

THE EFFECTS OF ECCENTRIC TRAINING ON STRENGTH AND MUSCLE
DEVELOPMENT IN PRE-PUBERTAL AND PUBERTAL BOYS

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ABSTRACT

It is now generally accepted that strength training in pubertal children will increase strength, but it is unlikely to induce morphological changes. However research in this area is limited as most studies fail to control for the confounding effects of normal growth, or employ appropriate training programs. To overcome these limitations it is suggested that researchers should use a within-subject design employing an exercise regime of sufficient intensity. In adults, eccentric training has been shown to have the greatest effect on hypertrophy and strength. The purpose of the study was to examine the effects of eccentric training on muscle strength and development in children, using a one arm training model. Seventeen boys in grades 6, 7, and 8 participated in an eight week eccentric elbow flexion training program; three training sessions per week. The program consisted of 2 – 5 sets of 6 – 10 reps using progressive resistance. Pre and post test strength (Eccentric and concentric elbow flexion maximal strength by a Biodex System 3 Dynamometer and 1 RM with dumbbells) and bicep thickness measurements were performed. The change in biceps thickness was significantly greater in the training arm versus the non-training arm (7.3 +/- 8.3% vs. 0.7 +/- 7.5%) ($p < 0.05$). No significant difference was found for isokinetic concentric strength gain between arms ($p > 0.05$), but isokinetic eccentric strength gain in the training arm was significantly greater than the non-training arm (25.4 +/- 16.6% vs. 2.4% +/- 15.6%) ($p < 0.05$). Training arm 1 RM isotonic strength significantly increased when compared to the non-training arm, both concentrically (35.0 +/- 15.8% vs. 14.8 +/- 13.1%) and eccentrically (45.0 +/- 16.1% vs. 21.8 +/- 8.0%) ($p < 0.05$). Results from this study indicate eccentric strength training can increase muscle strength and hypertrophy in pubertal boys.

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CHAPTER 1 SCIENTIFIC FRAMEWORK

1.1 Introduction

Strength training in children and adolescents has long been an issue surrounded by controversy. Researchers, coaches, parents, and the general public alike, have been very cautious regarding this topic. Because of this cautious approach, there is limited scientific research on the effects of strength training in children (Strong et al., 2005). Strength training can provide many health related benefits to growing children. Strength training is a safe and feasible exercise option for children (Faigenbaum & Kang, 2006). However, despite the ongoing research the general public still views strength training in children as a dangerous activity which should be avoided.

In the past 30 years technological advancements have led to drastic lifestyle changes in both adults and children alike. These changes include a decrease in physical activity, an increase in energy intake, and a resultant worsening in body composition (Fricke & Schoenau, 2005). Overweight and obesity in children is reaching epidemic proportions in North America. This has brought about an increase in body composition related diseases such as type 2 diabetes, hypertension, coronary heart disease, and others (Strock, Cottrell, Abang, Buschbacher, & Hannon, 2005). In an attempt to prevent such diseases, researchers and health professionals have stressed the importance of physical activity in children. However, most suggestions regarding physical activity have focused on aerobic activities, with little or no focus on activity which stresses the musculoskeletal system (Faigenbaum & Kang, 2006).

The benefits of strength training in children have been well documented. In light of all the newest research, national health organizations now recommend children participate in physical activity that will stress their musculoskeletal system. For example, the British

Association of Exercise and Sport Sciences recommends strength training as a regular component of any physical activity program (Stratton et al., 2004). In the USA, the Surgeon General's Physical Activity and Health report aims to increase the number of children six years and older who participate in activities that improve musculoskeletal fitness (Faigenbaum & Kang, 2006). Here in Canada, the Canadian Physical Activity Guide for Children (2006) stresses the importance of physical activities that build strength and muscles. Furthermore, the Canadian Society for Exercise Physiology's 2008 position paper (Behm, Faigenbaum, Falk, & Klentrou, 2008) states that a resistance training program can lead to numerous functional benefits including increased muscular strength, endurance, power, balance, and co-ordination, as well as general health benefits.

Muscular strength is a key feature of growth and development. Despite its importance on development, it has been virtually ignored in pediatric science (Neu, Rauch, Rittweger, Manz, & Schoenau, 2002). This is especially true from a physiological perspective. The current research, presented in the literature review, seems to have moved away from examining the physiological effects of strength training. Instead researchers today rely on previous research and accept the conclusions previously postulated. The majority of the studies performed now examine only the practical aspect of strength training in children. Program design considerations, such as exercise safety, optimal repetitions/sets/intensity, have become the focus (Faigenbaum & Kang, 2006).

The concern is that North American children have adopted a lifestyle of physical inactivity and caloric excess (Strock et al., 2005). This has led to unhealthy changes in body composition. Atrophic musculoskeletal systems are now a major health concern (Fricke & Schoenau, 2005); one prevention strategy that could be employed is strength training (Watts,

Jones, Davis, & Green, 2005). The health benefits of strength training are undisputable (Faigenbaum & Kang, 2006); however, this treatment/prevention strategy is underutilized because of the general public's fear of this type of exercise in children. This fear is unsubstantiated, yet it remains (Faigenbaum, 2000). In order for the general public to accept this as a positive exercise alternative, a greater physiological understanding is required. To improve our understanding, more research is needed, specifically research that deals with the physiology behind these training effects. Until we have a better physiological understanding of strength training in children, this is an area which will continue to be dominated by myths.

This study will examine the physiological effects, in particular the development of strength and muscle hypertrophy, which occur when children participate in a strength training program. Specifically, the study will determine if any changes in strength and muscle hypertrophy that occur during strength training are independent of normal growth and development.

1.2 Review of Literature

1.2.1 Natural Growth and Development

Physical growth is a continuous process which occurs throughout childhood right up until adulthood. Although it proceeds without specific stops or starts, the velocity of growth varies at different maturational stages. Growth velocity in general decreases from birth until it stops in the late teens or early twenties, depending on gender and hormonal factors. However, this consistent decrease in growth velocity is interrupted for a couple years; this time period is termed "adolescence." At this time there is a marked increase in the velocity of growth and this is termed the adolescent growth spurt. During this period of accelerated growth, which can also

be referred to as “puberty,” the body undergoes many drastic changes. These include changes to body size and shape, and relative proportions of bone, muscle, and fat. This is also the period of greatest sexual differentiation, including changes to reproductive organs and secondary sexual characteristics (Tanner, 1978).

Although every child goes through this adolescent period at their own unique timing and tempo, they all follow the same general trend. Also, the difference in growth between males and females is quite pronounced. On average females grow faster than males, with females normally reaching 50% of their adult height by 1.75 years of age, whereas males do not reach this point until 2 years of age (Tanner, 1978). Females also normally go through puberty earlier than males. Females attain their peak growth at an average of 12 years of age, whereas males do not attain their peak growth until 14 years on average (Rauch, Bailey, Baxter-Jones, Mirwald, & Falkner, 2004).

1.2.2 Natural Strength Development

Strength increases tremendously from childhood to adulthood, with the greatest gains during the adolescent years (Blimkie, 1989) (Figures 1-1, 1-2). Prior to adolescence, strength increases linearly, and this is the same for both boys and girls. As early as the age of 3, boys show a small strength advantage; this difference remains constant throughout preadolescence. As puberty approaches for males, around the age of 13 or 14, strength increases at a greater rate due to hormonal factors. Females do not show this trend as they go through puberty; they instead maintain their linear increase and eventually strength begins to plateau when they reach the age of 16 or 17 years (Malina & Roche, 1983). At the age of 7, females have approximately 92% of the absolute strength of males, whereas by the age of 18 they have less than 60% of the absolute strength of males (Blimkie, 1989).

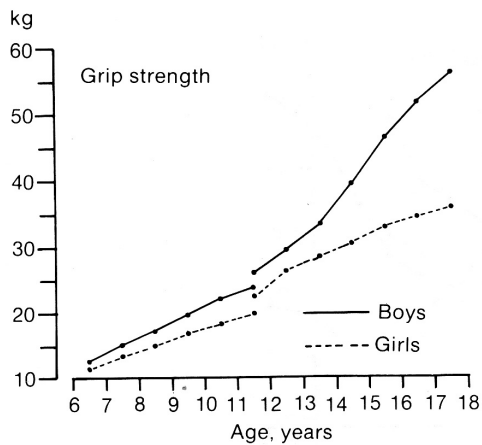


Figure 1-1 Change in grip strength (kg) in boys and girls throughout childhood and adolescence (Malina & Roche, 1983).

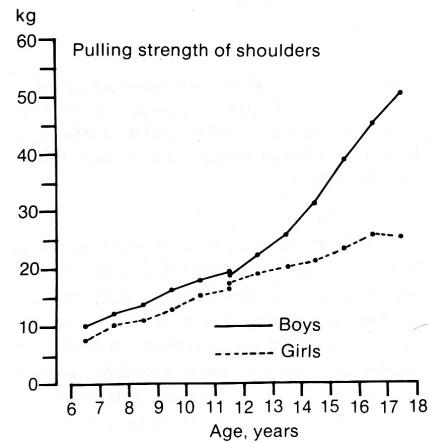


Figure 1-2 Change in pulling strength of shoulders (kg) in boys and girls throughout childhood and adolescence (Malina & Roche, 1983).

Longitudinal studies have reported that for most muscle groups, the adolescent strength spurt occurs approximately one year following peak height velocity (PHV). This strength spurt will often happen at the same time as the peak weight velocity. In females the data is limited, thus the results are unclear and also show tremendous individual variability (Blimkie, 1989). However, what is clear from this limited data, is that females still show an adolescent strength spurt, and it usually occurs after PHV, but this strength spurt is of much less magnitude than that of males (Blimkie & Sale, 1998).

During the prepubescent years, maturational differences have minimal if any effect on strength development. However, as children approach puberty these maturational differences become more prominent (Malina & Roche, 1983). As the timing and velocity of growth is so variable during the adolescent years, any comparisons using chronological age become inadequate (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). Throughout puberty early

maturing boys are stronger than average or late maturing boys at all age groups during adolescence. This maturational difference decreases after mid-puberty, and there is no significant strength difference between the maturational groups post puberty (Blimkie & Sale, 1998).

1.2.3 Natural Muscle Mass Development

The adolescent strength spurt is mostly due to the corresponding increase in muscle mass. The correlation between strength and muscle cross-sectional area (CSA) is moderate to strong for both males and females throughout growth (Davies, Dooley, McDonagh, & White, 1985). This increase in muscle CSA is due to increased protein content (hypertrophy), not cellular multiplication (hyperplasia). There is an approximate threefold increase in muscle fiber diameter between the age of one year and adolescence; however, muscle fiber number remains constant throughout this period (Oertel, 1988). Total body muscle mass increases 3.5 fold in females, and 5 fold in males between the age of 5 to 17.5 (Malina, 1969). The proportion of body mass accounted for by muscle mass also increases throughout growth. During mid-childhood muscle mass accounts for 40% (females) and 42% (males) of total body mass, whereas by late adolescence those values increase up to 42% (females) and 54% (males) (Malina, 1986).

With the strong relationship between strength and muscle mass, the development curve for muscle mass mimics that of strength (Figure 1-3). In both boys and girls, there is a linear increase throughout childhood, with males on average having a slight muscle mass advantage. Around mid-puberty this muscle mass difference becomes magnified and increases progressively throughout adolescence where it reaches its peak at early adulthood (Johnston & Malina, 1966). Data on British children from the Harpenden Growth Study show males have a

defined growth spurt in muscle tissue for both arm and calf musculature. Females however, do not show any defined spurt, as the growth rate increases only slightly during adolescence. This growth rate is then followed by a prolonged plateau for 4 to 5 years. This data also shows a significant difference between growth spurts of the calf and arm when comparing males to females. The growth rate of the arm during adolescence in males is almost double that of the female growth rate, whereas the difference for the calf is significantly lower (Tanner, Hughes, & Whitehouse, 1981). Further, Sale and Spriet (1996) showed that by late adolescence females only have 50% of the muscle size of males in the upper limb, but for the lower limb they have 70% of the muscle mass of males.

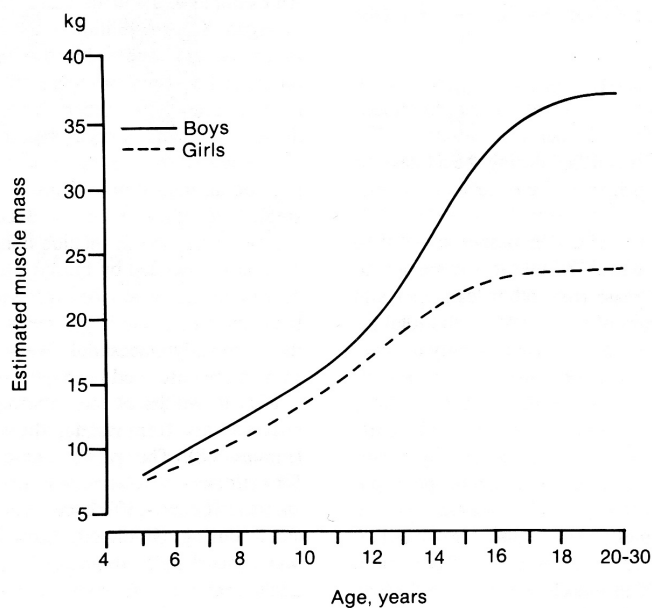


Figure 1-3 Change in estimated muscle mass (kg) in boys and girls throughout childhood and adolescence (Malina & Bouchard, 1991).

As with strength, the maturational and gender differences in muscle mass during development are hormonally influenced. Growth and development is affected by many different hormones, and the interaction amongst these hormones. Two of the major hormones are growth hormone (GH) and insulin-like growth factor (IGF-I). However testosterone, which

is a strong anabolic hormone, is believed to have the most influence on strength and muscle mass development during adolescence (Blimkie & Sale, 1998). During the prepubertal years, testosterone levels in males are very low; these levels begin to rise slowly in early adolescence at a rate of about 4 times that prior to adolescence. During the peak growth spurt testosterone levels increase rapidly so that by the end of puberty, these levels in males are about 20 times that of their pre-pubertal levels. As for females, their entire increase throughout adolescence is only about 4 times that of their pre-pubertal levels. Post pubertal testosterone levels for females are 15 times lower than males (Malina & Bouchard, 1991) (Figure 1.4).

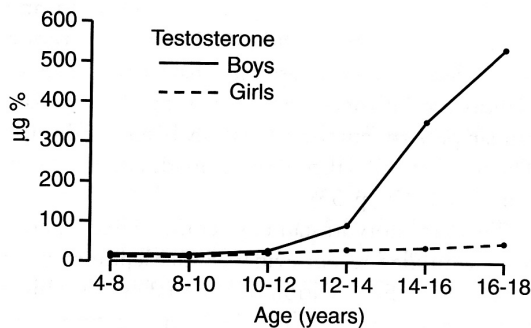


Figure 1-4 Change in serum levels of testosterone (µg%) in boys and girls throughout childhood and adolescence (Malina & Bouchard, 1991).

1.2.4 Strength Training in Children: Background

The importance of strength in relation to physical activity and general health has long been known. Over 65 years ago Cureton and Larson (1941) stated: “The positive and high relation of muscular strength to general health, physical fitness, or capacity for an activity can hardly be questioned. With no strength there can be no physical activity, moreover, when muscular strength is low all life processes are handicapped.” Despite the obvious importance of musculoskeletal strength and fitness, there is still controversy about strength training in

children. This is because there are still many concerns about the safety and usefulness of strength training in children. However, these concerns are based almost solely on potentially long standing myths that continue to persist today (Faigenbaum, 2000).

One of the myths involves the lack of hormones in children, specifically androgens, to facilitate strength gains. One of the earliest published studies, and maybe the most cited study on strength training in children, by Vrijens (1978), showed no significant increase in strength following a 12 week strength training study. However, numerous studies have refuted these results and shown that strength training appears to increase strength in children at all ages (Stratton et al. 2004; Ramsay, Blimkie, Smith, Garner, Macdougall, & Sale, 1990; Pfeiffer & Francis, 1986; Malina, 2006). Although children have smaller absolute gains in strength, they have similar, or even sometimes greater, relative gains in strength when compared to adults (Blimkie, 1993). A child's maturity appears to play an important role in strength development; however, testosterone levels in preadolescents remain virtually unchanged until puberty (Malina & Bouchard, 1991), while at the same time strength still increases. This suggests that muscle development can still occur when androgen levels are low.

Another myth is that strength training is only for young athletes. However, strength training has been shown to have many health benefits, including increased cardiorespiratory fitness (Faigenbaum & Kang, 2006), improved body composition (Watts et al., 2005; Lillegard, Brown, Wilson, Henderson, & Lewis, 1997) and blood lipid profiles (Fripp & Hodgson, 1987), improved motor performance skills and coordination (Malina, 2006), and increased self confidence and self-esteem (Faigenbaum, 2000). In regards to these improvements, it has been postulated that strength training would prove to be very beneficial for the treatment and prevention of obesity in children (Watts, et al., 2005).

Another persistent myth involves the safety of strength training programs in children. Although it has been speculated children participating in strength training have a high injury rate (Rians, Weltman, Cahill, Janney, Tippett, & Katch, 1987), this has been questioned by others (Faigenbaum & Kang, 2006). If a strength training program is well constructed and supervised by qualified fitness consultants it can be a very safe and feasible mode of exercise (Sothorn et al., 2000; Behm et al., 2008). In fact, strength training has actually been shown to decrease injury rates in sports and recreational activities (Smith, Andrish, & Micheli, 1993). With many youth sporting programs concentrating on sport-specific skills, rather than fundamental fitness, overuse injuries become an important concern. The American College of Sports Medicine (2000) estimated that if more emphasis was placed on overall fitness, including strength training, 50% of all overuse injuries that occur in youth sport could be prevented. Many exercise related injuries are attributed to muscle weaknesses and muscle-strength imbalances which occur during development, and these might be prevented through a strength training program (Kraemer, Fry, Frykman, Conroy, & Hoffman, 1989). Malina & Bouchard (1991) have proposed that as a child ages, more and more emphasis should be placed on aerobic and muscular fitness, and less on motor skills. By age 10, these components should be equal in the amount of time spent on each.

Probably the most common concern or myth about strength training and children is the fear it will stunt a child's statural growth. There is no evidence of any decrease in stature or damage to the bone following a strength training program (Falk & Eliakim, 2003). As in young adults, strength training may enhance bone mineral accrual in children (Morris, Naughton, Gibbs, Carlson, & Wark, 1997). Adolescence is the most important time for accruing bone mineral (Rauch et al., 2004). An increased bone mineral accrual, hence bone

density, at this young age, will have many health benefits in regards to osteoporosis prevention as one ages.

The scientific literature from the last 15 years seems to dispel all myths regarding youth strength training. The health benefits of strength training in children have been well documented (Behm et al., 2008), and no intervention studies have shown detrimental effects of strength training in children (Faigenbaum & Kang, 2006). It is now postulated that a well-designed and supervised strength training program is not only safe, but also very beneficial for children and adolescents (Watts et al., 2005). Yet despite all this, the myths are still prominent among the general public, and are still viewed as ‘common myths’ by researchers.

1.2.5 Strength Training in Children: The Progression

The early research on strength training and children proposed a ‘trigger hypothesis’ (Katch, 1983). Katch (1983) hypothesized that at some point during maturation, believed to be at the end of childhood or early adolescence, a dramatic increase in physiological precursors caused a ‘trigger effect.’ Prior to this critical period any physical training performed would have minimal or non-existent effects. The majority of the early studies supported this hypothesis, however, they were concerned mostly with aerobic training (Payne, Morrow, Johnson, & Dalton, 1997). An early strength training study by Vrijens (1978) found that strength training had no significant effect on strength development in prepubescent boys. Because of the lack of definitive research, the American Academy of Pediatrics (AAP) position on strength training in children in 1983 was, “prepubertal boys...do not significantly improve strength or increase muscle mass in a weight training program because of insufficient circulating androgens” (AAP, 1990, p. 158). However, since 1983 this ‘trigger hypothesis’ has been refuted and the majority of studies showed that significant strength gains could be

made (Falk & Eliakim, 2003). In 1990 new AAP recommendations were released, stating that “short term programs in which prepubescent athletes are trained and supervised by knowledgeable adults can increase strength without significant injury risk” (AAP, 1990, p.801). Since then the AAP position has once again been modified, and instead of only including young athletes they now recommend that strength training is a safe and effective training method which can increase strength, prevent/rehabilitate injuries, improve sport performance, and maybe most importantly enhance long term health in all children (AAP, 2001, p.1470). The newest position paper on this topic from the Canadian Society for Exercise Physiologists (Behm et al., 2008) reinforces the AAP position and stresses the importance of incorporating resistance training in any youth exercise program.

1.2.6 Strength Training Adaptations

In adults strength training causes significant physiological adaptations (Folland & Williams, 2007; Gabriel, Kamen, & Frost, 2006). These adaptations will enable the muscle to generate more force; hence, the muscle will become stronger. These adaptations can be either morphological or neurological in nature.

1.2.6 A.1 Strength Training Adaptations in Adults: Morphological

The major morphological change that occurs is an increase in muscle size. This increase in muscle size has been attributed to muscle fiber hypertrophy (Folland & Williams, 2007). Although muscle fiber hyperplasia has been argued to play a role in muscle size, general consensus is that hypertrophy accounts for 95 – 100% of the increase in muscle size (McCall, Byrnes, Dickinson, Pattany, & Fleck, 1996; Brooks, Fahey, White, & Baldwin, 1999).

Muscle hypertrophy is influenced by the delicate relationship between protein synthesis and protein degradation. It is the balance of these that will ultimately determine the amount of hypertrophy, or atrophy that will occur. These two pathways are influenced by the demands placed on the muscle in terms of mechanical stress, from physical activity. Yarasheski, Zachwieja, and Bier (1993) showed significant increases in protein synthesis following a strength training session from 4.5 hours up to 48 hours post exercise. Protein degradation also is increased following a strength training bout, however, this increase is to a lesser extent than that of the protein synthesis. Therefore, following a strength-training session there is an increase in the net protein balance which leads to muscle hypertrophy (Phillips, Tipton, Aarsland, Wolf, & Wolf, 1997). Other factors such as growth factors, nutrition, or illness, can also affect the relationship between protein synthesis and degradation, either positively or negatively (Favier, Benoit, & Freyssenet, 2008).

Satellite cells play a role in muscle fiber hypertrophy, and seem to be required for extreme hypertrophy (Folland & Williams, 2007). These satellite cells are activated following significant trauma to the muscle to the point where it requires muscle regeneration. Following activation, satellite cells will proliferate and travel down the fiber and fuse together with the preexisting fibers at the site of the damage. Satellite cell proliferation increases following strength training in humans (Kadi et al., 2004; Roth et al., 2001). Although the exact mechanisms responsible for satellite cell proliferation are unclear (Allen, Roy, & Edgerton, 1999), a few different hormonal factors appear to play a role (Favier et al., 2008). Of particular interest is IGF-I, which is under the control of GH and is mainly synthesized by the liver. IGF-I has been described as a master trigger of hypertrophy, as it is among the best anabolic agents for skeletal muscle (Sandri, 2008). McCall, Allen, Haddad, and Baldwin (2003) showed

increased IGF-I expression following the functional overload of a muscle. Also, overexpression of an IGF-I isoform in transgenic mice increases muscle-specific hypertrophy (Musaro et al., 2001).

Testosterone is another strong anabolic agent that can influence hypertrophy. Generally testosterone levels increase following a strength training session (Kraemer & Ratamess, 2005). The administration of testosterone will result in increased satellite cells (Favier et al., 2008); therefore, it is hypothesized that the increased testosterone levels following strength training also lead to an increase in satellite cell proliferation. Testosterone can also increase muscle mass by promoting the differentiation of pluripotent stem cells toward the myogenic lineage (Herbst & Bhasin, 2004). The supplementation of testosterone increases maximal strength and muscle power in humans, and it is hypothesized that this is due to the increased muscle mass that accompanies this supplementation (Herbst & Bhasin, 2004; Bhasin et al., 1996).

There are many factors that will affect the amount of muscle hypertrophy that will occur. Muscle fiber type will affect hypertrophy, as type II fibers increase to a greater extent than type I fibers (Hakkinen, Komi, & Tesch, 1981). Also, muscle groups vary in their hypertrophic response to strength training. Upper body muscle groups have significantly greater hypertrophy than lower body muscle groups when trained at the same intensity, volume, and duration (Folland & Williams, 2007; Abe, Pollock, & Garzarella, 2000). Contraction type and velocity also plays a role. Farthing and Chilibeck (2003b) showed fast eccentric contractions were the most beneficial for increasing hypertrophy.

1.2.6 A.2 Strength Training Adaptations in Children: Morphological

Muscle hypertrophy is often looked at in strength training studies. Although prominent hypertrophic gains are seen in adults, this is not the case in children (Behm et al., 2008). Most

recent strength training studies in preadolescents show a significant increase in strength without an accompanying increase in lean mass (Faigenbaum & Kang, 2006). This is consistent with previous work in children, which suggests that training induced changes in strength are primarily due to neuromuscular adaptations (Blimkie & Sale, 1998). It is now generally accepted that muscle hypertrophy does not occur in preadolescents (Faigenbaum & Kang, 2006). However, there have been a few studies where the results seem to refute this claim (Mersch & Stoboy, 1989; Fukunaga, Funato, & Ikegawa, 1992).

Mersch and Stoboy (1989) employed a one arm/one leg training program with identical twins. Using magnetic resonance imaging to assess muscle CSA, they showed an increase in strength and muscle size in both the thigh and upper arm for both the training and non-training limb, following a strength training program. The increase in strength and CSA were significantly greater in the training limb when compared to the non-training limb. However, the results from this study are often criticized as the data is only from two subjects.

Fukunaga et al. (1992) showed muscle hypertrophy in preadolescents. This study involved 99 children in grades 1, 3 and 5. Half participated in a 12 week strength training program, which consisted of maximal 10-second elbow flexion isometric contractions. The control group participated in regular physical education class. Muscle CSA was measured by ultrasound. Muscle CSA significantly increased in the training group when compared to the control group. However, the authors could not eliminate the possible individual effects of normal growth and development as the cause of these changes. Oddly, this study showed that elbow flexion training led to a greater increase in muscle size for the elbow extensors than elbow flexors. Furthermore, increases in elbow flexion strength were more prevalent in the control group than in the training group.

Although these two studies both displayed apparent muscle hypertrophy in preadolescents following a strength training program, the validity of these results are often questioned because of their low subject numbers or lack of specificity of training. Also, there is an abundance of other studies which have shown no effect on muscle hypertrophy (Behm et al., 2008; Falk & Eliakim, 2003). Further research with an appropriate training model that is effective for inducing muscle hypertrophy, but which corrects for regular muscle growth and development is needed.

1.2.6 A.3 Strength Training Adaptations in Children: Hormonal

Although this present study does not investigate the specific effects of testosterone on muscle or strength development, because of its importance, an understanding of the current literature in this area is important. The relationship between strength development and testosterone in children has limited research. Ramos, Frontera, Llopart, & Feliciano (1998) showed that in boys only 41% of the variability in strength was accounted for by testosterone. In girls this value was lower, as only 21% of the variability was accounted for by testosterone. Although girls also have a noticeable increase in estrogen during this period, estrogen has not been shown to have any effect on lean mass or strength development (Veldhuis et al., 2005). Neu et al. (2002) found that muscle CSA growth was influenced by hormonal changes. However, they also found that the increase in grip strength per muscle CSA was similar in both males and females, thus it appears to be independent of hormones. A study by Hansen, Bansbo, Twisk, & Klausen (1999) looked at the relationship between strength and hormone levels in 11-13 year old soccer players. Testosterone was important for strength development in children and adolescents. However, once they controlled for height, age, and hormone levels, elite soccer players were stronger than the non-elite, independent of testosterone levels.

The authors suggested that the training regime undertaken by the elite soccer players had a beneficial effect on strength.

The effect of strength training on testosterone levels has also been studied. Tsolakis, Vagenas, & Dessypris (2001) examined the effect of a strength training program on testosterone and free androgen index in preadolescents. They found a strength training program significantly increased both the testosterone and free androgen index in the training group by 125% and 75% respectively. These elevated levels of hormones persisted following two months of detraining. This study shows that strength training may increase the hormone levels in preadolescents which will in turn lead to increased strength, as opposed to the reverse traditional theory where an increase in androgen hormones is necessary before strength training will have any effect.

1.2.6 B.1 Strength Training Adaptations in Adults: Neurological

The increase in maximal strength following a strength training program in adults can only be partly explained by the increase in muscle mass. This unexplained part of the strength increase is often attributed to neuromuscular adaptations (Gabriel et al., 2006). These adaptations occur very early in training and therefore are the suggested mechanism for the early gains in strength that occur without any accompanying hypertrophy (Sale, 2001). Increases in surface EMG appear well before any increase in muscle size, suggesting these neuromuscular changes may be responsible for the early increase in strength (Gabriel et al., 2006). Humans are unable to fully activate their muscle voluntarily; however, strength training can improve this activation (Dowling, Konert, Ljucovic, & Andrews, 1994). A beneficial adaptation that occurs following strength training is increased agonist activation. This increase can be due to increased firing rate, increased motor unit recruitment, or increased motor unit

synchronization. Increased activation of synergist muscles can also play a role in maximal strength changes (Gabriel et al., 2006). Another factor which may affect strength is the relationship between the agonist and the antagonist (Sale, 2001). Although there is some evidence of antagonist deactivation following training, and this decrease positively affecting strength (Gabriel et al., 2006), this view has been questioned recently. Some studies have shown an increase in antagonist activity, and this antagonist activity accounting for some of the increase in strength due to improved stability of the joint (Sale, 2001). So it is hypothesized that the agonist-antagonist relationship is important, however the extent by which antagonists affect the maximal ability of the agonist is unclear (Gabriel et al., 2006).

1.2.6 B.2 Strength Training Adaptations in Children: Neurological

There are few studies which have examined neuromuscular changes in strength training intervention studies in children. Blimkie (1989) showed a 9% increase in motor unit activation following 10 weeks of strength training. In the same study, there was an increase in one repetition maximum of 40%. So the small improvement in motor unit activation did not approximate the large improvement in maximal strength. Ramsay et al. (1990) reported an increase in evoked twitch torque in boys after 20 weeks of strength training in the absence of muscle hypertrophy. The authors proposed that this increase was due in part to a change in excitation/contraction coupling; however, they could not attribute all of the strength gains to this. Similar to these findings, Ozmun, Mikesky, and Surburg (1994) showed a 17% increase in agonist muscle activation in pre-pubertal boys and girls following an eight week training program. Once again though, this could not fully explain the reported 28% increase in strength. It appears that neuromuscular adaptations do not completely explain the changes in strength observed in these studies, so there is still much research needed in this area.

1.2.7 Limitations of the Current Literature

The major problem with the current literature is the lack of physiological understanding of the exact effects strength training has on children. Without a complete understanding of the physiological processes associated with this type of training, it is difficult to convince people of the safety and effectiveness of strength training. There has been much physiological research on strength training in adults, but the research with children is limited.

The biggest limitation to research with children is the confounding effects of growth and development. Although all children undergo similar growth patterns, the timing and tempo of each individual child can differ drastically (Rauch et al., 2004), therefore studies investigating changes over time in children must control for maturity status. Failure to control for maturity, by using chronological age as opposed to biological age, leads to inconsistent findings with no definitive conclusions. Without performing longitudinal studies or employing invasive measures such as x-rays or Tanner staging, it is difficult to accurately determine a child's biological age. Even once maturity status has been controlled for as best as possible, it is still problematic to determine if any changes are independent of growth and development (Falk & Eliakim, 2003). This becomes even more difficult in strength training studies, as the dependent variable often assessed is either strength, muscle hypertrophy, or both. As children age they will become stronger and their muscles will grow, whether they strength train or not (Seger & Thorstensson, 2000). Determining if changes in these variables are caused by strength training, or are just part of the normal maturation process, is a problem which has plagued the research on this topic.

A unique design which is able to control for individual variability in a training study, is a within subject design. Training one limb and using the other limb as the control allows the

researcher to discard any potential effects of individual growth variance. Although it seems like a valuable design for studies assessing training in youth; it has been underutilized (Malina, 2006). Mersch and Stoboy (1989) is the only study in this area that I am aware of which has employed this design, and it is one of only two studies which show evidence of training-induced muscle hypertrophy in preadolescents (Falk & Elikam, 2003). However, as previously mentioned, this study only performed measurements on two subjects. Thus more research of this nature is needed using a within subject design.

Most studies which have examined muscle hypertrophy in children have significant methodological limitations. Either studies have employed strength training programs which lack the volume and intensity required to continuously overload the muscle, or were too short in duration (Faigenbaum, 2000). In adults, strength and neuromuscular adaptations occur before hypertrophy in inexperienced weight lifters, and consequently many studies are not long enough to induce significant hypertrophy (Sale, 2001). This pattern of change may be similar in children. Because of these limitations, the possibility of muscle hypertrophy in strength trained children cannot be ruled out. Future studies looking specifically at muscle hypertrophy must insure that the training program is of sufficient intensity and duration.

One training type that has not been used in children, but may prove advantageous for gaining a better physiological understanding of strength training, is eccentric (muscle lengthening) strength training. Eccentric training allows the subject to exercise higher up on their force velocity curve (Figure 1-5), allowing for greater force generation. As strength and muscle hypertrophy are dependent on force production, eccentric training is beneficial for increasing both strength and hypertrophy (Hortobagyi et al., 1996). In adults, eccentric training induces significantly greater hypertrophy and strength gains when compared to

concentric training (Farthing & Chilibeck, 2003b). Whether this is the case in children has yet to be investigated. Using eccentric training will ensure the training program is of sufficient intensity to induce strength and muscle hypertrophy, and therefore the effect of eccentric training in children should be examined.

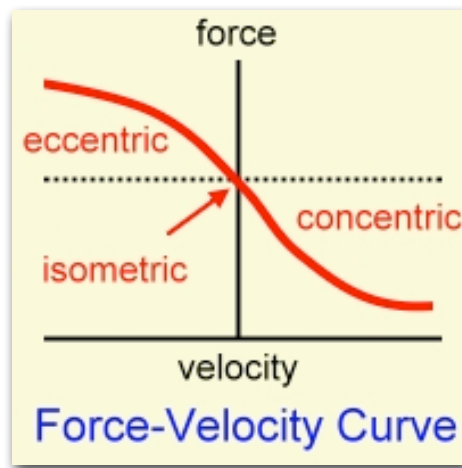


Figure 1-5 Force-Velocity relationship for eccentric, isometric, and concentric contractions. Retrieved from: <http://www.pt.ntu.edu.tw/hmchai/Kinesiology/KINmotion/Musculature.htm> (Oct. 24th 2006)

1.3 Statement of the Problem and Hypothesis

1.3.1 Statement of the Problem

Strength training is a safe mode of exercise for children and adolescents, and is accompanied by numerous health benefits (Faigenbaum & Kang, 2006). However, research in this area is limited, specifically regarding physiological changes. This is in part due to the difficulties in separating the effects of strength training from that of normal growth and development (Falk & Tenebaum, 1996). The exercise intensity typically employed in any children's strength training studies have been kept in the low to moderate range because of uncertainty surrounding this topic (Malina, 2006). Exercise intensity plays a major role in strength and hypertrophy, and eccentric strength training programs show the greatest effect (Farthing & Chilibeck, 2003b). Eccentric strength training has yet to be employed in a youth training study. Therefore, the purpose of this study is to examine the effects of eccentric training on muscle strength and development in children, using a within subjects, one arm training model.

1.3.2 Hypotheses

Hypothesis 1: There will be a significant increase in elbow flexor muscle thickness in the training arm compared to the non-training arm.

Hypothesis 2: There will be a significant increase in elbow flexor strength in the training arm compared to the non-training arm.

CHAPTER 2 METHODS

2.1 Research Design

This study employed a randomized pre post test design, where all measures were performed prior to, and immediately following the exercise intervention. In addition, all participants performed a familiarization trial exactly one week prior to their baseline test. This consisted of the same measurements, in the same order, which were performed during the baseline and post testing sessions. Each testing occasion included anthropometric measures, elbow flexion strength, and elbow flexor muscle thickness measures. All measures were performed in the Exercise Physiology Laboratory of the College of Kinesiology, at the University of Saskatchewan. The strength training phase consisted of an eight-week eccentric elbow flexor training program which was performed three days per week, using only one arm (randomized). This study was approved by the Ethics Review Board of the University of Saskatchewan, Saskatoon, Saskatchewan, Canada (BIO # 06-158) (Appendix A).

2.2 Test Protocol

The testing procedure is outlined in Figure 2.1. Following subject recruitment, each subject was contacted and attended a pre-study familiarization session in the laboratory. The testing procedures were explained in detail prior to the initial testing session. Before the testing, the participants were asked to refrain from partaking in any physical activity in the previous 24 hours. Anthropometric measures were performed first. These consisted of body weight, standing height, and sitting height. Following this they underwent elbow flexor muscle thickness measures on both arms. Eccentric and concentric isokinetic (Biodex) and isotonic (dumbbell) strength was tested after the muscle thickness measures. Isokinetic strength tests

preceded isotonic strength tests, and both arms were tested. The order of the concentric and eccentric tests was randomized for each individual (four labeled pieces of paper, each identifying a different contraction type and arm were randomly selected by the investigator), while alternating between their left and right arm to allow for more rest between repetitions on each arm. The order for each individual remained the same for all three testing occasions. After completing all the familiarization measures, the subjects returned one week later to go through the exact same procedure, and these results were used as their baseline levels. The familiarization trial was required to attempt to minimize any possible learning effect on subsequent testing. Also, the familiarization trial and baseline trial data were used to determine the coefficient of variation for the measures. Following the baseline tests the participants were randomly selected to train either the dominant arm or non-dominant arm. These training groups consisted of similar numbers (9 dominant, 8 non-dominant). The participants participated in an eight-week eccentric elbow flexion training program, for a total of 24 sessions (3 sessions per week). Following completion of the training program, the final testing was performed four to seven days after their final training session.

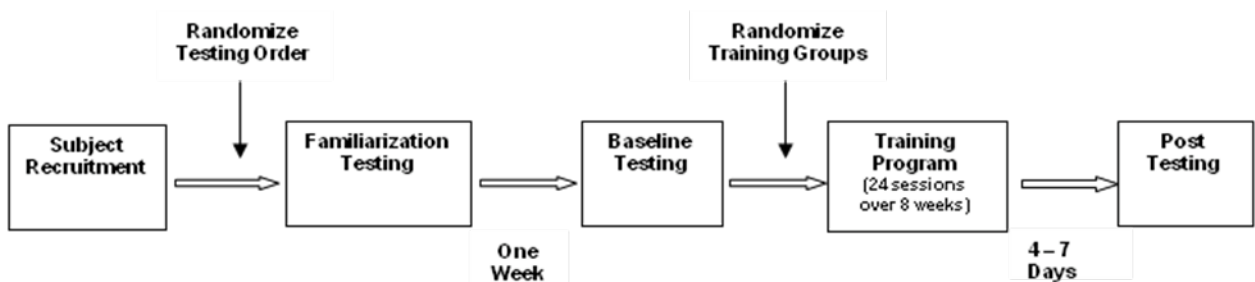


Figure 2-1 Testing Procedure

2.3 Participants

The participants in this study consisted of 17 healthy male school children in grades six, seven, and eight with an age range of 12 to 14 years. These 17 participants came from one of two local elementary schools, with nine from one school and eight from the other. The two schools selected were chosen at the suggestion of the Director of Education of the Saskatoon Catholic School Division (Appendix B). The students were recruited at an information session arranged by a teacher from each school. Interested participants were given a handout with a brief written explanation of the study to bring home to their parents or guardian (Appendix C). Exclusion criteria for this study included any child who was currently engaging in an upper body resistance program, or had a past injury to one or both of their arms which would interfere with their ability to perform the elbow flexion testing and/or training. All participants provided a written consent form signed (Appendix D) by their parent or guardian, as well as an assent form (Appendix E) which they signed themselves.

2.4 Procedures

2.4.1 Anthropometric Measures

The anthropometric measurements taken were height (cm), sitting height (cm), and weight (kg). Measurement protocols for these are those outlined by the Canadian Society for Exercise Physiology in their CEP Resource manual (1993). For each measurement three trials were performed. The average of the closest two measurements was used for the final measurement value. If all three measurements were equidistance apart, the middle value was used. For height and sitting height, if any measurement varied by more than 2 cm the measurement was repeated, and for weight if the measurement varied by more than 0.2 kg it

was repeated. Body weight was measured using an electronic scale (Toledo, United States). Height and sitting height was measured using a wall mounted stadiometer (University of Saskatchewan). For sitting height, the participants sat on a box of known height (51.3 cm), and the height of the box was subtracted from height recorded on the stadiometer. To ensure reliability and validity of the whole testing procedure, all measurements were taken by a CSEP (Canadian Society for Exercise Physiology) Certified Exercise Physiologist (CEP). A CEP is adequately trained and experienced in these types of measures. As well, for each specific measure, the same CEP tested all participants on all testing occasions.

2.4.2 Muscle Thickness

To assess muscle hypertrophy, muscle thickness was measured using B-mode ultrasound (Aloka SSD-500, Tokyo). This method is reliable, with a test-retest reliability of $r > 0.92$ (Ishida, Carroll, Pollock, Graves, & Leggett, 1992), ensuring accurate results. The coefficient of variation for elbow flexor muscle thickness is 1.8 % - 2.5% (Farthing & Chilibeck, 2003a; Candow & Chilibeck, 2005). Miyatani, Kanehisa, & Fukunaga (2000) showed ultrasound was highly correlated ($r = 0.96$) with MRI for estimating muscle volume of the arm. Using B-mode ultrasound, the muscle thickness (mm) of the elbow flexors were measured for each arm. To landmark the site the acromion process and olecranon process were located and marked, and then the distance between these was measured. Following this, a point two-thirds down from the acromion process on the bulk of the elbow flexors was marked. The subject then laid their arm down on a table in a supinated position with their biceps facing upwards. Using the point two-thirds down from the acromion process as the mid-point, an oval shape was drawn using a cut out transparency sheet in which the cut out part was the exact size and shape of the ultrasound probe (approximately 6cm long by 1 cm wide). Skin markings

were then traced onto the transparency sheet to ensure the identical location of the arm was used for subsequent measurements. A 5-MHz ultrasound probe with a water soluble transmission gel was placed onto the elbow flexors. A clear picture of the elbow flexors on the monitor was obtained and the picture was frozen. Three measurements were then taken from the monitor at three different sites; proximal, mid, and distal, which are equidistant apart. The distance from the top of the elbow flexors to the surface of the humerus bone was recorded at each site. The average of the closest two measurements at each site was then taken as the muscle thickness of that specific location. This measurement technique for ultrasound was the same as described by Farthing and Chilibeck (2003a). Reproducibility for all three sites (distal, mid, proximal) of muscle thickness was assessed on 15 subjects using the data from the familiarization and baseline tests. The one week test-retest correlation coefficients were 0.89, 0.94, 0.96 for the proximal, mid, and distal site respectively, and the coefficients of variation were 5.4%, 3.7%, and 3.4% respectively.

2.4.3 Isokinetic Strength

Strength was tested using the Biodex System 3 Isokinetic Dynamometer (Biodex Medical Systems). It has a high one week test-retest reliability (.82 - .97) in adults (Pincivero, Lephart, & Karunakara, 1997). No reliability studies were performed using children; however the Biodex has been used to test strength in children (Raynor, 2001). Concurrent validity of the Biodex has been shown by a high correlation (.87) with other similar isokinetic dynamometers (Cybex) (Dvir, 1995). The Biodex strength testing consisted of maximal concentric and eccentric elbow flexion. Before testing, each subject had the Biodex settings individualized for them. Modifications were made to the chair height, lever arm height, chair back depth, handle length, elbow pad height, and lever arm placement, so that both the subject

and the tester felt this was the best position to obtain a maximal contraction, as well as being comfortable for the subject. These chair and dynamometer settings were then recorded and used at all subsequent testing sessions. The Biodex chair was set at its fully upright position; the dynamometer was rotated outward at an angle of 20° with the upper arm rested on an arm pad. The rotational axis of the lever arm was set so it was in a coaxial position to the elbow axis; this was done by lining up the lateral epicondyle with the rotational axis of the lever arm. Range of motion was set using an end point of $\sim 160^{\circ}$ elbow extension. Once the end point was established, the start point was a full 90° from this end point. The same range of motion was used for both the eccentric and concentric contractions. The subject was strapped in with two stabilization belts which went across the chest. The arm being tested was strapped around the upper arm just above the elbow to maintain the position of the arm. The testing speed used was 30 degrees/sec (both eccentric and concentric), as this was the speed that best approximates the training speed used in this study. Strength was measured as torque in Newton meters (Nm). Each participant performed three maximal contractions separated by one minute rest for each contraction type. All three torques were recorded and the peak torque was used as the final value for that contraction type. Two minutes rest was given between each contraction type. Reproducibility of the isokinetic strength tests was assessed on 15 subjects, using the data from the familiarization and baseline tests. The concentric torque measurements had a one week test-retest correlation coefficient of 0.92, and the coefficient of variation was 7.1%. For the eccentric torque measurements, the one week test-retest correlation coefficient was 0.94, and the coefficient of variation was 9.5%.

2.4.4 Isotonic Strength

Isotonic eccentric and concentric maximal elbow flexion strength was tested using dumbbells. This consisted of performing single reps while gradually increasing weight until the maximum weight where the child can no longer complete and/or no longer complete while maintaining proper technique is determined. Two attempts at each weight were allowed when necessary. The last weight which the child successfully lifted was recorded as their maximum. Proper technique was clearly explained and demonstrated to the participants prior to starting. The participants stood with their back against a wall with their knees slightly bent and feet forward, allowing for most of their body weight to be supported by the wall. They were required to keep their upper arm by their side with their elbow in a position close to the wall throughout the entire repetition. These criteria minimized swinging and allowed for a more controlled movement. For the eccentric contraction, a repetition time of four seconds was used; this was timed using a metronome set at 60 beats per minute, hence one second per beat. To start the repetition, the tester would help the subject raise the weight up to their chest; once the subject was ready he would tell the tester and would start to lower the weight for a count of four beats. For a successful repetition, the subject had to control the weight for the entire four seconds while maintaining proper technique. For the concentric contraction speed was not measured. One repetition maximal testing utilizing strength training equipment is a safe and effective method for assessing strength in healthy children (Faigenbaum, Milliken, & Wescott, 2003). Reproducibility of the dumbbell strength tests was assessed on 15 subjects. The concentric torque measurements had a one week test-retest correlation coefficient of 0.97 and a coefficient of variation of 4.9%. For the eccentric torque measurements, the one week test-retest correlation coefficient was 0.96 and the coefficient of variation was 5.3%.

2.4.5 Training Program

Prior to the first training session, the children were shown how to properly perform the exercise routine, as well as how to spot their partners. For proper lifting technique, the children were instructed to maintain proper posture and core stability (as they were standing straight up not leaning against a wall, as they did during their strength testing) while minimizing movement of the surrounding joints and muscles. They were also instructed to exhale as they were lowering the weight. At every session the trainers were regularly giving technique cues to those who needed it. Spotting involved helping raise the weight up to the chest during the concentric phase of the movement, and then, if needed, the spotter would help control the speed on the way down if the child performing the repetitions was not able to lower the weight for a full four seconds. Whenever possible, the children were encouraged to spot with their training arm only. Each eccentric repetition was approximately four seconds in duration; the children were encouraged to use a “down one, down two, down three, down four” count. The participants were in groups of three and employed this rotation; one performed the repetitions, one had a rest period, and the third child helped to spot the one who was performing the repetitions. This rotation was repeated for the required number of sets. The strength training program used the progressive resistance program approach, as this type of program best emphasizes the “overload” principle which is very important for increasing strength (Faigenbaum, 2000). This approach involved increasing resistance progressively throughout the program as the participant adapts to each specific weight. Starting weight was approximately 65% (as determined during pilot testing) one repetition maximum of their eccentric dumbbell curl from the baseline test. Following each training session each participant recorded their level of perceived exertion as well as any stiffness or soreness related

to the training program in their workout log (Appendix F). Anytime the child recorded a Perceived Exertion for Children (PEC) (Faigenbaum, Miliken, & Cloutier, 2004) score of <7, the weight was increased by 2.5 lbs for the next session (Appendix G). This was also monitored by the trainer, and any modifications were made at their discretion. The training program consisted of 2 to 5 sets of 6 to 10 reps. To ease the children into the program the training program began with 2 sets of 10 repetitions and progressed slowly throughout the study up to 5 sets of 6 repetitions in the final week. For the complete training program see Table 2.2. During the first two weeks, two trainers were present at each session. After two weeks it was deemed that the children had learned to competently perform the training under the supervision of one trainer. All trainers were CEPs, and thus qualified to monitor this type of training. All participants had to complete all 24 sessions before they performed their final testing. Compliance rate was monitored by the trainer who took attendance at each session. They performed three training sessions per week, on Monday, Wednesday, and Friday. These training sessions were performed at their school at the beginning of lunch hour. Each training session was between 15 and 25 minutes in duration.

Table 2.1 Training Program

Week	# of Sets	# of Reps
1	2	10
2	3	8
3	3	8
4	4	8
5	4	8
6	4	6

7	4	6
8	5	6

2.4.6 Chronological and Biological Age

Chronological age (years) was reported in decimal age. This was determined by subtracting date of birth from the testing date. Biological age was reported as years from attainment of PHV. This is a commonly used method to report biological age in adolescent longitudinal studies (Malina & Bouchard, 1991). Peak height velocity is a landmark which represents the period of maximum growth during adolescence and can be used to determine where an adolescent is in terms of their maturational development. Mirwald et al., (2002) developed a method based on the relationship between segmental growth velocity and timing to predict PHV using a multiple regression equation which included the variables height, sitting height, leg length, chronological age, and gender. Years from PHV, or age of peak height velocity (APHV), is derived using this equation and is used as a continuous measure of biological age. Chronological and biological age was calculated using an online program (<http://taurus.usask.ca/growthutility/>). Once biological age was determined, the subjects were split into two different maturational groups, the first group consisted of those who were deemed to be within one year of PHV (> -0.5) or older (PHV), and the second group was those who were greater than one year away from PHV (<0.5) (Pre PHV). This age was chosen to separate the boys who were unlikely to have begun their dramatic increase in testosterone (Figure 1-4) and lean body mass, which normally occurs within one year of peak height velocity or later, (Rauch et al., 2004) from the ones who may be in the early stages of these natural changes.

2.5 Data Analysis

Descriptive statistics, means, standard deviations, and correlations were calculated. The analysis was performed in two stages. The first stage consisted of separate MANOVAs performed for both the muscle thickness measures (all 3 sites), and the strength measures (isokinetic concentric/eccentric and isotonic concentric/eccentric), to test for any differences in the training arm between maturational groups (as described in section 2.4.6). To simplify the data, the percentage change values were used. For these MANOVAs, only the differences in the training arm between maturational groups were analyzed. The purpose for this was to determine if the training effects were maturity dependent. Following this, the second stage of the analysis was performed using the entire group data (all 17 subjects). Seven separate 2 x 2 (time x arm) repeated measures ANOVAs were performed to determine any differences between the changes in the training and non-training arms for each dependent variable. If the interaction was significant, the simple main effects were analyzed post hoc using paired samples t-tests to determine any changes from pre to post in each individual arm. Statistical level of significance was set at an alpha of $p < 0.05$.

CHAPTER 3 RESULTS

3.1 Descriptives

Table 3.1 shows the descriptive statistics for the participants when the data is split into the two maturity categories, as well the combined data. A total of 18 subjects were recruited for this study, and 17 completed the study. The one drop out occurred prior to any testing and reason for withdrawal was time constraints. There was a significant difference ($p < 0.05$) for

age, height, and weight between the maturity groups. There was also a significant difference ($p < 0.01$) shown for APHV.

Table 3.1 Descriptives - Mean (SD)

	Pre PHV	PHV		Combined Data
N	8	9		17
Age (yrs)	12.7 (0.5)	13.5 (0.6)*		13.2 (0.6)
APHV (yrs)	-1.4 (0.5)	0.2 (0.6)*		-0.6 (1.0)
Height (cm)	149.9 (6.9)	163.8 (8.2)*		157.3 (10.3)
Weight (kg)	39.4 (7.1)	59.5 (20.1)*		50.1 (17.6)

*significant difference ($p < 0.05$) between groups

3.2 Strength and Muscle Thickness in the Trained Arm

Table 3.2 displays the pre and post absolute values of muscle thickness at all three sites for both maturity groups. Table 3.3 displays the pre and post absolute values and percent change of muscle strength of all four strength measures for both maturity groups. The one-way MANOVAs comparing the percent change in the training arm between groups revealed no significant differences ($p > 0.05$) for the muscle thickness or strength scores. Therefore, these results indicate that there was no significant difference between the maturational age categories for the changes brought about by the strength training program. As there was no effect of age category, subsequent analyses used entire group data.

Table 3.2 Training Arm Elbow Flexor Muscle Thickness - Mean (SD)

Elbow Flexor Muscle Thickness	Pre PHV (N=8)			PHV (N=9)		
	Pre	Post	Percent Change	Pre	Post	Percent Change

Proximal Site (cm)	2.8 (0.5)	2.9 (0.5)	2.9% (7.0)	3.2 (0.4)	3.4 (0.5)	7.3% (12.9)
Mid Site (cm)	3.1 (0.5)	3.2 (0.5)	6.4% (5.1)	3.5 (0.5)	3.7 (0.5)	9.1% (9.3)
Distal Site (cm)	3.3 (0.5)	3.5 (0.5)	7.0% (6.4)	3.6 (0.5)	4.0 (0.5)	10.7% (7.4)

Table 3.3 Training Arm Elbow Flexor Muscle Strength - Mean (SD)

Elbow Flexor Muscle Strength	Pre PHV (N=8)			PHV (N=9)		
	Pre	Post	Percent Change	Pre	Post	Percent Change
Biodex Concentric (Nm)	21.1 (8.8)	23.8 (8.1)	14.6% (9.8)	30.7 (11.4)	32.3 (9.9)	8.6% (15.1)
Biodex Eccentric (Nm)	25.0 (9.9)	30.6 (9.0)	27.1 % (17.4)	32.9 (11.1)	40.0 (12.2)	23.8% (16.7)
Dumbbell Concentric (kg)	6.0 (1.6)	8.0 (2.4)	31.8% (15.8)	8.0 (2.5)	10.7 (2.7)	37.8% (16.1)
Dumbbell Eccentric (kg)	8.1 (1.8)	12.1 (3.2)	47.6% (12.1)	11.4 (2.3)	16.2 (3.8)	42.7% (19.4)

3.3 Muscle Thickness (combined data)

Table 3.4 shows the pre and post values for the elbow flexor muscle thickness measure for the training and non-training arm. The time by arm interaction was significant, with the change in the trained arm significantly greater than the change in the untrained arm at all three muscle thickness sites ($p < 0.05$). The percent change values for the training arm were 5.1%, 7.5%, and 8.5% at the proximal, mid, and distal sites respectively. In the non-training arm these values were -1.5%, 0.1%, and 1.6% respectively. Figures 3-1 A, B, and C display the estimated marginal means for the three muscle thickness sites. Breaking down the results to the

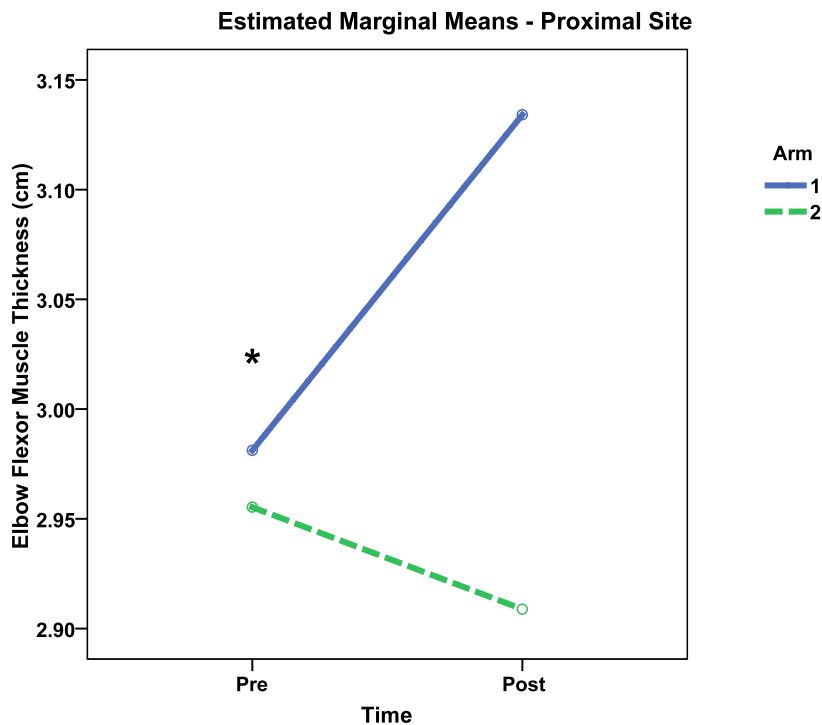
simple main effects, the change at the mid and distal sites in the training arm was significant ($p < 0.05$) from pre to post, while the proximal site on the training arm, and all three sites on the non-training arm were non-significant ($p > 0.05$).

Table 3.4 Muscle Thickness – Mean (SD)

		Trained Arm		Untrained Arm	
		Pre	Post	Pre	Post
Elbow Flexor Muscle Thickness	Proximal (cm)	3.0 (0.5)	3.1 (0.6)	3.0 (0.6)	2.9 (0.5)*
	Mid (cm)	3.3 (0.5)	3.5 (0.5) [†]	3.2 (0.5)	3.2 (0.5)*
	Distal (cm)	3.5 (0.5)	3.8 (0.5) [†]	3.5 (0.5)	3.5 (0.5)*

*significant interaction (time x arm) ($p < 0.05$)

[†] significant difference between pre and post (within arm) ($p < 0.05$)

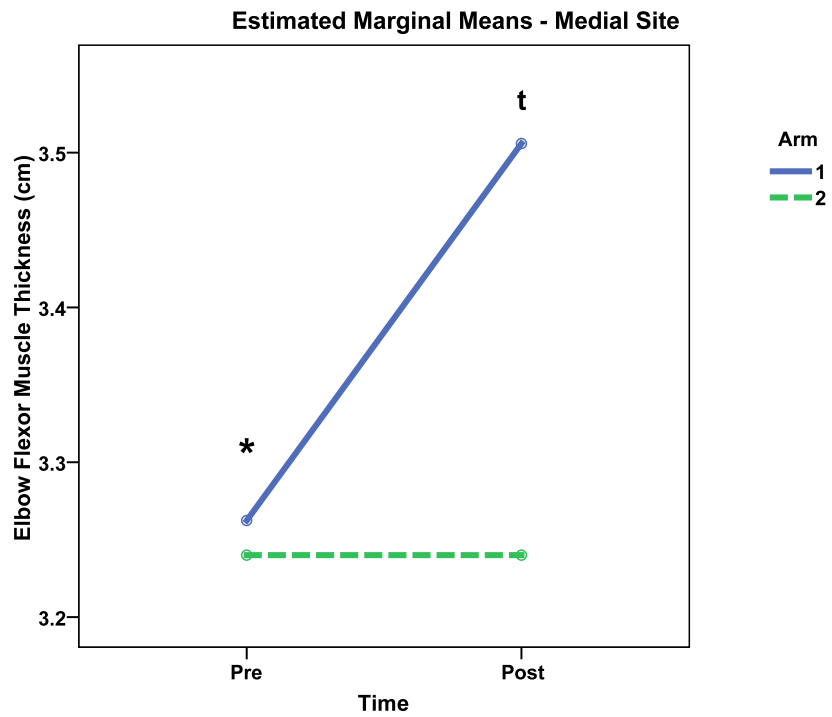


Arm 1: Training arm

Arm 2: Non-training arm

*significant interaction (time x arm) ($p < 0.05$)

Figure 3-1 A) Elbow Flexor Muscle Thickness – Proximal Site



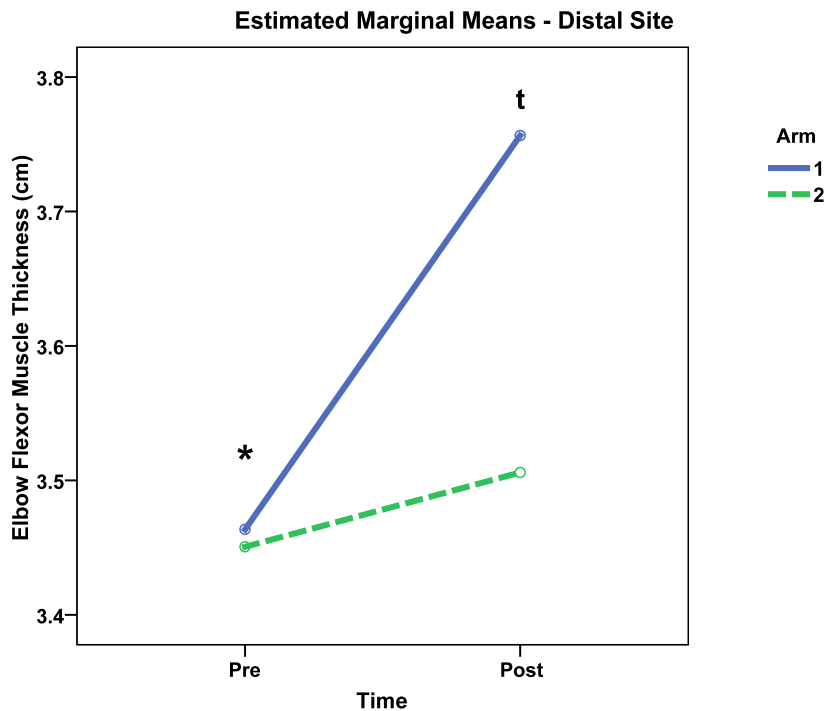
Arm 1: Training arm

Arm 2: Non-training arm

*significant interaction (time x arm) ($p < 0.05$)

^t significant difference between pre and post (within arm) ($p < 0.05$)

Figure 3-1 B) Elbow Flexor Muscle Thickness – Mid Site



Arm 1: Training arm

Arm 2: Non-training arm

*significant interaction (time x arm) ($p < 0.05$)

^t significant difference between pre and post (within arm) ($p < 0.05$)

Figure 3-1 C) Elbow Flexor Muscle Thickness – Distal

3.4 Isokinetic Strength (combined data)

Table 3.5 shows the change in isokinetic maximal strength from pre to post in the trained and untrained arm. For the concentric contraction, the time by arm interaction was non-significant ($p > 0.05$). The main effects of time and arm were also non-significant ($p > 0.05$). For the eccentric contraction, the time by arm interaction was significant, with the change over time in the trained arm significantly greater ($p < 0.05$) than the untrained arm. Breaking down the results to the simple main effects for the eccentric contraction, the training arm showed a significant increase ($p < 0.05$) from pre to post. The pre post changes in the non-trained arm

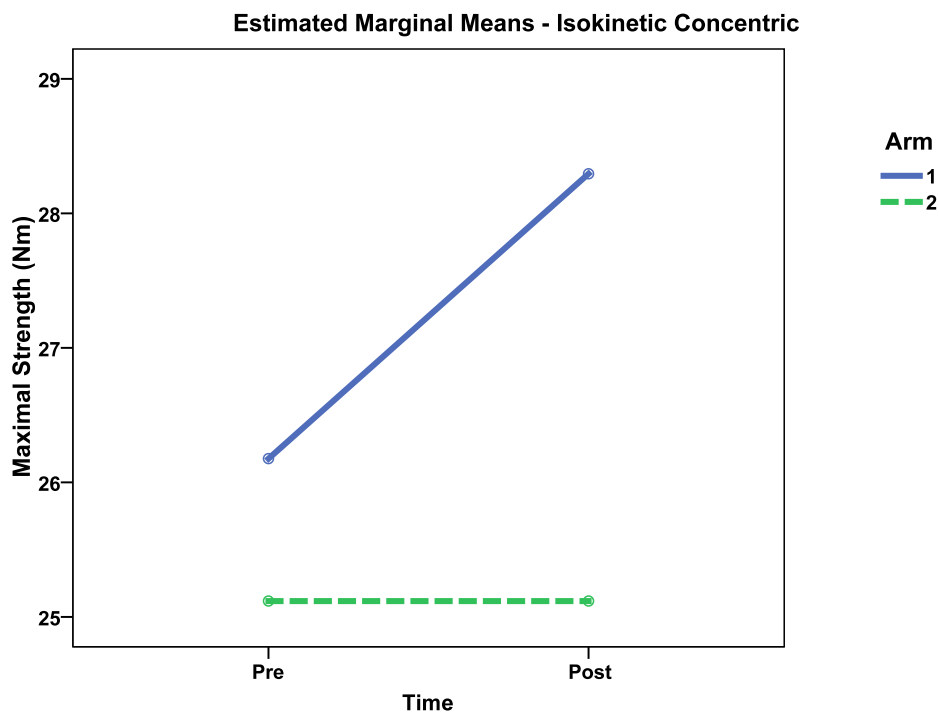
were non-significant ($p > 0.05$). The average percent change values were 8.1% (concentric) and 22.0% (eccentric) for the isokinetic strength measures in the trained arm, and 0.2% (concentric) and 1.0% (eccentric) in the non-trained arm. Figures 3.2 A and B display the estimated marginal means for the isokinetic strength measures.

Table 3.5 Isokinetic Strength – Mean (SD)

		Trained Arm		Untrained Arm	
		Pre	Post	Pre	Post
Isokinetic Strength	Concentric (Nm)	26.2 (11.1)	28.3 (9.9)	25.0 (11.8)	25.1 (10.8)
	Eccentric (Nm)	29.2 (11.0)	35.6 (13.8) [†]	30.1 (14.1)	30.4 (13.8)*

*significant interaction (time x arm) ($p < 0.05$)

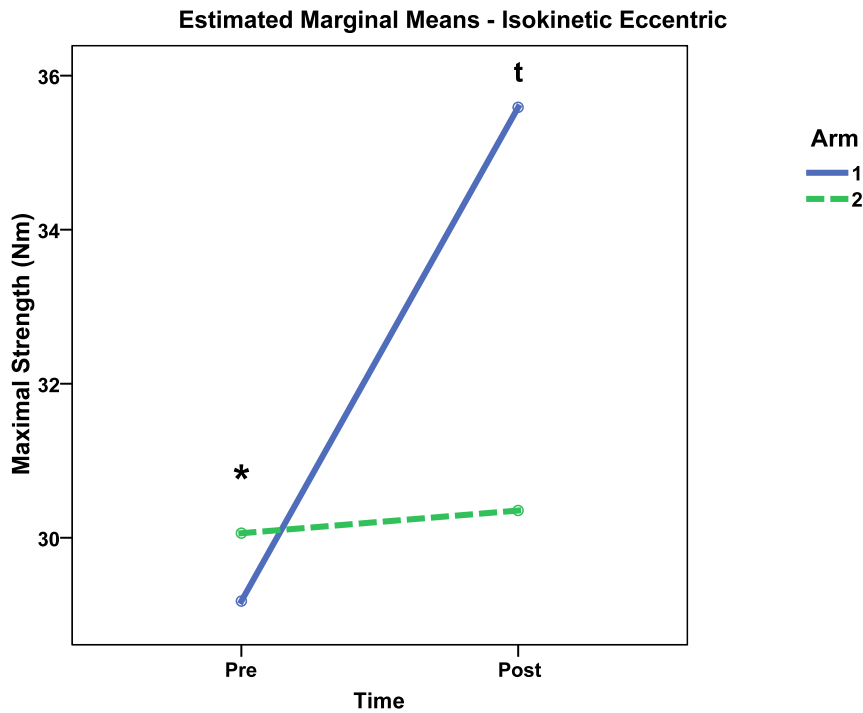
[†] significant difference between pre and post (within arm) ($p < 0.05$)



Arm 1: Training arm

Arm 2: Non-training arm

Figure 3-2 A) Elbow Flexor Strength – Isokinetic Concentric



Arm 1: Training arm

Arm 2: Non-training arm

*significant interaction (time x arm) ($p < 0.05$)

^t significant difference between pre and post (within arm) ($p < 0.05$)

Figure 3-2 B) Elbow Flexor Strength – Isokinetic Eccentric

3.5 Isotonic Strength (combined data)

Table 3.6 shows the change in maximal isotonic strength between the baseline and the post testing for the trained and untrained arm, for both concentric and eccentric contractions. A significant difference ($p < 0.05$) was shown for the concentric and eccentric contractions between the arms, with the trained arm displaying a greater increase for both types of contractions. The average percent change values were 34.3% (concentric) and 44.9% (eccentric) for the trained arm and 14.2% (concentric) and 23.0% (eccentric) for the non-trained arm. Figure 3.3 A and B display the estimated marginal means for the maximal

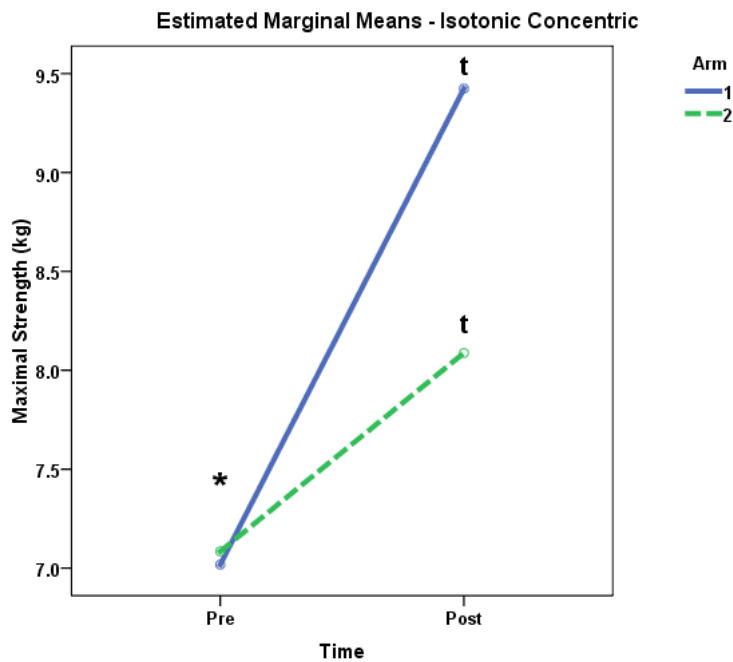
dumbbell strength measure. The simple main effects show concentric and eccentric pre post changes were significant ($p < 0.05$) in both the training and non-training arm.

Table 3.6 Isotonic Strength – Mean (SD)

		Trained Arm		Untrained Arm	
		Pre	Post	Pre	Post
Isotonic Strength	Concentric (kg)	7.0 (2.3)	9.4 (2.9) ^t	7.1 (2.4)	8.1 (2.8) ^{*t}
	Eccentric (kg)	9.8 (2.6)	14.2 (4.0) ^t	9.9 (2.8)	12.2 (3.8) ^{*t}

*significant interaction (time x arm) ($p < 0.05$)

^t significant difference between pre and post (within arm) ($p < 0.05$)



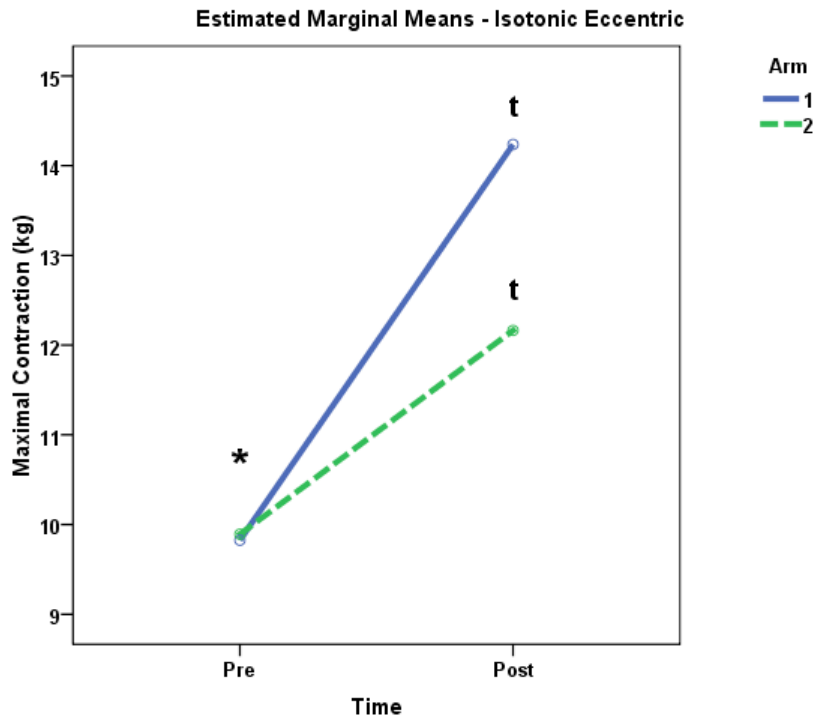
Arm 1: Training arm

Arm 2: Non-training arm

*significant interaction (time x arm) ($p < 0.05$)

^t significant difference between pre and post (within arm) ($p < 0.05$)

Figure 3-3 A) Elbow Flexor Strength – Isotonic Concentric



Arm 1: Training arm

Arm 2: Non-training arm

*significant interaction (time x arm) ($p < 0.05$)

^t significant difference between pre and post (within arm) ($p < 0.05$)

Figure 3-3 B) Elbow Flexor Strength – Isotonic Eccentric

CHAPTER 4 DISCUSSION

The results from this study showed that following an eccentric elbow flexor training program, there was an increase in strength and muscle thickness of the elbow flexors in young boys. The difference in the changes in the training arm between the maturational groups was non-significant ($p > 0.05$), for both strength and muscle thickness. These results indicate that training had the same affect on muscle strength and thickness in both maturational age categories.

In the whole group, eccentric strength training had a significant effect ($p < 0.05$) on muscle thickness and maximal strength of the training arm when compared to the non-training arm. The training arm increased significantly more ($p < 0.05$) than the non-training arm for eccentric isokinetic maximal strength, and both concentric and eccentric isotonic maximal strength. These results provide evidence to support the study hypothesis that eccentric strength training will increase muscle strength and muscle thickness in young boys.

Most recent studies have shown increased strength following a strength training program in preadolescent/adolescent boys (Malina, 2006). However, the upper body strength gains reported are normally of lesser extent than the gains in the current study. This is especially true when looking at the eccentric isotonic increases (Table 3.6), although no other studies have tested for eccentric strength gains. For changes in muscle thickness, or hypertrophy, it is generally reported that this type of morphological change does not occur in preadolescence (Behm et al., 2008). Our results show that strength training can increase muscle thickness, even in preadolescence. It is hypothesized that the reason for the morphological changes in this study is due to the high intensity strength training that was employed using eccentric contractions, as well as a heavy volume of repetitions and sets.

4.1 Strength and Muscle Thickness in the Trained Arm

Strength training affects young boys differently depending on if they are pre or early pubescent versus late pubescent (Sewall & Micheli, 1986). Some research has shown strength increases are minimal for pre-pubertal boys when compared to their older peers (Blimkie, 1992). However, strength gains made by pre-pubertal boys following a strength training program are similar, or sometimes even greater when expressed relatively, than the gains made by late pubertal or early adults following a program of similar intensity (Pfeiffer & Francis, 1986). The first analysis in this thesis was performed to determine if there were any significant differences between the changes in the training arm between the two different maturational groups. Hence, it was performed to determine if maturation status would differentially affect any changes the strength training program may cause. When comparing the change in elbow flexor strength and muscle thickness in the training arm between maturational groups there was no significant difference ($p > 0.05$). This shows that the strength training had the same effect on both strength and muscle thickness for the two maturational categories. These strength results are similar to what has been previously found. Studies by, Pfeiffer and Francis (1986), and Sailors and Berg (1987), reported similar relative strength increases in pre-pubertal boys when compared to late pubertal and young adult men.

One of the limiting factors of muscle hypertrophy and strength in pre-pubertal boys is the low serum levels of testosterone (Payne et al. 1997). Testosterone is often said to be the most important hormone for natural growth and development (Blimkie & Sale, 1998). Therefore the large increase in testosterone in boys (Figure 1-4), which occurs approximately one year prior to PHV (Malina & Bouchard, 2001), could play a major role in how the body adapts physiologically to the stresses that strength training imposes on the muscular system.

Although testosterone does have an obvious impact on muscle strength and hypertrophy, it is not solely responsible for it. One study showed that testosterone only accounted for 41% of the variability in strength in young boys (Ramos et al., 1998). Another study found that grip strength levels in both males and females were independent of hormones. Also, an interesting finding in the study by Tsolakis et al. (2001) showed that strength training in preadolescent males actually increases testosterone levels, as well as the free androgen index, and these increased levels remain two months after completion of the training program. Although the research in this area is limited, possible strength training effects in pre-pubertal boys cannot be ruled out solely on this reported low level of testosterone.

Although APHV was not calculated from longitudinal data, which is the most accurate, it was derived using a formula developed by Mirwald et al. (2002). This formula accurately predicts age of PHV within 0.5 years. Comparing descriptive statistics between the groups, as expected the more mature group (i.e. those deemed to be within one year of PHV or older) was significantly ($p < 0.05$) taller and heavier than their younger peers. This provides evidence that the two groups were in fact maturationally distinct. Assuming this is true, and having found no significant difference between the two groups for the change in muscle thickness or strength, it is fair to conclude that in this study, the maturational age categories did not have a significant differential effect on any possible adaptations of strength or hypertrophy. With this conclusion, the remainder of the analysis was performed using whole group data to determine any differences between the training and non-training arms, following the strength training program.

4.2 Muscle Thickness

Measuring change in muscle thickness is essentially measuring the amount of muscle hypertrophy that has occurred. An increase in muscle thickness, or muscle CSA, would be almost entirely attributed to an increase in myofibrillar size and number (Folland & Williams, 2007). Chronic exposure to strength activities increases muscle hypertrophy in adults (Favier et al., 2008). In pre and early pubertal boys this is not the case, as there have been only two previous studies which have provided some evidence of any apparent hypertrophy in children of this age (Behm et al., 2008). The results from these two studies (Mersch & Stoboy, 1989; Fukunaga et al., 1992) have been discredited in the majority of the research due to the numerous other studies which have shown no significant hypertrophy, and study flaws which have been previously stated.

The results from this study show a greater increase in muscle thickness in the training arm when compared to the non-training arm at all three sites. The percent change at the three sites; distal, medial, and proximal, were 5.2%, 7.8% and 8.9% respectively, with the latter two sites showing a significant pre post increase ($p < 0.05$). These results are similar to those reported by Mersch and Stoboy (1989), which ranged between 4 and 9%. Hypertrophy studies on adults have shown a wide range of percent changes in muscle thickness. In a recent study that employed a similar training program, muscle group, and muscle thickness measure, a 13% change was reported for the “fast eccentric” group, and 7.8% for the “slow eccentric” group (Farthing & Chilibeck, 2003b). The changes reported in the non-training arm in the current study were not significant for any of the sites; distal -1.1%, medial 0.1%, and proximal 1.8%. Although there was actually a decrease in muscle thickness at the distal site, this decrease was

non-significant ($p > 0.05$), and it is within the measurement error range which has been reported in previous muscle ultrasound studies.

The muscle thickness results from the current study conflict with most research on this topic. It has been widely reported that pre-pubertal boys are unable to increase muscle mass through strength training until they reach a certain biological age (Payne et al., 1997; Faigenbaum & Kang, 2006; Behm et al., 2008). These results could be due to a couple of different factors. One is the ability to control for maturation due to the within subject design. Most other studies use an exercise group and a control group, and although they often try to control for maturity by assessing it using various methods, it is impossible to account for all the individual differences. At this stage of development, it is especially hard to control for maturity and therefore the ability of the researcher to separate the effects of the training from the effects of natural growth and development. Another factor which may have led to the significant hypertrophy not normally shown is the strength training program which was employed in this study. Eccentric training has not been used in adolescent strength training studies, and in adults, several studies have shown that it is more beneficial than concentric or isometric strength training programs (Hortobágyi et al., 1996; Farthing & Chilibeck, 2003b). The intensity and volume of this study was greater than most other youth training studies, and these factors play a major role in the amplitude of hypertrophy in adults. So this may be true for adolescents as well. Another factor which could have played a role is the choice of muscle group. Upper body muscles are more responsive to strength training, in terms of muscle hypertrophy, than those of the lower body (Folland & Williams, 2007). Most other child strength training studies have examined hypertrophy of the lower body or whole body muscles

(Behm et al., 2008), whereby the focus of this study was to examine only changes in the elbow flexors.

4.3 Isokinetic Strength

The current study found eccentric isokinetic strength increased significantly ($p < 0.05$) in the training arm compared to the non-training arm. The relative reported change was 25.4% versus 2.4%. The concentric isokinetic strength in the training arm increased 11.4% versus 2.2% for the non-training arm. Although the concentric change displayed a trend to be greater in the training arm, the increase was not significant compared to the untrained arm ($p > 0.05$). There are no previous studies that tested eccentric strength in children, so there is no comparison for the values obtained in this study. However, there have been a couple of studies that have performed concentric strength testing on an isokinetic hydraulic resistance machine. Weltman et al. (1986) showed pre-pubertal boys increased concentric strength an average of 27% following a 14 week training program. Rians et al. (1987) showed a range of 21% to 32% improvement in concentric strength, also following 14 weeks of strength training. The higher values of concentric strength reported in these two studies may be due to specificity of training. Both studies trained concentrically using the same hydraulic resistance machine that was used for testing. Also, their training programs were almost twice as long as the one employed in the current study. However when comparing eccentric strength to the values of these two studies, the numbers are very similar. This again provides evidence for specificity of training, as the change in eccentric strength was almost twice that of the concentric strength.

4.4 Isotonic Strength

Free weight (isotonic) strength training and/or testing is more common in youth strength training studies than isokinetic training and/or testing. This study reported a significant increase ($p < 0.05$) in both concentric and eccentric elbow flexor strength, when compared to the non-training arm. Concentric strength increased 35.0% for the training arm and 14.8% for the non-training arm. Eccentric strength increases were 45.0% and 21.8%, with the training arm once again being greater. Numerous studies have examined changes in concentric isotonic strength following a strength training program (Ozmun et al., 1994; Pfeiffer & Francis, 1986; Ramsay et al., 1990; Sewell & Micheli, 1986). The percent improvement ranges anywhere between 10% and 40%. Most of these studies employed a light to medium intensity, with a repetition range of 8 – 12 and duration of 8 – 20 weeks. The 35% increase reported in this study is in the higher range of these results. This could be due to the previously mentioned factors of high intensity and volume of work during each training session. Also, as with hypertrophy, eccentric training is more beneficial for strength improvement than concentric training (Farthing & Chilibeck, 2003b). There are two studies which reported higher than average strength increases. Faigenbaum, Wescott, and Micheli (1996) and Sailors & Berg (1987) reported strength increases of up to 54% and 52% respectively. As with the current study, both of these studies were eight weeks in duration and used isotonic resistance. Also, both employed a low repetition range (5 – 8 reps) with maximal intensity, which is the type of program design that has been proven more beneficial for strength development than high repetition low intensity workouts (Kraemer & Ratamess, 2003). For isotonic strength, the non-training arm also showed significant improvement ($p < 0.05$) from pre to post, both concentrically and eccentrically. A possible explanation for this could be the

phenomenon known as cross-education. This is a neural adaptation that can occur following unilateral strength training where the strength of the non-trained contralateral limb increases as well (Lee & Carroll, 2007). This effect was more pronounced in the isotonic testing versus the isokinetic testing. This shows evidence of movement specific cross-education, as the training was isotonic.

4.5 Study Limitations

A major limitation of this study was the small sample size. Prior to recruitment a power calculation was performed, and it was determined a sample size of 17 was needed to have 80% power. There were 17 subjects who completed the current study, which was in line with the suggested sample size from the power calculation. However, when the group was split into two separate maturational groups, the recommended sample size was not met. Therefore, the between group analysis performed was underpowered, and this may have had an impact on the lack of any significant findings.

Another limitation was the age range of the boys. There was a range in biological age of 12.1 years to 14.3 years, and the range for maturational age was -2.0 YPHV to 1.2 YPHV. Therefore the boys were at very distinct parts of their development, and with numerous physiological changes which occur during this critical period; this may have an effect on the changes that were reported. However, it should be noted that the comparison between the two different maturational groups showed no difference in relative strength or hypertrophy adaptations following strength training. Having only one group of pre-pubertal boys would strengthen the study, as this is the age where hypertrophy is thought not to occur. Another related limitation is the estimation of maturational age using a prediction formula. Having longitudinal data on each child's growth pattern would allow for a more accurate estimation of

PHV. This however, as with most studies, is not usually a feasible option.

There are a couple limitations regarding the use of the ultrasound for muscle thickness measurements. Adipose tissue was not taken into consideration when performing the measurement, yet adipose tissue does account for a small amount of the thickness measured. It was thought that over an eight week timespan any change in adipose tissue in the upper arm would be negligible, however in some extreme cases this may not be true. Researcher bias is also a limitation, because for the muscle thickness measure, as well as the strength testing, the tester was not blinded to the training intervention.

Probably the greatest limitation of this study is the failure to test for important physiological variables which may account for strength or hypertrophy adaptations. The importance of hormonal changes in growth studies, as well as strength training studies has been repeatedly stressed. Therefore testing for hormones, specifically testosterone, growth hormone, and IGF-1, would greatly enhance a study of this design. As an added benefit for this testing, it could assist in assessing maturational age. Another physiological variable which plays a large role in strength development is neuromuscular adaptations. Therefore, using EMG measurements would also be very valuable.

4.6 Recommendations for Future Research

Future research in this area should test for other physiological variables. As mentioned when discussing the limitations of the current study, hormonal changes and neurological adaptations are of great importance and should be tested for. Performing EMG measurements during maximal strength testing would allow the researcher to better explain the change in strength. Testing for different hormones in children may increase difficulty for subject recruitment, or ethical approval, but the information gained would prove invaluable. However,

using salivary hormone measurements, which are less invasive than blood measurements, would be a feasible option. Incorporating a control group into a study design similar to this one would be advantageous as any learning effect from the familiarization and baseline testing on the post testing would be shown.

As this study focused only on elbow flexor muscles, future research could look at the effects of eccentric training on other muscle groups. Also, the effects of varying training programs, in terms of intensity, volume, and duration could be examined. The applicability of eccentric training on sport performance in young athletes is another area worth researching. One area where more research is definitely needed, and not only in regards to eccentric training and muscle hypertrophy, is the effects of strength training in young girls, as this area is often overlooked.

Future research should also examine the effects of eccentric training, as well as strength training in general, on various health components. If hypertrophy in young children is possible, eccentric training may be a possible treatment for atrophic childhood diseases. Also, some studies have been performed on strength training as a possible treatment for childhood obesity, and the results from these studies are favourable (Benson, Torode, & Singh, 2008b). However, not many have looked at it as a strategy for prevention of obesity in young children. Information on the relationship between body composition and strength training in children is limited. Also, it would be interesting to determine if strength training can have similar effects on basal metabolic rate and excess post-exercise oxygen consumption (EPOC) in children as it does in adults (Bloomer, 2005). Research on the application of strength training in children for health benefits is extremely limited. However this is an area which could be important as the incidence of childhood obesity continues to increase (Benson, Torode, & Singh, 2008a).

CHAPTER 5 SUMMARY AND CONCLUSIONS

5.1 Summary

Strength training in children is an area dominated by negative myths, and as a result was viewed as dangerous and impractical mode of exercise which should be avoided (Faigenbaum & Kang, 2006). However, most of the recent research has shown strength training is a safe mode of exercise with numerous health benefits and is now recommended as a valuable part of any child's suggested activity (Behm et al. 2008). Physiological research in this area is limited (Strong et al., 2005), however, it is now generally accepted that strength training in pre-pubertal and pubertal children will increase strength, but it is unlikely to induce morphological changes. The majority of research has been limited by two major flaws. One is a failure to control the effects of natural strength and development; and two, employing a training program with insufficient intensity required to produce significant adaptations (Faigenbaum, 2000). To overcome these limitations it is suggested that researchers should use a within-subject design employing an exercise regime of sufficient intensity. Research in adults indicates eccentric training causes the greatest increases in strength and hypertrophy (Farthing & Chilibeck, 2003b); however this mode of exercise has not been utilized in any youth training studies. The current study used a one arm training study to investigate the effects of an eccentric training program on both muscle strength and hypertrophy in pre-pubertal and pubertal boys.

Seventeen boys in grades 6, 7, or 8 participated in an eight week eccentric training program. The training was performed three days per week, for a total of 24 sessions, and consisted of 2 – 5 sets of 6 – 10 repetitions of dumbbell biceps curls at a controlled tempo using progressive resistance. Pre and post elbow flexor muscle thickness was measured using B-mode ultrasound (Aloka SSD-500). Strength was measured pre and post using an isokinetic

dynamometer (Biodex System 3, Biodex Medical Systems), as well as one repetition maximum using dumbbells. Strength measurements were performed on both arms, both concentrically and eccentrically. Muscle thickness increased significantly in the trained arm compared to the untrained arm. No significant difference was found for isokinetic concentric strength; however isokinetic eccentric strength increased significantly greater in the trained arm versus the untrained arm. Training arm one repetition maximum increased significantly greater than the untrained arm for both concentric and eccentric isotonic contractions. The changes that occurred due to the training program were not different between the two maturational age categories.

5.2 Conclusions

Results from this study indicate eccentric strength training can increase muscle strength and hypertrophy in pre-pubertal and pubertal boys. Further, these results appear to be maturationally independent.

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APPENDIX A: CERTIFICATE OF ETHICAL APPROVAL



Certificate of Approval

PRINCIPAL INVESTIGATOR Adam Baxter-Jones	DEPARTMENT Kinesiology	Bio # 06-158
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INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT
College of Kinesiology
105 Gymnasium Place
Saskatoon SK S7N 5C2

STUDENT RESEARCHER(S)
Jason Allen

SPONSORING AGENCIES
UNFUNDED

TITLE
The Effects of Eccentric Training on Strength and Muscle Development in Children

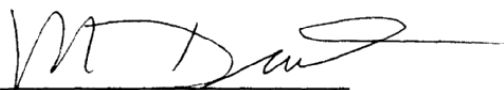
ORIGINAL APPROVAL DATE 03-Oct-2006	CURRENT EXPIRY DATE 02-Oct-2007	APPROVAL OF Revised Researcher's Summary (27-Sept-2006) Revised Consent Form (27-Sept-2006) Revised Assent Form (27-Sept-2006)
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CERTIFICATION

The University of Saskatchewan Biomedical Research Ethics Board has reviewed the above-named research project at a full-board meeting (any research classified as minimal risk is reviewed through the expedited review process). The proposal was found to be acceptable on ethical grounds. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project, and for ensuring that the authorized research is carried out according to governing law. This Approval is valid for the above time period provided there is no change in experimental protocol or in the consent process.

ONGOING REVIEW REQUIREMENTS/REB ATTESTATION

In order to receive annual renewal, a status report must be submitted to the Chair for Committee consideration within one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions: <http://www.usask.ca/research/ethics.shtml>. In respect to clinical trials, the University of Saskatchewan Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations and carries out its functions in a manner consistent with Good Clinical Practices. This approval and the views of this REB have been documented in writing.



Michel Desautels, Ph.D., Chair
University of Saskatchewan
Biomedical Research Ethics Board

Please send all correspondence to:

Ethics Office
University of Saskatchewan
Room 305 Kirk Hall, 117 Science Place
Saskatoon SK S7N 5C8
Telephone: (306) 966-4053 Fax: (306) 966-2069

**APPENDIX B: APPLICATION FOR PERMISSION TO CONDUCT RESEARCH IN
THE SASKATOON CATHOLIC SCHOOL DIVISION**

June 9, 2006,

Brendan Bitz
Director of Education
Saskatoon Catholic School Division

Dear Mr. Bitz:

I am writing today to seek your support for a research study we would like to conduct in your school division. We are interested in researching the effects of strength training in children in grades six, seven, and eight. Specifically, we want to determine the effects of a one arm eccentric strength training program on strength and muscle development in boys. As the health of our young people becomes an increasing concern we need to continue to challenge the old ideas and look for new ways to confront this issue. This innovative study will help us do this, as we will learn about the role strength training can play in improving the health of our young people.

I have attached a description of the study and the procedures we would like to follow. Once we have finished data collection and analysis we would be happy to give a presentation of the results to staff members the schools.

Thank you for considering this request. If you have any questions or concerns about this project, please do not hesitate to contact me (kolyic@yahoo.ca, 966 – 1123). I look forward to working with you on this exciting project.

Sincerely,

Jason B. Allen, M.Sc. Candidate, PFLC

Application for Permission to Conduct Research in the Saskatoon Catholic School Division

Title of Study: The Effects of Eccentric Training on Strength and Muscle Development in Children

Purpose of study:

This study is designed to:

- Examine the effects of eccentric training in children using a one arm training model.

Significance of the Study: To our knowledge, eccentric training as well as a one arm training model has yet to be used in a child strength training program study. The current literature on strength training in children is limited by two major flaws, controlling for maturation and training program design. This study design is unique to this type of research and it should prove beneficial for obtaining a greater physiological understanding of the effects of strength training in children. With a greater understanding on this topic, we will be able to help dismiss some of the common myths which dominate this type of activity in children. This is needed so strength training can be incorporated into every child's regular physical activity and so it can be used as an alternative mode of exercise as it has been shown to have numerous health benefits. This is especially important in today's society where the health of our children has become a very serious concern.

Research Methodology:

Who?

Approximately 25 - 30 male students in grades 6, 7, and 8. All participants will volunteer for the study.

What will the students be asked to do?

1. All participants will be asked to complete an assent form. As well, all parents of these students will be asked to fill out an informed consent form.
2. Prior to the training program baseline measures will be performed. Baseline measurements will include; height, sitting height, weight, bicep muscle thickness, and elbow flexion strength. These measurements will be performed at the University of Saskatchewan.
3. The participants will then take part in an 8 week strength training program. The training program will consist of eccentric elbow flexion and will be performed with dumbbells.
4. The participants will keep a training log and will record the weight they used and their perceived exertion after every training session. They will also make note of any muscle stiffness or soreness they might feel during or following the training sessions.
5. Following conclusion of the training program, all baseline measures will be repeated. These will once again be performed at the University of Saskatchewan.

What will the teachers be asked to do?

1. Encourage participation in the study.
2. Help monitor attendance at the training sessions.

How much time will be required?

1. Consent/Assent Form: These forms will be given to the participants at school and will be brought home and given to their parents to be filled out at home and returned to school.
 2. Baseline Measurements:
 - a. Anthropometric Measurements: Students height, sitting height and weight will be measured.
 - b. Bicep muscle thickness using ultrasound technology will be measured.
 - c. Elbow flexion strength will be measured.
- These measurements will all be taken during the same session and will take approximately one hour to complete. Testing time will be during non-school hours and will be arranged through the participant's parents.
3. The strength training program will go for an 8 week duration (a total of 24 training sessions), with each session taking approximately 15 minutes (including warm-up and cool-down). These training sessions will be performed on Monday, Wednesday, and Friday of each week, and will take place during the morning recess.
 4. Following the training program all baseline measures will be performed again using the same protocol.

Benefits to Participating in the Study:

1. The participants will have the opportunity to learn about and experience strength training under the supervision of qualified instructors.
2. The participants will receive a prediction of their adult height.
3. The participants will be given an assessment of their current fitness status.
4. A lecture on growth and development during adolescence, as well as one on the Do's and Dont's on youth strength training will be given to the class.

APPENDIX C: INFORMATION LETTER TO PARENTS

To Whom It May Concern:

Your child is being asked to participate in a strength training study for the College of Kinesiology at the University of Saskatchewan. This study has the support of the teachers and staff at Father Robinson School. It has been approved by the Biomedical Research Ethics Board of the University of Saskatchewan, and it has received both support and funding from the Saskatchewan Academy of Sports Medicine. The following is a brief overview of the study and the research team. Attached is the consent and asset form which describe the study more thoroughly.

In order to participate in this study, we require a commitment from you and your child to complete all aspects of the study. We are looking for up to a maximum of 30 boys in grade 7 or 8. The study will consist of two testing occasions prior to the training, followed by an 8 week training program, and once training is complete another testing session. The training program will begin on Wednesday February 21st and will be performed on Monday, Wednesday, and Friday during lunch hour at the school. Therefore your child will need to bring a lunch and stay at school on these days. Each training session will last between 15 and 20 minutes. Also, as the eight week training program will go through the Easter break, your child will need to be able to come in during that week for training, with the exception being Good Friday as well as any other long weekends. The actual training will consist of one simple and very safe exercise, a one arm bicep curl, and your child will only train one arm for the duration of the study. All training sessions will be supervised by a nationally accredited personal trainer. All three testing sessions will take place at the University of Saskatchewan during evenings or weekends, therefore you will be required to bring your child to the university for this testing. Each session will last approximately one hour, and the testing day and time will be flexible and will be individually arranged by you and the researcher. The first two tests must be done one week apart and completed before the start of the training program (Feb. 21st). The last test will be done within one week following the conclusion of the training program (all children must complete all 24 sessions before they do the final testing). Once all aspects of the study are completed you will be given your child's results, as well as the results of the entire study (individual results will remain anonymous).

The research team for this study consists of Jason Allen; a graduate student in the College of Kinesiology Masters program who is also Personal Lifestyle and Fitness Consultant

and has a lot of experience training children of this age. Dr. Adam Baxter-Jones; a professor at the University of Saskatchewan who is one of the world's leading experts in the pediatric exercise field. Mr. Bart Arnold; a lecturer at the University of Saskatchewan who teaches courses on the benefits of, and the theory behind strength and aerobic training. Previously he was the coordinator of the Human Performance Center where he trained people of all ages, levels, and abilities; including NHL and CFL players.

We strongly believe that this study is an exciting opportunity for both you and your child to take part in. We also think that it will be a valuable experience which will increase your understanding and awareness of your child's health, and the relationship between exercise and growth and development. It will also give your child the chance to train under a knowledgeable trainer and with a well designed program, where they can learn how to properly and safely participate in strength training.

If you have any questions or concerns please contact feel free to contact me. If your child is interested in participating, please have your child return the signed consent and assent forms to their teacher as soon as possible. Once these forms have been received we will be in contact with you to arrange testing times. Thanks for your time.

Jason Allen

M.Sc. Candidate, PFLC

jason.allen@usask.ca

966-1123

APPENDIX D: CONSENT FORM

**The Effects of Eccentric Training on Strength and Muscle Development in Children
College of Kinesiology, University of Saskatchewan**

Consent Form

Investigators: Mr. Jason Allen (BSc., MSc. Candidate, PFLC, College of Kinesiology), Dr. Adam Baxter-Jones (PhD, Associate Professor, College of Kinesiology) and Mr. Bart Arnold (BA, MSc., PFLC, Lecturer, College of Kinesiology)

Introduction: Your child is being asked to participate in a research study. This study involves an eight week strength training program which will take place three times a week, and will consist of approximately 15 minutes of exercise per session. Each session will take place at your child's school during recess. The exercise session will include a warm-up and cool-down consisting of both aerobic and flexibility exercises. The strength training component will be performed with one arm and will consist of lowering a weight at a slow speed (called eccentric training) for a number of repetitions and sets. We will measure your child's height, sitting height, weight, and bicep muscle thickness using ultrasound technology. As well there will be tests done to measure your child's strength. These tests will be performed twice before the study, once to get your child familiar with the tests, and the second time, about one week later, to get the baseline measures. Following the conclusion of the training program, these measures will be repeated.

Before you decide to allow your child to participate it is important for you to understand what the research involves. This consent form will tell you about the study, why the research is being done, what will happen to your child during the study and the possible benefits, risks and discomforts. If you wish your child to participate, you will be asked to sign this form. Your child's participation is entirely voluntary, so it is up to you to decide whether or not they take part in this study. If you do decide to allow your child take part in this study, you are free to withdraw at any time without giving any reasons for your decision nor will you lose the benefit of any medical care to which you are entitled or are presently receiving. Please take time to read the following information carefully and to discuss it with your family, friends, and doctor before you decide.

Purpose of the study: This study hopes to help better understand the physiological effects that occur when children participate in a strength training program, and to try and determine if these effects are independent of the normal changes that occur during growth and development. As the health of our young people becomes an increasing concern we need to continue to look for new ways to confront this issue. The more we understand the effects of strength training, and the exact mechanisms behind them, the better chance we have to develop efficient exercise regimens that will help to improve the health of our children. The purpose of this study is to examine the effects of a strength training program on strength and muscle development in children, using a one arm training model.

Possible benefits of the study: You will participate in a safe and well-constructed exercise program supervised by qualified instructors from the College of Kinesiology. You will also receive information about your child's current strength related fitness, and any improvements they make

over the course of the study. As well you will receive a prediction of your child's final adult height.

Although the study results will not benefit your child directly they will help scientists and health professionals better understand the links between strength training and health. This information may be very beneficial to health practitioners in the future, when dealing with childhood health problems, such as obesity.

Procedures: The following procedures will be performed by all participants on three separate occasions. Once as a familiarization trial, then one week later for baseline testing, and then once again one week following the conclusion of the study. These procedures will take place in the College of Kinesiology at the University of Saskatchewan and will take approximately 60 minutes each time:

- a) Assessment of bicep muscle thickness: Both biceps will be measured using B-mode ultrasound technology. The midpoint of the biceps will be the measurement site. These procedures will be administered by a professional fitness and lifestyle consultant (PFLC).
- b) Height, sitting height, weight, will be recorded. These procedures will be administered by a PFLC.
- c) Assessment of strength: The participants will be asked to exert maximal effort while performing elbow flexion while a System 3 Biodex machine will measure force production produced by the participant. Both eccentric and concentric strength will be tested, at speeds of 30°/sec and 120°/sec. Eccentric and concentric maximal elbow flexion strength will also be tested using dumbbells. To control for technique the participants must have their back up against a wall with their knees slightly bent and feet forward. For the eccentric contraction and repetition time of 4 seconds will be used, for the concentric contraction speed will not be measured. These procedures will be administered by a PFLC.

Following these tests the participants will be randomly assigned to a training group, either dominant arm or non-dominant arm. The participants will then participate in an eight week eccentric elbow flexion training program which was specifically designed for these participants by a PFLC. They will perform three training sessions per week, on Monday, Wednesday, and Friday. These training sessions will be performed at school during recess. Each session will consist of a short warm-up and cool-down, with both aerobic and flexibility components, as well as the strength training exercises. The training program will consist of 2 to 5 sets of 6 to 8 reps, each repetition will be approximately four seconds in duration. Starting weight will be determined at the initial strength testing session. Progressive resistance will be used, and this will be assessed using a perceived exertion scale that the children will be shown. Following each training session each participant will record their level of perceived exertion as well as any stiffness or soreness related to the training program.

Foreseeable risks, side effects or discomfort: When performing the strength tests, or while participating in the exercise program your child may experience minor discomfort or soreness in their muscles during or following their participation.

There will be no cost to you for your child's participation in this study. You will not be charged for any research procedures. You will be reimbursed for any parking expenses incurred during the testing sessions at the University of Saskatchewan.

Confidentiality: Precautions will be taken to protect your child's anonymity during the study. All data collected will be stored in a locked office in the College of Kinesiology. While absolute confidentiality cannot be guaranteed, every effort will be made to ensure that the information you provide for this study is kept entirely confidential. Your child's name will not be attached to any information, nor mentioned in any study report, nor be made available to anyone except the research team. It is the intention of the research team to publish results of this research in scientific journals and to present the findings at related conferences and workshops, but your child's identity will not be revealed.

Please be assured that you may ask questions at any time. We will be glad to discuss your child's results with you when they become available and we welcome your comments and suggestions.

If you have any questions please contact our office at:

Mr. Jason Allen (phone: 966-1123 email: kolyic@yahoo.ca)

Dr. Adam Baxter-Jones (phone: 966-1078 email: baxter.jones@usask.ca)

Mr. Bart Arnold (phone: 966-1007 email: bart.arnold@usask.ca)

Please read the following before signing this consent form:

- I have read or have had this read to me and understood the research subject information and consent form.
- I have had sufficient time to consider the information provided and to ask for advice if necessary.
- I have had the opportunity to ask questions and have had satisfactory responses to my questions.
- I understand that all of the information collected will be kept confidential and that the result will only be used for scientific objectives.
- I understand that my participation in this study is voluntary and that I am completely free to refuse to participate or to withdraw from this study at any time without changing in any way the quality of care that I receive.
- I understand that I am not waiving any of my legal rights as a result of signing this consent form.
- I understand that there is no guarantee that this study will provide any benefits to me (if applicable).
- I have read this form and I freely consent to participate in this study.
I have been told that I will receive a dated and signed copy of this form.

Parent or legal guardian's statement:

I, _____, understand the purpose and procedures of this study, as
(please print name)

I have read or have had described to me, and I voluntarily agree to allow my child to participate. I understand that at any time during the study my child will be free to withdraw without penalty. I understand the contents of the consent form, the proposed procedures and possible risks. I have had the opportunity to ask questions and have received satisfactory answers to all inquires regarding this study.

APPENDIX E: ASSENT FORM

The Effects of Eccentric Training on Strength and Muscle Development in Children
College of Kinesiology, University of Saskatchewan

Assent Form

You are being invited to participate in a research project. This participation is not part of the regular activities of school and is an optional activity.

Before the study we will measure your height and weight. We will then test your strength using a machine where you will sit with your arm strapped in, and then you will be required to bend your elbow. These tests will be hard as you will have to go to full effort. During the study you will participate in an exercise session with other children your same age. Each session will be during recess on Monday, Wednesday, and Friday, and will consist of lowering a weight with one of your arms. The exercises are safe and you will be supervised during the whole session. Following the exercise program you will have to do all the tests you did at the start of the study over again.

You can withdraw from the study at any time, for any reason, and this will not cause anyone to be upset or angry, and will not result in any type of penalty or affect your grades in school or your relationship with your teacher.

The strength tests and the exercises will be hard and therefore may cause some discomfort such as soreness in your muscles both during the exercise and possibly after.

Your contribution to this research will be kept private and not shared with others on your hockey team, your parents, or your coaches. The research results may be used in a university student's write-up project and may be published in a journal article, but you will not be identified in these.

You will be informed of any new information that may affect your decision to participate.

If you have any questions about the research you can call Mr. Jason Allen (966-1123), Dr. Adam Baxter-Jones (966-1078), or Mr. Bart Arnold (966-1007).

This research has been approved by the University of Saskatchewan, Biomedical Research Ethics Board (Bio-REB) on _____.

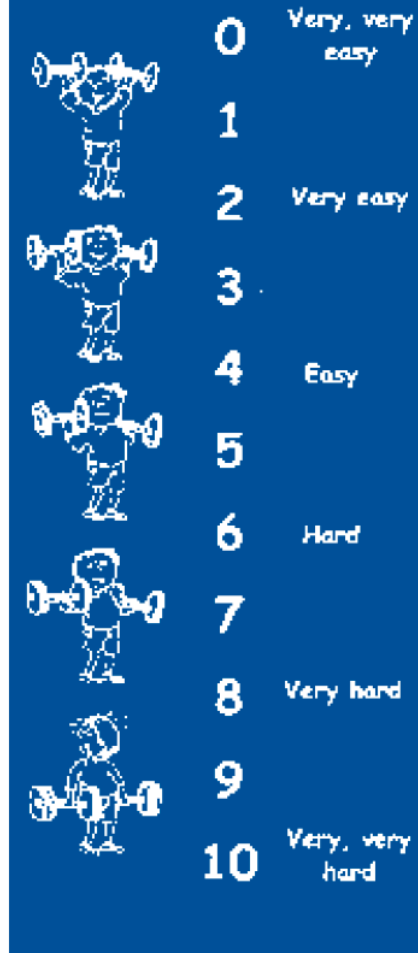
By Signing below, you acknowledge that the study and consent form have been explained, that you understand these, and that you agree to participate. You will receive a copy of this assent form.

Participant's Signature: _____ Date: _____

APPENDIX F: TRAINING JOURNAL

APPENDIX G: PERCEIVED EXERTION FOR CHILDREN SCALE(PEC)

Figure 1 - Perceived Exertion for Children (PEC) Scale
(from reference 7)



Faigenbaum, Miliken, Cloutier, & Wescott. (2004)