THE EFFECTS OF HIGH AND LOW REPETITION RESISTANCE TRAINING ON NEUROMUSCULAR FATIGUE AND RECOVERY IN CHILDREN AND ADULTS

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The Effects of High and Low Repetition Resistance Training on Neuromuscular Fatigue and Recovery in Children and Adults

By

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ABSTRACT

The major objectives for this thesis included: 1) determining the effects of high and low repetition resistance training on neuromuscular fatigue in children while utilizing one minute rest intervals, and 2) comparing the corresponding responses of children to adults. These objectives along with the integration of the known literature on fatigue and recovery in children will help develop appropriate standards with respect to rest intervals and resistance training in children. The existing literature on pediatric resistance training is scarce, but there are a few studies that indicate children recover quicker than adults. Despite this notion, it is important to understand why children recover quicker, or why child's body has a tendency not to fatigue to the same extent as an adult. The present study determined that children are more likely to exhibit decrements in performance due to problems with muscle coordination as oppose to neuromuscular fatigue. In addition, decreased ratings of perceived exertion may suggest that children may not truly understand the idea of maximum efforts to the same extent as an adult. As expected, children were reported to recover faster than the adults during both RT protocols.

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Life is all about how you interpret it and every moment can be positive no matter what comes your way. Embrace it, keep on smiling and remember life is like waves on the ocean it will have its ups and downs, but all you have to do is hang on and enjoy the ride.

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"Strong heart, strong mind, strong body"
J.Murphy

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LIST OF ABBREVIATIONS

1/2RT	Half Relaxation Time
BPM	Beats per Minute
Ca2+	Calcium
CMJ	Counter Movement Jump
CNS	Central Nervous System
EMD	Electromechanical Delay
EMG	Electromyography
HR	Heart Rate
HRM	High Repetition Maximum
IEMG	Integrated Electromyography
IT	Interpolated Twitch
ITT	Interpolated Twitch Technique
LRM	Low Repetition Maximum
ME	Muscular Endurance
ms	Millisecond
MS	Muscular Strength
mV	Millivolts
MVC	Maximal Voluntary Contraction
N	Newton
PAP	Post Activation Potentiation
RFD	Rate of Force Development
RI	Rest Interval
RM	Repetition Maximum
RPE	Rating of Perceived Exertion
RT	Resistance Training
s	Seconds
SD	Standard Deviation
VC	Voluntary Contraction

1 INTRODUCTION

INTRODUCTION 1.1

The pediatric literature on resistance training continues to gain insight on how children should train. It has been established that resistance training (RT) in children may help develop self-esteem [1], and bone density [2, 3], as well as help build strength, coordination [4, 5] and decrease the risk for injuries [6, 7]. General guidelines for children and RT have been established, however, recovery intervals are not one of the well established parameters. RI are developed in order to optimize training performance while decreasing the risk of overtraining and/or not training enough; essentially trying to optimize the time spent training. With the growing interest in youth athletics and development, it only seems necessary to ensure appropriate guidelines with respect to recovery [6, 8]. Although general recommendations may seem appropriate, training specificity has been shown to be the best approach to developing specific training goals [9]. There is a plethora of information regarding training principles in adults and RT [10-15], however, due to the physiological differences between children and adults, adult standards will not suffice in the pediatric population. Children have also been shown to recover quicker than adults [16-20]. Although specific adult standards are inappropriate for children, it may be a good approach to utilize the adult literature in order to develop appropriate methodologies for examining RT and recovery in children.

When observing the recovery paradigm from another angle, it is very important to understand why we need to recover in the first place. Ultimately, an individual needs to rest when they become fatigued. Therefore it should come as no surprise to see the positive correlation between the number of studies examining exercise induced fatigue and the amount of information that exists on recovery and rest intervals in the adult literature [21-27].

The pediatric literature has attempted to tackle specific mechanisms with respect to exercise induced fatigue, however, the literature in this area still approaches this from a metabolic standpoint. While there is evidence to support the notion that children rely more on oxidative rather than faster glyolytic pathways [28, 29], there is little research on neuromuscular meachanisms with respect to fatigue. The adult literature on the other hand is quite extensive [24, 30-33]. As mentioned previously, perhaps by attempting to adjust specific methodologies from the adult literature it is possible to further examine the variety of mechanisms that lead to exercise induced fatigue in children. More specifically, examining evoked contractile properties in relation to neuromuscular fatigue may shed some more light in the development of better RI standards for children and RT.

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2 REVIEW OF LITERATURE

2.1 INTRODUCTION

Over the past few decades resistance training (RT) for children has gained more acceptance as initial concerns regarding impairments in growth and development with RT have been refuted in the literature [1, 2]. RT in children has not only been reported to be safe, but has also been shown to be beneficial. Increased bone density [1, 2], self-esteem [3], and motor performance skills [4, 5], as well as a decreased risk of musculoskeletal injuries [6, 7] have been reported in the literature. Some general guidelines regarding RT in children have also been established and include; appropriate supervision, volume, intensity, and duration of training [4, 8, 9]. Although the importance of these guidelines is evident, there is one crucial parameter missing from the set; how much rest between sets should be given to children?

With respect to recovery intervals (RI), there are no standards. Interestingly though, the literature on RI in adults is quite extensive [10-13]. In fact, there are many review articles [14-16] discussing not only the importance of RI, but also ways of manipulating them in order to enhance performance. If RI is so important, then why is there a dearth of information in youth? Perhaps children can benefit from the standards set for adults? This is certainly not the case as children have been shown to recover faster than adults in a number of studies [17-21]. The few studies that have examined RI in children all report similar findings that children recover quicker than adults, and have been shown to be fully recovered at levels below the adult standards [22-30].

Using the adult literature as a guide, there seems to be a close relation between recovery and fatigue. Mechanisms controlling fatigue have been examined extensively in the adult literature [24-30]. The onset and extent of fatigue is dependent on a balance between fatigue processes (i.e. neural, muscular, metabolic) and neuromuscular potentiation. In regards to the latter, also referred to as post activation potentiation (PAP), the recognition of its role to counteract fatigue has been examined in the adult literature [31-33]. Unfortunately the same attention has not been applied to studies on children and very little is known in regards to fatigue and PAP in this population.

2.2 MUSCULAR FATIGUE

Many studies have suggested an appropriate definition of muscular fatigue [34-37]. Some authors have suggested that an increase in effort perception or a decrease in cognitive processing is indicative of muscular fatigue [38, 39]. Although both can be used as potential markers, muscle fatigue is more often associated with a decrease in force production [37]. There are a myriad of fatigue markers used in the literature such as changes in maximal isometric[34, 37], isotonic [25], and isokinetic force [40], rate of force development (RFD) [29, 41], range of motion (ROM) [42, 43], and muscle activation as measured by electromyography (EMG) [38, 44]. Central and peripheral mechanisms underlining fatigue have been extensively investigated in adults but not in children.

2.2.1 CENTRAL FATIGUE

Central fatigue encompasses factors involving the central nervous system (CNS) [45]. Failure of neurological transmission within the CNS, as well as decrements in motivation has been suggested as causes of central fatigue [39, 46]. Central fatigue has been measured by an individual's ability to activate all muscle fibers in order to produce a maximal voluntary contraction (MVC) [47]. A lack of full activation, or inactivation, signifies a disruption in the neural drive to the muscle, stemming from central factors [34, 45].

A lack of activation can be measured with a number of methods. It is believed that if an individual is giving a maximal effort to produce a contraction, any increase in force production with the introduction of muscle stimulation can be used as a measure for the amount of activation [37]. First illustrated by Merton [48], the interpolated twitch technique (ITT) of electrically stimulating a muscle in order produce a superimposed evoked twitch during a MVC, has been used for decades as a means of measuring the amount of muscle activation. Other methods of measuring central fatigue have included using a central activation ratio (CAR), as well as monitoring the change in electromyography (EMG) signal recorded during the maximal voluntary contraction (MVC) normalized to the compound muscle action potential (M-wave) [47]. Although these techniques have allowed for much research in the area of muscle activation and central fatigue, there has been debate on the ability of an individual to reach full activation. Both full activation [27, 49] and lack of full activation [26, 50] have been reported.

2.2.1.1 Central Fatigue and Adults

Aside from the different methods used to measure central fatigue, much of the research has been dominated by the use of the ITT. This method has been recognized as the most valid method for measuring muscle inactivation[51, 52]. Therefore much of the literature has utilized this technique to study central fatigue and various components including; the type and duration of exercise [25-28, 53-55], type and duration of contractions [25, 26, 28, 47], as well as and in various environments [56-58].

The contraction duration, as well as the contraction type may be an important consideration in the development of central fatigue. Much of the research on central fatigue has been conducted utilizing isometric contractions [26, 27, 47, 54]. Behm and St. Pierre [26] revealed that central fatigue may be duration dependent as shown by an activation decrease of 12±7.5% versus 5.8±4.5% in longer and shorter contraction durations respectively. Other authors have also reported sustained isometric contractions elicited a greater decrease in muscle activation than fatigue brought on by multiple isometric contractions performed intermittently [27, 28, 47, 54]. In contrast to the previous notion that central fatigue may be duration dependent, Behm et al. [25]did not report any significant difference between muscle contractions of 5, 10 or 20 repetition maximums lasting 35, 70, or 140 seconds respectively. Of particular note is the contraction duration used, as well as the type of contraction. Despite the lack of differences reported, contraction duration in the latter was shorter in length than the 4 to 19 minutes used in the previous study by Behm and St. Pierre [26]. Isotonic contractions were also performed opposed to isometric contractions. With respect to contraction type, Babault et al. [59] did report significantly lower activation levels for maximal eccentric and concentric contractions when compared to maximal isometric contractions. All of these findings suggest that both contraction type and contraction duration may be important in determining central fatigue.

There are a number of studies that have attempted to identify the types of activities that elicit the greatest central fatigue [25, 45, 53, 55, 60-62]. Saldanha et al. [55] determined that central mechanisms were the primary factor in the plantar flexors fatigue after running. They subjected 8 individuals to 2 hours of running at moderate to high intensity (75% of VO2max) and found a decrease 17±16% and 19±15% in both their MVC and activation respectively. In agreement with Saldanha et al. [55],a paper published by Noakes [60] argued a central governed method with respect to running. Due to the fact that marathon runners are able to maintain a state of physiological homeostasis throughout a race, despite suffering from a significant increase in fatigue, suggests that a central governor (brain) may regulate performance in order to allow the athlete to finish the race without sustaining undue harm [60]. It was also suggested that perceived exertion and motivation, both central factors [63], play a role in performance. Also in agreement, Martin et al. [53] reported a significant decrease in voluntary activation of the quadriceps following a 24-hour period of running. The authors suggested that longer duration aerobic activity would elicit greater central fatigue than shorter duration (anaerobic) activities. As central mechanisms (groups III and IV afferent feedback) are thought to play a role in reducing the level of exhaustion [45], there is an agreement that this may serve as a safety mechanism to prevent muscle damage with longer duration activities [37, 39, 45]. Further support can be found in the study by Lepers et al. [62], who reported that contractile properties were affected during the initial stages of prolonged cycling activity and that impairments in central drive came on in the latter stages. Despite the evidence of increased central fatigue from aerobic based (longer duration) activities, it should be noted that central fatigue has been recorded in shorter duration (anaerobic) activities as well. Similar to the previous studies utilizing short duration contractions/activities [25, 26, 28], Tomazin et al. [61] reported that sprint lengths of 200 and 400m were enough to increase central fatigue in their subjects. Despite the difference amongst methods of inducing central fatigue, it should be noted that Tomazin et al. [61]also reported that the decrease in force output was primarily due to peripheral mediators (changes in metabolites) and that central factors were secondary. It has been shown that both aerobic and anaerobic activities can induce central fatigue to an extent, however, it appears that longer duration activities have a greater impact on the extent of central fatigue sustained [26, 62].

Aside from the various activities, research on central fatigue in different environments has also provided some insight into the causes [56-58]. Paddock & Behm [58] used muscle activation as a measure for a study which simulated performance in an inverted position. The investigators did report differences in blood pressure, heart rate, force production, and coactivation of the quadriceps and hamstrings with respect to body position, however, no changes in muscle activation were noted and thus central fatigue was similar in both situations. Comparable findings were also reported in hypothermic conditions [57]. Drinkwater & Behm [57] did not report any differences in activation of the plantar flexors after inducing fatigue in twelve individuals in both normothermic and hypothermic conditions. With respect to atmospheric pressure, however, Behm et al. [56] did report an increase in central fatigue while utilizing a hyperbaric chamber. When exposed to greater atmospheric pressures, subjects were reported to have greater deficits in muscle activation. The authors suggested that the induced nitrogen narcosis due to increased pressure may play a role in supraspinal dysfunction and thus could affect neural drive to the motonueron.

The extent of research on central fatigue in adult populations has provided much insight into specific causes including the effect of various contractions, activities, and environments. Despite what has been indicated from the previous studies, also of important consideration is the physiological basis for central fatigue. As such, supraspinal and spinal mechanisms has been indicated in the literature for adult populations [34, 37, 45, 64]. With respect to supraspinal factors, increases in tryptophan and consequently increased serotonin levels have been reported to affect corticospinal drive, and thus decreasing impulses to motoneurons [45, 64]. An extensive review by Behm [34] shares much of the supraspinal factors indicated, but also discusses some spinal influences to central fatigue. Both reflex inhibition as well as a disfacilitation of motoneurons can be brought on by various peripheral afferents [34].

2.2.1.2 Central Fatigue and Children

Similar to the literature on muscle fatigue and recovery in children, specific mechanisms underlying central fatigue with children is scarce. To date there are only a few studies that have examined the levels of central fatigue in children.

The earliest study was conducted by Ramsay et al. [65]. The authors wanted to determine if strength training had any affects on voluntary activation in children. Subjects aged 9-11 completed 20 consecutive weeks of circuit training, incorporating whole body exercises, as well as some bias towards the two muscle groups interested in the study (quadriceps and biceps). Despite significant strength gains and changes in contractile muscle properties, there was no significant change in voluntary activation.

Streckis et al. [66] tested their hypothesis that adult men and women (19-27 years) are able to maintain higher levels of voluntary activation in knee extensor muscles than boys and girls (12-14 years). Each group was subjected to a fatiguing task which required them to perform 3 sets of 5 isometric MVC's with a 2 min rest between sets. Voluntary activation was measured prior to the sets as well as 30, 60, 90, and 120 seconds following the fatiguing trial using a 2min sustained isometric MVC. The authors concluded that children maintain a lower level of muscle voluntary activation than adults when exposed to continuous high-intensity exercise, suggesting an increased susceptibility to central fatigue.

Voluntary activation of the triceps surae was also examined in prepubescent children aged 7-11 years old by Grosset et al. [67]. Adults and children were asked to complete 2 trials of isometric plantar flexion (knee and ankle flexed at 120° and 90° respectively) for each of the succeeding levels; 25, 50, 75, and 100% MVC. All trials were randomly assigned and separated by 2 minute intervals. Contractions were held for 3-4 seconds. Posterior tibial nerve was stimulated once peak torque was reached, initiating a superimposed twitch, and again following the contraction. Activation levels for all contractions were determined and results indicated that all children were unable to fully activate the triceps surae to the level of the adult participants. Deficits of 12.97 ± 4.69%, 4.43 ± 1.03%, 3.30 ± 0.28%, and 1.48 ± 0.18% were seen for the children aged 7, 10, 11, and adults respectively. It was concluded that central mechanisms are the main cause of the lower torques developed by children and they appear to vary with age in prepubertal children.

With the dearth of literature exploring central fatigue in children, it comes as no surprise as to why there is so much support for different training parameters related to rest and fatigue for this group. The literature on adults has provided much information not only on the factors (contractions, activities, environment, etc.) that increase central fatigue, but also on biological markers that contribute to increased central fatigue. Although central mediators are just one factor to muscular fatigue, the notion of a central drive failure and possible motivational mechanisms contributing to fatigue should give more reason to conduct research with a bias towards central factors in youth.

2.2.2 PERIPHERAL FATIGUE

The issue of central versus peripheral influences on fatigue has had an extensive history in the literature [27, 34, 37, 47, 54]. What is the predominant site and cause of fatigue? While central factors contribute to muscular fatigue, there are many peripheral causes to muscle fatigue as well [41, 68, 69]. Peripheral fatigue can be defined as a decreased force production due to an impairment of excitation contraction coupling either due to a decrease in action potential propagation or calcium kinetics [30]. Others have also included changes in metabolic factors (lactic acid, inorganic phosphate) to contribute to peripheral fatigue [70, 71]. With respect to peripheral fatigue mechanisms, peripheral fatigue can be measured from the changes in evoked contractile properties [37]. In the presence of peripheral fatigue, decrements in twitch and tetanic amplitudes and increases half relaxation time (1/2RT) have been shown to occur [47, 54]. By monitoring contractile properties, studies have been able to assess the level of peripheral fatigue sustained through different variables including; duration of exercise [41], contraction type [30, 72], and type of exercise [29, 47, 69]. Mechanisms related to children [73-75] and adults [26, 30, 41] have also been examined, although more research has been conducted with the latter.

2.2.2.1 Peripheral Fatigue and Adults

Similar to the literature on central fatigue, peripheral fatigue has also been shown to vary depending on the type and duration of contraction used [30, 41, 54, 69, 72], as well as the type of activity and duration of activity engaged in [53, 62, 76-78].

Utilizing both isotonic and isometric contractions, Cheng & Rice [41] conducted a study on 13 adult males to determine the effects of peripheral fatigue. Subjects were required to complete as many isotonic contractions as possible at maximal velocity with a pre set load. Following the fatiguing protocol, voluntary and evoked twitch contractile properties were measured during both isotonic and isometric contractions at various recovery intervals. Results included a strong negative correlation between 1/2RT (increased) and isotonic velocity (decreased), as well as a significant decrease in isometric force. The authors concluded that this negative correlation relates to fatigue brought on from the high intensity contractions and is a result of increased metabolic factors interfering with actin-myosin cross bridging. Also of interesting note was the prolonged decrease in isometric force when compared to isotonic power which recovered quickly. This result provided the authors with some evidence to the notion that mechanisms of fatigue are contraction specific. There is agreement within the literature about different contractions causing peripheral fatigue [30, 54, 69, 72]. Nordlund et al. [54]and Babault et al. [72] reported decreases in twitch force following isometric contractions to fatigue. Babault et al. [72] also reported similar results utilizing concentric contractions, however the onset of peripheral fatigue was found to be quicker in concentric contractions. It was suggested that the difference in excitation contraction coupling and difference in metabolite production would contribute to the difference observed. Other authors reported peripheral fatigue with concentric contractions [30, 69]. Although both studies are in agreement with previous findings, Walker et al. [30] did suggest a different cause to peripheral fatigue. Aside from the suggestions of increased lactate production associated with peripheral fatigue, the lower intensity protocol with extended rest periods kept blood lactate to a minimal. The authors reported that impairment may occur at various levels of the excitation contraction coupling process, but were not a result of changes in pH. Increased acidosis may play a role in the level of peripheral fatigue, however, changes in pH cannot account for direct cause of peripheral fatigue [79].

Aside from the various types of contractions, peripheral fatigue was also found to be dependent on type of activity. Several studies have investigated the difference in peripheral fatigue sustained during long duration aerobic versus shorter anaerobic activities [53, 62, 76-78]. Theurel & Lepers [78] reported a greater increase in peripheral fatigue, as noted by a decrease in twitch force, during varied cycling sprints in comparison to long duration cycling at a constant pace. The authors concluded that the increase in power output and thus increase in anaerobic metabolism was enough to exacerbate the peripheral fatigue sustained [78]. Others have shared similar views comparing running sprint intervals with continuous sub-maximal running [80, 81]. This notion has also been refuted by others [76, 82, 83]. Lepers et al. [76] reported that there was no difference in peripheral fatigue sustained following cycling interventions of constant versus varied power output. Similarly, Palmer et al. [83] and Bernard et al. [82] did not report any significant differences in metabolic responses or changes in contractile properties that would suggest changes in peripheral fatigue following sustained and varied cycling interventions. However, it should be noted that the differences in conclusions amongst studies may be a result of the intensity of the varied conditions. During the varied sprints, power output was maintained at or less then each subject's maximal aerobic power (MAP) in the latter studies. Whereas the literature that has reported a difference between interventions, ensure subjects increase the intensity greater than MAP during the varied sprints. Despite these differences, there is also evidence to support the notion that sustained longer duration aerobic activity is more likely to contribute to central as opposed to peripheral fatigue [60].

2.2.2.2 Peripheral Fatigue and Children

Few studies have investigated the contractile properties associated with peripheral muscular fatigue in children. The majority of the pediatric literature continues to examine metabolic changes [18, 70, 84]. Many authors have reported decreases in enzyme activities important for glycolytic activity [85, 86], as well as decreases in lactic acid production; a byproduct of anaerobic metabolism [18, 23]. The importance of these findings suggest that children may rely more predominantly on oxidative rather than fast glycolytic pathways for energy production [87]. It is argued that children are more fatigue resistant because they do not suffer from many of the decrements brought on from peripheral fatigue. However, without research on the contractile properties of children with fatigue, the extent of impairment cannot be fully understood.

There are studies that have examined contractile properties in children [88, 89], however, only one study investigated the changes in contractile properties associated with fatigue;

Skurvydas et al. [74] investigated the effects of a high intensity plyometric training program on central and peripheral fatigue in prepubertal boys. Thirteen boys participated in an 10 week repeated measures study. Prior to the plyometric training program subjects were required to perform continuous 2-min isometric MVC's of the quadriceps to induce fatigue. Following the MVC's, subjects performed another MVC with a superimposed and potentiated twitch to assess the level of central and peripheral fatigue. Following pre-test measures was an 8 week plyometric program in which the boys participated in 2 training sessions per week (total of 16 sessions). Post-test measures were conducted in the same manner following the program. Significant findings included an increase in peak twitch by 323.2 ± 210.8 % and jump height by 36.7 ± 11.7 %. Interestingly, central fatigue significantly increased after plyometric training (15-20%), but peripheral fatigue decreased (~10%). Authors concluded that the plyometric training enhanced the boys' excitation-contraction coupling and therefore were less susceptible to peripheral fatigue following the fatiguing MVC.

Similar to the literature on central mechanisms to fatigue, the literature for peripheral mechanisms is lacking with respect to research on children. Aside from what is understood in relation to muscle metabolism and how certain byproducts of anaerobic metabolism hinder processes like excitation-contraction coupling, much research is needed in the area of fatigue and the effects on contractile properties in children. Perhaps it is true that children are more likely to utilize aerobic rather than anaerobic energy pathways and therefore may not suffer to the same extent from the metabolic byproducts of anaerobic metabolism. Although these notions have been addressed in the literature, they have yet to be followed up with research on contractile properties and fatigue in children.

2.3 MUSCLE POTENTIATION

Post activation potentiation (PAP) is the temporary increase in muscle contractile performance after previous contractile activity [90, 91]. Potentiation occurs as a result of phosphorylation of the myosin regulatory light chains (RLC), which increases Ca2+ sensitivity of the myofilaments and increases the number of force-producing cross-bridges resulting in increased force production [34, 92]. As potentiation has been shown to enhance muscle performance to some degree [93, 94], fatigue has quite the opposite effect on performance. The interaction of fatigue and potentiation has been examined in the literature in both adult [31-33], and child [42] populations. However, the effects of potentiation and fatigue in children are limited to only a few studies. Ongoing research on potentiation in adult studies has lead to some suggestions on how to manipulate training parameters to increase the benefits of PAP, and perhaps bypass fatigue to some extent. There is debate on whether or not PAP can help performance by counteracting the effects of fatigue [90].

2.3.1 POTENTIATION AND ADULTS

The literature on adults and PAP is quite extensive. As such, there are many studies discussing the role of PAP on muscular fatigue [31, 33, 34, 91, 92, 95, 96]. Some authors have suggested that PAP may counteract the effects of fatigue [32, 92, 97, 98], while others have demonstrated the possibility of the coexistence of PAP and muscular fatigue [31, 33, 34, 95]. With respect to PAP and performance, both training experience, as well as activity type has also been indicated in affecting PAP [96-103].

Comparing the extent of PAP on athletes and recreational active individuals, Chiu et al. (2003) determined that trained athletes may benefit from potentiating effects whereas recreationally active individuals may not. In accordance, Hamada et al. (2000) reported an increase in level of potentiation, as determined by percentage change in peak twitch torque post MVC, in trained endurance athletes versus sedentary individuals. Others have also reported similar findings [100-102]. There is one study, however, that did not report any differences in the extent of PAP based on training level. Using three different groups of individuals with various training experience Batista et al. [104]were unable to produce significant differences in PAP effects between the groups and thus concluded that training experience is not correlated to PAP ability. Despite the differentiating views, all of the aforementioned studies showing increased potentiation in trained individuals examined the effects based on relative changes, whereas in the study by Batista et al. [104], conclusions were based on absolute values. The smaller changes in the latter may be responsible for the lack of significance.

The literature also varies with respect to type of activity employed in order to enhance PAP, and the majority of studies utilize heavy loads [94, 96, 97, 100-102] or explosive movements [93, 99, 101, 103].

With respect to heavy loads, Weber et al. [94]demonstrated an increase in counter movement jump (CMJ) height after a 5 repetition back squat using 85% of a 1 repetition maximum (RM). Compared to the control of 5 CMJ's, the 5RM revealed both an increase in CMJ height, as well as an increase in ground reaction forces. The authors attribute the increase in performance to the potentiated effects of the back squat. Others have also reported similar findings using variations of back squats including 1[97], 3[100, 101] and

5[102] RM's. Although each of these studies attribute the performance increases to PAP, only one study has examined the actual effects of a back squat on evoked contractile properties with corresponding performance benefits [102]. Mitchell et al. [102] examined the effect of a 5RM back squat on both CMJ height as well as evoked contractile properties. It was reported that the 5RM back squat did increase subsequent jump performance and the authors concluded that the effects were in fact due to PAP as indicated by a significant increase in twitch torque. Despite the evidence that supports an increase in performance measures using various repetitions of back squats, there is also evidence to suggest back squats may have no effect in improving performance [96]. Jones & Lee [96] were unable to show an improvement in CMJ performance following a 5RM back squat. However, it could be argued that although the methods for all experiments were similar, all of the studies that reported an increase in performance used collegiate level athletes where as Jones & Lee [96] used strength trained individuals not exposed to explosive training. It should also be noted that although performance did not increase, there was also no increase in fatigue. It could be argued that the type of individuals used may have been more susceptible to fatigue, but not display any indications since fatigue and PAP have been shown to coexist [31-33].

In addition to the previous studies examining heavy loads and PAP, both Masamoto et al. [93] and Smilios et al. [103] report increased squat and CMJ performance following conditioning trials of explosive jumps. The results from the following studies indicate that explosive movements along with loaded squats can also elicit PAP and thus enhance performance. However, it should also be noted that Esformes et al. [99] were unable to enhance CMJ performance with the use of a plyometric conditioning stimulus. Compared to the previous results, it could be argued that the duration of the conditioning trial (70s) was too long to enhance PAP. This notion is in agreement with previous findings that suggest muscle contractions longer than 10s may decrease effects of PAP due to increased fatigue [91]. Also in agreement with Esformes et al. [99], McBride et al. [101] concluded that loaded CMJ's were unable to increase 40m sprint performance. However, because the loaded CMJ's were limited to 3 jumps, contraction time was minimal and fatigue may have not been the limiting factor [91]. Volume of the activity may have also been too low in order to elicit a PAP response [101].

Aside from the methods of enhancing performance through PAP, a balance between PAP and fatigue has also been recognized in the literature [31-33, 92, 95]. Similar to previous studies in which performance was not enhanced by PAP, Gossen & Sale [95] reported a failed attempt to maximize PAP by way of a 10 second isometric MVC. The authors compared the velocity performance of dynamic knee extensions in two conditions (PAP vs. Control). No significant increases in performance as a result of inducing PAP prior to exercise were found, but instead the velocity of the first repetition in the PAP condition was significant slower than the control. The authors hypothesized that the isometric MVC used to elicit PAP may have also induced some fatigue. Despite the lack of benefits in the study from Gossen & Sale [95], Behm et al. [31] hypothesized that perhaps more MVC's might contributed to greater potentiation and may better augment the effects of fatigue. Although it was determined that 3 MVC's would improve the extent of potentiation, the authors also reported a failed attempt to increase performance and concluded that the short recovery period did not allow for sufficient recovery from fatigue. In accordance with these findings, reviews by Rassier & MacIntosh [33] and Behm [31] both suggest that the opposing effects of fatigue and potentiation can coexist in the muscle. As fatigue may be masked by potentiation care must be taken in interpreting results of such research [33].

2.3.2 POTENTIATION AND CHILDREN

The literature on potentiation and its effects on performance and fatigue in children have not received the same attention as adults. In fact, there is only one recent study that examined the effects of potentiation on recovery and performance in this population. A study by Chaouachi et al. [42] examined these effects in 16 boys aged 11 – 14. Subjects completed 8 trials consisting of two interventions (60° or 300°/second isokinetic contractions) and various rest intervals (RI) (2, 3, 4, and 5 min). During each trial, subjects were required to complete 10 isokinetic contractions at the prescribed velocity, followed by one of the various RI. Pre and post test measures included 3 isokinetic contractions of the same velocity used for the intervention. Rate of perceived exertion (RPE) was measured after the intervention, whereas lactate was measured during pre and post test measures. Results indicated significant increases of 3.5%, 2.7% and 5.6% in hamstrings mean power, total work and peak torque at the 2 minute RI (300°/second) respectively. The quadriceps also showed a significant increase of 5.5% in peak torque at the same interval and velocity when compared to pretest measures. These results indicated a potentiating effect. It was also noted that boys had recovered to baseline measurements by the 2 minute RI in 83% of the measures tested.

In regards to potentiation observed, there are some factors that may contribute. As it has been reported that type 2 fibers have greater potential at eliciting PAP [92], and children have a greater proportion of type 1 fibers [105], the potentiation observed may be associated with neural contributions. Training status of the individual can also play a role in potentiation effects [106]. As the children were trained martial artists, it was suggested that they may have greater potential to express potentiation rather than fatigue.

The ability to maintain submaximal force involves an intricate interplay of internal facilitatory and inhibitory influences [31]. Potentiation falls into the category of facilitating and has been shown to affect performance and diminish the effects of fatigue. Despite the evidence for this notion, the research conducted to obtain this information has been primarily collected using adults. With the lack of support for children, it only seems necessary to continue to investigate this population in order to determine how potentiation may affect a child's performance and possibly influence fatigue. Differences in muscle physiology and training status may account for what little has been shown in children, but the lack of research indicates the need for further investigation.

2.4 RECOVERY INTERVALS

The literature on adult resistance training (RT) is quite extensive and has allowed for establishing many training parameters including; intensity, volume, duration, frequency, and recovery intervals (RI). Although the area of resistance training in youth populations has received more attention over the past several years, there are no defined measures for these same training parameters. There are some general guidelines for RT in youth, but despite the position papers [4, 8], and review articles [22, 23] guidelines for RI in children are incomplete. For adult RI, many of the known standards can be attributed to studies on various performance measures and metabolic responses including, phospho-creatine synthesis [14, 107], lactate recovery [79, 108], static and dynamic force production [13, 109], as well as vertical jump and sprints [12, 110, 111]. Inadequate recovery leads to overtraining, and as a result individuals become more susceptible to performance decrements and injuries [112]. This notion, as well as the fact that "a certain amount of rest between sets is essential" [16], highlights the importance of RI. Not only in adults, but any individual partaking in RT, including children. The literature has begun to develop a foundation in order to support appropriate guidelines, but there is still much to examine. As it is right now, our understanding of why children recover faster than adults is limited to metabolic energy pathways, as well as the possibility of inadequate performance of maximal efforts. Some authors have conducted experiments comparing children to adults, while varying RI [17, 20, 87, 113]. Few have also tried to examine neuromuscular mechanisms with respect to RI, but these studies are also limited [19, 21, 114].

2.4.1 RECOVERY IN CHILDREN

There is a widely accepted understanding that children have the ability to recover faster than adults after performing a similar task [8]. Although researchers would agree that children posses some ability to allow them to recover quicker, there is evidence to suggest reasons for quicker recovery. Early biopsy studies from Oertel [105] suggest that children possess a greater proportional area of type 1 muscle fibers, which have been shown to be more fatigue resistant than type 2 fibers [70]. Other researchers have examined energy pathways to determine methods of utilization in children [85, 86, 115]. Kaczor et al. [86] examined aerobic and anaerobic enzymes in 32 males (20 children and 12 adults). Some of the enzymes included lactate dehydrogenase (LHD) and carnitine palmitoyltransferase (CPT). LDH is important precursor in anaerobic metabolism, whereas CPT is important for aerobic metabolism. The analysis revealed that LDH activity was higher in adults (118.2 ± 20.1) compared with children (27.8 ± 10.1μmol / min· g) ($p<0.0002$). There was no age difference in the activity of CPT; however, the ratio of CPT/LDH was much greater in children. The results indicate that children may rely to a greater extent on aerobic energy pathways. Similarly, Eriksson et al. [115] reported that children have lower activities of anaerobic enzymes PFK, and LDH and higher activity of aerobic enzymes, succinate dehydrogenase and fumarase. Much of the literature is in accordance with the results of the two previous studies. Suggesting that perhaps children are able to recover faster because they do not suffer from the same metabolic stressors brought on through anaerobic metabolism. Ratel et al. [113] applied these theories and measured acid-base balance in children and adults after repeated cycling sprints. Eleven boys and ten adult males performed ten 10 second sprints on a cycle ergometer separated by 30 second recovery intervals. Measuring lactate concentration and pH levels pre, post test, and throughout a 25 minute recovery period, the authors determined that the boys were unable to produce the same levels of lactic acid, and the drop in blood pH was less significant.

All of the previous results suggest that due to a child's immature muscle structure and the inability to produce metabolites in significant amounts, children are able to recover quicker and longer recovery periods may not be needed. Aside from the extensive literature on muscle structure and metabolic properties, there is still a gap in regards to the faster recovery observed in children and the relationship to neuromuscular properties.

2.4.2 RATING OF PERCEIVED EXERTION (RPE) AND CHILDREN

Perceived exertion or effort perception can be defined as the ability to detect different bodily sensations brought on through exercise and the understanding of how to interpret them [116]. There is some debate on whether or not a child can accurately describe their level of effort [117-120]. Initial reasons about why children may not be able to accurately describe their effort were believed to be a result of RPE scales being too complex for a child's interpretation [121]. Scales have been adjusted to included pictures and words a child would use in their vocabulary [121]. Faigenbaum et al. [119] designed a RPE scale similar to the Children's Effort Rating Table CERT [121] in order to help children differentiate between aerobic exercise and RT. The authors tested the new RPE scale using 26 children and 2 different exercises (bench press & leg press), with 3 increasing loads (35, 55, & 75% of 1RM). The results of the study revealed that RPE scores increased with increasing loads, r=.70 and r=.77 for the bench press and leg press respectively. Strong correlations, including the ones from the previous study, have been found when using RPE scales that are more applicable to children [122]. Upgrading the RPE scales for greater comprehension in children may result in better estimates of exertion. However, as perceived exertion is highly dependent on experience, the ability of a young inexperienced child to rate their exertion may still be compromised [118]. With respect to recovery, it is likely that a child may recover quicker as a result of not exerting themselves maximally. Due to the equivocal data regarding RPE and children, and the lack of research regarding RPE and recovery intervals, future studies are needed to confirm these notions.

2.4.3 CHILDREN VS. ADULTS

The literature examining RI in adults and children has been limited mainly to studies conducted on cycle ergometers [20, 22, 113], isometric [19, 114], and isokinetic devices [21, 42, 87]. Only one study to date has used actual RT to compare RI in adults and children [17].

Hebestreit et al. [20] examined the effects of RI on mean power in boys and men after performing 2 consecutive 30 second all out cycling tasks (Wingate). All subjects completed 3 trials of 2 Wingate tests, separated by randomly assigned rest periods (1, 2, or 10 minutes). Results revealed a greater recovery of mean power for boys (89.8±3.6%, 96.4±2.3%, & 103.5±1.3%) when compared to men (71.2±2.6%, 77.1±2.4%, & 94.0±1.3%) at 1, 2, and 10 minute rest intervals respectively. A study by Ratel et al. [113] supported the results of the previous study. They had 3 groups (children, teens, and adults) perform 10 consecutive 10 second bike sprints, separated by either a 30 second, 1, or 5 minute RI. Investigating peak power and lactate concentration, the results revealed a significantly faster recovery of baseline peak power and lactate concentrations in the children, when compared to both teens and adults. It was reported that children only needed 30 second rest intervals, versus the 5 minutes needed for both teens and adults.

Kotzamanidou et al. [21] investigated peak torque recovery following an isokinetic fatiguing task in boys (10.5 ± 0.6 years) and men (24.3 ± 2.5 years). Three minutes after a fatiguing task of 25 leg extensions at a rate of 60°/s, subjects were required to perform 3 isokinetic MVC's, each separated by 3 minutes. The drop in peak torque was found to be more significant in the men when compared to the boys over all 3 MVC's. Boys had showed significant recovery by the first MVC, whereas men did not fully recover even by the 3rd MVC. In accordance, Zafeiridis et al. [87] went a little further by investigating different RI with different exercise protocols, in boys, teens, and men. The exercise protocols consisted of either 4 sets of 30 second intermittent work with a 1 minute RI between sets, or 2 sets of 60 second intermittent work with a 2 minute RI between sets. Similar to Kotzamanidou et al. [21], results indicate that men had greater peak torque, but were unable to maintain it over the course of each set. Boys showed significantly greater recovery of peak torque after the both protocols, when compared to men and teens.

In contrast to the methods of all previous studies, Faigenbaum et al. [17] examined the effects of RI on repetitions, average velocity (AV), and average power (AP) with a bench press RT protocol in boys, teens and men. Despite being the only study to examine RI under RT conditions, the findings are still in agreement with all others in that children recover quicker than both teens and men. In particular boys showed full recovery with one minute RI's, whereas teens and men showed full recovery at two and three minute RI's respectively.

Despite the difference in methodologies (cycle ergometers, isokinetic devices, or RT) for examining the effects of RI, all studies report a greater recovery in children and a possible need to lower their RI to maintain exercise intensity. Of particular note, only a few of the studies examining RI also investigated mechanisms involved in the quicker recovery of children [21, 87, 113, 114]. Both Armatas et al. [114] and Kotzamanidou et al. [21] suggest neural mechanisms for quicker recovery. Kotzamanidou et al. [21] reported quicker recovery of agonist activity, while Armatas et al. [114] suggested an increased recovery due to lack of agonist inhibition in children. Zafeiridis et al. [87] and Ratel et al. [113] both examined lactate production and utilization during their experiments. Due to the lower concentrations of lactate produced, as well as quicker utilization, both studies proposed these findings as mechanisms relating to the quicker recovery observed.

With respect to RT and RI for children, there is much room for improvement. Although the research to date suggests that the length of RI is age-specific, how it can be applied to specific training programs is unknown. There have been significant contributions to understanding the mechanisms stemming from metabolite accumulation and energy pathway utilization. However, neural mechanisms involved in the quicker recovery of children need to be explored further. An inability to give a maximal effort has also been reported to explain the quicker recovery seen in children [116]. Although it may not be the case in experienced children [120], future studies could also utilize RPE scales to help ensure maximal efforts in RI experiments.

2.5 SUMMARY

The widespread acceptance of RT in younger populations continues to gain support in the literature. However, the majority of information available has only contributed to an increase in knowledge about the safety, and benefits of RT in children. There have also been guidelines established for appropriate intensity ranges, and training volumes, but the literature has yet to include appropriate standards for RI. As children have been shown to recover quicker than adults, the same standards known for adults will not suffice for this population. Conclusions about appropriate RI for adult populations have been based not only on applied performance measures, but also on physiological factors, including muscular fatigue. Much of the research on mechanisms contributing to muscular fatigue and its role in recovery has helped contribute to the standards known for adults. As such, it is no wonder why appropriate recommendations have yet to be made for children; there are still missing links in the literature. Contributing factors to fatigue, including both central and peripheral mechanisms, have yet to be investigated with recovery intervals. Muscle potentiation is also another area that has yet to receive much attention. As it has been shown to contribute to performance and possibly counteract the effects of fatigue in adult studies, it is necessary to examine its role in children. Finally, while there have been different methods used to induce fatigue and study recovery, there have been no studies comparing various RT repetition loads on fatigue and recovery in children.

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3 CO-AUTHORSHIP STATEMENT

The following statements are a detailed list of my role in the development, execution and preparation of this thesis

- **Research Design**
  The methodology was developed through a collaboration of discussions based on my own ideas and from previous work conducted by Dr. Behm. Through the guidance of Dr. Behm I was able to obtain approval of my research proposal.

- **Data Collection**
  All data was collected entirely by me.

- **Data Analysis**
  With the guidance of Dr. Behm I performed all data analysis procedures.

- **Manuscript Preparation**
  With the guidance of Dr. Behm, I prepared the manuscript.

4 CHILDREN ARE LESS SUSCEPTIBLE TO NEUROMUSCULAR FATIGUE FOLLOWING HIGH AND LOW REPETITION RESISTANCE TRAINING

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4.1 ABSTRACT

The objective of this study was to determine the effect of high and low repetition resistance training on neuromuscular fatigue and recovery in children as well as compare these effects to adults. Twenty male participants (10 children and 10 adults) completed two resistance training (RT) protocols consisting of three sets of high and low repetitions (HRM and LRM respectively). Recovery intervals (RI's) of one minute were fixed between each set in both protocols. Experimental measures were conducted before, after, and within each protocol. Dependant variables for pre and post-test included voluntary and evoked contractile properties, whereas the dependant variables within the protocols included voluntary measures, heart rate (HR), and rating of perceived exertion (RPE). Results for within measures reveled that Children a) performed more ($P \leq 0.001$) repetitions in subsequent sets, b) had a faster ($P \leq 0.001$) HR recovery following both protocols, and c) reported lower ($P \leq 0.001$) RPE scores when compared to adults. Post-test measures also revealed a decrease ($P \leq 0.001$) in MVC's force in children, but the decrease was less ($P \leq 0.001$) than that of the adults. There were no significant changes to evoked contractile properties that would indicate neuromuscular mechanisms to the fatigue observed in children. However, the greater ($P \leq 0.001$) antagonist activation observed in children post-test would suggest problems in muscle coordination as the primary mechanism for the decrease in MVC force. In addition, the lower RPE scores and similar agonist activity during submaximal and maximal contractions may also indicate an inability for children to perceive and/or produce a maximal effort. Despite these notions, children were less susceptible to neuromuscular fatigue and showed better recovery during 1 minute RI than adults following HRM and LRM RT.

4.2 INTRODUCTION

Concerns regarding the safety of resistance training (RT) in children has been addressed in the literature and there is a general acceptance that as long as guidelines are followed, RT can be implemented safely [1-4]. In fact, RT in children has been shown to be beneficial at increasing bone density [1, 2], motor coordination [3, 5], and self-esteem [6], while also decreasing the risk of musculoskeletal injuries [7, 8]. Although the guidelines for children address specific areas including duration, intensity, and frequency of exercise, the amount of recovery a child should receive is not well established. In contrast to the dearth of information regarding recovery intervals (RI) in children, the research on RI in adults is extensive [9-12]. Coinciding with the research conducted on RI and adults is the extensive work examining fatigue with respect to RT [13-19]. Although manipulating RI can enhance different performance goals, it is first important to understand all the parameters involved in adopting appropriate RI, including fatigue [20].

Exercise-induced fatigue has been indicated as a cause to performance decrements [21]. More specifically, it has been shown that exercise induced fatigue stems from two possible sites of origin; from within the muscle (peripherally) or from the central nervous system (centrally) [22-25]. Both origins have been addressed in the adult literature to account for the various activities, environments and even different types of contractions that elicit fatigue responses. This pertinent information on specific mechanisms with respect to exercise induced fatigue has continually allowed for the adoption of various training parameters, including RI in adults. Children have been shown to recover quicker than adults and therefore the same principles will not apply [13-19, 26, 27]. Some of the factors attributing to the quicker recovery in children are; lower reliance on glycolysis [28, 29], quicker phosphocreatine resynthesis [30], faster acid base regulation [31, 32], and increased fatigue resistance due to a lower power output [26, 33]. Despite the information on mechanisms related to the quicker recovery, there is still little known about neuromuscular mechanisms with respect to exercise induced fatigue. Few studies have attempted to address the relationship between recovery intervals and neuromuscular mechanisms with children. Secondly, all the studies have used either isometric [34, 35] or isokinetic [29, 36, 37] contractions and none have utilized isotonic contractions which are most predominant in activities of daily living (ADLs). The only study to use isotonic contractions did report quicker recovery of children when compared to adolescents and adults following RI as low as 1 minute, but did not address any associated mechanisms [38].

Based on the few previous studies comparing adults to children, it is still unknown whether or not children respond differently to high (endurance) and low (strength) repetitions following similar RI and whether or not the response in children will be different from adults under both conditions. Although children have been shown to recover quicker than adults in various activities, no studies have used isotonic RT to examine this phenomenon while utilizing different repetition protocols. Also, neuromuscular mechanism relating to exercise induced fatigue and the faster recovery are limited. Therefore, the objective of this study was to examine the extent of neuromuscular fatigue in children under high and low isotonic contractions of the quadriceps and to compare the responses to adults. It was hypothesized that despite the difference in repetitions, children would a) respond similarly for both conditions, b) show less neuromuscular fatigue than adults under both conditions and thus c) recover faster.

4.3 MATERIALS AND METHODS

4.3.1 Subjects

Ten prepubescent males (age, 8 - 11 years ; height, 104.2 ± 2.8 cm; weight, 36.6 ± 3.2 kg) and ten adult males (age, 23—32 years ; height, 179.3 ± 3.6 cm; weight, 82.7 ± 6.5 kg) participated in this study. Prepubescent and adult subjects were recruited from youth athletic associations (Hockey, Soccer, & Kickboxing) and the university population (Memorial University of Newfoundland, St. Johns, N.L.) respectively. Youth subjects were classified as competitive athletes as per their competition based sports. Adult subjects had a history of participating in competitive sports, however, all were currently recreational athletes. Thorough explanation of the procedures, risks, and benefits of the study, were given and written informed consent was obtained from the men, the boys' parents, and the boys. Physical activity readiness questionnaires (PAR-Q) were also signed prior to participation. Children were given a modified PAR-Q form [39].Maturation status for prepubescent boys was determined by a self-assessment questionnaire in which subjects assess their genital and pubic hair development according to the criteria of Tanner [40, 41]. All subjects rated themselves at Tanner level 1, representative of prepubescence. This study was granted ethical approval by Memorial University's (St. Johns, N.L.) Human Investigations Committee.

4.3.2 Testing Protocol

Prior to testing all subjects were given 2 orientation sessions held on non-consecutive days to allow for familiarization of the equipment being used in the experiment and to determine repetition maximums (RM) for different exercise protocols. The exercise protocols included;

- *High Rep Maximum* (HRM) – 17 repetitions
- *Low Rep Maximum* (LRM) - 7 repetitions

Specific numbers for RM's were determined during pilot testing. In determining appropriate repetition protocols, two different repetition ranges of 5-10, and 15-20 were followed during pilot testing. Results showed that average repetitions amongst subjects for the high and low protocols were 17 and 7 respectively.

RM's were determined using a Cybex isotonic leg extension machine and followed the procedure for RM testing outlined by Baechle and Earle [9] and the methods of Faigenbaum et al. [42]. Techniques were monitored and adjustments were made to equipment in order to account for differences in size. Anthropometric measures including height and weight were also recorded during the orientation session.

Following the orientation sessions, the order of testing sessions was randomized for each subject. Subjects completed 2 testing sessions of about 1 hour in duration for each. Included in each session were an exercise protocol (HRM or LRM) and a recovery period (1min). Subjects were given instruction to refrain from any high intensity exercise 48 hours prior to each session, and were asked to restrict any food intake up to 3 hours before testing.

At the beginning of each trial, a maximum evoked twitch was elicited in order to determine the standard stimulator setting to use for the evoked contractile properties during the experiment. As a standard warm up, subjects were asked to perform 2-3 maximal voluntary contractions (MVC) followed by 5 minutes of pedaling on a Monark cycle ergometer. Adults were instructed to pedal at 1 kp and 70 rpm (70 watts), whereas children were required to select a comfortable resistance and cadence, but not to exceed the adult standard [34]. Following the warm up, participants were given a five minute recovery in order to allow for heart rate (HR) to return to baseline. Pre-test and post-test included a nonpotentiated twitch (NPT), a MVC, and a potentiated twitch (PT). Subjects rested another 5 minutes before the exercise intervention began. Depending on the session, subjects either performed 3 sets of a 17RM or a 7RM, with 1min rest interval (RI) between sets. Following the third set, subjects were positioned on the isometric leg extension chair in order to perform post-test measures. Throughout the experiment, HR was monitored using Polar heart rate monitor, and repetitions were recorded during each exercise set. There were approximately 48 hours between each test session, and each subject was tested at similar times of the day for each subsequent session to ensure differences in diurnal rhythms did not affect the results [43]. For further details of experimental design see figure 1.

4.3.3 Testing Apparatus

The study was conducted with subjects seated in a straight back isometric leg extension chair and on a Cybex leg extension machine that allowed for both their hips and knees to be flexed at 90°(fully extended leg was set as 0°). As there is no difference reported in knee joint angle at which peak knee extension moment occurs between children and adults, both groups were positioned in the same manner to allow for identical knee joint angles (O'Brien 2009). In order to measure quadriceps force production in the isometric chair, a reinforced strap was placed around the ankle, attached by a high-tension wire to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., Don Mills, Ont.), perpendicular to the lower limb. The subject's body was secured in the chair via straps around chest and dominant leg. Dominance was determined from kicking and one legged jump preference. Testing that was conducted on the Cybex machine allowed for adjusting of the padded leg extension arm and seat to fit each subject.

4.3.4 Electromyography

Upon arrival to the lab, subjects' dominant limb was prepared for testing. Measurements of the limb were taken to determine electromyography (EMG) pad placement. The agonist and antagonist muscles (rectus femoris and biceps femoris) were monitored for EMG activity. Electrode placement for the agonist muscle was determined from the midpoint between the anterior superior iliac spine to the apex of the patella. Antagonist electrode placement was determined on the posterior thigh at the midpoint between the ischial tuberosity and the posterior aspect of the lateral epicondyle of the femur. Skin preparations for all electrodes included shaving the area of interest (using a sterile razor), followed by removal of dead epithelial cells with a piece of sandpaper, and cleansing with isopropyl rubbing alcohol (70%). A ground electrode and placed on the proximal head of the fibula. EMG activity was measured during evoked and voluntary contractions (isometric and dynamic). The EMG signal was sampled at 2000 Hz, with a Blackman — 61 dB band-pass filter between 10 to 500 Hz, amplified (bipolar differential amplifier; input impedance = 2 MO; common mode rejection ratio > 110 dB min (50/60 Hz); gain 1000; noise > 5 mV), and analog-to-digitally converted (Biopac MP150) and stored on a personal computer for further analysis. Further analysis of EMG included rectifying and integrating during a 500ms interval during the maximal point of each MVC. The mean amplitude of the signal was determined and all results were normalized to pre-test values. Similar analysis was conducted for the first two (early) and last two (late) dynamic repetitions during each intervention.

During pre-test and post-test measures, muscle action potential wave (Mwave) amplitudes were analyzed from the evoked twitches, and maximum values were recorded. For comparison purposes of children and adults, all post-test values were normalized as a percentage of pre-test results.

4.3.5 Evoked Contractile Properties

Measurements for evoked twitch electrode placement were established over the over the inguinal triangle region and just superior to the apex of the patella. This placement was used to ensure femoral nerve stimulation [44]. The stimulating electrodes were constructed in the laboratory from aluminum foil (approximately 10-12cm by 3-4cm) and were coated with a conducting gel (EcoGel 200; multipurpose ultrasound gel). Electrodes were then wrapped in paper towel and soaked in an aqueous solution. Electrode position was maintained from test to test by outlining the electrode position with ink. The amperage (maximum 1 A) and voltage (maximum 400V) of the stimulation

(Digitimer Stimulator, Model DS7H+, Welwyn Garden City, Hertfordshire, UK) were both progressively increased until reaching a maximum twitch force plateau. Pulse duration was maintained at 50 ms. Force about the knee joint was measured by the strain gauge, amplified (DA 100 and analog to digital converter MP150 WSW, Biopac Systems Inc., Holliston, Mass.), and monitored on a computer (Compaq, St. Johns, Nfld.). All data were collected at 2000 Hz and then stored on a computer. Potentiated twitches were conducted 5 seconds following each MVC. For each twitch, half relaxation time (1/2RT) was calculated as the time period for the peak twitch force to decrease to 50% of the peak twitch force. The time to peak twitch (TPT) was measured as the time period of the peak-to-peak value from baseline to the peak twitch force. Electromechanical delay (EMD) was measured using the methods of Grosset et al. [45]. Similar to previous measures, all evoked contractile properties recorded post-test were normalized as a percentage of their corresponding pretest values in order for comparison purposes between children and adults.

4.3.6 Maximal Voluntary and Dynamic Contractions

During the warm-up, subjects performed 2-3 submaximal (subjects were encouraged to contract at around 50% of a MVC) to help prepare them for subsequent MVC's. Following the submaximal contractions, 2 minutes of rest was given and subjects were then instructed to complete a MVC. Another MVC was performed following a RI of 2 minutes. Verbal instructions to maximally contract the quadriceps as hard and fast as possible were given to each subject prior to each MVC. The subject's hands were placed on railings beside their thighs, and the ankle was placed in a padded strap and the cable was maintained in a taut position to help prevent movement of the knee joint during the data collection. Verbal motivation was given by the investigator during the contraction to promote a maximal response. Each contraction lasted for 5s followed by relaxation. Peak force was measured as the greatest difference between baseline or resting position and the greatest force amplitude. If there was a >5% difference between the first 2 MVC trials, the subject was asked to perform a third trial, separated by 2 min, and the highest MVC force was recorded. This procedure was performed to ensure that subjects were able to provide a maximum contraction. The warm-up was concluded with 2 minutes of rest and instruction on the upcoming procedures. During the pre-test and post-test measures, MVC's were conducted in the same manner as describe for the warm-up, but only one MVC was preformed.

All voluntary and evoked forces were collected by a strain gauge (Massload strain gauge; ML200 Shearbeam Loadcell, 301 – 47th street east, Saskatoon, SK, Canada), amplified and recorded in Acknowledge 4.1 Software. Dynamic contractions were performed during the exercise protocols. Subjects were monitored and verbally encouraged during exercise sets. The total numbers of repetitions were determined using a potentiometer to measure knee joint angles. Failure to meet the cutoff criteria of 75° or greater would eliminate the repetition from being counted.

4.3.7 Rate of Perceived Exertion & Heart Rate

Heart rate (HR) was monitored using a Polar™ HR monitor, and recorded throughout testing. Specifically, heart rate was recorded before and after warm-up, after each exercise set, and at the end of each corresponding recovery phase. Rate of perceived exertion (RPE) was determined immediately after the warm-up, and after each exercise set using the Children's Effort Rating Table [46]. The sensations responding to each value of the scale were explained to each subject before the test. In order to standardize results for comparison to adults, the adults were given the Borg CR10 exertion scale which uses a similar ten point scale [47]. In order to determine the efficiency of HR recovery, the analysis of HR includes the difference between post recovery HR and resting HR. Reference to this analysis is referred to as delta HR (ΔHR).

4.3.8 Statistical Analysis

A three-way ANOVA with repeated measures was performed on all dependent variables (SPSS 18.0 for Macintosh, IBM Corporation, Armonk, New York, USA). The three factors included time (pre- and post-test), group (children and adults), and intervention (high and low repetition protocols). A 3-way ANOVA with repeated measures was also performed on all dependent variables recorded during testing interventions. The three factors included time (sets 1, 2, and 3), group (children and adults), and intervention (high and low repetition protocols). F ratios were considered significant at $p<0.05$. A Bonferroni correction was applied for multiple planned contrasts to test for significant differences between interactions. Descriptive statistics include means +/- standard deviation (SD) for both the text and figures.

4.4 RESULTS

All experimental data and p values are reported in tables 1-4.

Voluntary Measures

Within set repetitions. A main effect for group was revealed with children performing 27.8% more repetitions than adults (P<0.001). There were also main effects (P<0.001) for sets with sets 2 and 3 having 18.3% and 33.3% less repetitions than set 1 respectively.

Significant interactions (P<0.001) revealed that during the low repetition sets, children performed 21.4% and 31.4% more repetitions than adults in sets 2 and 3 respectively (Figure 2). Similar interactions were found during the high repetition sets with children performing 21.6% and 35.9% more repetitions than adults in sets 2 and 3 respectively (Figure 3). In the high repetition sets adults were reported to have significant decrease in repetitions by 36.2% and 46.5% for sets 2 and 3 when compared to set 1 respectively (P<0.001). The same was found for adults during the low repetition sets which included significant decrease in repetitions by 37.2% and 41.1% for sets 2 and 3 when compared to set 1 respectively (P<0.001). Repetitions in sets 3 were also found to be 17.4% and 16.1% significantly lower when compared to set 2 for adults during low repetition and high repetition sets respectively (P<0.01). Children were reported to have a significant decrease of 13.7% in set 3 when compared to set 1 for the high repetition exercise only (P<0.01).

Maximal voluntary contraction. A main effect for group was found with children performing a greater percentage of their MVC, 97.4% versus 88.1%, over adults respectively (P≤0.001). A main effect was also found for time with post test MVCs being 13.6% less than the pretest MVCs (P≤0.001).

There was a significant interaction between group and time ($P\leq0.001$). Post-test measures showed a greater decrease in percentage of MVC following the sets for adults (23.7%) when compared to children (5.7%) (Figure 4).

Electromyography (EMG) during the exercise protocol A main effect for group was found with children showing 47.8% greater quadriceps activity than adults ($P\leq0.001$). A main effect was also found for exercise type with the low repetition exercise resulting in 8.9% greater quadriceps activity than the high repetition exercise ($P\leq0.001$). In general, quadriceps activity at the end of each set was on average 19.2% greater than activity at the beginning of the same set ($P\leq0.001$) . A main effect was found for sets with set 3 resulting in 6.8 ($P\leq0.001$) and 14.2% ($P\leq0.001$) greater quadriceps activity than sets 2 and 1 respectively. Muscle activity in set 2 was also 7.4% greater than in set 1 ($P\leq0.001$).

Significant interactions were found between group and EMG within set ($P\leq0.001$), as well as for group, exercise type and EMG within set ($P\leq0.005$). Muscle activity for children was on average 52.4 and 33.1% greater than adults at the beginning and end of the exercise sets respectively (Figure 4). More specifically, children were found to have 45.7% and 52.1% greater muscle activity than adults during the beginning and end of the low repetition sets, as well as 56.6% and 35.2% greater activity than adults at the beginning and end of the high repetition sets respectively (Figure 6). Adults also showed a significant increase of 37.5 % in muscle activity at the end of each exercise set when compared to the beginning ($P\leq0.001$).

Pre- & post-exercise MVC electromyography (EMG). A main effect for group was found with children showing 9% and 11.2% increases in quadriceps ($P\leq0.001$) and hamstrings ($P\leq0.001$) muscle activity compared to adults. A main effect for exercise type also revealed that low repetition exercise sets resulted in 3, and 6.6% greater muscle activity than the high repetition sets for the quadriceps ($P\leq0.05$) and hamstrings ($P\leq0.005$) respectively . A third main effect was determined for time with post test measures showing a decrease of 4.8%, and increase of 15.6% in quadriceps ($P\leq0.005$) and hamstring ($P\leq0.001$) muscle activity respectively.

Significant interactions were found for group and time [quadriceps ($P\leq0.001$) & hamstrings ($P\leq0.001$)], as well as exercise type and time [quadriceps ($P\leq0.001$) & hamstrings ($P\leq0.001$)]. During the 1 minute post-test measures, children showed a 17.9, and 22.2% greater activity in the quadriceps and hamstrings, when compared to adults respectively (Figure 7). Compared to pre-test measures, adults showed a significant ($P\leq0.001$)decrease of 15.2% in post-test quadriceps activation, whereas the children showed a significant ($P\leq0.001$) increase of 20.6% in post-test hamstring activation. The low repetition exercise sets also resulted in greater activity of the quadriceps (5.9%) and hamstrings (13%) than the high repetition sets (Figure 8).

Evoked Contractile Properties

There were no significant findings for time to peak twitch and electromechanical delay.

Peak twitch force A main effect for group was found with children showing a twitch force, relative to pre-test, of 4.7% greater than adults ($P\leq0.05$). The low repetition exercise also revealed a main effect for an increased twitch force of 5.9% when compared to the high repetition exercise ($P \leq 0.01$).

There were significant interactions found between group and time ($P \leq 0.05$), and between exercise type and time ($P \leq 0.01$). During post-tests, twitch force for children was 10.7% greater than the twitch force for adults. Post-test twitch results for children were found to be 4.5% ($P \leq 0.05$) greater than pre-test results, whereas adults were 6.2% ($P \leq 0.05$) lower (Figure 9). The low repetition exercise also revealed an increased twitch force of 11.8% when compared to the high repetition exercise at 1 minute post test (Figure 10).

Half relaxation time (1/2 RT). A main effect for group was revealed with children having a ½ RT that was 7.2% faster than adults ($P \leq 0.05$). A main effect was also found for time with post-test ½ RT being 16.8% slower than pre test measures ($P \leq 0.001$).

Significant interactions were found for group and time ($P \leq 0.001$). Post-test measures showed a greater increase in ½ RT for adults (24.1%) when compared to children (3.1%). Post-test ½ RT for adults were also found to be significantly greater than their pre-test measures (Figure 11).

Muscle Action Potential Wave (M-Wave) Amplitude. A main effect was found for exercise type with the low repetition exercise sets resulting in a M-Wave amplitude 1.6% greater than the high repetition sets($P \leq 0.005$).

Significant interactions included group and time ($P \leq 0.01$), and exercise type and time ($P \leq 0.05$). Post test M-wave amplitudes for children were 5.8% greater than adults

(Figure 12). Post-test M-waves for the low repetition sets were 2.4% greater than post test M-waves following the high repetition sets (Figure 13). Compared to pre-test values, post-test M-wave amplitudes were 2.6% ($P \leq 0.05$) greater for children, but were 3.5% ($P \leq 0.05$) less for adults.

Rating of Perceived Exertion (RPE)

RPE A main effect for group was found with children having a 15.5% lower RPE than adults ($P \leq 0.005$). A main effect was found for sets with set 3 resulting in a 3.5 ($P \leq 0.001$) and 12.5% ($P \leq 0.001$) greater RPE than sets 2 and 1 respectively. RPE in set 2 was also 9% greater than in set 1 ($P \leq 0.001$). A main effect was also found for exercise type with low repetition exercise resulting in a 2% greater RPE than the high repetition exercise ($P \leq 0.001$).

Significant interactions were found for both group and sets ($P \leq 0.001$), and for sets and exercise type ($P \leq 0.001$). Children were found to have a 17.5, 17.5, and 11.5% lower RPE than adults in sets 1, 2, and 3 respectively (Figure 14). RPE scores for children were 16.5 and 7% greater in set 3 when compared to sets 1($P \leq 0.001$) and 2($P \leq 0.001$) respectively. Also, scores in set 2 were 9% ($P \leq 0.001$) greater than set 1. RPE scores for adults were 10.5 and 7% greater in set 3 when compared to sets 1($P \leq 0.001$) and 2($P \leq 0.001$) respectively. Scores in set 2 were also 7% greater than set 1($P \leq 0.001$).

Low repetition exercise resulted in 0.5, 0.5, and 4.5% greater RPE scores than the high repetition exercise in sets 1, 2, and 3 respectively (Figure 15). RPE scores for the low repetition protocol were 6.5 and 13% greater in set 3 when compared to sets 2($P \leq 0.001$) and 1($P \leq 0.001$) respectively. Also, RPE scores in set 2 were 7% greater than set 1($P \leq 0.001$). Similarly, the scores for set 3 of the high repetition protocol were 3.5 and 12% greater in set 3 when compared to sets 2($P \leq 0.001$) and 1($P \leq 0.001$) respectively and scores in set 2 were 8% greater than set 1($P \leq 0.001$).

Heart Rate (HR)

Delta HR (recovery – resting) A main effect for group was found with children having a smaller difference (9.1 beats/min) in recovery and resting HR than adults (38.8 beats/min) ($P \leq 0.001$). A main effect for sets revealed a 3.9 and 4.1 beats/min smaller difference in recovery and resting HR for set 1 when compared to sets 2, and 3 respectively ($P \leq 0.001$).

Significant interactions were found for group and exercise type ($P \leq 0.001$), group and sets ($P \leq 0.001$). The low repetition and high repetition exercises resulted in a 30.5 and 28.9 beats/min lower HR difference for children when compared to adults respectively (Figure 16). Children also had a 28.5, 30.4 and 30.3 beats/min smaller difference when compared to adults for sets 1, 2, and 3 respectively (Figure 17).

4.5 DISCUSSION

The most significant findings of this study were that children exhibited less fatigue with 3 sets of isotonic resistance training and recovered more rapidly than adults. Furthermore, rather than exhibiting the typical adult response of a reduction in EMG activity with fatigue, children responded with greater muscle activity with the completion of the 3 sets of leg extensions. This lack of neural activation meditated fatigue was accompanied by a lack of peripheral fatigue as evidenced by no significant changes in children's evoked contractile properties. Hence, the fatigue associated with the children was related more to increased antagonist activity than with adults.

In accordance with Falk (2006), children in this study may not have fatigued to a significant extent due to an inability to provide a maximal exertion [26]. The supposition that the children were unable to produce a maximal contraction was based on the significantly lower fatigue when compared to adults, and the lack of change in twitch contractile properties post-fatigue as found in this study. In adults, muscle (EMG) activity declines with fatiguing maximal or near maximal intensity contractions [25, 34]. The possibility that maximal or near maximal activation was not achieved with the children is in accordance with much of the pediatric literature which supports the notion that full activation may be compromised with younger populations [26, 28, 48].

However, it should be noted that some researchers have reported complete activation in children. Belanger and McComas (1989) found that 8 of the 10 children tested were able to fully activate their plantar flexors [49]. One possible argument for this discrepancy might be due to the fact that they used the plantar flexors in their study, and muscle activation has been shown to be different amongst different muscle groups [50]. In adults, the quadriceps have been shown to be more difficult to fully activate than the plantar flexors [13]. Also, the majority of the children in the Belanger and McComas study were older (12 and 13 years old) than the 8 to 11 year old children in the present study.

Further evidence to support the proposition that children were unable to fully activate was illustrated by the similar EMG activity throughout the resistance exercise interventions as compared to the EMG activity of the maximal intent pre-test MVC's.

Agonist activity remained relatively high for children following the exercise protocols, whereas it decreased significantly for adults. During repetitive submaximal contractions, EMG activity typically increases with fatigue [25, 35, 51]. The increased EMG with continued submaximal contractions, reported in both adults [22] and children [35] has been attributed to increases in motor unit recruitment, rate coding and synchronization [22]. To our knowledge, there have only been a few studies examining EMG activity during fatigue with submaximal exercise in children and adults [35, 37, 51, 52]. The results of the present study are consistent with the literature, with increases in agonist activity for both children and adults during prolonged submaximal contractions. However, the present study displayed similar activity EMG levels for both the low repetition (strength) and high repetition (endurance) protocols for the children. Again this provides evidence that the children had difficulty perceiving the difference between maximal and submaximal contractions.

Other authors have also documented the inability of children to fatigue to the same extent as adults [34, 35, 53]. Another factor to consider, not measured in this study, is muscle fiber types. It is well documented that children have a greater proportional area of type I muscle fibers in comparison to their adult counterparts [26, 27, 54]. Greater proportional area of type II fibres in adults contributes not only to greater force production, but also greater anaerobic capacities leading to greater increases in metabolites [31], resulting in greater fatigue originating at the muscle and/or spinal cord (chemoreceptor reflex inhibition) level [55].

The evoked twitch contractile properties and M-wave results also confirm the lower fatigue results observed in children, and provide possible mechanisms related to the greater fatigue sustained by the adult men. Because both the twitch torque and M-wave during post-test measures were potentiated in children, there is reason to believe they did not succumb to the impairments related to increased glycolytic metabolism [28]. The depressed twitch force in adults indicate possible impairments with excitation contraction coupling process [15]. A depressed M-wave could suggest failures in the muscle membrane potential [56]. However, there was no significant difference with TPT, but a significant increase in post-test 1/2RT. Hence, the fatigue observed in the adults was more likely a result of impairments in Ca^{2+} sequestering [15]. As no significant differences were found with pre- and post-exercise evoked contractile properties in children, there were likely no substantial peripheral mechanisms contributing to fatigue. To our knowledge, there are no studies examining isotonic fatigue in children using evoked contractile properties. The notion that children rely less on glycolytic metabolism as a result of their fiber predominance [3, 28], suggests that it is plausible that peripheral mechanisms did not affect the fatigue processes in the children to an appreciable amount.

With respect to the potentiation observed in the children, it should be noted that both potentiation and fatigue can occur simultaneously [57, 58], and thus it has been suggested that the results be interpreted carefully [57]. To our knowledge there is only one study that addresses potentiation and fatigue in children [36]. In accordance with our findings, Chaouachi et al. 2011 reported full recovery and potentiation effects within 2 minutes post-exercise. Greater potentiation is known to occur in muscles with predominantly type II fibres [58], submaximal contractions [59], and in trained individuals [58]. From the previous discussion on fiber types, and the fact that the children in our study were trained athletes, there is reason to believe that the latter two contributed to the potentiation observed. It was also suggested that potentiation may be dependent on the duration of the exercise and velocity of contraction [36]. In the present study the decreased potentiation following the high repetition protocol and greater potentiation following the strength sets may have been attributed to increased metabolites with the prolonged duration of the high repetition sets.

In addition, fatigue has also been defined as an increase in the perceived effort needed to exert a desired force [23]. With respect to evaluating perceived effort, RPE scores indicated that children had a lower perceived effort than adults [27, 34]. This finding was supported by the lower maximal HR found in the children following the exercise sets, and may also explain why they were less fatigable than adults. Lower RPE scores may be related to the inability to produce a maximal effort [60]. Barkley & Roemmich [61] also suggested that the lower rating in children may be a result of lack of experience, and not having a previous reference point to compare perceived exertion. Although there is some discrepancy in the literature as some authors argue about a child's ability to rate their exertion [46, 60, 62], other studies utilizing child friendly scales have reported otherwise [63, 64].

As there were no significant signs of peripheral or central activation fatigue in the children, the significant decrease in number of repetitions and post-exercises MVC torque, might be explained by the significant increase in antagonist activity. Previous studies have suggested that decreased torque may be a result of the lack of coordination in agonist and antagonist activation [65, 66]. As coordination is known to play a role in executing motor tasks [67], and has been shown to be age dependent [68] it is also quite possible that the increased antagonist activity observed in children contributed to the decrease in torque output and number of repetitions. One possibility may be a result of unfamiliarity with performing the contraction (motor task). Parachos et al. [65] also suggested that the increased antagonist activity may be a result of the discomfort for children to perform maximal contractions. Other authors have not reported similar results [52, 69, 70]. Bassa et al. [52] suggested that decreased torque in children is more likely due to a decreased efficiency of activating agonist muscles. Although the aforementioned studies did not attempt to induce fatigue, the increased antagonist activity in the present study might be a result of fatigue-induced impairments to coordination [66].

Children have been shown to recover more rapidly than adults using a variety of methods including cycle ergometers [71, 72], isokinetic [29, 35], isometric [34, 73], and isotonic [38] contractions. In accordance with the literature, the children in the present study recovered more rapidly in all parameters (performance, neuromuscular, and cardiovascular) than adults following both exercise interventions.

Similar to the present findings, there is evidence of children recovering as quickly as 1 min post exercise [38], whereas adults have reported fatigue or performance decrements for at least 3 minutes of recovery [14]. Children were able to produce more repetitions than the adult men following a 1 minute RI, regardless of intervention. This is interesting considering that reports on recovery show that RI's for bouts of muscular endurance should be shorter than muscular strength [20, 74]. These reviews, however, are based on adult studies and thus may not apply to children. There are general guidelines for resistance training and recovery in children in the literature [3, 4]. Although the details regarding RI's for endurance and strength are not given, it should be noted that our results fall within the general guidelines which state that rest intervals for children can be anywhere from 1 to 3 minutes when resistance training with children [4].

Although the adults showed a significant increase in agonist EMG activity over each set, this was not the case for children. For children, there was a trend towards increasing EMG activity, but this was not statistically significant. The lack of significant increases in EMG activity in children may insinuate either a faster recovery or perhaps the load was unable to fatigue them to the same extent as the adults. Although subjects were allowed to perform until volitional fatigue, ROM was monitored during each set and a cutoff standard was used to objectively determine when a subject became fatigued. As all subjects fell within the cutoff criteria prior to volitional fatigue, there is reason to reject the second possibility. The use of EMG in the literature with respect to RI's and children is limited, but there are two studies that share our results [35, 37]. Kotzamanidou et al. [37] reported that children showed a quicker recovery of both vastus medialis and vastus lateralis muscles than adults following 25 isokinetic contractions. Although the authors reported a greater rate of fatigue in the adults, Hatzikotoulas et al. [35] reported similar recovery findings for children and also showed a similar rate of fatigue using isometric contractions to fatigue.

With respect to HR recovery, children's HR returned to baseline values following the 1 minute RI in both protocols, whereas the adults remained elevated. These findings are supported in the literature. [29, 71, 72]. It has been suggested that a greater relative capillary density may be responsible for the faster recovery in children [26, 27]. Aside from aforementioned rationales for the decreased fatigue in children (fiber types, decreased muscle activation), other studies have also attributed a quicker recovery in children to lower reliance on glycolysis [28, 29], quicker phosphocreatine resynthesis [30], faster acid base regulation [31, 32], and increased fatigue resistance due to a lower power output [26, 33].

4.6 CONCLUSION

Children did illustrate some fatigue induced impairments as attributed by a decrease in intervention repetitions as well as a decrease in post-test MVC's. Despite the increase in fatigue it was also reported that children were able to recover faster than adults and the impairments sustained by adults were more significant than those of the children. Although the fatigue incurred by the children could not be explained by increases in peripheral nor central fatigue, the increased antagonistic activity of the hamstrings suggested that the fatigue observed, is more likely to be a result of issues with muscle coordination. With respect to children and adults, potentiating effects, as well as the inability of children to provide maximal efforts may have also contributed to the diminished fatigue measures on comparison. As a result of the findings, one minute RIs in resistance training programs for children can be utilized for both low repetition and high repetition, strength and endurance exercises respectively. Future studies should investigate the effectiveness of training programs tailored towards increasing strength and endurance in children while utilizing various rest intervals.

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4.8 TABLE LEGEND

Table 4.1: Experimental data and p-values listed for post-test measures. Variables are defined as follows; Twitch (evoked twitch), 1/2RT (half relaxation time), MW (MWave), MVC (maximal voluntary contraction), EMG (electromyography – quadriceps & hamstrings), EMD (electromechanical delay), TPT (time to peak twitch).

Table 4.2: Experimental data and p-values listed for within intervention measures (Repetitions and EMGQuad). LRP and HRP represent low repetition protocol and high repetition protocol respectively. Comparisons for repetitions were conducted during each set (1, 2, and 3). Comparisons for EMGQuad (Electromyography of the quadriceps) were conducted during the first 2 repetitions of the first set (Early) and the last 2 repetitions of the third set (Late).

Table 4.3: Experimental data and p-values listed for within intervention measures (HR). LRP and HRP represent low repetition protocol and high repetition protocol respectively. HR represents heart-rate. Values are listed as the difference between post recovery heart-rate and resting HR. Comparisons for HR were conducted post exercise intervention.

Table 4.4: Experimental data and p-values listed for within intervention measures (Combined Intervention HR and RPE). Overall represents the combined total between both protocols (High & Low repetitions). HR represents heart-rate. Values are listed as the difference between post recovery heart-rate and resting HR. RPE represents rating of perceived exertion. Values listed for RPE are based on 10 point effort scale (0=no effort, 10=max effort). Comparisons for HR and RPE are conducted after each set (1, 2, and 3)

4.9 FIGURE LEGEND

Figure 4.1: Experimental Design

Figure 4.2: Represents differences in repetition performance each set during a low repetition protocol as well as differences in each set between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between children and adults, whereas asterisks (*) and (**) with horizontal bar indicate statistically significant differences of ($P<0.001$) and ($P<0.01$) between sets.

Figure 4.3 Represents differences in repetition performance each set during a high repetition protocol as well as differences in each set between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between children and adults, whereas asterisks (*) and (**) with horizontal bar indicate statistically significant differences of ($P<0.001$) and ($P<0.01$) between sets.

Figure 4.4 Represent differences in normalized MVC torque pre and post test, as well as differences in post test between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P\leq0.05$) between children and pretest, whereas double asterisks (**) indicate statistically significant differences ($P\leq0.001$) between Adults and children as well as adults and pretest.

Figure 4.5 Represent differences in normalized quadriceps EMG activity for early and late repetitions, as well as differences quadriceps EMG activity between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between children and adults, whereas asterisks (*) with horizontal bar indicate statistically significant differences of ($P<0.001$) between early and late EMG activity of adults.

Figure 4.6 Represent differences in normalized quadriceps EMG activity for early and late repetitions during high and low repetition protocols for children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.005$) between children and adults. Low and high repetitions refer to 7 and 17 repetitions respectively. Early and late refer to the first 2 and last 2 contractions performed during the intervention respectively.

Figure 4.7 Represent differences in normalized EMG activity pre and post test for quadriceps and hamstrings, as well as differences in EMG activity between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between children and adults. Asterisks (*) with horizontal bar indicate statistically significant differences of ($P<0.001$) between pre and post test hamstring activity for children and pre and post test quadriceps activity for adults.

Figure 4.8 Represent differences in normalized quadriceps and hamstrings EMG activity of high and low repetition rotocols. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between high and low repetitions. Low and high repetitions refer to 7 and 17 repetitions respectively.

Figure 4.9 Represent differences in normalized twitch torque pre and post test, as well as differences in post test between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P\leq0.05$) between children and adults, whereas single asterisks (*) and horizontal bar indicate statistically significant differences ($P\leq0.05$) between children and pre test as well as adults and pre test.

Figure 4.10 Represent differences in normalized twitch torque post test between high and low repetition protocols. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.01$) between high and low repetitions. Low and high repetitions refer to 7 and 17 repetitions respectively.

Figure 4.11 Represent differences in normalized ½ RT pre and post test, as well as differences in post test between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P\leq0.001$) between children and adults, and between adults pre and post test.

Figure 4.12 Represent differences in normalized mwave activity pre and post test, as well as differences in post test between children and adults. Columns and bars represent means and standard deviation. Double asterisks (**) indicate statistically significant differences ($P \leq 0.01$) between children and adults, whereas single asterisks (*) and horizontal bar indicate statistically significant differences ($P \leq 0.05$) between children and pre test as well as adults and pre test.

Figure 4.13 Represent differences in normalized mwave activity of high and low repetition protocols between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.05$) between children and adults. Low and high repetitions refer to 7 and 17 repetitions respectively.

Figure 4.14 Represent differences in RPE scores each set as well as differences in each set between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between children and adults at each set. Single asterisks (*) and horizontal bar indicate statistically significant ($P \leq 0.001$) differences between sets [(3 & 1), (2 & 1), (3 & 1)] for children and adults.

Figure 4.15 Represent differences in RPE scores each set as well as differences in each set between high and low repetition protocols. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences

($P<0.001$) between children and adults at each set. Single asterisks (*) and horizontal bar indicate statistically significant ($P\leq0.001$) differences between sets [(3 & 1), (2 & 1), (3 & 1)] for high and low repetitions. Low and high repetitions refer to 7 and 17 repetitions respectively.

Figure 4.16 Represent differences in delta HR of high and low repetition protocols between children and adults. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between children and adults. Low and high repetitions refer to 7 and 17 repetitions respectively.

Figure 4.17 Represent differences in delta HR between children and adults each set. Columns and bars represent means and standard deviation. Single asterisks (*) indicate statistically significant differences ($P<0.001$) between children and adults.

Table 4.1

Variables	**Post-test** *(% of pre-test)*				**Adults vs. Children**	**Children**	**Adults**
	Adults		*Children*		*P-Value*	*P-Value (Pre vs. Post)*	
	Mean	*SD*	*Mean*	*SD*			
Twitch	93.8	4.8	104.5	5.7	0.05	0.05	0.05
1/2RT	124.1	9.4	103.1	7.2	0.001	0.115	0.001
MW	96.5	0.5	102.3	0.6	0.01	0.05	0.05
MVC	76.3	4.1	94.3	6.1	0.001	0.05	0.001
EMGQuad	86.2	3.8	104.1	6.8	0.001	0.096	0.001
EMGHam	103.5	6.7	125.7	9.2	0.001	0.001	0.102
EMD	99.8	1.9	99.7	2.7	0.157	0.322	0.376
TPT	100.5	2.1	99.4	2.4	0.211	0.187	0.138

Table 4.2

LRP	**Set 1**				*P value*	**Set 2**				*P value*	**Set 3**				*P value*
	Adult		*Child*			*Adult*		*Child*			*Adult*		*Child*		
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*	
Repetitions	7	0	7	0	1	5.2	0.4	6.7	0.5	0.001	3.5	0.5	5.7	0.5	0.001
	Early										**Late**				
	Adult		*Child*								*Adult*		*Child*		
	Mean	*SD*	*Mean*	*SD*							*Mean*	*SD*	*Mean*	*SD*	
EMGQuad	60.4	6.7	106.1	9.8	0.001						80.5	6.2	124.3	9.3	0.001
HRP	**Set 1**					**Set 2**					**Set 3**				
	Adult		*Child*			*Adult*		*Child*			*Adult*		*Child*		
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*	
Repetitions	17	0	17	0	1	11	1.4	15.3	0.6	0.001	3.5	0.5	5.7	0.5	0.001
	Early										**Late**				
	Adult		*Child*								*Adult*		*Child*		
	Mean	*SD*	*Mean*	*SD*							*Mean*	*SD*	*Mean*	*SD*	
EMGQuad	45.8	8.5	102,8	9.4	0.001						73.2	4.8	108.4	9.6	0.001

Table 4.3

LRP	**Post-Exercise**				*P-value*
	Adult		*Child*		
	Mean	*SD*	*Mean*	*SD*	
HR	39.9	8.6	9.4	3.7	0.001
HRP	**Post-Exercise**				
	Adult		*Child*		
	Mean	*SD*	*Mean*	*SD*	
HR	37.7	9.2	8.8	4.9	0.001

Table 4.4

OVERALL	**Set 1**				*P value*	**Set 2**				*P value*	**Set 3**				*P value*
	Adult		*Child*			*Adult*		*Child*			*Adult*		*Child*		
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*	
HR	35.6	6.4	7.1	4.3	0.001	40.4	8.3	10	4.5	0.001	40.5	9.1	10.2	3.8	0.001
	Set 1					**Set 2**					**Set 3**				
	Adult		*Child*			*Adult*		*Child*			*Adult*		*Child*		
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*	
RPE	7.4	0.5	5.6	0.4	0.001	8.3	0.4	6.5	0.6	0.001	8.3	0.3	7.2	0.3	0.001

Figure 4.1

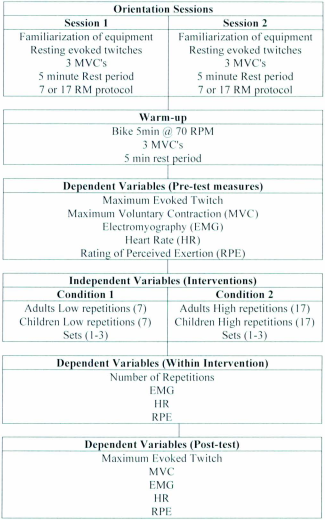
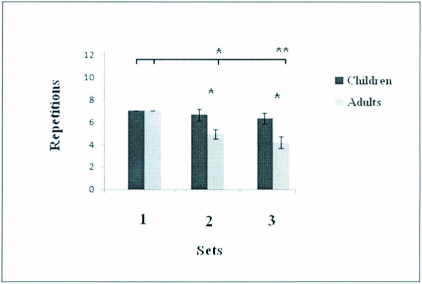

Orientation Sessions
Session 1
Familiarization of equipment
Resting evoked twitches
3 MVC's
5 minute Rest period
7 or 17 RM protocol
Session 2
Familiarization of equipment
Resting evoked twitches
3 MVC's
5 minute Rest period
7 or 17 RM protocol
Warm-up
Bike 5min @ 70 RPM
3 MVC's
5 min rest period
Dependent Variables (Pre-test measures)
Maximum Evoked Twitch
Maximum Voluntary Contraction (MVC)
Electromyography (EMG)
Heart Rate (HR)
Rating of Perceived Exertion (RPE)
Independent Variables (Interventions)
Condition 1
Adults Low repetitions (7)
Children Low repetitions (7)
Sets (1-3)
Condition 2
Adults High repetitions (17)
Children High repetitions (17)
Sets (1-3)
Dependent Variables (Within Intervention)
Number of Repetitions
EMG
HR
RPE
Dependent Variables (Post-test)
Maximum Evoked Twitch
MVC
EMG
HR
RPE

Figure 4.2



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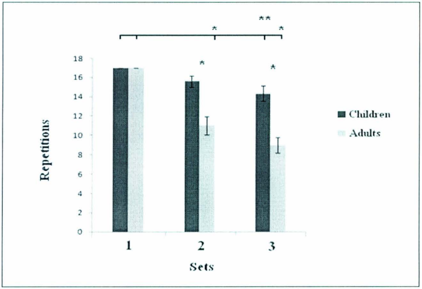

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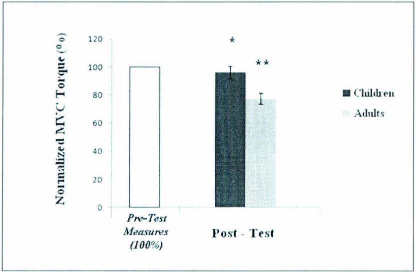

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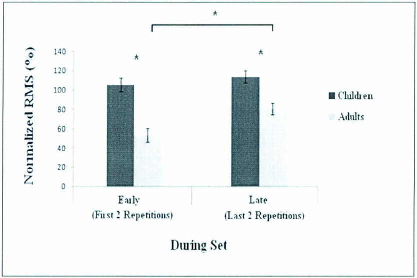

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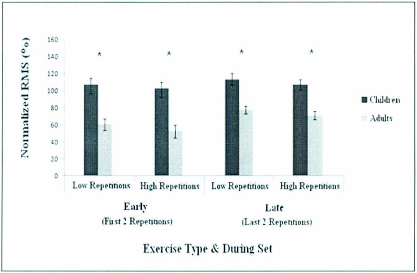

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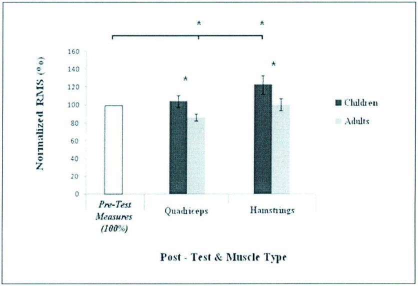

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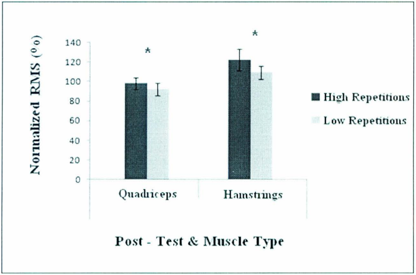

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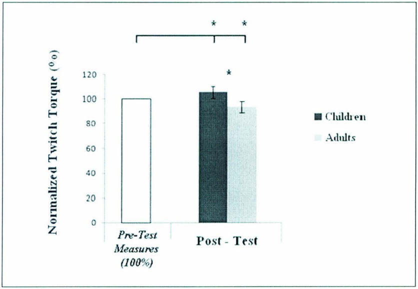

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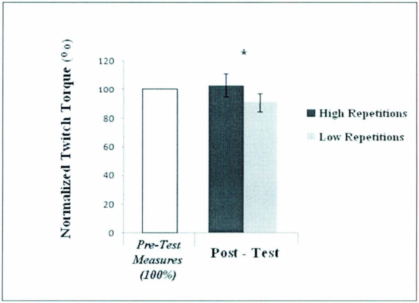

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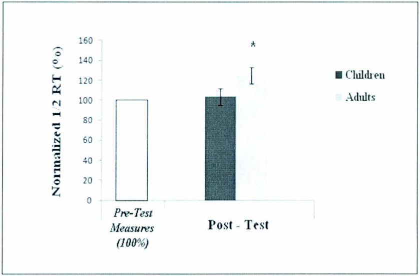

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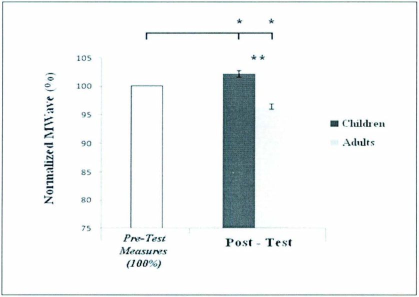

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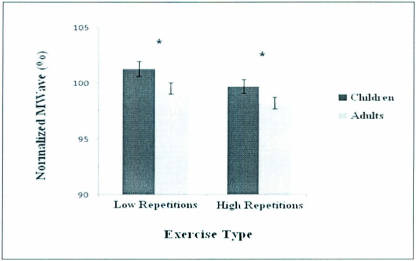

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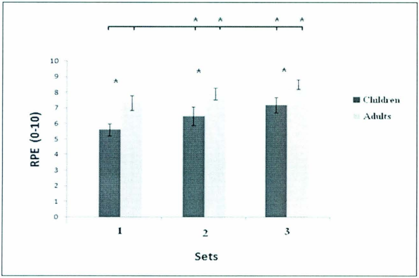

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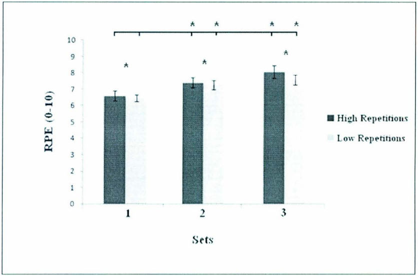

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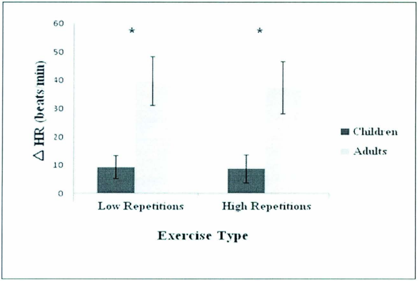

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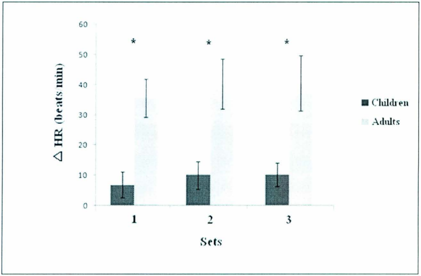

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