help of a parent, completed a Confidential Medical and Activity Questionnaire and provided evidence of a cleared physical from a medical doctor within the last calendar year. Throughout the duration of the study, participants were not allowed to use any ergogenic nutritional supplements. The parents of all participants provided informed consent prior to beginning the study, along with a verbal assent from the participant. Six participants did not complete the study due to scheduling conflicts.

### Research Design

The current study utilized an experimental design to compare the effects of a 4-week sprint interval training program on metabolic and neuromuscular fatigue thresholds amongst adolescent males of different maturational groups. Participants were grouped according to their number of years from peak height velocity (PHV), an estimation of somatic maturity status, into PRE-, PERI-, and POST-PHV groups. All participants completed a single pre-testing session, 8 sprint interval training session, and a single post-testing session. This study was approved by the University of Central Florida Institutional Review Board.

### Variables

The independent variables included in this study were: (a) maturational group [PRE vs. PERI vs. POST] and (b) time [pre-testing vs. post-testing]. The dependent variables in this study were: (a) maximal measures from the ramp exercise protocol [workload, oxygen consumption ( $\dot{V}O_2$ ), carbon dioxide production ( $\dot{V}CO_2$ ), and ventilation ( $\dot{V}E$ )], (b) metabolic and

neuromuscular fatigue thresholds [gas exchange threshold, ventilatory threshold, respiratory compensation point, neuromuscular fatigue threshold, deoxyhemoglobin breakpoint, and oxygenation deflection point], and (c) sprint interval training results [peak revolutions per minute (RPM), peak power, and total work].

### Instrumentation

- Participant standing height was measured using a Health-o-meter Professional (Patient Weighing Scale, Model 500 KL, Pelstar, Alsip, IL, USA).
- Body composition was measured with air displacement plethysmography (BOD POD GS, COSMED, Rome, Italy).
- The ramp exercise protocol was completed on an electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, the Netherlands).
- $\dot{V}O_2$ ,  $\dot{V}CO_2$ , RER, and ventilation was collected and analyzed using a metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT, USA).
- A data acquisition system (MP150, BIOPAC Systems, Inc., Santa Barbara, CA) with a differential amplifier (BioNomadix 2-Channel EMG, BIOPAC Systems, Inc., Santa Barbara, CA) and accompanying software (AcqKnowledge v4.2, BIOPAC Systems, Inc., Santa Barbara, CA) was used to collect and analyze electromyography (EMG) data
- A near-infrared spectroscopy (NIRS) optode (PortaLite, Artinis Medical Systems, Gelderland, the Netherlands) was used to measure oxygen concentration of hemoglobin in the vastus lateralis.
- A cycle ergometer (894E, Monark Exercise AB, Vansbro, Sweden) was used to complete all sprint interval training sessions.

## Testing Sessions

The pre-testing session consisted of PHV estimation, body composition testing, and a ramp exercise protocol. The post-testing testing session included PHV estimation and a ramp exercise protocol. Participants reported to each testing session in a euhydrated state and fasted for a period of 4 hours. During the testing sessions, all procedures were overseen by Certified Strength and Conditioning Specialists (CSCS). All testing sessions were completed at a similar time of day during a single day. Pre-testing was completed at least 48 hours before the training program and post-testing was completed at least 48 hours after the training program was completed.

### *Peak Height Velocity Estimation Methods*

Each participant's years from PHV was estimated using standing height, seated height, body mass, and age. Standing height was measured using a Health-o-meter Professional (Patient Weighing Scale, Model 500 KL, Pelstar, Alsip, IL, USA). Seated height was measured using a bench to ensure the participant hips and knees were at 90 degrees. Seated height was measured from the base of the seat to the top of the head using a tape measurer. Leg length was calculated by subtracting seated height from standing height. Body mass was measured using a calibrated scale attached to the BOD POD. Equation 1 was used to calculate years from PHV (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002).

$$\begin{aligned}
\text{Years from PHV} = & -9.236 + (0.0002708 * (\text{Leg Length} * \text{Seated Height})) + \\
& (-0.001663 * (\text{Age} * \text{Leg length})) + (0.007216 * (\text{Age} * \text{Seated Height})) + \left( 0.02292 * \right. \\
& \left. \left( \frac{\text{Weight}}{\text{Height}} * 100 \right) \right)
\end{aligned} \tag{1}$$

A negative value from the prediction equation indicates the number of years until the participant reaches their PHV, while a positive number indicates the number of years since the participant had their PHV. Years from PHV was used to determine maturational groups. The cutoff for determining groups was less than -1.5 (PRE), greater than +1.5 (POST), and between -1.5 and +1.5 (PERI).

#### *Body Composition Methods*

Body composition was measured, via air displacement plethysmography, during pre-testing as a descriptive measure. Participants dressed down to spandex-style undergarments, removed their footwear, including socks, put on a swim cap, and sat in the BOD POD (BOD POD GS, COSMED, Rome, Italy) to determine body composition. Thoracic gas volume was predicted by the BOD POD and Lohman's density model (Lohman, 1989), via the BOD POD software, was used for all participants. Values for body fat percentage were recorded for BOD POD testing. Pre-testing measures of age, maturity offset, height, body mass, and body fat are presented in Table 1.

#### *Ramp Exercise Protocol Methods*

For the ramp exercise protocol, each participant was equipped with EMG and NIRS on each leg while breathing into a metabolic cart. After equipment setup, the participant was seated on a cycle ergometer (Lode, Excalibur Sport, Groningen, the Netherlands), which was adjusted to a comfortable position for each participant. The ramp exercise protocol began with a 3-minute

rest period to allow for acclimatization to the equipment and normalize all readings, then there was a 3-minute warm-up of unloaded cycling. Once the warm-up was completed, the ramp portion of the test began with an initial workload of 30 watts, which increased 1 watt every 3 seconds ( $20 \text{ watts} \cdot \text{minute}^{-1}$ ). Throughout the warm-up and ramp portions of the test, each participant was required to maintain 65-85 revolutions per minute. The test was terminated when the participant could not maintain 65 revolutions per minute despite strong verbal encouragement.

#### *Metabolic Cart Methods*

To assess  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , and  $\dot{V}E$  during the ramp exercise protocol, a flexible mask was fitted over each participant's mouth and nose to collect expired air. The expired air was sampled and analyzed by a metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT, USA) to determine the gases expired with each breath. Heart rate,  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , and  $\dot{V}E$  were measured and 10-second averages were calculated.

#### *Electromyography Methods*

To assess muscle activity during the ramp exercise protocol, a bipolar (4.6 cm center-to-center) surface electrode (Quinton Quick-Prep silver-silver chloride) arrangement was placed over the vastus lateralis muscle of each leg, at approximately 66 percent of the line from the anterior superior iliac spine to the superior lateral border of the patella (Hermens et al., 1999). The reference electrode was placed over Gerdy's tubercle. Inter-electrode impedance was kept below 5,000 ohms with shaving and abrasion of the skin beneath the electrodes. The raw EMG signals were pre-amplified using a differential amplifier (BioNomadix 2-Channel EMG,

BIOPAC Systems, Inc., Santa Barbara, CA), sampled at 1,000 Hz, and stored on a personal computer (Dell Latitude E6530, Dell Inc., Round Rock, TX) for off-line analysis.

Using computer software (AcqKnowledge v4.2, BIOPAC Systems, Inc., Santa Barbara, CA), the raw EMG data was filtered using a bandpass Butterworth filter at 10-500 Hz. From the filtered signals, root mean square (RMS) was calculated of the vastus lateralis from each leg. Averages were calculated for each 10-second epoch of the ramp exercise protocol.

#### *Near-Infrared Spectroscopy Methods*

To assess tissue oxygenation during the ramp exercise protocol, a NIRS optode (PortaLite, Artinis Medical Systems, Gelderland, the Netherlands) was placed over the vastus lateralis muscle of each leg, just lateral to the previously stated EMG placement. The optode was secured using a self-adhering bandage. A modified form of the Beer-Lambert Law was used to calculate micromolar changes in oxygenated hemoglobin (O<sub>2</sub>Hb) and deoxygenated hemoglobin (HHb) during the ramp exercise protocol. Tissue oxygenation was then calculated by subtracting HHb from O<sub>2</sub>Hb to determine the balance between oxygen supply and oxygen consumption (van der Zwaard et al., 2016). Averages for each measure were calculated for each 10-second epoch of the ramp exercise protocol.

#### *Threshold Determination Methods*

Six total fatigue thresholds were determined from the ramp exercise protocol. The three systemic pulmonary fatigue thresholds were gas exchange threshold (GET), ventilatory threshold (VT), and respiratory compensation point (RCP). GET was determined as the nonlinear inflection in the relationship between  $\dot{V}CO_2$  and  $\dot{V}O_2$  (Beaver, Wasserman, & Whipp, 1986). VT was determined as the nonlinear inflection in the  $\dot{V}E$  versus  $\dot{V}O_2$  relationship (Anderson & Mahon, 2007). RCP was the  $\dot{V}O_2$  value corresponding to the nonlinear inflection in the  $\dot{V}E$



versus  $\dot{V}CO_2$  relationship (Beaver et al., 1986). The three localized muscular thresholds were neuromuscular fatigue threshold (NFT), deoxyhemoglobin breakpoint (HHbBP), and oxygenation deflection point (OxDP). NFT was determined from the nonlinear inflection in the RMS, from the vastus lateralis, versus  $\dot{V}O_2$  relationship (Riffe et al., 2017). HHbBP was determined as the nonlinear deflection in the HHbBP versus  $\dot{V}O_2$  relationship (Boone, Vandekerckhove, Coomans, Prieur, & Bourgois, 2016). OxDP was determined as the nonlinear deflection in the tissue oxygenation versus  $\dot{V}O_2$  relationship (van der Zwaard et al., 2016). Localized muscular fatigue thresholds were determined for each leg and averaged between the two legs. All fatigue thresholds were determined using the maximal deviation (Dmax) methodology proposed by Cheng and colleagues (1992). For each physiological variable, 30-second moving averages were calculated from the 10-second averages obtained from each respective software. The 30-second moving averages were then plotted on a graph versus  $\dot{V}O_2$ , and the data points were fitted with a third-order polynomial regression line. Then, a linear regression line was computed from the first and last data points. The point on the third-order polynomial line of best fit that was the furthest perpendicular distance from the linear line was considered the fatigue threshold. Equation 2 was utilized to calculate the Dmax point (Machado, Nakamura, & Moraes, 2012).

$$Dmax = \frac{\left\{ -b \pm \sqrt{[(b^2 - 3 \times a(c - \Delta))]} \right\}}{3 \times a} \quad (2)$$

Where a, b, and c are the parameters of the third-order polynomial equation and delta ( $\Delta$ ) is the slope of the linear line connecting the first and last data points. An example of the Dmax determination is presented Figure 1.

### Sprint Interval Training

After completing the pre-testing session, participants were enrolled in a 4-week sprint interval training program. The training program was adapted from previously published research (Barker, Day, et al., 2014; Logan, Harris, Duncan, & Schofield, 2014). Training sessions were conducted 2 days per week with at least 24 hours of rest in between each training session. Each training session consisted of 20-second maximal sprints on a cycle ergometer (894E, Monark Exercise AB, Vansbro, Sweden) against a load equivalent to 7.5% of the participant's body mass. Prior to beginning each training session, participants were given a 5-minute warm-up at a self-selected intensity, with intermittent practice sprints. Prior to each sprint, participants were given a 3-second countdown, during which time they were instructed to rapidly increase their RPM. Once participants achieved 120 RPM the sprint load was applied to the cycle ergometer. A 4-minute active recovery period was provided between each sprint. The sprint interval training program was progressive, with an additional sprint added each week, except for the last training session which served as a taper. All training sessions were overseen by a CSCS. Peak RPM were recorded for the first training sessions. Throughout the training program, peak power and total work were recorded and made relative to participant body mass and expressed as an average per training session. The training program is presented in Table 2.

### Statistical Analysis

All data are reported as mean  $\pm$  standard deviation. Delta scores were calculated as the change from pre-testing to post-testing for all maximal aerobic performance and fatigue threshold data. Maximal aerobic performance data were analyzed with separate two-way [group (PRE vs. PERI vs. POST)  $\times$  time (pre-testing vs. post-testing)] mixed factorial analysis of variance (ANOVA). Any significant group $\times$ time interactions were followed by dependent t-tests

for each group and one-way ANOVAs at pre- and post-testing. Fatigue thresholds were analyzed using a three-way [group (PRE vs. PERI vs. POST) × threshold (GET vs. VT. vs. RCP vs. NFT vs. HHbBP vs. OxDP) × time (pre-testing vs. post-testing)] mixed factorial ANOVA. A significant group×time interaction was followed with a dependent t-test for each group and a one-way ANOVA at pre- and post-testing with data collapsed across fatigue thresholds. Any significant threshold×time interactions were assessed with a dependent t-test for each threshold and a repeated measures ANOVA at pre-, post-testing, and for delta scores with data collapsed across groups. Training data were assessed with respective one-way ANOVAs. Main effects of group and time were followed by least significant differences pairwise comparisons collapsed across time and group, respectively. Statistical software (SPSS; V. 20.0; SPSS, Inc, Chicago, IL, USA) was used for all parametric statistics. Results were considered significant at an alpha level of  $p \leq 0.05$ .

In addition, magnitude-based inferences were run to assess the changes within each group and compare the changes between groups. For each variable, the smallest worthwhile change was calculated as 20% of the grand standard deviation at pre-testing (Batterham & Hopkins, 2005). Using an online spreadsheet, the probability that within-group changes were positive, trivial, or negative were determined (Hopkins, 2007). For between-group comparisons, the probabilities were in favor of group 1, trivial, or in favor of group 2. Unclear results were reported if the observed 90% confidence interval overlapped both positive and negative probabilities by least 5%. All other inferences were made according to the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; and 99.5%, most likely (Hopkins, Marshall, Batterham, & Hanin, 2009).

## CHAPTER FOUR: RESULTS

### Sprint Interval Training Differences

During the first training session, there was a main effect of group for maximum RPM ( $F=6.523, p=0.005, \eta^2=0.352$ ), with PERI ( $140.64\pm 11.43$  RPM) and POST ( $149.14\pm 15.08$  RPM) being significantly greater than PRE ( $128.18\pm 4.20$  RPM;  $p=0.042$  and  $p=0.001$ , respectively). No significant differences in maximum RPM were observed between PERI and POST ( $p=0.119$ ). Magnitude based inferences revealed that POST had *Most Likely* and *Likely* greater maximum RPM in the first session when compared to PRE and PERI, respectively. Furthermore, maximum RPM were *Very Likely* greater in PERI when compared to PRE.

Across the entire training program, there were significant main effects of group for relative work completed per session ( $F=7.183, p=0.004, \eta^2=0.374$ ) and relative peak power attained per session ( $F=3.664, p=0.041, \eta^2=0.234$ ). For relative work completed per session, PRE ( $637.26\pm 169.98$  J·kg<sup>-1</sup>) completed significantly less than PERI ( $823.80\pm 71.94$  J·kg<sup>-1</sup>;  $p=0.002$ ) and POST ( $818.52\pm 90.22$  J·kg<sup>-1</sup>;  $p=0.003$ ), with no differences between PERI and POST ( $p=0.916$ ). Similarly, relative peak power attained per session was significantly less in PRE ( $9.50\pm 1.81$  W·kg<sup>-1</sup>) when compared to PERI ( $12.68\pm 2.62$  W·kg<sup>-1</sup>;  $p=0.023$ ) and POST ( $12.64\pm 3.13$  W·kg<sup>-1</sup>;  $p=0.025$ ), with no differences between PERI and POST ( $p=0.973$ ). Magnitude based inferences revealed that PERI and POST had *Very Likely* greater relative work completed and relative peak power attained per session than PRE, with *Unclear* differences between PERI and POST.

### Changes in Maximal Aerobic Performance

The pre- and post-testing data for the measures of maximal aerobic performance are presented in Table 3. When assessing absolute  $\dot{V}O_{2\max}$ , the two-way ANOVA revealed no

significant group×time interaction ( $F=0.990, p=0.386, \eta^2=0.076$ ) or main effect of time ( $F=3.678, p=0.067, \eta^2=0.133$ ). However, there was a significant main effect of group ( $F=63.036, p<0.001, \eta^2=0.840$ ), with POST being significantly greater than PERI ( $p<0.001$ ) and PRE ( $p<0.001$ ), while PERI was also significantly greater ( $p<0.001$ ) than PRE. For relative  $\dot{V}O_{2max}$ , there was no significant group×time interaction ( $F=1.124, p=0.341, \eta^2=0.086$ ), main effect of time ( $F=2.487, p=0.128, \eta^2=0.094$ ), or main effect of group ( $F=1.787, p=0.189, \eta^2=0.130$ ). When comparing maximum workload, there was not a significant group×time interaction ( $F=0.534, p=0.593, \eta^2=0.043$ ); however, there was a significant main effect of time ( $F=11.798, p=0.002, \eta^2=0.330$ ) and main effect of group ( $F=55.263, p<0.001, \eta^2=0.822$ ). Post hoc analyses revealed a significant increase in maximum workload from pre-testing to post-testing, with significantly greater maximum workload values in POST when compared to PRE ( $p<0.001$ ) and PERI ( $p<0.001$ ), while PERI was also significantly greater ( $p<0.001$ ) than PRE.

The changes in absolute  $\dot{V}O_{2max}$ , relative  $\dot{V}O_{2max}$ , and maximum workload are presented in Table 4. The changes in absolute  $\dot{V}O_{2max}$  from pre-testing to post-testing for PRE ( $0.02\pm 0.09 \text{ L}\cdot\text{min}^{-1}$ ), PERI ( $0.09\pm 0.29 \text{ L}\cdot\text{min}^{-1}$ ), and POST ( $0.20\pm 0.33 \text{ L}\cdot\text{min}^{-1}$ ) were interpreted as *Likely Trivial*, *Unclear*, and *Likely Positive*, respectively. Similarly, the changes in relative  $\dot{V}O_{2max}$  for PRE ( $-0.10\pm 1.77 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), PERI ( $1.03\pm 4.64 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), and POST ( $2.84\pm 4.58 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) were interpreted as *Very Likely Trivial*, *Unclear*, and *Likely Positive*, respectively. For maximum workload, PERI ( $10.06\pm 13.08 \text{ W}$ ) and POST ( $10.92\pm 12.5 \text{ W}$ ) had *Likely Positive* changes, while PRE ( $4.75\pm 12.78 \text{ W}$ ) had a *Possibly Trivial* change. When comparing the changes in absolute  $\dot{V}O_{2max}$  and maximum workload between PRE and PERI the results were *Likely Trivial*, while the differences in the changes in relative  $\dot{V}O_{2max}$  were *Unclear*. Similarly, there were *Possibly Trivial*, *Unclear*, and *Likely Trivial* results when

comparing the changes in absolute  $\dot{V}O_{2\max}$ , relative  $\dot{V}O_{2\max}$ , and maximum workload, respectively, between PERI and POST. Furthermore, there was a *Likely Trivial* difference when comparing the changes in maximum workload between PRE and POST. However, the changes in absolute  $\dot{V}O_{2\max}$  and relative  $\dot{V}O_{2\max}$  were *Possibly Greater* and *Likely Greater*, respectively, in POST when compared to PRE.

#### Changes in Fatigue Thresholds

The pre- and post-testing data for the systemic pulmonary and localized muscular fatigue thresholds are presented in Table 5. The results of the group $\times$ time $\times$ threshold ANOVA revealed no significant three-way interaction ( $F=0.326$ ,  $p=0.888$ ,  $\eta^2=0.026$ ). However, there were significant group $\times$ threshold ( $F=3.328$ ,  $p=0.011$ ,  $\eta^2=0.217$ ), time $\times$ threshold ( $F=3.799$ ,  $p=0.022$ ,  $\eta^2=0.137$ ), and group $\times$ time ( $F=4.059$ ,  $p=0.030$ ,  $\eta^2=0.253$ ) interactions. As the group $\times$ threshold interaction did not contribute to the purpose of this manuscript, the maturational differences in the response to training, it was not included in these results. Post hoc analysis of the time $\times$ threshold interaction revealed that there was a main effect of threshold at pre-testing ( $F=33.226$ ,  $p<0.001$ ,  $\eta^2=0.561$ ) and post-testing ( $F=58.436$ ,  $p<0.001$ ,  $\eta^2=0.692$ ). At pre-testing, GET and OxDP were statistically similar ( $p=0.278$ ), but both were less than VT ( $p<0.001$ ), RCP ( $p<0.001$ ), NFT ( $p<0.001$ ), and HHbBP ( $p<0.001$ ). Furthermore, at baseline VT was less than RCP ( $p<0.001$ ), NFT ( $p<0.001$ ), and HHbBP ( $p=0.021$ ). However, at baseline RCP, NFT, and HHbBP were all statistically similar to each other. At post-testing, the only changes in statistical significance were that RCP was now significantly less than NFT ( $p=0.006$ ) and HHbBP ( $p=0.001$ ). When comparing the delta scores in thresholds, there was a significant main effect of threshold ( $F=4.240$ ,  $p=0.014$ ,  $\eta^2=0.140$ ) with HHbBP having significantly greater changes than GET ( $p=0.016$ ), VT ( $p=0.015$ ), RCP ( $p=0.014$ ), and OxDP ( $p=0.020$ ). Furthermore, dependent t-

tests for each fatigue threshold collapsed across maturational groups revealed that only GET ( $p=0.047$ ), NFT ( $p=0.001$ ), and HHbBP ( $p=0.002$ ) significantly changed from pre-testing to post-testing, while VT ( $p=0.137$ ), RCP ( $p=0.092$ ), and OxDP ( $p=0.198$ ) did not significantly change.

When assessing the significant group $\times$ time interaction, it was revealed that there was a main effect for group at pre-testing ( $F=33.074$ ,  $p<0.001$ ,  $\eta^2=0.734$ ), post-testing ( $F=47.250$ ,  $p<0.001$ ,  $\eta^2=0.797$ ), and in delta scores ( $F=3.958$ ,  $p=0.033$ ,  $\eta^2=0.248$ ) when collapsed across fatigue thresholds. At pre- and post-testing, POST was greater than PERI and PRE, while PERI was greater than PRE. When comparing delta scores POST was greater than PERI ( $p=0.023$ ) and PRE ( $p=0.026$ ), while there was no significant difference between PRE and PERI ( $p=0.861$ ). Furthermore, dependent t-tests revealed that only POST had a significant increase in fatigue thresholds ( $p<0.001$ ) from pre-testing to post-testing, while no significant changes were observed in PRE ( $p=0.186$ ) and PERI ( $p=0.356$ ).

#### *Systemic Pulmonary Fatigue Thresholds*

The changes in the systemic pulmonary fatigue thresholds are presented in Table 6. For PRE, the changes in GET ( $0.01\pm 0.14$  L $\cdot$ min $^{-1}$ ), VT ( $0.00\pm 0.09$  L $\cdot$ min $^{-1}$ ), and RCP ( $-0.01\pm 0.06$  L $\cdot$ min $^{-1}$ ) were *Unclear*, *Unclear*, and *Likely Trivial*, respectively. Similarly, PERI had *Likely Trivial*, *Unclear*, and *Unclear* changes in GET ( $0.01\pm 0.06$  L $\cdot$ min $^{-1}$ ), VT ( $0.01\pm 0.11$  L $\cdot$ min $^{-1}$ ), and RCP ( $0.03\pm 0.15$  L $\cdot$ min $^{-1}$ ), respectively. However, POST had *Likely Positive* changes for GET ( $0.14\pm 0.10$  L $\cdot$ min $^{-1}$ ), VT ( $0.12\pm 0.12$  L $\cdot$ min $^{-1}$ ), and RCP ( $0.13\pm 0.11$  L $\cdot$ min $^{-1}$ ). When comparing the changes in GET, VT, and RCP between PRE and PERI, all results were *Likely Trivial*. However, POST had *Possibly Greater* changes in all three systemic pulmonary fatigue thresholds than PRE. When compared to PERI, POST had *Possibly Greater* changes in GET and

VT, but *Possibly Trivial* differences were observed for RCP.

#### *Localized Muscular Fatigue Thresholds*

The changes in the localized muscular fatigue thresholds are presented in Table 6. PRE had *Very Likely Positive* and *Likely Positive* changes in NFT ( $0.11 \pm 0.06 \text{ L} \cdot \text{min}^{-1}$ ) and HHbBP ( $0.13 \pm 0.11 \text{ L} \cdot \text{min}^{-1}$ ), but *Unclear* changes in OxDP ( $0.01 \pm 0.06 \text{ L} \cdot \text{min}^{-1}$ ). Similarly, PERI had *Possibly Positive* changes in NFT ( $0.09 \pm 0.10 \text{ L} \cdot \text{min}^{-1}$ ) and *Likely Positive* changes in HHbBP, but *Unclear* changes in OxDP ( $0.00 \pm 0.16 \text{ L} \cdot \text{min}^{-1}$ ). For POST, there were *Likely Positive*, *Very Likely Positive*, and *Likely Positive* changes in NFT ( $0.18 \pm 0.18 \text{ L} \cdot \text{min}^{-1}$ ), HHbBP ( $0.40 \pm 0.34 \text{ L} \cdot \text{min}^{-1}$ ), and OxDP ( $0.17 \pm 0.20 \text{ L} \cdot \text{min}^{-1}$ ), respectively. When comparing the changes in NFT between groups, there were *Very Likely Trivial* differences between PRE and PERI, *Possibly Trivial* differences between PRE and POST, and *Possibly Trivial* differences between PERI and POST. For HHbBP, POST had *Likely Greater* changes than PRE and PERI, but the differences between PRE and PERI were *Unclear*. Similarly, POST had *Possibly Greater* changes in OxDP than PRE and PERI, but *Unclear* differences were observed between PRE and PERI.



## CHAPTER FIVE: DISCUSSION

The primary finding of this study was that maturity status had a significant impact on the adaptations to four weeks of sprint interval training amongst adolescent males. POST had improvements in all measures of maximal aerobic performance; while, PERI had improvements in maximum workload and PRE had no changes in maximal aerobic performance. In terms of fatigue thresholds, POST had an overall significant improvement in fatigue thresholds, which was greater than the non-significant changes observed in PRE and PERI. Specifically, POST improved all systemic pulmonary and localized muscular fatigue thresholds in response to training; whereas, PRE and PERI only had improvements in NFT and HHbBP.

While many reviews and meta-analyses have supported the trainability of  $\dot{V}O_{2\max}$  in response to high-intensity interval training amongst children of all maturity groups (Costigan et al., 2015; Logan et al., 2014), this is the first study to provide a direct comparison of the adaptations to sprint interval training between maturity groups amongst adolescent males. In the current study, significant improvements in absolute  $\dot{V}O_{2\max}$  ( $0.20 \text{ L}\cdot\text{min}^{-1}$ ), relative  $\dot{V}O_{2\max}$  ( $2.84 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), and maximum workload ( $10.92\text{W}$ ) were only observed in POST after four weeks of sprint interval training. Barker and colleagues (2014) observed significant increases in absolute and relative  $\dot{V}O_{2\max}$  ( $0.19 \text{ L}\cdot\text{min}^{-1}$  and  $2.7 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) in POST following a 2-week sprint interval training program that was similar to the training program utilized in the current study. While the current study did not observe significant improvements in  $\dot{V}O_{2\max}$  in PERI ( $0.09 \text{ L}\cdot\text{min}^{-1}$  and  $1.03 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), previous investigations have observed significant increases in  $\dot{V}O_{2\max}$  ( $\sim 4 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) in response to running-based high-intensity interval training (Koubaa et al., 2013; Sperlich et al., 2011) in 13-year-old males; however, neither study quantified maturity status, which may explain the discrepancy in the results. Prior to puberty, the

trainability of  $\dot{V}O_{2\max}$  in children appears to be blunted when compared to adults; however, there is still a marked improvement of approximately 5% (Matos & Winsley, 2007). Previous research has demonstrated significant increases in  $\dot{V}O_{2\max}$  ( $2.50\text{-}5.51 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) amongst PRE following running-based sprint interval training programs (Baquet et al., 2010, 2002; Mucci et al., 2013); however, the current study did not observe adaptations in  $\dot{V}O_{2\max}$  in PRE ( $0.02 \text{ L}\cdot\text{min}^{-1}$  and  $-0.01 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) following the cycling-based sprint interval training program. The discrepancies between the current study findings and previous research in regards to PRE may be due to differences in training modality or duration. No previous investigation has assessed the efficacy of a cycling-based sprint interval training program amongst PRE and PERI. Moreover, exercise intensity has been shown to be the most important variable in the trainability of aerobic performance amongst PRE, with intensities greater than 80% of maximum heart rate resulting in the greatest adaptations (Baquet, Van Praagh, & Berthoin, 2003; Massicotte & Macnab, 1974). In the current study, heart rate was not recorded during training; however, the intensity was considered “all-out” which has been shown to improve maximal aerobic performance amongst POST (Barker, Day, et al., 2014), but has equivocal results amongst PRE (McManus, Cheng, Leung, Yung, & Macfarlane, 2005; Williams et al., 2000). Future research should examine maturity-related differences in the heart rate response to “all-out” sprint interval training of different loads and duration.

The current study observed significant increases in all measured systemic pulmonary and localized muscular fatigue thresholds within POST, but amongst PRE and PERI there were only increases in NFT and HHbBP. The observed similarities between PRE, PERI, and POST in the improvements of NFT ( $0.11 \text{ L}\cdot\text{min}^{-1}$ ,  $0.09 \text{ L}\cdot\text{min}^{-1}$ , and  $0.18 \text{ L}\cdot\text{min}^{-1}$ , respectively) may be due improved neuromuscular activation and coordination in response to training, which can occur

across all stages of maturation (Virus et al., 1999). In terms of systemic pulmonary fatigue thresholds, Barker and colleagues (2014) observed a significant increase in GET, when expressed as an absolute  $\dot{V}O_2$  ( $0.09 \text{ L} \cdot \text{min}^{-1}$ ) but not as a percent of  $\dot{V}O_{2\text{peak}}$ , in POST; which was similar in magnitude to changes in the current study ( $0.14 \text{ L} \cdot \text{min}^{-1}$ ). Prior to puberty, lactate threshold (Rotstein et al., 1986), GET, and RCP (Mucci et al., 2013) have been shown to increase following interval training programs of at least eight weeks, which is twice as long as the current training program. Furthermore, Faude and colleagues (2013, 2014) observed significant increases in individual anaerobic threshold amongst PERI after completing 16-20 sessions of high-intensity interval training, high volume endurance training, or small-sided soccer games. It is possible that prior to, and during puberty, children need greater exposure to the interval training stimulus, via longer duration training programs, to elicit adaptations in fatigue thresholds.

When comparing maturational groups, McNarry and colleagues (2011) observed significant improvements in muscle deoxygenation responses and GET between trained and untrained girls at PRE, PERI, and POST, with similar differences between trained and untrained girls across all maturational groups, indicating no effect of maturity. However, this study was cross-sectional and did not compare adaptations to the same training program. Wright and colleagues (2016) examined the maturity-related responses to a mixed-modality high-intensity interval training program amongst girl soccer athletes, and observed limited improvements in agility performance as well as decrements in repeated sprint ability within PRE and PERI, while POST had significant improvements in intermittent running performance and agility with no performance decrements. While this is the only other study to provide a direct comparison of adaptations to high-intensity interval training amongst maturational groups, the current study is

the first to compare adaptations in maximal aerobic performance and fatigue thresholds.

Previous research has purported that the trainability of aerobic fitness throughout maturation does not appear to be affected by a ‘maturation threshold’ (Barker, Lloyd, Buchheit, Williams, & Oliver, 2014; Lloyd & Oliver, 2012); however, there is a lack of research examining the role of sprint interval training during the natural ‘windows of opportunity’ that occur during maturation (Ford et al., 2011). While maximal aerobic performance appears to be trainable throughout maturation (Barker, Lloyd, et al., 2014; Lloyd & Oliver, 2012), it has been well-established that children have diminished anaerobic capabilities prior to puberty (Armstrong, Welsman, & Kirby, 1997; Beneke et al., 2007). Evidence of this diminished anaerobic capacity was observed in the current training program, as PERI and POST had *Very Likely* greater average work completed and relative peak power attained per session than PRE. Furthermore, POST achieved *Most Likely* and *Likely* greater peak RPMs during their first two sprints compared to PRE and PERI, respectively. Previous research has shown that sprint speed is significantly correlated with the change in individual anaerobic threshold in response to high-intensity interval training amongst male youth athletes (Faude et al., 2013). It is possible that the maturity-related differences in the adaptations to sprint interval training are due to the limited anaerobic capacity prior to puberty, which affects the training stimulus, rather than a lack of trainability amongst children who have not reached puberty.

In conclusion, the sprint interval training program utilized in the current study may only be an effective means to improve maximal aerobic performance and fatigue thresholds in postpubescent boys. The maturity-related differences in the adaptation to high-intensity interval training may be due to the design of the training program, the trainability of the measures within each maturational group, or the differences in performance during the training program. While

the current sprint interval training program may be a time-efficient way to improve aerobic exercise performance during adolescence, more research is needed to determine the optimal high-intensity interval training program design to elicit the greatest adaptations across all maturational groups.

## APPENDIX A: FIGURES

## Determination of Neuromuscular Fatigue Threshold

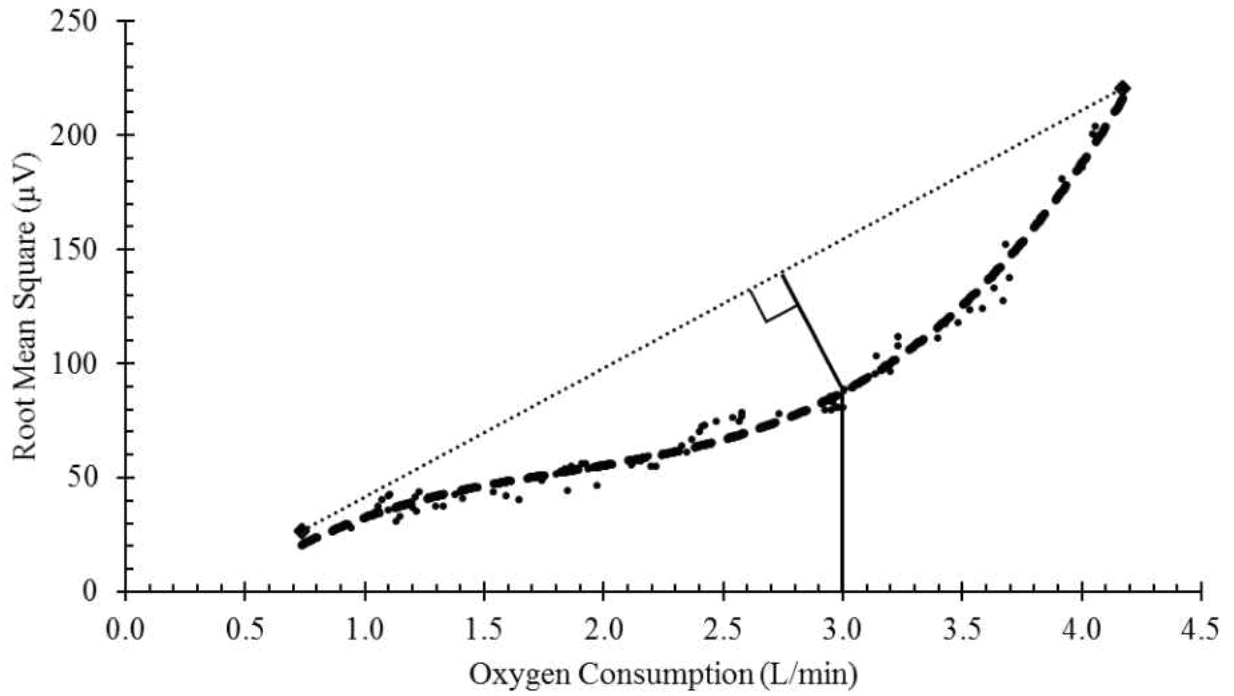


Figure 1: Example of the maximal deviation method used to determine fatigue thresholds. Actual participant data is presented to determine neuromuscular fatigue threshold.

## **APPENDIX B: TABLES**



Table 1: Pre-testing descriptive data

	<b>All (n=27)</b>	<b>PRE (n=7)</b>	<b>PERI (n=10)</b>	<b>POST (n=10)</b>
Chronological Age (years)	14.63±2.33	11.57±0.57	14.33±1.12	17.06±0.60
Maturity Offset (years)	0.56±2.11	-2.21±0.47	0.25±0.88	2.81±0.50
Height (cm)	166.63±14.10	148.37±8.81	167.56±6.92	178.48±7.64
Mass (kg)	59.13±17.59	39.8±7.05	55.07±6.71	76.76±12.75
Body Fat (%)	15.68±8.11	20.89±11.43	14.45±4.68	13.27±7.21

Table 2: Sprint interval training program

<b>Training Session</b>	<b>Number of Sprints</b>	<b>Resistance</b>	<b>Duration of Sprints</b>	<b>Duration of Recovery</b>	<b>Total Session Time</b>
Week 1 Day 1	4	7.5% of body mass	20 s (1.33 min total)	4 min	14 min
Week 1 Day 2	4	7.5% of body mass	20 s (1.33 min total)	4 min	14 min
Week 2 Day 1	5	7.5% of body mass	20 s (1.67 min total)	4 min	18.5 min
Week 2 Day 2	5	7.5% of body mass	20 s (1.67 min total)	4 min	18.5 min
Week 3 Day 1	6	7.5% of body mass	20 s (2 min total)	4 min	23 min
Week 3 Day 2	6	7.5% of body mass	20 s (2 min total)	4 min	23 min
Week 4 Day 1	7	7.5% of body mass	20 s (2.33min total)	4 min	27.5 min
Week 4 Day 2	4	7.5% of body mass	20 s (1.33 min total)	4 min	14 min

Table 3: Absolute  $\dot{V}O_{2\max}$  ( $L \cdot \min^{-1}$ ), relative  $\dot{V}O_{2\max}$  ( $mL \cdot kg^{-1} \cdot \min^{-1}$ ), and maximal workload (W) before and after training amongst maturational groups with results from the within-group magnitude based inferences.

Measure	Group	Pre-Testing	Post-Testing	Mechanistic Inference	Percent Chance (Negative/Trivial/Positive)
Absolute $\dot{V}O_{2\max}$	PRE	1.73±0.32	1.75±0.29	<i>Likely Trivial</i>	(3.6/80.1/16.3)
	PERI	2.74±0.32	2.83±0.23	<i>Unclear</i>	(6.0/33.7/60.3)
	POST	3.49±0.45	3.69±0.46	<i>Likely Positive</i>	(0.8/15.9/83.3)
Relative $\dot{V}O_{2\max}$	PRE	44.21±7.96	44.11±7.53	<i>Very Likely Trivial</i>	(2.9/95.3/1.8)
	PERI	50.15±6.02	51.18±5.84	<i>Unclear</i>	(7.6/47.0/45.4)
	POST	46.16±7.23	49.00±9.02	<i>Likely Positive</i>	(0.6/18.3/81.1)
Maximum Workload	PRE	136.17±30.29	140.91±23.18	<i>Possibly Trivial</i>	(2.6/57.5/39.9)
	PERI	216.30±25.31	226.36±18.62	<i>Likely Positive</i>	(0.2/13.9/85.9)
	POST	266.82±32.95	277.75±27.11	<i>Likely Positive</i>	(0.0/16.7/83.3)

Table 4: Changes in absolute  $\dot{V}O_2\text{max}$  ( $\text{L}\cdot\text{min}^{-1}$ ), relative  $\dot{V}O_2\text{max}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), and maximal workload (W) amongst maturational groups with results from the between-group magnitude based inferences.

Measure	PRE	PERI	POST	PRE vs PERI (PRE/Trivial/PERI)	PRE vs POST (PRE/Trivial/POST)	PERI vs POST (PERI/Trivial/POST)
Absolute $\dot{V}O_2\text{max}$	0.02±0.09	0.09±0.29	0.20±0.33	<i>Likely Trivial</i> (2.8/75.2/22.0)	<i>Possibly POST</i> (0.5/41.4/58.1)	<i>Possibly Trivial</i> (3.6/59.6/36.9)
Relative $\dot{V}O_2\text{max}$	-0.01±1.77	1.03±4.64	2.84±4.58	<i>Unclear</i> (9.4/47.0/43.6)	<i>Likely POST</i> (0.9/17.3/81.8)	<i>Unclear</i> (6.7/36.2/57.1)
Maximum Workload	4.75±12.78	10.06±13.08	10.92±12.50	<i>Likely Trivial</i> (0.8/83.1/16.1)	<i>Likely Trivial</i> (0.5/80.7/18.7)	<i>Likely Trivial</i> (2.0/94.5/3.5)

Table 5: Systemic pulmonary and localized muscular fatigue thresholds ( $L \cdot \text{min}^{-1}$ ) before and after training amongst maturational groups with results from the within-group magnitude based inferences

Threshold	Group	Pre-Testing	Post-Testing	Mechanistic Inference	Percent Chance (Negative/Trivial/Positive)	
Systemic Pulmonary	GET	PRE	1.09±0.17	1.10±0.18	<i>Unclear</i>	(24.9/39.5/35.5)
		PERI	1.67±0.26	1.68±0.23	<i>Likely Trivial</i>	(2.1/90.0/7.9)
		POST	1.98±0.40	2.12±0.31	<i>Likely Positive</i>	(0.0/10.5/89.5)
	VT	PRE	1.21±0.23	1.21±0.22	<i>Unclear</i>	(15.7/69.7/14.7)
		PERI	1.88±0.26	1.89±0.21	<i>Unclear</i>	(12.1/66.8/21.1)
		POST	2.32±0.39	2.44±0.29	<i>Likely Positive</i>	(0.1/22.6/77.3)
	RCP	PRE	1.37±0.26	1.36±0.24	<i>Likely Trivial</i>	(7.7/90.2/2.1)
		PERI	2.04±0.27	2.07±0.18	<i>Unclear</i>	(13.3/49.3/37.4)
		POST	2.55±0.38	2.68±0.31	<i>Likely Positive</i>	(0.0/14.7/85.2)
Localized Muscular	NFT	PRE	1.34±0.25	1.45±0.30	<i>Very Likely Positive</i>	(0.0/3.3/96.7)
		PERI	2.13±0.29	2.22±0.23	<i>Possibly Positive</i>	(0.3/24.9/74.8)
		POST	2.56±0.32	2.74±0.38	<i>Likely Positive</i>	(0.6/9.3/90.1)
	HHbBP	PRE	1.39±0.28	1.52±0.25	<i>Likely Positive</i>	(0.1/8.2/91.7)
		PERI	1.97±0.35	2.14±0.32	<i>Likely Positive</i>	(2.5/17.4/80.1)
		POST	2.5±0.35	2.90±0.37	<i>Very Likely Positive</i>	(0.5/2.4/97.1)
	OxDP	PRE	1.14±0.20	1.15±0.20	<i>Unclear</i>	(5.2/79.0/15.8)
		PERI	1.48±0.22	1.48±0.27	<i>Unclear</i>	(30.6/42.3/27.1)
		POST	1.97±0.50	2.14±0.50	<i>Likely Positive</i>	(0.6/23.2/76.1)

GET: Gas Exchange Threshold; VT: Ventilatory Threshold; RCP: Respiratory Compensation Point; NFT: Neuromuscular Fatigue Threshold; HHbBP: Deoxyhemoglobin Breakpoint; OxDP: Oxygenation Deflection Point

Table 6: Changes in systemic pulmonary and localized muscular fatigue thresholds ( $L \cdot \text{min}^{-1}$ ) amongst maturational groups with results from the between-group magnitude based inferences.

Threshold	PRE	PERI	POST	PRE vs PERI (PRE/Trivial/PERI)	PRE vs POST (PRE/Trivial/POST)	PERI vs POST (PERI/Trivial/POST)	
Systemic Pulmonary	GET	0.01±0.10	0.02±0.18	0.14±0.13	<i>Likely Trivial</i> (4.1/88.1/7.8)	<i>Possibly POST</i> (0.1/25.7/74.2)	<i>Possibly POST</i> (0.3/34.1/65.5)
	VT	0.00±0.09	0.01±0.20	0.12±0.16	<i>Likely Trivial</i> (2.5/92.7/4.8)	<i>Possibly POST</i> (0.1/41.1/58.8)	<i>Possibly POST</i> (0.8/47.5/51.7)
	RCP	-0.01±0.09	0.03±0.19	0.13±0.14	<i>Likely Trivial</i> (4.3/75.5/20.1)	<i>Possibly POST</i> (0.0/31.9/68.0)	<i>Possibly Trivial</i> (0.5/55.3/44.1)
Localized Muscular	NFT	0.11±0.06	0.09±0.14	0.18±0.26	<i>Very Likely Trivial</i> (3.7/95.5/0.8)	<i>Possibly Trivial</i> (2.6/66.4/31.0)	<i>Possibly Trivial</i> (1.9/57.6/40.5)
	HHbBP	0.13±0.11	0.16±0.34	0.40±0.47	<i>Unclear</i> (11.8/63.6/24.6)	<i>Likely POST</i> (2.6/16.7/80.7)	<i>Likely POST</i> (3.7/20.7/75.6)
	OxDP	0.02±0.13	0.00±0.27	0.16±0.28	<i>Unclear</i> (23.4/63.0/13.6)	<i>Possibly POST</i> (1.5/31.1/67.4)	<i>Possibly POST</i> (2.2/27.3/70.5)

GET: Gas Exchange Threshold; VT: Ventilatory Threshold; RCP: Respiratory Compensation Point; NFT: Neuromuscular Fatigue Threshold; HHbBP: Deoxyhemoglobin Breakpoint; OxDP: Oxygenation Deflection Point

## **APPENDIX C: IRB APPROVAL**



University of Central Florida Institutional Review Board  
Office of Research & Commercialization  
12201 Research Parkway, Suite 501  
Orlando, Florida 32826-3246  
Telephone: 407-823-2901 or 407-882-2276  
[www.research.ucf.edu/compliance/irb.html](http://www.research.ucf.edu/compliance/irb.html)

### Approval of Human Research

From: **UCF Institutional Review Board #1  
FWA00000351, IRB00001138**

To: **Jeffrey Ray Stout and Co-PIs: David Fukuda, Kyle S. Beyer**

Date: **January 27, 2016**

Dear Researcher:

On 01/27/2016 the IRB approved the following human participant research until 01/26/2017 inclusive:

Type of Review: Submission Response for UCF Initial Review Submission Form  
Expedited Review

Project Title: The reliability and trainability of a ramp exercise protocol to determine metabolic and neuromuscular fatigue thresholds in adolescents.

Investigator: Jeffrey Ray Stout

IRB Number: SBE-15-11910

Funding Agency:

Grant Title:

Research ID: N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30 days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at <https://iris.research.ucf.edu>.

If continuing review approval is not granted before the expiration date of 01/26/2017, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the [Investigator Manual](#).

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:





Signature applied by Patricia Davis on 01/27/2016 01:38:55 PM EST

IRB Coordinator

## **APPENDIX D: INFORMED CONSENT**



**The reliability and trainability of a ramp exercise protocol to determine metabolic and neuromuscular fatigue thresholds in adolescents.**

**Informed Consent**

Principal Investigator: Jeffrey R. Stout, Ph.D.

Co-Investigator(s): David H. Fukuda, Ph.D.  
Kyle S. Beyer, M.S.

Sub-Investigator(s): Michael J. Redd, M.S.  
Kayla Baker, B.S.

Investigational Site(s): University of Central Florida, Institute of Exercise Physiology & Wellness

How to Return this Consent Form: You are provided with two copies of this consent form. If you give consent for your child to participate in the research, please sign one copy and return it to the researcher and keep the other copy for your records.

**Introduction:** Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. Because you are the parent or legal guardian, you are being asked to allow your child to take part in a research study which will include about 45 people at UCF. Your child is being invited to take part in this research study because he is between the ages of 11 and 17 years old. Prior to participation in this study, you will be asked to fill out a medical questionnaire and this document.

Jeffrey R. Stout, Ph.D.: The person doing this research is a Professor and researcher in the Institute of Exercise Physiology and Wellness at UCF. Dr. Stout will be assisted in this study by Kyle Beyer, a UCF graduate student. This research study will serve as Kyle Beyer's dissertation.

**What you should know about a research study:**

- Someone will explain this research study to you.
- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should allow your child to take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you or your child.
- The procedures will have no medical or personal value to your child.
- Feel free to ask all the questions you want before you decide.

**Purpose of the research study:** The purpose of Phase I of this study is to evaluate the reliability of a maximal exercise test at determining fatigue thresholds in adolescents. The purpose of Phase II of this study is to compare how these fatigue thresholds change in response to interval training amongst different maturity groups.

**What your child will be asked to do in the study:** Aside from the current screening visit, your child will be asked to complete Phase I (2 pre-testing visits) and Phase II (8 training visits and 1 post-testing visit). The pre-testing visits will be completed within 7 days of each other. The week after the second pre-testing visit, your child will be enrolled in a 4-week high intensity interval training program. The training program will be consist of 2 training visits per week with at least 1 day in between visits. The final post-testing visit will be complete the week after the conclusion of the training program. A detailed description of the procedures being performed during each visit can be seen below:

**Options to complete the study:** Once enrolled in the study, you and your child will choose one of three options to complete the study. Option 1 consists of completing only Phase I, option 2 consists of completing Phases I and II in immediate succession, and option 3 consists of completing Phase I, taking time off, and then completing Phase II. If you and your child choose option 3, there will be an additional pre-testing visits at the start of Phase II.

Screening Visit (1):

You will be asked to complete this informed consent document, with your child before any other study-related procedures are performed. Upon completion of the informed consent document, you will be asked to complete a Confidential Medical and Activity Questionnaire to assess health and activity level of your child. This questionnaire will be filled out with your child. We will follow-up with your child to ensure all information is accurate. If your child has had a current (within the last 12 months) EL2 physical form, or equivalent, signed and cleared by a physician, then they will not need physician clearance. However, if this is not the case, we will require physician's clearance. Upon being admitted to the study your child will be assigned a subject number.

Then, your child's standing and seated height will be measured to determine their group assignment. Your child's group assignment will not affect overall time requirements. All groups will complete all testing and training visits. Any participant may schedule testing or training on any day, at any time. The research staff will ensure that participant privacy is maintained during all visits.

#### Testing Visits (3 or 4):

Your child will be required to complete two testing visits throughout Phases I and one testing visit in Phase II. The first two visits will be completed at least 1 day, but no more than 7 days apart. The third testing session will be completed after a 4-week high intensity interval training session. During each testing visit your child will complete anthropometric, body composition, and exercise testing. Your child will be asked to be normally hydrated and four hours fasted for all testing sessions.

#### *Anthropometric and Body Composition Testing*

Anthropometric testing will consist of standing height, seated height, and body weight. Body composition testing will consist of bioelectrical impedance analysis and BOD POD testing. Bioelectrical impedance analysis will require your child to remove their footwear, including socks, and stand on a platform while holding two handles out to the side. Your child's hands and feet will be placed in contact with a machine that will send electricity (that is safe and cannot be seen or felt) through the body to determine body composition. BOD POD testing will require your child to sit in an enclosed, air-filled chamber (see picture) for approximately two minutes as the machines determines body fat percentage. In order to accurately measure body fat percentage it is required for your child to dress down to spandex-style shorts, remove footwear, including socks, put on a swim cap to cover their hair. The BOD POD testing will take place in a private room with only the research personnel present. Your child will also fill out a sports mental toughness questionnaire, which is a 14-item questionnaire assessing their perception of stress during physical activity and sports. There are no risks associated with either anthropometric, body composition testing, or the questionnaire.



#### *Exercise Testing*

After completion of anthropometric and body composition testing, your child will be asked to complete a ramp exercise protocol on a cycle ergometer. The cycle ergometer seat will be adjusted to a comfortable position for your child, who will begin the test with a 3-minute warm up against no resistance. Once the warm up is complete, your child will continue to pedal against a resistance that is constantly increasing until they can no longer continue at a certain pace. During this test, your child will have their heart rate, expired air, neuromuscular recruitment, and tissue oxygenation levels measured. There are no reported risks with any of the measurements being obtained during this test and all of the methodologies are considered non-invasive.

#### Training Visits (8):

During Phase II of the study, your child will be asked to complete 4 weeks of high intensity interval training. All training session will occur in the Strength and Conditioning Laboratory, 2 times per week for a total of 8 training visits. There will be at least 24 hours between your child's training sessions to allow for proper recovery. Your child's training load will be set at 7.5% of your child's body weight. Each training sessions will consists of a 5-minute warm up at a self-selected resistance, followed by a protocol of 4-7 30-second exercise bouts. There will be a 4-minute rest interval in between exercise bouts. On the first and last training session, your child will also be asked to complete a skeletal muscle ultrasound exam before and after the exercise. For this, your child will be asked to lie flat on their back on an examination table with their legs extended. A lubricated probe will be placed over their thigh to collect images of their muscle. The images will be collected and store on a laptop, then



transferred to a desktop for analysis. There are no risks or dangers associated with the ultrasound exam.

**Location:** All testing will be conducting in the Human Performance Lab in the College of Education and Human Performance building at the University of Central Florida. All training sessions will be completed within the Strength and Conditioning Laboratory in the College of Education and Human Performance building at the University of Central Florida.

**Time required:** In addition to the current screening visit (lasting approximately 20 minutes), we expect that your child will be in this research study for approximately 6 weeks and will consist of 12 total visits (13 if choosing option 3 to complete the study). The testing visits will each last approximately an hour and a half. Training visits will last no more than an hour. All visits to the Human Performance Lab will be scheduled with Kyle Beyer. It will be expected that your child provide their own transportation to and from the Human Performance Lab. It is not required for you, the parent to attend; however, if you are present you will be welcome to observe any testing/training.

**Risks:** There is minimal risk involved with participation in this study. Participants may experience muscle fatigue, muscle strain, and elevated heart rate during the exercise testing and training protocols. All testing and training will be overseen by Certified Strength and Conditioning Specialists who are also certified in CPR and to use an automated external defibrillator (AED). An AED is located in the building where testing and training will occur. If immediate assistance, such as first aid, CPR, or AED, is needed it will be provided, but you must seek your own physician for any further medical treatment. Participants are instructed to notify the research team if they feel uncomfortable at any time.

**Benefits:** We cannot promise any benefits to your child from taking part in this research. Any information or data obtained will be made available to you at your request. However, your child will be receiving four weeks of personalized high intensity interval training from a Certified Strength and Conditioning Specialist.

**Compensation or payment:** There is no compensation or other payment to you or your child for your child's part in this study.

**Confidentiality:** We will limit your personal data collected in this study. Efforts will be made to limit your child's personal information to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of UCF.

The results of this study will be published as a group as part of a scientific publication. No individual results will be published or shared with any person or party. All information attained from the Confidential Medical and Activity questionnaires or performance tests will be held in strict confidence. Individual results will remain confidential and only be relayed to the participant upon request. All Confidential Medical and Activity questionnaires, as well as data collection sheets will be kept in a locked cabinet during and following the study. All information will be destroyed five years from the end of the study and not used for other research purposes. Participant folders will be marked with an I.D. number to protect against a breach of confidentiality, and the ID number will be removed upon disposal. Any information or data obtained will be made available to you at your request.

**Study contact for questions about the study or to report a problem:** If you have questions, concerns, or complaints, or think the research has hurt your child talk to Kyle Beyer or Dr. Jeffrey Stout, Human Performance Laboratory, Sport and Exercise Science (407) 823-2367 or by email at [jeffrey.stout@ucf.edu](mailto:jeffrey.stout@ucf.edu).

**IRB contact about you and your child's rights in the study or to report a complaint:** Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

**If your child is harmed because he or she takes part in this study:** If your child is injured or made sick from taking part in this research study, medical care will be provided. Depending on the circumstances, this care may be provided at no cost to you. Contact the investigator for more information.

**Withdrawing from the study:** You may decide not to have your child continue in the research study at any time without it being held against you or your child. Participation in the study may also be terminated at any time by the researchers in charge of the project. This could be based upon your refusal to follow study instructions or follow the study protocol.

**Results of the research:** Upon request, results will be shared with parent or legal guardian of the participant at the conclusion of all data collection and analyses.

Your signature below indicates your permission for the child named below to take part in this research.

**DO NOT SIGN THIS FORM AFTER THE IRB EXPIRATION DATE BELOW**

_____	
Name of participant	
_____	_____
Signature of parent or guardian	Date
_____	<input type="checkbox"/> Parent
Printed name of parent or guardian	<input type="checkbox"/> Guardian (See note below)
<input type="checkbox"/> Assent Obtained	

My signature and date indicates that the information in the consent document and any other written information was accurately explained to, and apparently understood by, the participant or the participant's legally authorized representative, and that informed consent was freely given by the participant or the legally authorized representative.

**Note on permission by guardians:** An individual may provide permission for a child only if that individual can provide a written document indicating that he or she is legally authorized to consent to the child's general medical care. Attach the documentation to the signed document.

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