

QUANTIFICATION OF MUSCLE FATIGUE IN CEREBRAL PALSY AND ITS
RELATIONSHIP TO IMPAIRMENTS AND FUNCTION

A Dissertation

Submitted to the Graduate School of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Kinesiology

By

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B.S., Louisiana State University Medical Center, 1996
May 2007

ACKNOWLEDGEMENTS

“To know even one life has breathed easier because you have lived.
This is to have succeeded.”

-Ralph Waldo Emerson

I would like to first thank the members of my dissertation committee for their guidance throughout this process: Dr. Magill, for your valuable insight, encouragement, and support; Dr. Geaghan, for taking a great interest in my project and providing me with valuable statistics support; Dr. Landin for your enthusiasm regarding my project and our chats over the “Biodex”; My outside committee member, Dr. Lauer, whom it has been a pleasure to know. Dr. Li, despite our different backgrounds and often, differences of opinion, I have learned so much from you. Thank you for your guidance in this process. Dr. Damiano, it has truly been a pleasure to work with you. Thank you for your guidance and support. I would also like to thank you for dedicating your time to this project and for taking a vested interest in my career development. To my friend and mentor, Suzanne Tinsley, who first saw the potential in me to be a teacher and researcher and encouraged me to pursue my goals. Thank you!

I would like to thank Susan Ducote and Brian Delaune from Neurotherapy Specialists, Beth Hayes of Shriners Hospital, and George Bunch for their help in recruiting subjects for the study. I would also like to thank the young men and women who participated in the project in an effort to further the understanding and research of secondary impairments associated with cerebral palsy. This project would not have been possible without these individuals.

I would like to thank my wonderful friends in Baton Rouge who have made this journey over the last 4 years fun and eventful. I feel so fortunate to have such a wonderful group of people in my life. I would like to personally mention my longtime friend, Sara Wriborg, who

made my transition here so much smoother and introduced me to so many wonderful people. Also, a special thanks to Janene Grodesky for her friendship and support as we navigated through this process together. Also, thanks to the motor behavior group for your comradeship.

I would not be who I am today without the continuous love and support of my parents. Mom and Dad, thank you for always believing in me and encouraging me to go after my dreams. You have taught me about hard work, honesty, integrity, and perseverance, to name a few. I would also like to thank my sister, Miche, who has been my lifelong role model, and my brother, Jacques for their support. To my dear grandmother, MamaEl, who passed away last year: I'm sorry you are not here to see me complete this milestone. I know you would be proud of me.

Lastly, I would like to thank my partner, Carolyn, for *everything*. Your love, support, and never-ending faith in me have meant so much. Words cannot rightfully express my gratitude. Also, thank you for your last minute proof reading. I know you'll never let me forget a comma! I cannot forget my babies, (my dogs) Shea and Nettie, for their unconditional love and for reminding me not to take life too seriously, as they attack me with slobbering kisses at the door. Our long walks and runs on the levee have often provided me with inspiration!

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ABSTRACT

Three experiments were designed to explore the measurement of muscle fatigue in people with cerebral palsy (CP). The four aims were to 1) develop a feasible and reliable isokinetic protocol to assess muscle fatigue of the knee flexors and extensors in this population, 2) determine if muscle fatigue of the knee flexors and extensors in people with CP differs from subjects without a motor disorder, 3) determine whether muscle fatigue is related to functional measures of activity and participation, and 4) investigate possible contributing factors of muscle fatigue. Results show that muscle fatigue can be reliably assessed through an isokinetic protocol consisting of 35 consecutive knee extension and flexion repetitions at 60 degrees/second by calculation of a fatigue index (FI) and the slope of the decline in peak torque. When compared to a control group of age-matched peers without motor disorder, the knee flexors and extensors in subjects with CP were observed to be less fatigable. Furthermore, muscle fatigue of the knee extensors and flexors in the group with CP was positively correlated with transfers and basic mobility. Muscle fatigue of the knee extensors was also positively correlated with overall global functioning, participation in sports and physical function, and fast walking velocity. Lower Gross Motor Function Classification System Levels (GMFCS) (i.e. less involved subjects) were also associated with higher levels of muscle fatigability. Strength was directly related to muscle fatigability, where weaker subjects had lower levels of fatigue, regardless of muscle. Cocontraction and quadriceps stiffness, on the other hand, were inversely related to muscle fatigability. The strongest predictors of hamstring fatigability were hamstrings strength and quadriceps stiffness, whereas the strongest predictor of quadriceps fatigability was hamstring cocontraction. The presence of spasticity, regardless of muscle group, was associated with lower fatigability compared to control subjects. In summary, the results indicate that the knee flexors and extensors of people with CP are less fatigable than age-matched peers without motor

disability. In addition, lower levels of muscle fatigability are associated with lower levels of function and participation. Furthermore, weakness, spasticity, stiffness, and cocontraction are possible contributing factors to the observed fatigue resistance.

CHAPTER 1: INTRODUCTION

Cerebral palsy (CP) describes a collection of disorders “of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain” (Bax et al., 2005). CP is not a disease, per se, but rather, a descriptive term that describes a heterogeneous group of children who often manifest with chronic motor impairment. Although variability exists with respect to the degree of impairments individuals with CP may exhibit, common impairments include loss of selective motor control, spasticity, muscle weakness, co-contraction, and contractures. In turn, these impairments can lead to activity restrictions such as difficulty in walking and other activities of daily living, with many patients experiencing worsening disability throughout the lifespan.

Studies over the last 10 to 15 years have documented a gradual onset of newly recognized problems in adults with CP, such as fatigue, musculoskeletal pain, and deterioration of functional skills (Andersson & Mattsson, 2001; Bottos, Feliciangeli, Sciuto, Gericke, & Vianello, 2001; Cathels & Reddihough, 1993; Gajdosik & Cicirello, 2001; Jahnsen, Villien, Egeland, Stanghelle, & Holm, 2004; Jahnsen, Villien, Stanghelle, & Holm, 2003; Murphy, Molnar, & Lankasky, 1995; Pimm, 1992). These problems manifest in adolescence and early adulthood and have consequences for activities and participation in work and social situations. Furthermore, these studies provide evidence of the progression of secondary impairments in CP and the need for targeted interventions throughout the life span, despite the non-progressive brain lesion

Physical fatigue, in particular, has been identified as a significant impairment in adults with CP compared with the general population and has been significantly associated with deterioration of functional skills, bodily pain, limitations in physical and emotion role function, and low life satisfaction (Jahnsen et al., 2003). In fact, adults with CP report fatigue as a main cause of the deterioration or cessation of their walking ability (Bottos et al., 2001; Jahnsen et al.,

2004; Murphy et al., 1995). Murphy et al. (1995) reported that 75% of subjects ceased to walk by the age of 25 due to fatigue and inefficiency of ambulation. Jahnsen et al. (2004) reported that 44% of subjects had deterioration of walking due to fatigue, pain, and lack of adapted physical activity. However, fatigue was assessed subjectively in these studies through the use of questionnaires and interviews and did not attempt to differentiate among cardiorespiratory fatigue (e.g. heart beating too fast or person feeling out of breath), neural or psychological fatigue (increased sense of effort or feeling as if muscles are going to 'give out') or local muscle fatigue (muscles cannot produce as much or any force as they could at onset of task).

Fatigue may be studied as a subjective symptom or the state of being fatigued. Conversely, fatigue can also be studied as an objective process with measurable signs, such as reduction in peak torque or work, and is often referred to as muscle fatigue (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983). However, the two do not always correlate (Iriarte & de, 1998; Sharma, Kent-Braun, Mynhier, Weiner, & Miller, 1995). The term "fatigue" as a subjective phenomenon has been used to describe a multitude of mental and physical symptoms and is often confused with other symptoms, such as weakness (Schwid, Covington, Segal, & Goodman, 2002). For example, a question in the Fatigue Questionnaire (Chalder et al., 1993) used in the Jahnsen et al. (2003) study reads "Do you have less strength in your muscles?" Another question reads "Do you feel weak?" Therefore, these self-report questionnaires are not adequate in the assessment of the objective or physical signs of fatigue (Schwid et al., 2002).

Background Information

Because of the broad use of the term fatigue, it is important to operationally define fatigue. Muscle fatigue, or fatigability, will be defined as a reduction in the force-generating capacity of the neuromuscular system, which occurs during sustained activity (Bigland-Ritchie et al., 1983). Muscle endurance, on the other hand, is resistance to fatigue or the ability to

withstand fatigue. These terms are often used interchangeably throughout the literature with muscle endurance tests often employed to assess muscle fatigue.

The first published test of muscle fatigue in children with neuromuscular disease was measured as the length of time that the subject could hold the extended lower extremity 45 degrees off of the ground while in a supine position (Hosking, Bhat, Dubowitz, & Edwards, 1976). Although this test was able to discriminate between children with and without neuromuscular disease, it was very difficult to standardize and did not show sufficient reproducibility to be recommended for future testing.

Other attempts to measure cardiorespiratory endurance in children with CP employed physiological measures of energy expenditure, such as oxygen consumption, heart rate, perceived exertion, and other measures of cardiorespiratory function (Hoofwijk, Unnithan, & Bar-Or, 1995; Rose, Haskell, & Gamble, 1993; Unnithan, Dowling, Frost, & Bar-Or, 1996). It has been well documented that children and adolescents with CP have lower VO_{2max} than able-bodied peers as assessed during tasks, such as lower extremity cycling (Lundberg, 1978) and treadmill ambulation (Hoofwijk et al., 1995; Rose et al., 1993). However, these authors independently suggested that additional factors other than cardiorespiratory were responsible for the limitations in the respective activities. Lundberg (1978) and Hoofwijk et al. (1995) suggested that spasticity may have decreased venous return and inhibited muscle lactate clearance during exercise, thereby increasing local muscle fatigue and leading to a decrease in VO_{2max} values. Furthermore, because some believe that movement in children with CP is often accomplished through discrete bursts of activity, it has been suggested that aerobic function is unlikely to be a limiting factor in the ability of a child with CP to perform activities (Unnithan, Clifford, & Bar-Or, 1998). Rather, anaerobic power has been considered to be the better measure of functional capacity in people with neuromuscular diseases, including CP (Unnithan et al., 1998).

Several investigators have studied muscle endurance from an anaerobic perspective in children and adolescents with CP by means of the Wingate Anaerobic Cycling Test (WAnT). The WAnT is a widely used, validated measure of anaerobic performance (Bar-Or, Dotan, & Inbar, 1977). It is reliable in both adults and children (Bar-Or, 1987) as well as in children with neuromuscular diseases, including those with CP (Tirosh, Bar-Or, & Rosenbaum, 1990). It is a 30-second test, during which the subject pedals at maximal speed against a predetermined constant resistance based on body weight. From this test, peak power and mean power are calculated. Peak power is a measure of explosiveness and is moderately correlated with the percentage of fast twitch fibers in the vastus lateralis muscle (Bar-Or et al., 1980). Peak power is calculated as the product of flywheel resistance x number of revolutions x distance per revolution divided by time (usually 3 second sampling period). Proponents of anaerobic testing purport to measure muscle endurance by measuring mean power of the lower extremities during the WAnT. *Mean power* is the average of all power values measured at each sampling period. Results from these studies indicate that peak muscle power and mean power, as a measure of muscle endurance, are markedly deficient in people with CP (Parker, Carriere, Hebestreit, & Bar-Or, 1992; Parker, Carriere, Hebestreit, Salsberg, & Bar-Or, 1993; Tirosh et al., 1990). However, this test cannot differentiate between right and left extremities nor can it differentiate among muscle groups; therefore, it is a non-specific, gross physiologic measurement of endurance. Furthermore, the measurement of mean power does not reflect the decline in force during sustained activity. Rather, it is an absolute measure that reflects the average level of explosiveness or power. Mean power has been directly correlated ($r = 0.75$) to relative fast twitch fiber size, where higher mean power equals higher endurance and preponderance of fast twitch fibers (Bar-Or et al., 1980). It is well established that fast twitch fibers are more fatigable; therefore, if mean power is a measure of muscle endurance, it does not correlate with our current

understanding of muscle physiology. We propose that this measurement does not reflect the decline in the force-generating capacity of the muscle, but rather reflects average power production throughout the test.

Isokinetic dynamometry, on the other hand, has the ability to isolate a single muscle group under controlled conditions with stabilization of other joints, thus providing a measure of localized muscle fatigue. Reliable isokinetic fatigue protocols have been established for children (De Ste Croix, Armstrong, & Welsman, 2003), adults (Pincivero, Lephart, & Karunakara, 1997), and the neurologically impaired (Lambert, Archer, & Evans, 2001). However, to date, there are no studies that have quantitatively assessed localized muscle fatigue via isokinetic or isometric means in individuals with CP. The most commonly assessed muscle groups in these studies are the knee flexors and extensors. Clinically, it is important to study lower extremity muscles, particularly of the knee flexors and extensors, because they have been shown to be correlated to motor function in people with CP (Damiano & Abel, 1998; Damiano, Martellotta, Sullivan, Granata, & Abel, 2000; MacPhail & Kramer, 1995). Furthermore, it is important to study more than one muscle group because muscle characteristics such as size, fiber type distribution, fiber arrangement, recruitment and rate coding strategies differ considerably across muscle groups. These differences may become even more exaggerated in persons with CP because factors like spasticity, weakness, and selective motor control may affect different muscle groups to varying degrees.

Experiments

The World Health Organization's International Classification of Functioning, Disability and Health (ICF) model was used as a framework in the investigation of muscle fatigue within the population of CP (World Health Organization, 2001). The ICF is a classification of health related domains that describe body functions and structures, activities, and participation in an

effort to understand and measure health outcomes. Three levels of human functioning are classified by ICF: functioning at the level of body or body part (body functions and structures), the whole person (activities), and the whole person in a social context (participation). The formal definitions of the components of the ICF are provided in Table 1.1.

Table 1.1. Definitions of the components of the World Health Organization’s ICF model (2001)

Terms	Definition
Body functions	Physiological functions of body systems (including psychological components)
Body structures	Anatomical parts of the body such as organs, limbs, and their components
Impairments	Problems in body function or structure such as a significant deviation or loss
Activity	Execution of a task or action by an individual
Activity Limitations	Difficulties an individual may have in executing activities
Participation	Involvement in a life situation
Participation Limitations	Problems an individual may experience in involvement in life situations

Based on this model, three experiments have been designed to further explore the measurement of muscle fatigue of the knee flexors and extensors; possible contributing factors to muscle fatigue at the body function level; activity limitations and participation restrictions associated with muscle fatigue; and the relationship of muscle fatigue to aspects of psychosocial well-being. Figure 1.1 illustrates the experiments within the context of the ICF model.

Despite the evidence that fatigue is a problem in this population, there are no studies that have quantitatively assessed muscle fatigue. Therefore, the feasibility of an isokinetic muscle fatigue protocol for the knee flexors and extensors in ambulatory children with CP was investigated in Chapter 2 (experiment 1). In addition, the reliability of 3 fatigue measurement parameters was reported.

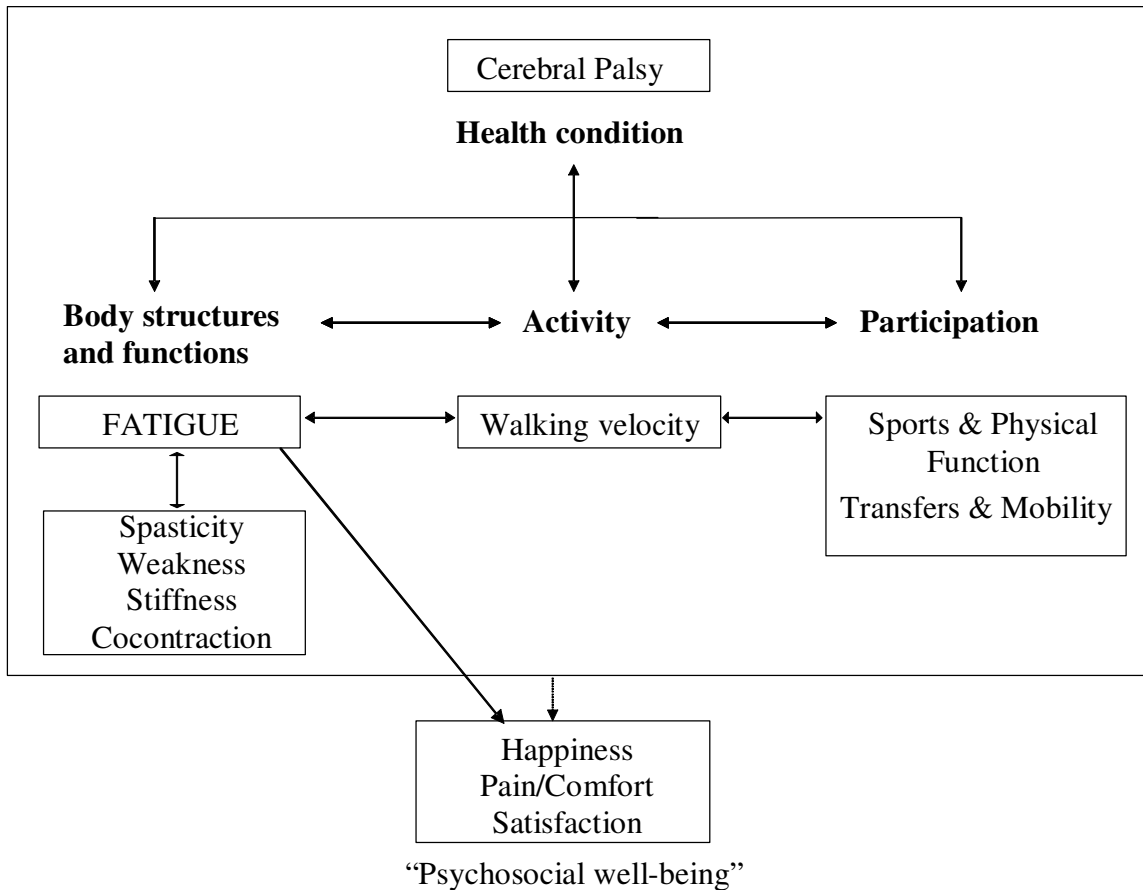


Figure 1.1. Illustration of the WHO ICF (2001) framework for the investigation of muscle fatigue within the health condition of CP; possible contributing factors to fatigue at the body function level, which are spasticity, stiffness, weakness, and cocontraction; activity limitations; participation restrictions; and the relationship of muscle fatigue to aspects of psychosocial well-being. It should be noted that psychosocial well-being is not a part of the ICF model.

In Chapter 3 (experiment 2), the protocol established in Chapter 1 was utilized to investigate whether muscle fatigue of the knee flexors and extensors was greater in individuals with CP compared to those without disability. Furthermore, as illustrated in Figure 1.1, the relationship of muscle fatigue (body functions) in individuals with CP (health condition) to activities (walking velocity); participation in sports and physical function; transfers and basic mobility; and aspects of psychosocial well-being such as happiness, satisfaction, and pain/comfort, was investigated.

In Chapter 4 (experiment 3) the relationship of muscle fatigue (body functions) to other impairments at the body function level were investigated to determine whether these factors contributed significantly to the level of muscle fatigue observed in our subjects with CP. CP is a multifaceted disorder and as such, complex interrelationships exist among upper motor neuron lesion impairments. The relationships among muscle fatigue and other impairments at the body function level are important in the understanding of fatigue, as these impairments may, in fact, contribute directly or indirectly to the level of muscle fatigability. As a result, four possible contributors to the level of muscle fatigability at the impairment/body function level were investigated and are presented in Figure 1.1: spasticity, weakness, co-contraction, and stiffness. Finally, synthesis of the conclusions presented in these chapters is presented in Chapter 5.

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CHAPTER 2: A FEASIBLE AND RELIABLE MUSCLE FATIGUE ASSESSMENT PROTOCOL FOR INDIVIDUALS WITH CEREBRAL PALSY

Introduction

Lower extremity muscle strength, particularly of the knee flexors and extensors, has been shown to be correlated to motor function in cerebral palsy (CP) (Damiano & Abel, 1998; Damiano, Martellotta, Sullivan, Granata, & Abel, 2000; MacPhail & Kramer, 1995). As a result, routine isokinetic and isometric measurements of strength are becoming increasingly common in this population. While the importance of maintaining muscle strength is being increasingly recognized for those with chronic motor disabilities such as CP, recent studies have indicated that 'fatigue' is an even more frequent complaint of adults with CP and has been cited as a major limiting factor in diminished ambulatory capacity in early to middle adulthood (Jahnsen, Villien, Egeland, Stanghelle, & Holm, 2004). Corroborating this subjective complaint is objective evidence that cardiorespiratory endurance is reduced in individuals with CP (Lundberg, 1976; Lundberg, 1978). However, while muscle endurance, or resistance to fatigue, is known to be an important component of normal muscle performance, a search of the medical literature to date revealed no investigations of fatigue at the muscle level in CP. Muscle fatigue is defined as a reduction in the force-generating capacity of the neuromuscular system, which occurs during sustained activity (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983). Muscle endurance is defined as the ability to withstand fatigue. The term muscle endurance is often used in the literature as the antonym, or positive, of muscle fatigue, similar to the use of strength vs. weakness.

The first reported test of muscle fatigue in children with neuromuscular diseases was by Hosking, Bhat, Dubowitz, and Edwards (1976). In their protocol, the length of time the lower leg could be held out straight with the hip flexed to 45 degrees and the head at 45 degrees above the horizontal were recorded with the subject in the supine position. Although this test was able to

discriminate between children with and without neuromuscular disease, it did not show sufficient reproducibility to be recommended for future testing.

Reported measures of cardiorespiratory endurance in children with CP have included physiological assessments of energy expenditure, oxygen consumption, heart rate, and subjective reports of perceived exertion among other measures of cardiorespiratory function (Lundberg, 1976; Rose, Haskell, & Gamble, 1993). Others have studied endurance from an aerobic (Lundberg, 1978) versus anaerobic perspective (Parker, Carriere, Hebestreit, & Bar-Or, 1992). However, these cardiorespiratory assessments are distinctly different both physiologically and methodologically from tests of endurance at the muscle level.

With respect to the latter, isokinetic dynamometry has the ability to isolate a group of muscles about a specific joint under controlled conditions with stabilization of other joints, thus providing a measure of muscle fatigue. It also provides a controlled, safe environment where no resistance (load) is applied once the movement has ceased, since it accommodates to the amount of muscle force that is applied (Jones & Stratton, 2000). Isokinetic muscle fatigue protocols for the knee have been extensively developed in the healthy adult population. The most widely used protocol consists of performance of a predetermined number of maximal repetitions, usually between 25 and 50, at 180 degrees/second (Burdett & Van Swearingen, 1987; Pincivero, Gear, & Sterner, 2001; Thorstensson & Karlsson, 1976). Another common protocol involves the performance of consecutive repetitions until the peak torque or work decreases to 50% of the maximum (Emery, Sitler, & Ryan, 1994). Calculation of a fatigue index (FI), which represents the percentage decline in work or torque from the beginning to the end of the protocol, is the most frequently reported parameter (Burdett & Van Swearingen, 1987; Pincivero et al., 2001; Thorstensson & Karlsson, 1976), despite the fact that some have questioned its reliability (Burdett & Van Swearingen, 1987). Alternatively, some authors have calculated the slope of the

regression line as a measurement of the decline in force and have found it to be more reliable than the FI (Pincivero et al., 2001).

Existing isokinetic fatigue protocols have been modified for use with children (De Ste Croix, Armstrong, & Welsman, 2003) and with other neurological populations, such as multiple sclerosis (Lambert, Archer, & Evans, 2001). For example, slower testing speeds less than 100 degrees/second have been recommended for normally developing children due to difficulty producing force at higher speeds (De Ste Croix et al., 2003; Gaul, 1996). Although no studies were identified that have examined isokinetic muscle fatigue in individuals with CP, speeds of 30 (Van den Berg-Emons RJ, Van Baak, de, Speth, & Saris, 1996) and 90 (Ayalon, Ben-Sira, Hutzler, & Gilad, 2000) degrees/second have been shown to be reliable in children with CP for isokinetic strength assessment. In addition, isokinetic strength testing at 60 degrees/second has been observed to be reliable in adults with CP (Holland, McCubbin, Nelson, & Steinman, 1994).

Reliable isokinetic fatigue protocols for the knee flexors and extensors have been established for healthy children (De Ste Croix et al., 2003), adults (Emery et al., 1994; Thorstensson & Karlsson., 1976), and those with various neurological impairments (Lambert et al., 2001), with no studies found to date that have quantitatively assessed muscle fatigue via isokinetic means in individuals with CP. Therefore, the primary purpose of this study was to develop a feasible and reliable isokinetic fatigue protocol for use in CP, so that we could later pose the question as to whether this aspect of muscle performance is impaired in this population. The aim of the feasibility assessment was to determine if a group of mild to moderately impaired subjects with CP of varying ages would be able to complete a muscle fatigue protocol. The aim of the reliability assessment was to determine the repeatability of the fatigue parameters obtained from the protocol. In order to evaluate the feasibility and reliability of these protocols, we decided to study the knee flexors and extensors, since these are the most commonly studied

muscles in isokinetic protocols. In addition, we wanted to study more than one muscle group because muscle characteristics may vary considerably across muscle groups, yielding different results with respect to the determination of the presence or degree of muscle fatigability.

Methods

Subjects

Twelve subjects with a diagnosis of CP ranging in age from 10 to 22 years were recruited for the feasibility assessment. Five of the 12 subjects were tested on two occasions, exactly one-week apart at the same time of day, for the reliability analysis. All subjects were able to ambulate at least short a distance with or without assistance and thus fell within Gross Motor Function Classification System (GMFCS) levels I, II, and III (Table 2.1). Subjects were excluded if they underwent orthopedic surgery within 9 months prior to the testing, received Botulinum toxin injections to the quadriceps or hamstrings within 6 months prior to the testing, or suffered from knee pain. Passive range of motion of the knee was also assessed prior to testing to determine if the subject had sufficient range of motion to complete the test.

The protocol was approved by the Institutional Review Board at our institution. Written permission from each participant over 18 years of age was obtained before beginning this study. Participants under 18 years of age were required to have a parental permission form signed by one parent or legal guardian. In addition, the minor was required to read and sign a child assent form.

Procedures

An isokinetic dynamometer (Biodex Medical Systems Incorporated, Shirley, NY, USA) was used to evaluate muscle fatigue and 'strength' by means of peak voluntary torque of the knee flexors and extensors. Following familiarization with the isokinetic equipment and explanation of procedures, the subject was positioned in the Biodex chair in a semireclining

sitting position with the angle of the hip joint at 70 degrees. The more involved lower extremity was tested for subjects with bilateral involvement if they had sufficient motion and mobility in that limb to perform the test. The involved lower extremity was tested for subjects with unilateral involvement. The subject's knee joint center was aligned with the center of rotation of the isokinetic device. The leg was secured against the knee attachment pad and additional stabilizing straps around the waist, the trunk, and over the mid-thigh portion were used to restrain trunk and hip movement during testing. Following set-up, the passive range of motion designated as "comfortable" by the patient, given the restrictions imposed by the chair which limits flexion, was determined and used to set the limits of motion for the rest of testing session. Subjects were instructed to keep their arms folded across their chest for all trials.

Table 2.1
Subject Characteristics and Feasibility Data

Subject	Age, yr	Gender	GMFCS level	KE 50% rep	KF 50% rep	Reason for termination of test
1	10.3*	M	I	27	16	+
2	11.2	M	I	24		self @ 35reps
3	11.4	F	I		15	self @ 35reps
4	13.1	M	II			100 reps
5	13.3*	F	I	26	26	+
6	14.4	F	III		30	† @ 50reps
7	17.2	F	I	30	21	+
8	19.9	F	I		30	100 reps
9	20.6	F	II	43	30	+
10	20.8*	F	II		32	self @ 35reps
11	22.5*	F	II	23	14	+
12	23.3*	M	III	73	55	+

KE50% rep = repetition where criteria for 50% decline were met for knee extension; KF50% rep = repetition where criteria for 50% decline were met for knee flexion; self = self-termination

* = subjects tested twice, 1-week apart

+ = Goal of 35 repetitions and 50% decline in maximum peak torque achieved

† = unable to complete range of motion and reach target velocity

Subjects performed 8-12 submaximal concentric, reciprocal knee flexion and extension repetitions to familiarize themselves with the procedure. After a 2 minute rest period, subjects

then performed 3 maximal concentric exertions for each muscle group at 60 degrees per second. Strength was measured as the peak voluntary torque of each muscle group. Subjects were instructed to “push” and “pull” their leg against the lever of the Biodex as hard and fast as possible. Verbal encouragement was given for each repetition. One minute of rest was given between repetitions and five minutes of rest was given prior to the muscle fatigue protocol to prevent the occurrence of muscle fatigue.

During the protocol development phase prior to this study, it was determined that 60 degrees/second was the most comfortable speed for the majority of subjects. Therefore, the fatigue protocol consisted of reciprocal, maximal concentric knee extension and flexion at 60 degrees/second until at least 35 repetitions were performed and peak torque declined to 50% of maximum. This point was defined when the peak torque of 2-3 consecutive repetitions fell below 50% of the maximum torque value obtained during the fatigue protocol. A maximum of 100 repetitions was allowed to achieve the 50% decline in peak torque. In this manner, two isokinetic testing protocols (35 repetitions and 50% decline) were imbedded within one session. Again, the subjects were instructed to “push” and “pull” their leg against the lever as hard as possible. Strong verbal encouragement was given for every repetition to encourage maximal effort on all repetitions. The test was terminated if the subject could no longer move through their available ROM at the desired velocity of 60 degrees/second or if self-terminated.

Data Analysis

Feasibility

During the fatigue protocol, the repetition in which the maximum torque occurred, as well as the repetition in which the criteria for the 50% decline in peak torque were met, was recorded. In addition, paired t-tests were used to test the difference between peak torques obtained during the strength assessment versus the fatigue test.

Test-Retest Reliability

Data were gravity corrected, and only the constant velocity portion was used. Two accepted measures of fatigue were computed for each of the two embedded protocols: 1) percent decline in peak torque, calculated as a Fatigue Index (FI) (Pincivero, Gandaio, & Ito, 2003):

$$FI = 100 - \left[\frac{PT \text{ last } 5 \text{ reps}}{PT \text{ highest } 5 \text{ reps}} \times 100\% \right]$$

and 2) rate of decline in PT represented by the slope of the linear regression, beginning with the first value of the highest 5 consecutive repetitions and ending with the last repetition (Pincivero et al., 2001). The slope was also normalized by peak torque as a method for comparison across individuals (Felicetti, Zelaschi, & Di Patrizi, 1994) (Figure 2.1). Intraclass correlation coefficients (ICC) were calculated to determine test-retest reliability for the slope, normalized slope, and FI (Portney & Watkins, 2000). Alpha level was set at .05.

(Shrout & Fleiss model from Portney & Watkins, 2000) $ICC = \frac{BMS - EMS}{BMS}$

where BMS is the between-subjects mean square, and EMS is the error mean square.

Results

Feasibility

In half of the 12 subjects tested, peak torque failed to decline to 50% of maximum in either one or both directions during the fatigue protocol (Table 1). However, all subjects were able to complete 35 repetitions. Furthermore, when the criteria for the 50% decline in peak torque were met, it occurred before the 35th repetition in 82% of the trials. Reasons for termination of the fatigue testing session are listed in Table 2.1 for each subject. Peak torque obtained from the fatigue test for the knee extensors (55.6 ± 20.8) was significantly greater than the value obtained during the single repetition strength assessment (42.7 ± 15.7 , $p = 0.001$).

However, there was no difference in peak torque for the knee flexors observed during the fatigue test (24.6 ± 12.7) versus the strength test (22.5 ± 14.8 , $p = 0.18$). It was noted that the maximum torque during the fatigue test occurred between the 3rd and 27th repetition for the knee extensors (9.3 ± 7.8) and between the 1st and 20th repetition for the knee flexors (5.0 ± 6.5).

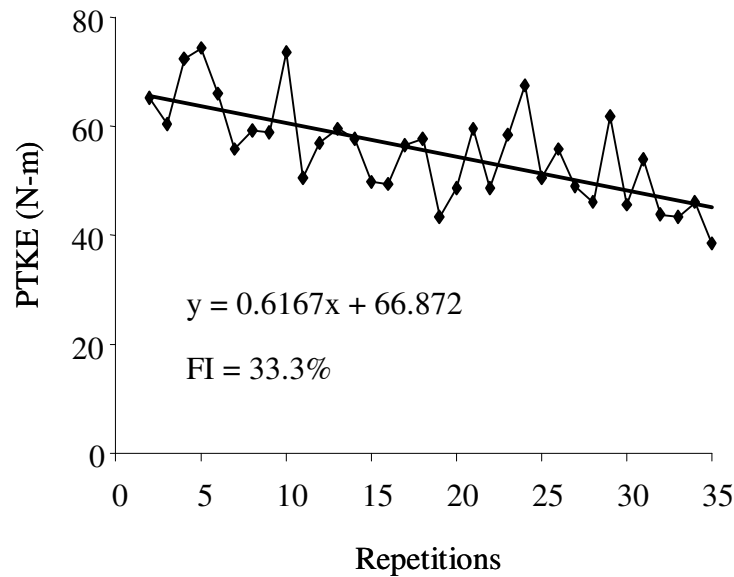


Figure 2.1. Exemplar peak torque data during knee extension (PTKE) over 35 repetitions from one subject represented by the diamond marker (♦). Slope of the linear regression and the fatigue index (FI) were calculated and presented with the raw data.

Test-Retest Reliability

Because the 50% decline in peak torque did not occur in all subjects, fatigue parameters were calculated only for the 35 repetitions. In one subject, the starting value, or the first of the highest 5 consecutive repetitions, occurred later than the 15th repetition consistently for both muscle groups during both test sessions. As a result, the protocol was extended to achieve a sufficient number of repetitions beyond that point.

The ICC values of the absolute slope for the knee flexors and extensors were 0.94 and 0.97, while the ICC values of the normalized slope for the knee flexors and extensors were 0.83

and 0.99, respectively. The ICC values of the FI were 0.86 and 0.73 for the knee flexors and extensors, respectively. The ICC values of the peak torque from the strength test were 0.96 and 0.95, and the ICC values of the peak torque from the fatigue test were 0.89 and 0.87 for the flexors and extensors, respectively (Table 2.2).

Table 2.2
Intraclass Correlation Coefficients (ICC) for Test-retest Reliability Analysis

	Knee Extension			Knee Flexion		
	Test 1	Test 2	ICC	Test 1	Test 2	ICC
FI	22.36 (14.89)	32.77 (8.57)	.73	42.44 (11.59)	50.92 (14.95)	.86
Slope (Abs)	0.613 (0.380)	0.479 (0.298)	.97	0.198 (0.121)	0.246 (0.156)	.94
Slope/PT	0.013 (0.008)	0.010 (0.007)	.99	0.012 (0.008)	0.011 (0.008)	.83
StrengthPT	39.24 (20.42)	37.42 (16.32)	.95	18.18 (14.57)	18.21 (13.63)	.96
FatiguePT	49.54 (17.05)	49.48 (10.96)	.87	18.21 (12.13)	22.09 (9.10)	.89

Peak torque (PT) given in N-m. All the ICC values were significant at $p < 0.05$

FI = Fatigue Index; (Abs) = absolute value; Slope/PT = slope normalized by peak torque;

StrengthPT = peak torque calculated from strength test; FatiguePT = peak torque calculated from fatigue test

Discussion

The results of this study demonstrate that muscle fatigue of the knee flexors and extensors can be feasibly and reliably assessed in children and young adults with mild to moderate CP over 35 repetitions at an isokinetic speed of 60 degrees/second. According to Portney and Watkins (2000), ICC coefficients from .050 to 0.75 designate moderate reliability, and values above 0.75 indicate good reliability. In addition, Shrout and Fleiss (Shrout & Fleiss, 1979) define ICCs exceeding 0.75 as excellent. Based on these guidelines, both the absolute and normalized slope was observed to have good/excellent reliability for both the knee flexors and extensors, whereas the FI presented with good/excellent reliability for the knee flexors only. Moderate reliability (0.73) was observed for the FI of the knee extensors.

The 50% decline protocol was not appropriate for use in this sample of individuals with mild to moderate CP since only half of the subjects tested were able to achieve a 50% decline in peak torque with the imposed limitations of 100 repetitions, self-termination, or inability to complete the task. However, if the rate of decline is linear, it is possible that based on the slope, this point could be extrapolated. When the 50% decline in peak torque was met, it occurred prior to the 35th repetition in over 80% of the trials. Therefore, the protocol that required 35 repetitions was more feasible for most subjects. However, in some subjects, the protocol may need to be extended when the maximum torque occurs past the 15th repetition, as less than 20 repetitions was not adequate in capturing the decline in torque in this sample of subjects. Testing at speeds other than 60 degrees/second may produce different results than observed in this study. It is possible that fewer repetitions could have been completed at 30 degrees/second. Since CP encompasses such a wide range of motor disabilities, and subjects in this study tended to fall on the milder end of the spectrum, these protocols may be increasingly problematic for individuals with greater involvement (GMFCS levels IV and V) and may require further modification. It is anticipated that reliable assessment of fatigue in those with greater involvement may not even be possible.

Although the FI has been questioned in terms of its reliability (Burdett & Van Swearingen, 1987), our results indicate that the FI has moderate to good reliability in the CP population. Our results are comparable with other studies that have showed moderate to good reliability of the FI for the non-dominant knee flexors and extensors (ICC = 0.84 and 0.74) in the healthy adult population (Pincivero, Lephart, & Karunakara, 1997). The good/excellent reliability of the slope calculations is also comparable to other studies in the healthy adult population for the same muscle groups (ICC = 0.78 to 0.86) (Felicetti et al., 1994; Pincivero et al., 2001).

Assessment of peak voluntary torque at 60 degrees/second as a measure of strength presented with good/excellent reliability, with ICC values of 0.96 and 0.95 for the knee flexors and extensors, respectively. Very little information is available in the literature regarding the reliability of isokinetic testing speeds in CP. Based on Van den Berg-Emons et al. (1996) reliability study, clinicians and researchers have considered the isokinetic speed of 30 degrees/second as the “gold standard” for strength assessment for people with CP. However, faster angular velocities are more typical of everyday activities and movement. Furthermore, recent research suggests that a faster speed of 90 degrees/second is also reliable for children and adolescents with mild to moderate CP for the knee flexors and extensors (ICC = 0.98) (Ayalon et al., 2000). Holland et al. (1994) also tested 14 adults (ages 17 to 38) at 60 degrees/second and reported generalizability coefficients (ρ^2) of 0.91 and 0.80 for the flexors and extensors, respectively. The results of this study are comparable and provide further evidence to support the reliability of speeds greater than 30 degrees/second for isokinetic strength assessments.

It is of clinical importance that peak torque was observed to be greater for the knee extensors during the fatigue test as compared to the strength test. In non-disabled, healthy adults and children, maximum torque is achieved during the first 5 repetitions (Burdett & Van Swearingen, 1987; De Ste Croix et al., 2003; Pincivero et al., 2001; Pincivero et al., 1997). Therefore, it is customary to utilize 3 to 5 isokinetic repetitions for maximum strength assessments even in individuals with chronic motor disorders, such as CP (Ayalon et al., 2000; Damiano & Abel, 1998; Holland et al., 1994; Van den Berg-Emons RJ et al., 1996). However, according to our study, not only was peak torque greater for the knee extensors during the fatigue test, but it occurred on average during the 9th repetition. The results indicate that we may not be giving our subjects enough repetitions to achieve maximum torque during strength assessments and may, in fact, be under representing their strength. Another reason for this discrepancy may

be that the subjects initiated knee extension during the strength test from a static position, followed by knee flexion motion and a rest period before the next trial. Although the fatigue test is initiated in this same manner, repetitions are performed consecutively without rest or pause, where knee extension is not initiated from a static position on subsequent repetitions. Hence, knee extension is preceded by a pre-stretch of the muscle (active knee flexion) during subsequent trials, which may have a potentiation effect on the contractile machinery of the quadriceps. This same phenomenon has been observed in stroke subjects during stretch-shortening cycles compared to contractions from a static starting position (Svantesson, Grimby, & Thomee, 1994). Knee flexion, on the other hand, begins from a dynamic position of pre-stretch on all trials for both the strength and fatigue test, which may explain why a discrepancy did not exist. However, further research is needed in order to decipher the influence of dynamic versus contractions from a static position. Still other explanations, such as decreased neural activation, need to be explored, because the production of the maximal torque after more than a few repetitions is quite a deviation from normal muscle performance and may suggest that the effort cannot possibly be maximal in those cases.

In conclusion, performance of 35 repetitions at 60 degrees/second is a feasible and reliable isokinetic muscle fatigue protocol for both children and young adults with mild to moderate CP and has widespread clinical and research applications. In addition, the number of repetitions given and the type of contraction (dynamic/pre-stretch vs. static) may influence the assessment of peak voluntary torque in subjects with CP.

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CHAPTER 3: ARE MUSCLES MORE FATIGABLE IN INDIVIDUALS WITH CEREBRAL PALSY?

Introduction

Measures of physiological capacity, such as lower extremity muscle strength, have been correlated with functional measures in people with cerebral palsy (CP) and other disabilities (Damiano & Abel, 1998; Damiano, Kelly, & Vaughn, 1995; Kramer & MacPhail, 1994). However, neither muscle strength nor measures of physical function have been shown to be related to psychosocial aspects of quality of life (QOL), such as comfort and happiness (Pirpiris et al., 2006). Self-reported physical fatigue, on the other hand, has been significantly associated with QOL measures of psychosocial well-being, such as bodily pain, limitations in physical and emotion role function, and low life satisfaction in adults with CP (Jahnsen, Villien, Stanghelle, & Holm, 2003). Furthermore, adults with CP report fatigue as a main cause of the deterioration or cessation of their walking ability (Bottos, Feliciangeli, Sciuto, Gericke, & Vianello, 2001; Jahnsen, Villien, Egeland, Stanghelle, & Holm, 2004; Murphy, Molnar, & Lankasky, 1995). However, these studies assessed fatigue using questionnaires and interviews and did not attempt to differentiate among objective measures of fatigue.

There are different types of objective measures of fatigue, such as cardiorespiratory fatigue (e.g. heart beating too fast or person feeling out of breath), neural or psychological fatigue (increased sense of effort or feeling as if muscles are going to 'give out') or local muscle fatigue. Muscle fatigue, or fatigability, was defined as a reduction in force output that occurs during sustained activity (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983). Fatigue resistance is also referred to as muscle endurance, which is the term most often used in the literature as the antonym, or opposite, of muscle fatigue, similar to the use of strength vs. weakness.

Previous objective clinical measures of fatigue in people with CP were focused primarily on the cardiorespiratory system. Although it has been well documented that children and adolescents with CP have lower VO_{2max} than their typically developing peers, most authors agreed that local muscle factors, such as muscle fatigue, were responsible for the lower VO_{2max} and limitations in activity (Hoofwijk, Unnithan, & Bar-Or, 1995; Lundberg, 1978; Rose, Haskell, & Gamble, 1993; Tobimatsu, Nakamura, Kusano, & Iwasaki, 1998; Unnithan, Dowling, Frost, & Bar-Or, 1996). Following this same argument, Lundberg (1978) and Hoofwijk et al. (1995) suggested that spastic muscles may have decreased venous return and inhibited muscle lactate clearance during exercise, thereby increasing local muscle fatigue and leading to a decrease in VO_{2max} values.

Several investigators have studied muscle endurance from an anaerobic perspective in children and adolescents with CP by means of the Wingate Anaerobic Cycling Test (WAnT). The WAnT is a widely used, validated measure of anaerobic performance during which the subject pedals at maximal speed against a predetermined constant resistance for 30 seconds (Bar-Or, Dotan, & Inbar, 1977). Results from these studies indicate that mean muscle power, as a measure of muscle endurance, is markedly deficient in people with CP (Parker, Carriere, Hebestreit, & Bar-Or, 1992; Parker, Carriere, Hebestreit, Salsberg, & Bar-Or, 1993; Tirosh, Bar-Or, & Rosenbaum, 1990). However, due to the focus on speed and the short duration of the test, the validity of this test as a measure of muscle endurance is debatable. Also, it cannot differentiate between right and left extremities nor can it differentiate among muscle groups. Therefore, it is at best a non-specific, gross physiologic measurement of endurance or, perhaps more appropriately, of muscle power.

Because muscles adapt to the amount and type of neural stimulation being imposed upon them, secondary effects of spasticity on muscle tissue can also have a profound impact on the

ability to generate and maintain muscle force. Muscle abnormalities such as alterations in muscle fiber size and fiber type distribution, excessive collagen accumulation, and increased stiffness of spastic muscle cells have been extensively reported (Booth, Cortina-Borja, & Theologis, 2001; Castle, Reyman, & Schneider, 1979; Friden & Lieber, 2003; Ito et al., 1996; Marbini et al., 2002; Romanini, Villani, Meloni, & Calvisi, 1989; Rose et al., 1994). These alterations of muscle properties can have major implications for essential aspects of muscle performance, such as the ability to generate force and to sustain force output. In cerebral palsy and other motor disorders, different muscle groups can be affected to varying degrees; therefore, these changes may also be muscle-specific.

Isokinetic muscle fatigue protocols for the knee have been extensively developed in the healthy adult population. (Burdett & Van Swearingen, 1987; Pincivero, Gear, & Sterner, 2001; Thorstensson & Karlsson, 1976) and have been modified for use with children (De Ste Croix, Armstrong, & Welsman, 2003) and with other neurological populations, such as multiple sclerosis (Lambert, Archer, & Evans, 2001). Isokinetic dynamometry has the ability to isolate a group of muscles about a specific joint under controlled conditions with stabilization of other joints, thus providing a device with which to measure muscle fatigue. It also provides a controlled, safe environment where no resistance (load) is applied once the movement has ceased, since it accommodates to the amount of muscle force that is applied (Jones & Stratton, 2000). An isokinetic fatigue protocol was developed recently by our group for use in children and young adults with mild to moderate CP and was shown to be feasible and reliable for testing the knee flexors and extensors (Moreau, Li, & Damiano, 2006).

The primary purpose of this study was to determine whether muscle fatigue in the knee flexors and extensors in individuals with CP differs from those without a motor disability. A secondary purpose of the study was to determine the relationship of fatigue to functional level,

walking velocity, and psychosocial well-being and activity / participation as measured by the Pediatric Outcomes Data Collection Instrument (PODCI). We hypothesized that individuals with CP would have greater levels of muscle fatigability compared to non-disabled peers, and that this aspect of muscle performance would be inversely related to functional level, walking velocity, activity and participation, and psychosocial well-being.

Methods

Subjects

A group of 18 subjects with cerebral palsy (CP) and 16 control subjects without a motor disability between the ages of 10 and 25 were recruited for the study. Gender and age distribution was similar across groups. Physical demographics of the subjects are listed in Table 3.1. All subjects were able to ambulate at least a short distance with or without assistive devices. Subjects were excluded if they had orthopedic surgery within 12 months prior to the testing, received Botulinum toxin injections to the quadriceps or hamstrings within 6 months prior to testing, or complained of existing knee pain. Passive range of motion of the knee was also assessed prior to testing to determine if the subject had sufficient range of motion to complete the test.

The study was approved by the Institutional Review Board at our institution. Written informed consent from each participant over 18 years of age was obtained before beginning this study. Participants younger than 18 years of age were required to have a parental consent form signed by one parent or legal guardian. In addition, the minor was required to read and sign a child assent form.

Gross Motor Function Classification System

All subjects were assigned a Gross Motor Function Classification System (GMFCS) level and were restricted to levels I, II, and III, secondary to ambulation requirements of the study. The

GMFCS is a standardized evaluation that allows for the classification of children with CP into levels based on functional ability. Emphasis is on the child's usual performance in home, school, and community settings. The GMFCS has been suggested to have good to excellent interrater reliability for severity of gross motor function limitations in children with CP (Palisano et al., 1997; Wood & Rosenbaum, 2000). In addition, it has been shown to be a valid instrument in both cross-sectional (Palisano et al., 1997) and longitudinal (Wood & Rosenbaum, 2000) studies.

Table 3.1.
Physical Demographics

	Gender	Age range	Age (yr) \pm SD	Height (m) \pm SD	Weight (kg) \pm SD
CP	13F/5M	10 – 25	17.49 \pm 5.03	1.52 \pm 0.08	47.57 \pm 9.92
Control	13F/3M	10 – 23	16.61 \pm 4.45	1.59 \pm 0.09*	53.97 \pm 9.72

M = male; F = female. *The control group was significantly taller than the CP group (P = 0.01)

Pediatric Outcomes Data Collection Instrument (PODCI)

The Pediatric Outcomes Data Collection Instrument (PODCI) questionnaire was completed separately by the parent and child or by the adult subject only (AAOS/POSNA, Version 2.0, (Daltroy, Liang, Fossel, & Goldberg, 1998). The PODCI was designed to assess self-reported physical function and psychosocial aspects of health status in children with mild to moderate musculoskeletal disability. The PODCI contains 108 short questions and takes about 10-20 minutes to complete. Each scale is computed to generate a score from 0 to 100 (worst to best). The following scales generated from this instrument were analyzed:

- Transfer and Basic Mobility Scale: Measures difficulty experienced in performing routine motion and motor activities in daily activities.
- Sports/Physical Functioning Scale: Measures difficulty or limitations encountered in participating in more active activities or sports.

- Pain/Comfort Scale: Measures the level of pain experienced during the past week.
- Global Functioning Scale: A general combined scale calculated from the first three scales listed above and the ‘Upper Extremity and Physical Function Scale’.
- Happiness Scale: Measures overall satisfaction with personal looks and sense of similarity to friends and others of own age.
- Satisfaction with Symptoms Scale: Measures the patient's acceptance of current limitations should this be a life long state.

Gait Velocity

Gait velocity was assessed over level ground prior to isokinetic testing. A 10-m distance was marked on the floor with tape. Subsequent marks were placed 2-m from the starting point and 2-m from the ending point, thus allowing a 6-m timed middle section for the test. Timing began when the subject crossed the initial 2-m mark and ended when the subject crossed the final 2-m mark. Each subject was given 2-4 trials at a comfortable walking speed and at a fast walking speed. The instructions for comfortable walking speed were, “When I say ‘go’, walk all the way to the last piece of tape at your comfortable walking speed.” For the fast walking speed, the instructions were, “When I say ‘go’, walk all the way to the last piece of tape as fast as possible but without running”. Time was recorded by a stopwatch in seconds, and velocity was calculated as meters per second. Two representative trials at each speed were averaged (Brusse, Zimdars, Zalewski, & Steffen, 2005).

Isokinetic Testing

An isokinetic dynamometer (Biodex Medical Systems Incorporated, Shirley, NY, USA) was used to record torque of the knee flexors and extensors during maximum voluntary contraction throughout the available range of motion. Following familiarization with the isokinetic equipment and explanation of procedures, the subject was positioned in the Biodex

chair in a semireclining sitting position with the angle of the hip joint at 70 degrees (thigh horizontal and trunk 70 degrees above horizontal). The more involved lower extremity was tested for subjects with bilateral or unilateral involvement if they had sufficient motion and mobility in that limb to perform the test. The left lower extremity was tested for control subjects. The subject's knee joint center was aligned with the center of rotation of the dynamometer. The leg was secured against the knee attachment pad, and additional stabilizing straps around the waist, the trunk, and over the mid-thigh portion were used to restrain trunk and hip movement during testing. Following set-up, the passive range of motion designated as "comfortable" by the patient, given the restrictions imposed by the chair itself which limits flexion, was determined and used to set the limits of motion for the rest of testing session. Subjects were instructed to keep their arms folded across their chest for all trials.

Subjects performed 8-12 submaximal concentric, reciprocal knee flexion and extension repetitions to familiarize themselves with the procedure. After a 2-minute rest period, subjects then performed 3 maximal concentric exertions for each muscle group at 60 degrees per second. Five minutes of rest was given prior to the muscle fatigue protocol to prevent the occurrence of muscle fatigue.

The fatigue protocol consisted of reciprocal, maximal concentric knee extension and flexion at 60 degrees/second for 35 repetitions. The subjects were instructed to "push" and "pull" their leg against the lever as hard as possible. Strong verbal encouragement was given for every repetition to encourage maximal effort on all repetitions (Moreau et al., 2006).

Data were gravity corrected, and only the constant velocity portion was used for the following calculations. Two accepted measures of fatigue were computed as illustrated in Figure 3.1: 1) percent decline in peak torque (PT), calculated as a Fatigue Index (FI) (Pincivero,

Gandaio, & Ito, 2003):
$$FI = 100 - \left[\frac{PT \text{ last 5 reps}}{PT \text{ highest 5 reps}} \times 100\% \right]$$

and 2) rate of decline in PT represented by the slope of the linear regression, beginning with the first value of the highest 5 consecutive repetitions and ending with the last repetition (Pincivero

et al., 2001):
$$Slope = \frac{\Delta PT}{\Delta Repts}$$

This fatigue protocol was previously shown to be feasible and reliable in children and young adults with mild to moderate CP (Moreau et al., 2006).

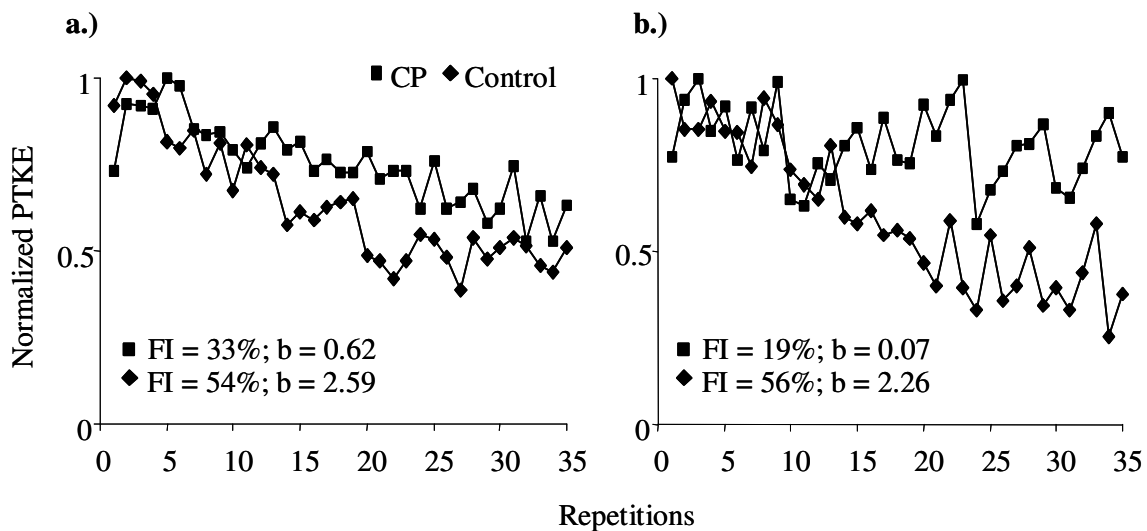


Figure 3.1. Exemplar peak torque data during knee extension (PTKE) over 35 repetitions from **a.)** one subject with CP classified as GMFCS level I and **b.)** one subject classified as GMFCS level III. Two age-matched subjects from the Control group are illustrated for comparison. Slope (b) of the linear regression and the fatigue index (FI) were calculated and presented with the raw data. For illustrative purposes, PT was normalized by the maximum torque to yield a scale of 0 to 1.

Statistical Analysis

Factorial Repeated Measures Analysis of Variance (ANOVA) procedures, with muscle (extensors/flexors) as the repeated measure, were used to test for differences in fatigue parameters between groups. Within the group with CP, Pearson correlation procedures were used

to relate gait velocity and PODCI scores to fatigue parameters, and a Spearman rank procedure was used for comparisons with the ordinal GMFCS categorization (levels I, II, and III). ANOVA procedures were also used to compare fatigue parameters across GMFCS levels in the subjects with CP. Alpha level was set at 0.05.

Results

The demographics of the two groups were similar with the control group slightly taller than the group with CP ($p = 0.01$, Table 3.1). The peak absolute torque of the knee extensors obtained during the fatigue protocol for the group with CP and the control group were 54.2 ± 20.8 and 108.4 ± 37.9 N-m, respectively. For the knee flexors, the peak absolute torque was 24.2 ± 11.3 and 57.7 ± 21.3 N-m for the group with CP and the control group, respectively. The slope of the knee extensors and flexors were significantly correlated with age only for the control group (Control: $r = 0.71$ and 0.82 , $p < 0.05$; CP: $r = 0.002$ and -0.12 , respectively). Gender did not have a significant effect on within group or between group comparisons for either the FI or the slope. Therefore, gender was excluded as a factor in the ANOVA procedures.

Fatigue

PT occurred at the 22nd and 27th repetition during the fatigue protocol for knee extension in 2 subjects. Therefore, the protocol was extended to 50 repetitions, so that a sufficient number of data points were obtained to see a clear trend and to be able to make equal comparisons across subjects. Figure 3.2 illustrates the mean and standard error of the mean (SEM) of the slope for the knee flexors and extensors for both groups. Compared to the group with CP, the control group was associated with greater slope values for both the knee flexors and extensors, indicating greater fatigability of the control group (Group: $F_{1,60} = 36.90$, $P < 0.0001$). The knee extensors were associated with greater slope values than the knee flexors across both groups (Muscle: $F_{1,60} = 21.86$, $P < 0.0001$). No significant group and muscle interaction was observed.

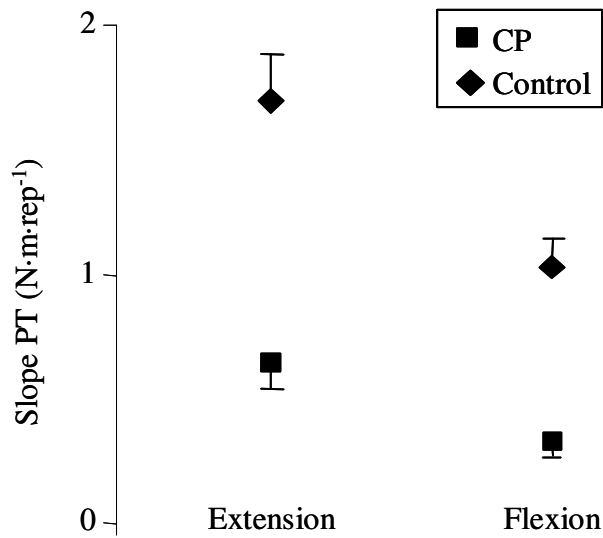


Figure 3.2. Mean and SEM of the slope for knee flexion and extension for the group with CP and the control group. Significant differences were observed among the different groups ($P < 0.0001$) and different muscles ($P < 0.0001$). No significant interaction between Group and Muscle was observed.

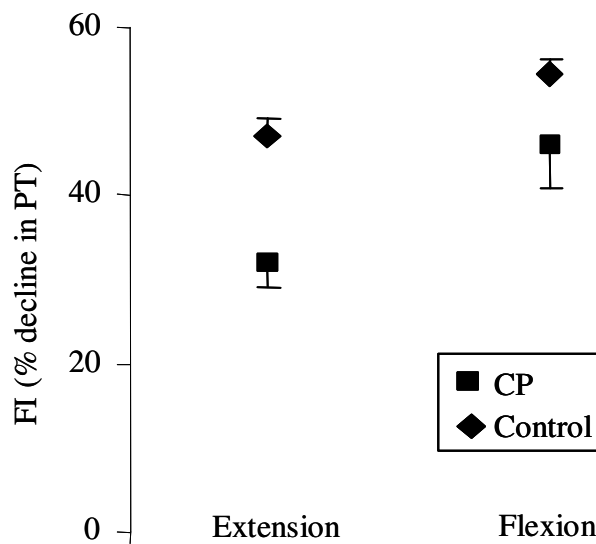


Figure 3.3. Mean and SEM of the Fatigue Index (FI) for knee flexion and extension for the group with CP and the control group. Significant differences were observed among the different groups ($P = 0.009$) and different muscles ($P = 0.004$). No significant interaction between Group and Muscle was observed.

GMFCS

Greater slope values were associated with lower GMFCS levels in the group with CP, regardless of muscle group ($F_{2,27} = 5.25$, $P = 0.012$). Post-hoc analysis with Tukey adjustments revealed significant differences between GMFCS levels I and III and between levels II and III ($P = 0.009$ and 0.037 , respectively). Figures 3.1a and 3.1b illustrate the FI and the slope of the decline in knee extensor PT for a subject within GMFCS level I and level III, respectively. A significant interaction between GMFCS and muscle group was not observed. Spearman rank correlations revealed a significant negative association between GMFCS level and the slope for knee extension only, as illustrated in Figure 3.4 ($r = -0.47$, $P = 0.047$). Thus, more proficient ambulators with CP, i.e. lower GMFCS levels, had greater levels of knee extensor fatigability. There were no significant main effects or interactions for the FI across GMFCS levels.

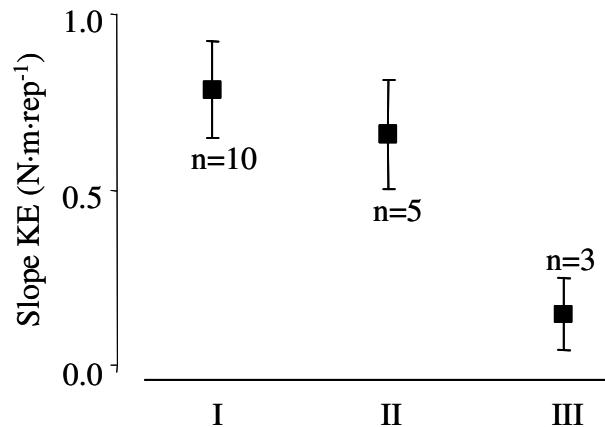


Figure 3.4. Spearman rank (r) correlation between the slope of the knee extensors (KE) and GMFCS levels I, II, and III ($r = -0.474$, $P = 0.047$). Mean and SEM are illustrated.

PODCI

The Global Function scale of the PODCI was directly correlated with both the slope and FI of the knee extensors, while the Sports and Physical Function scale was directly related to the

slope only. Transfers and basic mobility were directly correlated to the slope and FI of the knee extensors, as well as to the slope of the knee flexors. A positive correlation indicates that people with higher levels of functioning (i.e. higher scores on the PODCI) have increased levels of fatigability. None of the scales related to psychosocial well-being (Pain/comfort, happiness, satisfaction) were correlated with the fatigue parameters. Correlation coefficients are listed in Table 3.2.

Velocity

Among the normalized and non-normalized self-selected and fast velocities, only non-normalized fast velocity was significantly correlated to the slope of the knee extensors ($r = 0.51$, $P = 0.03$). Therefore, the capacity to walk faster is associated with greater levels of knee extensor fatigability among the subjects with CP.

Table 3.2
Pearson (r) correlations of PODCI subscales and velocity data with fatigue parameters

	Slope KE	Slope KF	FI KE	FI KF
PODCI Sports & Physical Function	0.50*	0.40	0.40	0.23
PODCI Transfers & Basic Mobility	0.55*	0.49*	0.55*	0.37
PODCI Global Functioning	0.47*	0.30	0.50*	0.29
PODCI Happiness Scale	0.34	0.43	0.23	-0.09
PODCI Pain & Comfort	0.01	0.02	-0.25	0.07
PODCI Satisfaction	0.10	0.13	-0.18	0.14

PODCI = Pediatric Outcomes Data Collection Instrument; Slope KE = slope of peak torque for knee extension; Slope KF = slope of peak torque for knee flexion; FI = Fatigue Index

Discussion

Contrary to our hypotheses, the knee flexors and extensors in our sample of subjects with CP were actually less fatigable than in the age-matched control group, as indicated by both Slope and FI. Furthermore, higher levels of fatigability (Slope) were associated with higher functioning GMFCS levels, higher levels of function as measured by the PODCI Transfers and Basic Mobility scale and fast velocity, and greater levels of participation in sports and other activities for the CP group. Counterintuitively, it appears as though lower levels of fatigability of the knee flexors and extensors are characteristic of greater disability.

This fatigue protocol was designed as a measure of volitional activity, which would be more representative of everyday function versus an electrically elicited fatigue test or an isometric test. Nevertheless, our results are similar to a study that utilized an electrically elicited fatigue test where the quadriceps were found to be less fatigable than a control group (Stackhouse, Binder-Macleod, & Lee, 2005). However, it should be noted that voluntary contractions, which form the basis of our study, were not part of the fatigue test. Because the muscles were electrically stimulated, only peripheral aspects of muscle fatigue distal to the peripheral motor nerve were assessed. Our study, on the other hand, encompassed both central and peripheral aspects of muscle fatigue, from the central nervous system command to the contractile apparatus of the muscle itself. Furthermore, electrically elicited fatigue tests differ from volitional fatigue tests in the order of activation of muscle fibers, as well as in the firing rate and synchrony of nerve depolarizations (Delitto & Snyder-Mackler, 1990). Therefore, similarities between the two studies should be interpreted within this context.

Our results differ from anaerobic tests previously reported by Parker et al. (1992, 1993) and Tirosh et al. (1990). Results from these studies indicate that peak muscle power and mean power, as a measure of muscle endurance, are markedly deficient in people with CP (Parker et

al., 1992; Parker et al., 1993; Tirosh et al., 1990). However, these authors assessed muscle endurance, or fatigue resistance, in subjects with CP by means of the Wingate Anaerobic Cycling Test (WAnT). From this 30-second, maximal cycling test, mean power is calculated as a measure of endurance. However, mean power is an absolute measure that reflects the average level of explosiveness or power and does not reflect the decline in the force-generating capacity of the muscle. Therefore, the differences in measurement parameters between our study and the aforementioned explain the discrepancy in results.

Several mechanisms can be suggested to explain the greater fatigue resistance of the CP group, the first of which are maximal torque level (strength) and muscle mass. It has been suggested that males are more fatigable than females (Hunter & Enoka, 2001; Pincivero et al., 2003), and adults are more fatigable than children (Kanehisa, Okuyama, Ikegawa, & Fukunaga, 1995) and older adults (Lanza, Russ, & Kent-Braun, 2004) due to greater strength and/or greater muscle mass. The muscle mass or strength hypothesis states that stronger subjects would have more blood flow occlusion than weaker subjects at the same relative load, particularly during isometric tasks (Barnes, 1980). While gender was not predictive of muscle fatigue in our sample of subjects with CP, the peak absolute torque of both muscle groups obtained during the fatigue test was 50% lower in the CP group compared to the control group and could partially explain the greater fatigue resistance. Perhaps, the lower capacity for force production in the subjects with CP prohibits the rapid decline in torque that was observed in the control group. However, it should be noted that gender and age differences in fatigability due to absolute strength differences have been refuted by some researchers (Hunter, Critchlow, Shin, & Enoka, 2004; Lindstrom, Lexell, Gerdle, & Downham, 1997). Some authors claim that weakness leads to disuse atrophy and increased levels of fatigability (Edgerton, Roy, Allen, & Monti, 2002). A secondary consequence of weakness and muscle atrophy is the recruitment of more motor units

or the greater frequency of excitation required to perform a given task. As a consequence of recruiting more motor units, the overall fatigability will likely increase because increased numbers of upper threshold units will be recruited, which include more fast fatiguing fibers. Although these are all plausible theories, the relationship between absolute strength and muscle fatigue is not fully understood and warrants further investigation.

Second, predominance of a particular fiber type can influence fatigue, as Type I (slow twitch) fibers are more fatigue-resistant, while Type II (fast twitch) fibers are more fatigable (Burke, Levine, Tsairis, & Zajac, 1973; Thorstensson & Karlsson, 1976). Decreased muscle fatigue of children and the elderly as compared to adults has also been attributed to an increased proportion of Type I, fatigue resistant fibers (Jansson, 1996; Larsson, Sjodin, & Karlsson, 1978). Similarly, it has been postulated that a greater proportion of type II muscle fibers in men may account for the greater fatigability of men compared to women observed in certain studies (Bilodeau, Schindler-Ivens, Williams, Chandran, & Sharma, 2003). Although there are reports of increased type I fibers in CP, there has been no consensus on fiber type predominance (Castle et al., 1979; Ito et al., 1996; Marbini et al., 2002; Ponten, Friden, Thornell, & Lieber, 2005; Romanini et al., 1989; Rose et al., 1994). These studies sampled muscle fibers across numerous muscles and clinical presentations in addition to other methodological differences. Therefore, it is not surprising that there is no general consensus on fiber type predominance. However, the main results of this study could partially be explained if the disease process of CP does result in muscle adaptations, which include increased proportions of Type I fibers. Other muscle abnormalities in individuals with CP include collagen accumulation (Booth et al., 2001) and increased stiffness at both the cellular (Friden & Lieber, 2003) and whole muscle level (Hufschmidt & Mauritz, 1985). Perhaps, these muscle adaptations play a role in the development of fatigue resistance as well.

Third, the issue of voluntary muscle activation must be considered. Lower voluntary muscle activation in older adults has been postulated to contribute to differences in muscle fatigue between older and younger adults (Bilodeau, Erb, Nichols, Joiner, & Weeks, 2001; Stackhouse et al., 2001). Similarly, Stackhouse, Binder-Macleod, and Lee (2005) observed voluntary muscle activation ratios of approximately 0.45 of the quadriceps and triceps surae in children with CP ages 7 to 13 compared to 0.68 and 0.92, respectively, in age-matched typically developing children. Therefore, despite the fact that the subjects with CP were giving 100% effort, it is possible that they were not activating all of their motor units secondary to impaired motor pathways. As a result, type I fibers may be preferentially recruited with lower firing rates, contributing to the fatigue resistance. A limitation of the Stackhouse et al. (2005) study and others that have examined voluntary or central activation ratios by means of twitch interpolation is that voluntary activation is not assessed during the fatigue testing protocol. Therefore, it is difficult to determine the extent to which voluntary activation levels contribute to the decline in torque during the fatigue test. Further research is necessary to determine if there is a relationship between level of voluntary muscle activation and muscle fatigue, as evidence for this theory is lacking in the literature.

Differences in fatigability of the hamstrings measured during knee flexion and the quadriceps measured during knee extension emerged across both groups. However, the differences were not consistent for both fatigue parameters. According to the FI, the hamstrings were more fatigable than the quadriceps. Conversely, the quadriceps were more fatigable than the hamstrings, as indicated by a greater slope. This discrepancy may be due to the manner in which the fatigue parameters are calculated.

The formula for the FI (%) can be reorganized as $\Delta PT / \text{maximum torque}$. Thus, FI is inversely influenced by the maximum PT values, where the slope is not, e.g. $\text{Slope} = \Delta PT /$

Δ Reps. The following theoretical discussion illustrates that extremely low PT could artificially inflate FI values. The following torque values are approximated to the actual values for ease of interpretation. For simplification, assume Δ Reps equals 50 repetitions, and that the average of the PT of the last 5 repetitions is theoretically equivalent to the PT of the last rep and that the average of the highest consecutive 5 reps is equivalent to the first of the highest 5 reps. For the quadriceps, the average PT of the last repetition was approximately 50 N-m, and the average PT of the first of the highest 5 consecutive repetitions was 80 N-m, averaged across groups. This would result in a slope of 0.6 and a FI of 37.5%, with a max torque of 80 and Δ PT of 30 N-m. For the weaker hamstrings in this study, the average PT of the last repetition was 20 N-m, and the average PT of the first of the highest 5 consecutive repetitions was 40 N-m. This would result in a slope and FI of 0.4 and 66%, respectively, with a max torque of 40 and Δ PT of 20 N-m. It is clear that the much lower maximum torque inversely influenced the FI, e.g., $FI \propto \Delta PT / \text{maximum torque}$. The slope, on the other hand, was only influenced by the magnitude of the difference between the lowest and highest PT value, where $\text{Slope} \propto \Delta PT$. Therefore, the slope of the hamstrings was less than the quadriceps due to the smaller Δ PT, but the FI was biased by the much lower maximum torque of the hamstrings, resulting in a higher FI value. The difference in the way the two parameters are calculated explains the discrepancy between the results of the FI and slope for the effect of muscle groups (hamstrings and quadriceps). The same trend was observed for the quadriceps and hamstrings when the fatigue parameters were calculated separately for the group with CP and the control group. This observation is similar to other studies that have shown the weaker hamstrings to be more fatigable than the quadriceps by calculation of a FI in a healthy adult population (Gleeson & Mercer, 1992).

Most studies of muscle function in people with CP have focused on strength. However, muscle endurance, or resistance to fatigue, is an important component of muscle performance

and has been overlooked in people with CP. Similar to studies of muscle strength, muscle fatigue in this study was directly related to functional aspects, such as global functioning, transfers and mobility, and sports and participation, and unrelated to psychosocial aspects. However, the interpretation of these results is the converse (i.e., greater fatigue resistance, or endurance, is predictive of lower levels of function and participation, as measured by the PODCI and GMFCS). Until we understand the mechanisms behind the apparent fatigue resistance observed in subjects with CP, we cannot fully understand the relationship between fatigue and function.

In summary, the results of our study indicate that the knee flexors and extensors of people with CP are less fatigable than age-matched peers without motor disability. In addition, lower levels of muscle fatigability are associated with lower levels of function and participation. These results suggest that a certain level of muscle fatigability is typical of a normally developed muscle. It is postulated that the fatigue resistance may be attributed to weakness or lower absolute torque levels, decreased voluntary activation, or muscle fiber type changes secondary to hypertonia. However, further research is needed in order to explore these mechanisms and the potential effect on muscle fatigability.

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CHAPTER 4: MUSCLE FATIGUE IN CEREBRAL PALSY: RELATIONSHIP TO SPASTICITY, STRENGTH, STIFFNESS, AND COCONTRACTION

Introduction

Muscle fatigue, or fatigability, is defined as a reduction in force output that occurs during sustained activity (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983). Debate over the mechanisms responsible for lower levels of muscle fatigue, known as fatigue resistance, in certain populations has been the topic of discussion for many years. For example, greater fatigue resistance has been observed in children and healthy older adults compared to young adults and females compared to males. Despite the fact that the results are equivocal, several mechanisms have been proposed to explain the fatigue resistance, primarily differences in the following: muscle mass, muscle morphology, voluntary activation, patterns of motor unit recruitment and rate modulation, and energy metabolism or substrate utilization (Lanza, Russ, & Kent-Braun, 2004; Pincivero, Gandaio, & Ito, 2003; Ratel, Lazaar, Williams, Bedu, & Duche, 2003).

We have shown in a previous study that the knee flexors and extensors in children and young adults with cerebral palsy (CP) are more fatigue resistant than those of typically developing peers (Moreau, Li, & Damiano, 2006b). In addition to the aforementioned factors, there are additional factors related to neurological injury that may play a significant role in the fatigue-resistance observed in our sample of subjects with CP. Factors that may contribute to muscle fatigue are weakness, cocontraction, spasticity, and stiffness. CP is a multifaceted disorder and as such, complex interrelationships exist among upper motor neuron lesion impairments. The relationships between muscle fatigue and other impairments are important in the understanding of fatigue, as these impairments may, in fact, contribute directly or indirectly to the level of muscle fatigability.

It is well-recognized that many children with CP have spasticity, or a velocity-dependent increased resistance to movement due to hyperexcitable stretch reflexes (Lance, 1980). Although

the primary lesion of CP is neural, it is important to discuss the properties of spastic muscle because muscles adapt to the amount and type of neural stimulation that is imposed upon them. In general, fiber type distribution and muscle fiber size are indicators of the amount and type of activity imposed upon a muscle and as such, are often investigated in spastic muscle in order to determine a muscle's usage pattern (Lenman, Tulley, Vrbova, Dimitrijevic, & Towle, 1989; Miller, Green, Moussavi, Carson, & Weiner, 1990; Rose et al., 1994). Predominance of a particular fiber type can influence fatigue, as Type I (slow twitch) fibers are more fatigue-resistant while Type II (fast twitch) fibers are more fatigable (Burke, Levine, Tsairis, & Zajac, 1973; Thorstensson & Karlsson, 1976). Therefore, investigation of the muscle adaptations which may occur secondary to spasticity has provided insight into the effects of the disease process on muscle characteristics over an extended period of time (Lieber, Steinman, Barash, & Chambers, 2004). Several authors have reported increased percentages of type I fibers in children with CP (Ito et al., 1996; Marbini et al., 2002; Rose et al., 1994). If greater loss or transformation of Type II to Type I fibers occurs as a secondary adaptation to spasticity, then this could contribute to lower levels of fatigability. However, the results are not conclusive as there have also been reports of no differences in fiber type (Castle, Reyman, & Schneider, 1979; Romanini, Villani, Meloni, & Calvisi, 1989). These studies sampled fibers across numerous muscles in addition to other methodological differences, so it is not surprising that there are discrepancies. Furthermore, spasticity may not affect certain muscles while affecting others to varying degrees within and between individuals, so it is important to document both the presence and magnitude of spasticity for the muscles under investigation.

Other muscle abnormalities which may play a role in the development of fatigue resistance in individuals with CP include excessive collagen accumulation (Booth, Cortina-Borja, & Theologis, 2001) and increased stiffness at both the cellular (Friden & Lieber, 2003)

and whole muscle level (Hufschmidt & Mauritz, 1985). Stiffness is defined as a length-dependent resistance to movement and quantified as the slope of the torque/angle curve. It has been suggested that increased stiffness may be a compensation for weakness, thus allowing better utilization of elastic energy during functional activities, such as gait (Lamontagne, Malouin, & Richards, 2000; Svantesson & Sunnerhagen, 1997). Therefore, stiffness may also contribute to fatigue resistance through altered mechanical properties of muscle.

Strength deficits as high as 50% or greater have been well documented in children with CP. The exact nature of the weakness is unclear and is thought to be a result of either decreased central drive to the agonist due to the lesion itself, spasticity, cocontraction, secondary changes in the properties of the muscles fibers, or some combination of the above (Damiano, Quinlivan, Owen, Shaffrey, & Abel, 2001). Cocontraction refers to the simultaneous activation of agonist and antagonist muscles during voluntary movement. Cocontraction, in particular, may impair the full activation of the agonist due to reciprocal inhibition, leading to weakness (Milner, Cloutier, Leger, & Franklin, 1995; Tyler & Hutton, 1986). Differences in strength have been postulated to explain the differences in fatigability observed between older and younger adults (Hunter & Enoka, 2001; Pincivero et al., 2003), children and young adults (Kanehisa, Okuyama, Ikegawa, & Fukunaga, 1995), and females and males (Hunter & Enoka, 2001; Pincivero et al., 2003). The muscle mass or strength hypothesis states that stronger subjects would have more blood flow occlusion than weaker subjects at the same relative load, particularly during isometric tasks, leading to higher levels of fatigability (Barnes, 1980). Still others feel that stronger individuals have a higher susceptibility to fatigue due to the ability to generate higher absolute torque levels (Pincivero et al., 2003).

Although we have previously shown that the knee flexors and extensors in people with CP are less fatigable than typically developing peers, possible contributors to the fatigue

resistance have yet to be investigated. Therefore, the purpose of this study was to quantify spasticity, stiffness, cocontraction, and strength of the quadriceps and hamstrings in a group of subjects with mild to moderate CP in order to determine whether these variables are associated with fatigue-resistance of these muscle groups. We hypothesized that subjects with spasticity would have lower levels of muscle fatigability. In addition, we hypothesized that the magnitude of spasticity would be inversely related to the amount of muscle fatigue in the spastic muscle. For example, those with spasticity of the hamstrings would have lower levels of muscle fatigue of the hamstrings compared to those without hamstring spasticity. Furthermore, higher magnitudes of spasticity as measured by resistive torque would be associated with lower levels of muscle fatigue. Due to the interrelationships of muscle weakness with stiffness and cocontraction, we also hypothesized that higher levels of weakness, stiffness, and cocontraction would be associated with lower levels of muscle fatigue about the knee joint.

Methods

Participants

Seventeen subjects with cerebral palsy (CP) between the ages of 10 and 25 were recruited for the study. Physical demographics of the subjects are listed in Table 4.1. All subjects were able to ambulate at least a short distance with or without assistive devices. Subjects were excluded if they underwent orthopedic surgery within 12 months prior to the testing, received Botulinum toxin injections to the quadriceps or hamstrings within 6 months prior to the testing, or suffered from knee pain. Passive range of motion of the knee was also assessed prior to testing to determine if the subject had sufficient range of motion to complete the test. A control group of 14 subjects without motor disability (ages 10-24) was used for comparison and illustrative purposes.

Table 4.1
Physical Demographics

	Sex	Age		Height (m)	Weight (kg)	GMFCS		
		range	mean/sd			I	II	III
CP	12F/5M	10 - 23	17.5 ± 5.0	1.5 ± 0.1	47.6 ± 9.9	9	5	3
Control	11F/3M	10 - 23	16.6 ± 4.4	1.6 ± 0.1	54.0 ± 9.7	na	Na	na

M = male; F = female; na = not applicable

The study was approved by the Institutional Review Board at our institution. A written consent form was obtained from each participant over 18 years of age. A parental permission form signed by one parent or legal guardian was required for participants under 18 years of age. In addition, the minor was required to read and sign a child assent form (APPENDIX 2).

Instruments

Isokinetic Dynamometry

An isokinetic dynamometer (Biodex Medical Systems Incorporated, Shirley, NY, USA) was used to collect angular displacement, angular velocity, and torque data for both the passive and active trials. These were then used to calculate strength, spasticity, stiffness, and muscle fatigue of the knee flexors and extensors. Consistent throughout the paper, the terms knee extension and flexion will refer to the direction of motion, regardless of whether the trial was active or passive.

Electromyography

Surface electromyography (EMG) of the lateral hamstrings and quadriceps was collected with the MA-300 EMG system (Motion Lab Systems, Baton Rouge, LA, USA). The skin of the participant was cleansed and abraded with alcohol prep pads before placement of the electrodes. The Ag-AgCl bipolar electrode pair was positioned one-third of the distance between the ischial tuberosities and the popliteal crease on the muscle bellies of the biceps femoris and

semitendinosus. The circular 1.0 cm diameter electrode pair was positioned 2.0 cm, center to center, from each other and longitudinally along the muscles. The MA-311 (Motion Lab Systems, Baton Rouge, LA, USA) surface EMG pre-amplifiers were placed on the muscle bellies of the rectus femoris and vastus medialis, on the proximal and distal one-third of the distance between the anterior iliac superior spine and the patella, respectively. A ground electrode was placed on the anterolateral surface of the participant's upper thigh. Proper electrode placement was verified through use of the WinDaq Acquisition software (Dataq Instruments, Dayton, OH, USA) in conjunction with manual muscle testing of each muscle. The bandpass width used for collection was 0 – 500 Hz, and the signal was sampled at 1000 Hz per channel with an amplification of up to 20,000. The common mode rejection ratio (CMRR) was 100 dB. The EMG was collected using a 12 bit analog to digital conversion board via the EMG system and saved for future processing. Angular displacement, angular velocity, and torque data from the dynamometer were collected with the EMG data and internally synchronized using the WinDaq Acquisition software.

Protocol

Setup

The electrodes were positioned as described above. The subject was positioned in the Biodex chair in a semireclining sitting position with the thigh horizontal and trunk 70 degrees above horizontal. The more involved lower extremity was tested for subjects with bilateral or unilateral involvement if they had sufficient motion and mobility in that limb to perform the test. The left lower extremity was tested for control subjects. The subject's knee joint center was aligned with the center of rotation of the isokinetic device. The leg was secured against the knee attachment pad and additional stabilizing straps around the waist, the trunk, and over the mid-thigh portion were used to restrain trunk and hip movement during testing. The passive range of

motion designated as “comfortable” by the patient was determined and used to set the limits of motion for the rest of testing sessions. Subjects were instructed to keep their arms folded across their chest for all trials.

Isokinetic Passive Testing

The passive testing consisted of repeated extension and flexion of the knee within the preset range of motion with a 1 second pause during the reversal of motion. The subjects were instructed to relax their muscles. Surface EMG of the quadriceps and hamstrings were monitored during the test to provide verification that the muscles were not active. Three passive repetitions were performed at 5, 10, 30, 60, 90, and 120 degrees/second. A 30 second rest period was provided between each velocity. Peak resistive torque (RT) was calculated for both knee flexion and extension motions (Damiano et al., 2002; Damiano et al., 2001).

Isokinetic Strength Testing

The subjects performed 5-10 submaximal concentric, reciprocal knee flexion and extension repetitions to familiarize themselves with the procedure. The subjects then performed 3 maximal concentric exertions for each muscle group at 60 degrees per second. One minute of rest was given between repetitions to minimize muscle fatigue (Damiano et al., 2001). The subjects were instructed to “push” and “pull” their leg against the lever as hard as possible. Verbal encouragement and visual feedback of the torque value presented on the monitor was used to encourage maximum effort.

Isokinetic Fatigue Testing

Five minutes of rest was given prior to the muscle fatigue protocol. The fatigue protocol consisted of reciprocal, maximal concentric knee extension and flexion at 60 degrees/second for 35 repetitions. This protocol was shown to be feasible in a group of subjects with mild to moderate CP (Moreau, Li, & Damiano, 2006a). The subjects were instructed to “push” and

“pull” their leg against the lever as hard as possible. Strong verbal encouragement was given for every repetition to encourage maximal effort on all repetitions. The subject was able to terminate the test at any time either verbally or through use of a safety switch.

Data Analysis

Spasticity

Table 4.2 lists all of the abbreviations used to identify variables by category in the data analysis. Only data in the constant velocity portion of the passive trials were analyzed, thereby negating the effects of inertia. Gravity correction calculation of the limb’s weight was taken between 30 and 45 degrees of knee flexion in order to remove the gravitational effects of the limb and attachment from each trial. The algorithm provided by the Biodex Advantage Software Operations Manual (Version 3.29/3.30) was utilized for the gravity correction. Spasticity was measured as the peak resistive torque (RT) during the isokinetic portion of the range at 60 and 120 degrees/second, with EMG verification of a stretch response. 60 degrees/second was chosen because the voluntary tests of strength and muscle fatigue were tested at this speed. Due to the velocity dependent nature of spasticity, the fastest speed of 120 degrees/second was also chosen as a representative measure of spasticity. Spasticity of the hamstrings was measured as the peak RT during passive knee extension (RTH), and spasticity of the quadriceps was measured as the peak RT during passive knee flexion (RTQ).

EMG data were used to verify the presence or absence of a stretch response, or spasticity, during each passive trial at 30, 60, 90, and 120 degrees/second separately for the hamstrings and quadriceps. Participants were categorized by whether or not they demonstrated hamstrings or quadriceps stretch responses. The speed at which the stretch response began, or the velocity threshold, was recorded for each subject (Damiano et al., 2002; Damiano et al., 2001).

Table 4.2

List of abbreviations (by category) used to identify the various variables

Variables (units)	Description
<i>Universal</i>	
KE	Knee extension
KF	Knee flexion
PT (N·m)	Peak torque
<i>Fatigue variables</i>	
Slope PTQ (N·m·rep ⁻¹)	Slope of the decline in quadriceps PT (KE) over 35 reps
Slope PTH (N·m·rep ⁻¹)	Slope of the decline in hamstring PT (KF) over 35 reps
FIQ (% decline)	Fatigue index of quadriceps (% decline in PTKE) over 35 reps
FIH (% decline)	Fatigue index of hamstrings (% decline in PTKF) over 35 reps
<i>Strength variables</i>	
PTQ (N·m)	Strength (PT) of the quadriceps during active KE
PTH (N·m)	Strength (PT) of the hamstrings during active KF
FatPTQ (N·m)	PT of quadriceps over all KE repetitions of the fatigue test
FatPTH (N·m)	PT of hamstrings over all KF repetitions of the fatigue test
<i>Spasticity</i>	
RT (N·m)	Resistive torque
RTQ60 and RTQ120 (N·m)	Peak RT of the quadriceps during passive KF at 60 and 120 degrees/second, respectively
RTH60 and RTH120 (N·m)	Peak RT of the hamstrings during passive KE at 60 and 120 degrees/second, respectively
<i>Stiffness</i>	
StiffQ5, StiffQ30, StiffQ60, StiffQ90 (N·m·deg ⁻¹)	Stiffness of quadriceps (slope of torque/angle curve) measured during passive KF at 5, 30, 60, & 90 deg/sec, respectively
StiffH5, StiffH30, StiffH60, StiffH90 (N·m·deg ⁻¹)	Stiffness of hamstrings (slope of torque/angle curve) measured during passive KE at 5, 30, 60, & 90 deg/sec, respectively
<i>Cocontraction</i>	
CoconQ (%)	Cocontraction of quads as % of activity working as an agonist
CoconH (%)	Cocontraction of hams as % of activity working as an agonist

Stiffness

Gravity correction and removal of the acceleration and deceleration phases of the trials were performed as described above. Passive tissue properties can be characterized as viscoelastic (Lehmann, Price, deLateur, Hinderer, & Traynor, 1989). Passive elastic stiffness was measured by the slope of the resistance torque by angle curve during the constant velocity portion of the 5 degree per second passive trial in the absence of EMG activity. Simultaneous collection of

surface EMG of the quadriceps and hamstrings provided verification that the muscles were not active during this slow, passive trial. The slow speed was used in order to minimize the effect of velocity and reflexive activity (Lee, Huang, Chen, & Hwang, 2002). In this manner, the resistance provided by the passive mechanical properties of the tissues, such as non-active muscle tissue, joint capsule, and surrounding connective tissue was measured. For simplification, stiffness measured during knee extension will be referred to as stiffness of the hamstrings (StiffH), and stiffness measured during knee flexion will be referred to as stiffness of the quadriceps (StiffQ). To provide a measure of velocity-dependency, stiffness was also calculated as the slope of the resistance torque by angle curve at 30, 60 and 90 degrees/second (Damiano et al., 2001). Both reflexive and elastic stiffness play a role in those with spastic responses at these higher velocities. We were unable to calculate stiffness at 120 degrees/second in the majority of subjects secondary to the truncated constant velocity range.

Cocontraction

The recorded EMG data from the strength assessment were full-wave rectified and smoothed with a low pass filter at 6 Hz using a fourth-order zero lag Butterworth filter. The filtered EMG was separated into a flexion and extension phase during the isokinetic portion and the mean absolute value (MAV) was calculated. Hamstring cocontraction (CoconH) during the maximal knee extension contraction was calculated as the ratio of the MAV of the biceps femoris EMG activity during the extension phase to the EMG activity during the flexion phase, multiplied by 100. Quadriceps cocontraction (CoconQ) during the maximal knee flexion contraction was calculated as the ratio of the MAV of the rectus femoris EMG activity during the flexion phase to the EMG activity during the extension phase, multiplied by 100 (Baratta et al., 1988; Weir, Keefe, Eaton, Augustine, & Tobin, 1998).

Strength

Torque data from the strength assessment were also gravity corrected and only the constant velocity portion was used. Voluntary peak torque (PT) was calculated for each of the 3 repetitions of the strength test for both extension and flexion. The maximum of these values over the 3 repetitions was the measure of strength for each muscle group (Damiano et al., 2001). Strength of the quadriceps (StrPTQ) was measured as the voluntary PT during knee extension. Strength of the hamstrings (StrPTH) was measured as the voluntary PT during knee flexion. The maximum PT over the 35 repetitions of the fatigue protocol was also recorded as a measure of strength for the quadriceps (FatPTQ) and the hamstrings (FatPTH).

Fatigue

Two accepted measures of fatigue were computed: 1.) percent decline in peak torque over the 35 repetitions, calculated as a Fatigue Index (FI) (Pincivero et al., 2003):

$$FI = 100 - \left[\frac{PT \text{ last } 5 \text{ reps}}{PT \text{ highest } 5 \text{ reps}} \times 100\% \right]$$

2.) rate of decline in PT represented by the slope of the linear regression, beginning with the first value of the highest 5 consecutive repetitions and ending with the last repetition (Pincivero, Gear, & Sterner, 2001). Because FI and slope calculations began with the first value of the highest 5 consecutive repetitions, the protocol was extended to 50 repetitions in subjects when the initial highest torque value occurred later than the 15th repetition. Torque data from the fatigue protocol were gravity corrected and only the constant velocity portion was used as described previously. Fatigue of the quadriceps muscle group was measured as the FI (FIQ) and slope (SlopePTQ) calculated during knee extension, and fatigue of the hamstrings was measured as the FI (FIH) and (SlopePTH) during knee flexion. This fatigue protocol was previously shown to be reliable in children and young adults with mild to moderate CP (Moreau et al., 2006a).

Statistical Analyses

Linear regression was used to determine the relationships between the fatigue parameters (slope and FI) and stiffness, spasticity, strength, and cocontraction for both knee extension and flexion. Stepwise multiple regression analyses were performed in order to identify which of these factors or combination of factors best explained the variations in fatigability. The dependent variables were the FI and slope for the knee extensors and flexors. Measures of stiffness, spasticity, strength, and co-contraction were entered as independent variables. The criterion for entry into the regression equation and removal was $p < 0.05$. An R-Square selection option was also run to see if other combinations of variables predicted similar amounts of variance as the resulting step-wise regression models. For example, if a two factor model was predicted by the step-wise multiple regression analysis, then other two factor models were compared to see if a similar amount of variance could be explained with a different combination of variables. One-way ANOVA was used to test for differences in fatigability between subjects with and without hamstring and quadriceps spasticity and control subjects. Tukey's HSD was used for post-hoc analysis. Finally, t-tests were used to test for differences in the peak torque obtained from the strength test versus the fatigue protocol for both muscle groups.

Results

The maximum torque during the fatigue test occurred between the 3rd and 27th repetition for the knee extensors (9.3 ± 7.2) and between the 1st and 20th repetition for the knee flexors (5.0 ± 6.1) for the group with CP. In the control group, the maximum torque during the fatigue test occurred on average during the 3rd repetition for both knee extension (3.4 ± 2.1) and knee flexion (3.4 ± 3.7). As illustrated in Table 4.3, maximum peak torque of the quadriceps obtained during the strength test (PTQ) was significantly less than the maximum torque obtained during the fatigue test (FatPTQ) for the group with CP. However, values from the two tests for the

hamstrings were similar. No significant differences between the PT values of the strength and fatigue tests were observed in the control group for either muscle (Table 4.3). Because strength of the quadriceps in the group with CP was underestimated by PTQ in this study and a previous study (Moreau et al., 2006a), the PT values obtained during the fatigue test were used in subsequent analyses as the measure of strength. After normalizing strength by body weight, the subjects with CP were on average 40% and 60% weaker than the age-matched control group for the quadriceps and hamstrings, respectively.

Table 4.3
Comparison of voluntary peak torque obtained during the strength versus the fatigue test

		Strength test	Fatigue test
<u>CP</u>			
	Quad	41.2 ± 3.9	55.0 ± 5.1*
	nQuad	89.9 ± 8.9	120.9 ± 12.0*
	Hams	22.8 ± 3.2	23.9 ± 2.8
	nHams	49.8 ± 6.8	52.3 ± 6.2
<u>Control</u>			
	Quad	110.2 ± 8.8	113.0 ± 9.5
	nQuad	197.4 ± 10.9	200.9 ± 11.9
	Hams	63.0 ± 6.4	60.2 ± 5.5
	nHams	111.7 ± 8.5	107.0 ± 6.9

Peak torque (PT) given in N-m ; * = $p < .0001$;
Quad = PT obtained during knee extension; Hams = PT obtained during knee flexion; nQuad = Quad normalized by body weight; nHams = Hams normalized by body weight

Regression Analyses

Figures 4.1 and 4.2 illustrate the means and SEM of the stiffness and RT values, respectively, for the quadriceps and hamstrings. Figure 4.3 illustrates the means and SEM of the cocontraction values of the quadriceps (CoconQ) and hamstrings (CoconH). The results of both the linear and stepwise multiple regression analyses for the slope of the quadriceps (SlopePTQ) as a measure of fatigue are presented in Table 4.4. Strength of the hamstrings and quadriceps

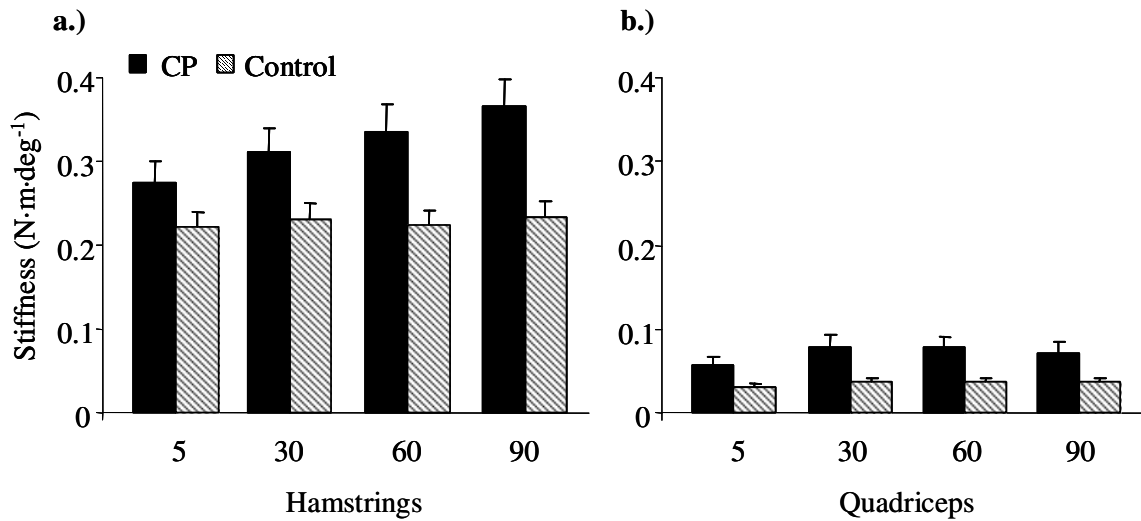


Figure 4.1. Mean and SEM of **a.)** hamstring stiffness and **b.)** quadriceps stiffness at 5, 30, 60, and 90 degrees/second for the group with CP and the control group.

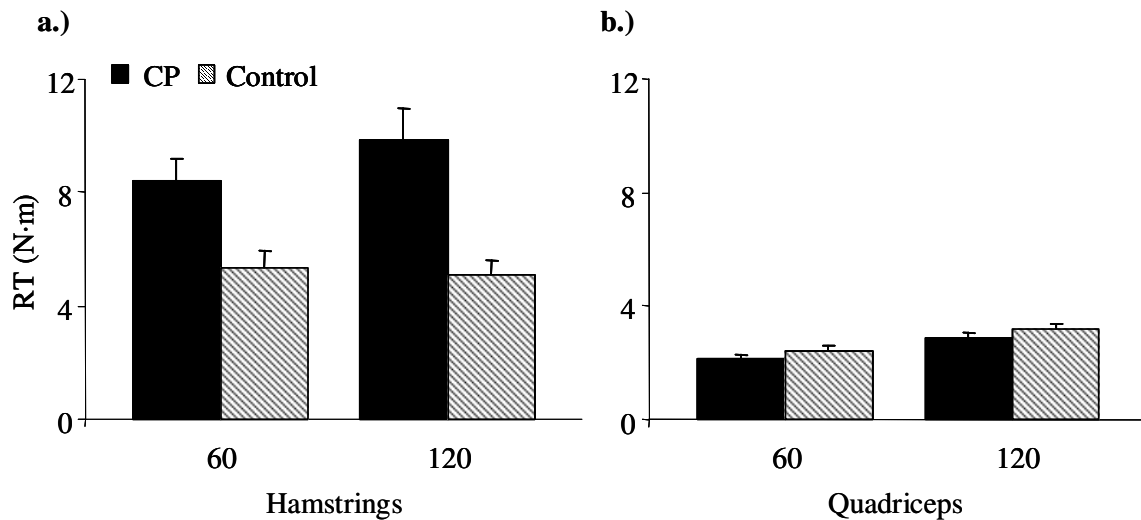


Figure 4.2. Mean and SEM of **a.)** resistance torque (RT) of the hamstrings and **b.)** RT of the quadriceps at 60 and 120 degrees/second as a measure of spasticity for the group with CP and the control group.

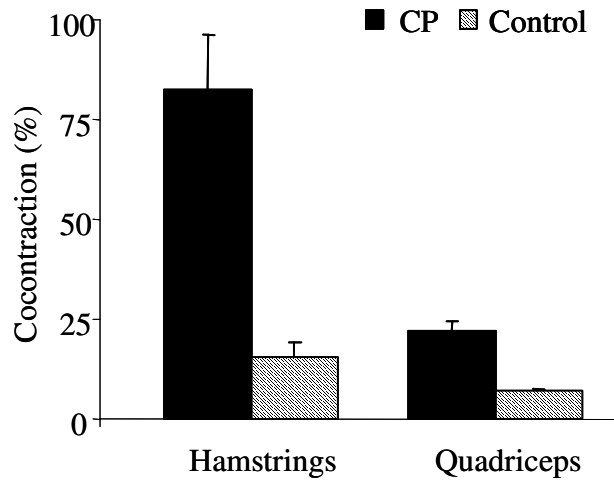


Figure 4.3. Cocontraction of the hamstrings (CoconH) and quadriceps (CoconQ) for the group with CP and the control group.

Table 4.4

Linear and stepwise multiple regression analysis of variables potentially related to muscle fatigue of the knee extensors as represented by the slope of the decline in peak torque across repetitions (SlopePTQ).

Variables	Linear regression coefficient (r)	p	Multiple linear regression parameter est.	Partial R-square	Model R-square	p
FatPTQ	0.69	0.002	-	-	-	-
FatPTH	0.74	0.001	-	-	-	-
StiffH5	0.31	0.22	-	-	-	-
StiffH30	0.20	0.44	-	-	-	-
StiffH60	0.16	0.53	-	-	-	-
StiffH90	0.15	0.58	-	-	-	-
StiffQ5	-0.49	0.04	-	-	-	-
StiffQ30	-0.43	0.08	-	-	-	-
StiffQ60	-0.36	0.15	-	-	-	-
StiffQ90	-0.64	0.02	-	-	-	-
RTH60	0.20	0.45	-	-	-	-
RTH120	-0.06	0.83	-	-	-	-
RTQ60	-0.17	0.53	-	-	-	-
RTQ120	-0.13	0.64	-	-	-	-
CoconH	-0.57	0.02	-0.004	0.43	0.43	0.03
CoconQ	-0.54	0.03	-	-	-	-

est. = estimate

(FatPTH and FatPTQ) were positively correlated to the SlopePTQ, where those who were weaker had lower levels of muscle fatigue of the quadriceps. CoconH and CoconQ were inversely correlated to the SlopePTQ, where higher cocontraction was related to lower levels of quadriceps fatigability. Stiffness of the quadriceps at both 5 (StiffQ5) and 90 (StiffQ90) degrees/second were also inversely correlated to SlopePTQ, such that increased stiffness of the quadriceps was related to lower levels fatigability of the quadriceps. Although strength, stiffness, and cocontraction of both muscle groups were related to fatigability of the quadriceps in the univariate analysis, CoconH was the only significant predictor of SlopePTQ in the multiple regression analysis, explaining 43% of the variance. Both univariate linear regression coefficients and parameter estimates indicate that increased levels of cocontraction of the antagonistic hamstrings muscle group are associated with lower levels of quadriceps fatigability. No other single factor models predicted a similar amount of variance in SlopePTQ.

Table 4.5 illustrates the results of both the linear and stepwise multiple regression analyses for the slope as a measure of fatigue of the hamstrings (SlopePTH). Similarly, FatPTH and FatPTQ were positively correlated to the SlopePTH, where weaker individuals had lower levels of hamstring fatigability. Likewise, StiffQ5, StiffQ90, and CoconH were inversely related to fatigability of the hamstrings. Multiple regression analysis revealed that FatPTH and StiffQ5 were significant predictors of hamstring fatigability as measured by SlopePTH, explaining a total of 72% of the variance. Univariate linear regression coefficients and parameter estimates indicate that weaker hamstrings and stiffer quadriceps are associated with lower levels of hamstring fatigability. No other two factor models predicted a similar amount of variance in SlopePTH.

None of the variables in the univariate linear regression analysis were significantly correlated with the FI of the quadriceps (FIQ), although CoconH approached significance ($r = -0.49$, $p = 0.056$). Only StiffQ90 displayed a significant inverse relationship to FI of the

hamstrings (FIH: $r = -0.68$, $p = 0.01$). Because only one variable was correlated with FIH and none with FIQ, multiple regression analyses were not performed for these variables, and subsequent analyses were only performed on the fatigue slope values.

Table 4.5

Linear and stepwise multiple regression analysis of variables potentially related to muscle fatigue of the knee flexors as represented by the slope of the decline in peak torque across repetitions (SlopePTH).

Variables	Linear regression coefficient (r)	p	Multiple linear regression parameter est.	Partial R-square	Model R-square	P
FatPTQ	0.54	0.02	-	-	-	-
FatPTH	0.78	0.001	0.01	0.27	0.27	0.02
StiffH5	0.27	0.30	-	-	-	-
StiffH30	0.06	0.81	-	-	-	-
StiffH60	0.15	0.56	-	-	-	-
StiffH90	0.13	0.62	-	-	-	-
StiffQ5	-0.49	0.04	-5.60	0.45	0.72	0.02
StiffQ30	-0.24	0.36	-	-	-	-
StiffQ60	-0.22	0.40	-	-	-	-
StiffQ90	-0.72	0.01	-	-	-	-
RTH60	0.10	0.70	-	-	-	-
RTH120	-0.11	0.68	-	-	-	-
RTQ60	-0.30	0.27	-	-	-	-
RTQ120	-0.15	0.59	-	-	-	-
CoconH	-0.52	0.04	-	-	-	-
CoconQ	-0.42	0.11	-	-	-	-

est. = estimate

Presence of Spasticity

Out of the 17 subjects with CP, 10 had hamstring spasticity only, none had quadriceps spasticity only, 4 had quadriceps and hamstrings spasticity, and 3 had no spasticity of either muscle group. Spastic or reflexive stretch responses were detected at 30 degrees/second in 13 of the 18 muscles with spasticity. In the remaining 5 muscle groups, stretch responses were detected at 60 degrees/second in 4 and at 120 degrees/second in 1. All subjects who demonstrated a spastic response at a lower velocity also demonstrated a response at the higher velocities. A

significant difference was observed between groups for both quadriceps ($F_{3,27} = 13.04$, $p < 0.0001$) and hamstring ($F_{3,27} = 10.09$, $p < 0.0001$) fatigability as measured by the slope. Post hoc analyses reveal significant differences between the control group without disability and the two groups with spasticity for SlopePTQ and Slope PTH as illustrated in Figures 4.4a and 4.4b, respectively. The control group was more fatigable than the two groups with spasticity. However, there were no significant differences between the control group and the group without spasticity for both SlopePTQ and SlopePTH, nor were there any differences between the 3 groups with CP.

Discussion

Results of this study indicate that strength, spasticity, stiffness, and cocontraction are related to muscle fatigability of the quadriceps and hamstrings, as measured by the slope. More specifically, strength was directly related to muscle fatigability, where weaker subjects had lower levels of fatigability, regardless of muscle. Cocontraction and quadriceps stiffness, on the other hand, were inversely related to muscle fatigability, where higher cocontraction and quadriceps stiffness yielded lower levels of hamstrings and quadriceps fatigue. When controlling for confounding variables in the multiple regression analysis, the strongest predictors of hamstring fatigability were hamstrings strength and quadriceps stiffness (StiffQ5). A positive relationship of hamstrings strength and an inverse relationship of quadriceps stiffness (StiffQ5) to hamstring yielded lower levels of hamstring fatigability. When controlling for confounding variables in the multiple regression analysis, the strongest predictor of quadriceps fatigability was hamstring cocontraction. An inverse antagonistic relationship of hamstring cocontraction to quadriceps fatigability was observed, where increased cocontraction of the hamstrings was related to lower levels of quadriceps fatigability. Furthermore, the presence of spasticity was also able to

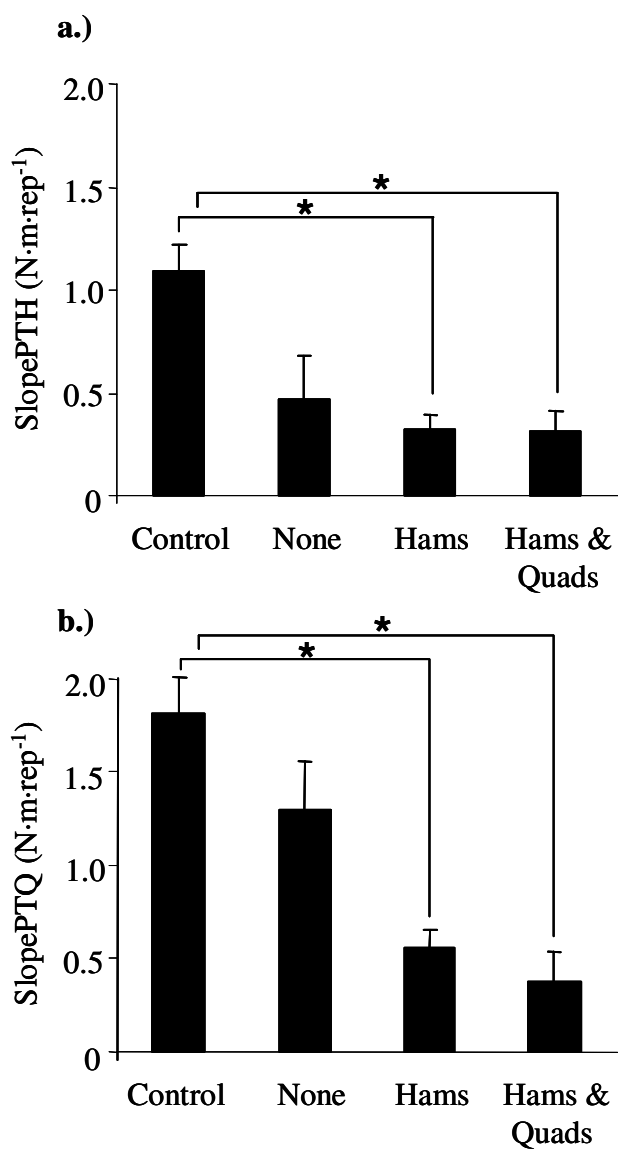


Figure 4.4. Differences in **a.)** hamstring fatigability (SlopePTH) and **b.)** quadriceps fatigability (SlopePTQ) as represented by the slope among groups characterized by presence of spasticity: control group, none, hamstring spasticity only (Hams), and hamstring and quadriceps spasticity (Hams & Quads). * indicates $p < 0.01$ for post-hoc Tukey HSD pairwise comparisons

distinguish between the fatigability of the subjects with CP and the control group, regardless of muscle group.

The direct relationship of strength and muscle fatigue has been observed in other studies (Hunter, Critchlow, Shin, & Enoka, 2004; Pincivero, Gear, Sterner, & Karunakara, 2000); however, the relationship of muscle stiffness and cocontraction to fatigability has not been previously investigated. An antagonistic relationship of fatigability with cocontraction and stiffness emerged in the results of the multiple regression analyses. Perhaps this antagonistic relationship was due to the mechanical effect of cocontraction and stiffness on the net torque measured by the dynamometer. Cocontraction, as well as stiffness of an antagonistic muscle, generates opposing joint torque throughout the range of motion of the agonist. The mechanical effect of the opposing torque would be a decrease in the net agonist torque. Hamstring cocontraction, in particular, has been previously shown to cause a significant decrease in the net moment during knee extension in children with CP (Ikeda, Abel, Granata, & Damiano, 1998). Therefore, the lower absolute torque level, or weakness, may predispose the smaller decline in quadriceps PT, and thus, a lesser slope value.

The presence of spasticity was an important factor that explained the differences in fatigability between the control group and the group with CP. Although there were only 3 subjects without a spastic response in either muscle, there was no significant difference in SlopePTQ or SlopePTH between this group and the control group. However, there were significant differences between the control group and the 2 groups with spasticity. The effect was robust and appeared to be independent of whether spasticity was present in the hamstrings only or the hamstrings and quadriceps for both SlopePTQ and SlopePTH. Differences between the spasticity groups were not detected probably due to the fact that we had a group with mixed quadriceps and hamstrings spasticity rather than a group with isolated quadriceps spasticity.

Nevertheless, subjects without spasticity in the group with CP had similar fatigue values as the control group for both muscle groups.

Surprisingly, the magnitude of spasticity of both the hamstrings (RTH) and quadriceps (RTQ) was not correlated with either the SlopePTQ or SlopePTH. Perhaps, the small sample size and range of RT data were not sufficient to achieve a significant correlation. Our data were comparable to a previous study where RT was calculated at 60 and 120 degrees/second for both the hamstrings and quadriceps; however, a direct comparison cannot be made between the 2 studies because the RT was normalized by body weight in the previous study (Damiano et al., 2001). Stiffness values for both the hamstrings and quadriceps in this study were also comparable to the previous study.

Although the two extremes of stiffness values (Stiff5 and Stiff90) were inversely correlated with SlopePTQ and SlopePTH, StiffQ30 and StiffQ60 were not correlated with either fatigue measure. StiffQ5 represents the elastic or intrinsic stiffness of the muscle in the absence of reflexive activity, whereas stiffness measured at higher velocities is influenced by reflexive activity for those with spasticity. Because the onset of stretch reflex activity occurred at either 30 or 60 degrees/second in the majority of subjects, we would expect greater variability in StiffQ30 and StiffQ60 in regards to the representation of reflexive stiffness. Furthermore, because of the velocity dependent nature of reflexive activity, we would expect StiffQ90 to be a more representative measure of elastic plus reflexive stiffness and StiffQ5 to be more representative of intrinsic elastic stiffness.

We observed a significant difference in the PT of the quadriceps measured during the strength test (PTQ) versus the fatigue test (FatPTQ) for the group with CP only. This same phenomenon was observed in a previous study (Moreau et al., 2006a) and is believed to be of great clinical importance. During the strength assessment, knee extension always begins from a

static position with a 1 minute rest between trials. However, during the fatigue test knee extension is preceded by a pre-stretch of the muscle (active knee flexion) during subsequent trials, which may have a potentiation effect on the contractile machinery of the quadriceps. This enhancement of force production due to pre-stretch has been observed to be significantly greater in subjects post-stroke compared to healthy subjects during stretch-shortening cycles (Svantesson, Grimby, & Thomee, 1994). Perhaps force was enhanced in our group of subjects with CP due to heightened stretch reflex responses or spasticity during pre-stretch of the quadriceps. For the hamstrings, knee flexion is preceded by pre-stretch (active knee extension) during all trials of both the strength and fatigue test. The fact that no difference was observed for the hamstrings between the two measures provides further support for this hypothesis.

Low correlations were observed between the FI and other tested parameters with only significant correlation between FIH and FIQ observed. Although there was consistency of results between the FI and the slope, there were more significant correlations for the slope versus the FI. Despite its popularity of use, the high degree of variability of the FI has been a common finding (Burdett & Van Swearingen, 1987; Sinacore, Bander, & Delitto, 1994). Greater variability makes it difficult to detect changes or relationships between variables and could explain the lack of significance. Furthermore, we have previously shown that the FI is influenced greatly by the maximum torque value, $FI \propto (\Delta PT/Max PT)*100\%$ (Moreau et al., 2006b). Therefore, it appears that the slope is a more sensitive measure of muscle fatigability than the FI.

It is important to note that other factors, beyond the scope of this study, such as energy metabolism, morphological differences, patterns of motor unit recruitment, and voluntary activation may play a role in the differences in fatigability between the two groups. Future studies are needed to decipher the influence of these variables on the level of fatigability. Lastly, caution should be used in extrapolating the results of this study to muscle groups other than the

knee flexors and extensors, as muscle characteristics such as size, fiber type distribution, fiber arrangement, recruitment, and rate coding strategies differ considerably across muscle groups.

In conclusion, the results of this study suggest that the maximum absolute torque level played a significant role in the fatigue resistance observed in the group with CP. The opposing torque created by cocontraction of the hamstrings, which was inversely related to quadriceps fatigability, and the opposing torque generated by intrinsic stiffness of the quadriceps, which was inversely related to hamstring fatigability, possibly contributed to the lower net agonist torque level. Furthermore, the presence of spasticity, regardless of muscle group, was related to lower levels of fatigability compared to control subjects without motor disability.

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CHAPTER 5: GENERAL DISCUSSION

Summary of Results

Fatigue is a frequent subjective complaint in individuals with cerebral palsy (CP) and has been cited as a cause of worsening disability in adulthood (Bottos, Feliciangeli, Sciuto, Gericke, & Vianello, 2001; Jahnsen, Villien, Egeland, Stanghelle, & Holm, 2004). Previous work on fatigue in people with CP has focused primarily on the cardiorespiratory system. This approach has led to limited success as most authors agree that local muscle factors, such as muscle fatigue are responsible for the lower VO_{2max} and limitations in activity (Hoofwijk, Unnithan, & Bar-Or, 1995; Rose, Haskell, & Gamble, 1993; Unnithan, Dowling, Frost, & Bar-Or, 1996). Therefore, the purpose of the experiments presented in Chapters 2, 3, and 4 was to further the measurement and understanding of muscle fatigue in the CP population utilizing the WHO ICF (2001) model as a conceptual framework. Based on this model, the measurement of muscle fatigue at the body function level, the relationship of fatigue to activities and participation, and the possible contributing factors to fatigue at the body function level were investigated.

In Chapter 2, an isokinetic muscle fatigue protocol consisting of the performance of 35 consecutive knee flexion and extension repetitions at 60 degrees/second was determined to be feasible for mild to moderately impaired subjects with CP over a wide age range. Furthermore, two established measures of muscle fatigability (fatigue index and rate of decline in peak torque) were reliably measured from the muscle fatigue protocol. In Chapter 3, the muscle fatigability of the hamstrings and quadriceps in individuals with CP were compared to a control group of age-matched peers without CP. Contrary to our original hypothesis, the hamstrings and quadriceps in individuals with CP were observed to be less fatigable than in age-matched peers without motor disability. Furthermore, lower levels of function, participation, and walking velocity were associated with lower levels of muscle fatigability in the group with CP. In Chapter 4, it was

hypothesized that other impairments at the body function level, such as weakness, spasticity, stiffness, and cocontraction, may contribute to the fatigue resistance observed in the subjects with CP. Results indicate that hamstring strength and antagonistic quadriceps stiffness were the strongest predictors of hamstring fatigability, while cocontraction of the hamstrings was the strongest predictor of quadriceps fatigability. Furthermore, the level of fatigability in subjects with CP who did not have spasticity did not differ from the control subjects, indicating that spasticity may play a role in the fatigue resistance observed in this population.

Discussion of Results and Future Studies

The 3 main findings from these experiments are the following 1.) Muscle fatigue of the hamstrings and quadriceps can be reliably measured in mild to moderately involved individuals with CP utilizing an isokinetic protocol; 2.) The hamstrings and quadriceps of individuals with CP are less fatigable than those of age-matched peers without motor disability, and the lower levels of fatigability are inversely related to measures of function and participation; and 3.) The fatigue resistance observed in the hamstrings and quadriceps of individuals with CP is related to weakness, spasticity, stiffness, and cocontraction of the muscles in question.

Muscle fatigue has been investigated in healthy adults as well as in other neurological populations, such as multiple sclerosis, stroke, and spinal cord injury that present with spasticity and other similar impairments to those seen in CP. Although subjective complaints of fatigue have been documented in people with CP, muscle fatigue has been overlooked in the assessment of muscle performance. Therefore, it was critical to establish a feasible and reliable assessment of muscle fatigue in this population. First, it was necessary to define muscle fatigue before establishing a measurement protocol. Muscle fatigue, or fatigability, was defined as a reduction in the force-generating capacity of the neuromuscular system that occurs during sustained activity (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983). Based on this definition, an

isokinetic muscle fatigue protocol was tested in people with CP over 10 years of age. This protocol was observed to be reliable in mild to moderately impaired children and young adults.

Based on this protocol, the results of the 2nd and 3rd experiments indicate that stronger, more functional people with and without CP have higher levels of muscle fatigability of the hamstrings and quadriceps compared to those with CP who are weaker and less functional. These results do not imply that the muscles of people with CP are somehow superior to those without disability due to the observed fatigue-resistance. Rather, the results suggest that a certain level of muscle fatigability, as measured by the slope and FI, is typical of a normally developed muscle. So how do we explain that the knee muscles of people with CP are less fatigable than those without motor disability? Results suggest a discernable relationship of agonist and antagonistic forces with muscle fatigability. An agonist relationship of hamstring strength and an antagonistic relationship of quadriceps stiffness to hamstring fatigability were observed. Similarly, an antagonistic relationship of hamstrings cocontraction with quadriceps fatigability was observed. The positive relationship between the strength of an agonist muscle and the fatigability of that muscle has shown by others and is thought to be the result of muscle mass differences. According to the muscle mass or strength hypothesis, stronger subjects have more blood flow occlusion than weaker subjects at the same relative load, resulting in greater fatigability (Barnes, 1980). Others believe that the higher absolute torque level predisposes the muscle to a greater rate of decline (Pincivero, Gandaio, & Ito, 2003). This may be due to a greater proportion of type II, fast, fatigable fibers, which are typical of stronger muscles (Miller, MacDougall, Tarnopolsky, & Sale, 1993). The inverse relationship between antagonistic stiffness and cocontraction with fatigability, however, has not been investigated previously. We have proposed a mechanical hypothesis to explain this relationship. According to this hypothesis, antagonistic stiffness and cocontraction would generate opposing torque throughout the range of

motion of the agonist. Because cocontraction and stiffness are inherently higher in this population, the amount of agonist torque negated by these opposing forces would be substantial. This would result in a lower measured (net) torque level, hence weakness. Weakness would further predispose the muscle to be less fatigable.

Theoretically, to assess the effect of strength on the level of fatigability, we would need to match subjects with and without CP for strength for comparison between groups (Hunter, Critchlow, Shin, & Enoka, 2004). Realistically, this would not be feasible, as in our study alone we found strength differences as high as 60% between groups. Perhaps, an alternative would be to investigate the differences between the groups with a measure of fatigue that is not dependent on the maximum torque level. The FI and the slope are both proportional to the difference between the highest and lowest torque, which can be influenced by the maximum torque. The FI is further inversely proportional to the maximum torque level, as observed in Chapter 4. However, Sinacore, Bander, and Delitto (1994) showed that recovery of peak torque of the quadriceps after completion of a fatigue protocol is a reliable measure that is not dependent on the maximum torque level. Furthermore, the measure was responsive to 12 weeks of endurance training, whereas the percentage decline in peak torque (FI) was not altered as a result of training. Future studies should investigate the differences in recovery of peak torque between subjects with and without CP after completion of the fatigue protocol described in Chapter 2 to see if the differences in fatigability persist. The results of this study should provide further insight into the influence of maximum torque level, or strength, on the level of muscle fatigability.

In order to further explore the relationship between cocontraction and fatigability, future studies should investigate the relative contribution of antagonist muscle activity to the net moment measured throughout the fatigue protocol. For example, if both agonist and antagonist

force production decline at similar rates during the fatigue protocol for subjects with CP, then the torque output should remain relatively constant throughout the protocol due to the reduced contribution of the antagonist. This would result in a small rate of decline in PT and hence, a low rate of fatigability as measured by the slope. The results of this study would provide direct evidence of the contribution of antagonist cocontraction to the rate of decline in peak torque of the agonist muscle. Figure 5.1 illustrates a hypothetical situation where the rate of decline (slope) of agonist torque is identical for the groups with and without CP, but the magnitude of torque output is substantially lower for the group with CP secondary to weakness. The contribution of antagonist force production to the net torque remains constant for the control group, as has been observed by Kellis (2003) in healthy subjects. In contrast, the magnitude of antagonist force production and rate of decline is much greater for the group with CP. Therefore, the result is a substantially lower net torque output and a lower rate of decline for the group with CP, similar to the results of our experiments.

The presence of spasticity, regardless of muscle group, was also a contributing factor to the lower muscle fatigability observed in the subjects with CP. The fatigability of the subjects in the CP group without spasticity did not differ from the control subjects. Only those subjects with spasticity of either muscle group had lower levels of fatigability compared to controls. This result provides indirect support that spasticity results in alterations of muscle properties that may include fiber type changes that would predispose the muscles to a lower rate of fatigue.

Future studies are needed in order to address the effects of spasticity on fiber type composition and the resultant effect on the level of muscle fatigability observed in this population. An issue that has not been addressed in these biopsy studies of spastic muscle is the presence and amount of spasticity, if any, in the muscles sampled. Both clinically and experimentally, it is common to have spasticity in certain muscle groups and not in others

(Damiano et al., 2002; Katz, Rovai, Brait, & Rymer, 1992). For example, it is more common to have spasticity of the hamstrings than in the quadriceps. However, the relationship of fiber type to the amount of spasticity has not been explored. Therefore, if spasticity is believed to result in secondary myopathic changes, the presence and degree of spasticity should be documented for the muscles in question. Until this is documented and investigated experimentally, we cannot accurately say that these findings are representative of “spastic” muscle. Future studies should include biopsies of identical muscles across individuals with EMG verification of the presence of spasticity of each muscle. Fiber type compositions could then be compared to investigate whether or not the relationship exists. The results of this study would shed considerable light on the effect of spasticity on muscle fiber type composition and the resulting effect on muscle performance.

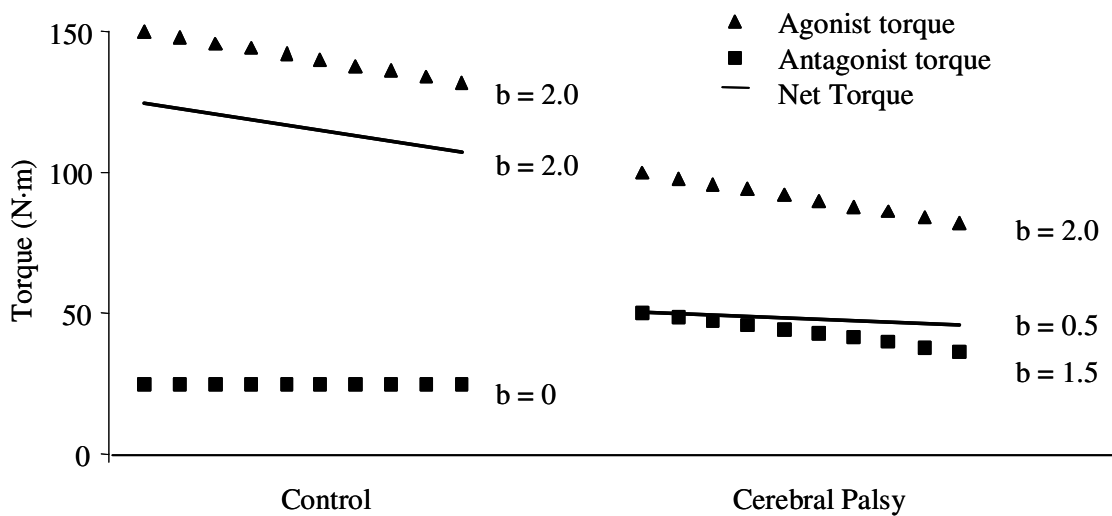


Figure 5.1. Hypothetical example of agonist and antagonist contributions to the net joint torque, represented by a straight line, over 10 consecutive repetitions for a control group and a group with CP. The effect on the rate of the decline in peak torque is represented by the absolute value of the slope (b).

Clinical Significance

Although previous research has focused on the amelioration of spasticity as a primary goal of treatment, current research has shown that other aspects of muscle performance, such as strength, have higher correlations with gross motor function and walking velocity, and are amenable to treatment. Therefore, most studies of muscle function in people with CP have focused on lower extremity strength, thereby overlooking muscle fatigue as an important component of muscle function. A search of the medical literature revealed there are no established muscle fatigue protocols for people with CP. Therefore, this is the first investigation of localized muscle fatigue in this population by means of voluntary contraction in conjunction with measures of strength, hypertonia, and function. The establishment of a feasible and reliable muscle fatigue protocol in this population has widespread applications for future research as well as for clinical assessment.

The WHO ICF model was developed as a framework to assist in the understanding and measurement of health outcomes. By investigating muscle fatigue at the body function level, as well as the level of functioning of the individual (activities) and the whole person in a social context (participation), we have provided a more comprehensive view of muscle fatigue. For example, this series of experiments has provided unique insight into the muscle fatigue characteristics of this population and the relationship to function. For example, based on the results of our study, a clinician would expect muscle fatigue to increase, not decrease, as walking velocity and strength improved as the result of an intervention program in a person with CP. This runs counter-intuitive to the view that increased muscle fatigue is a negative symptom that would occur in lower functioning patients. Based on our definition and measurement of fatigue, the results of our study challenge the notion that less fatigable is better in this population. It raises

the question of whether the fatigue resistance observed in this population is the product of disordered motor control and possibly, muscle property alterations.

Traditionally, muscle fatigue was thought to occur exclusively either in the central nervous system or the peripheral nervous system. However, since muscle activity depends on the integrity of the entire chain of events, muscle fatigue may occur at central and peripheral sites simultaneously (McComas, Miller, & Gandevia, 1995). Thus, muscle fatigue should be viewed as the result of the interaction of several different processes in both the central and peripheral nervous system. This series of experiments provides a unique contribution to the literature, thereby supporting the interaction of the central and peripheral nervous system in the process of muscle fatigue induced by voluntary muscle contractions in people with CP.

Lastly, these results provide a better understanding of the possible contributing factors to fatigue resistance, improving our understanding of muscle fatigue in this population. In addition, the results have increased our understanding of the complex interrelationships among impairments in CP, such as strength, cocontraction, spasticity, and stiffness. The results of this study open the door for further exploration into this area of study and the possible muscle adaptations that may occur secondary to CP.

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APPENDIX 1: EXPANDED LITERATURE REVIEW

Introduction

This review is designed to build a foundation for understanding muscle fatigue in Cerebral Palsy (CP) and its potential role in the disablement process. The relationships between muscle fatigue and other impairments will be explored, as well as how fatigue, in general, has been shown to impact activity, participation, and quality of life. The World Health Organization's International Classification of Functioning, Disability and Health (ICF) will be used as a framework to illustrate this process (Figure A.1) (World Health Organization, 2001). The formal definitions of the ICF are provided in Table A.1.

Table A.1
WHO ICF Model Definitions

Body Functions are physiological functions of body systems (including psychological functions).

Body Structures are anatomical parts of the body such as organs, limbs and their components.

Impairments are problems in body function or structure such as a significant deviation or loss.

Activity is the execution of a task or action by an individual.

Participation is involvement in a life situation.

Activity Limitations are difficulties an individual may have in executing activities.

Participation Restrictions are problems an individual may experience in involvement in life situations.

Environmental Factors
environment in which people live and conduct their lives

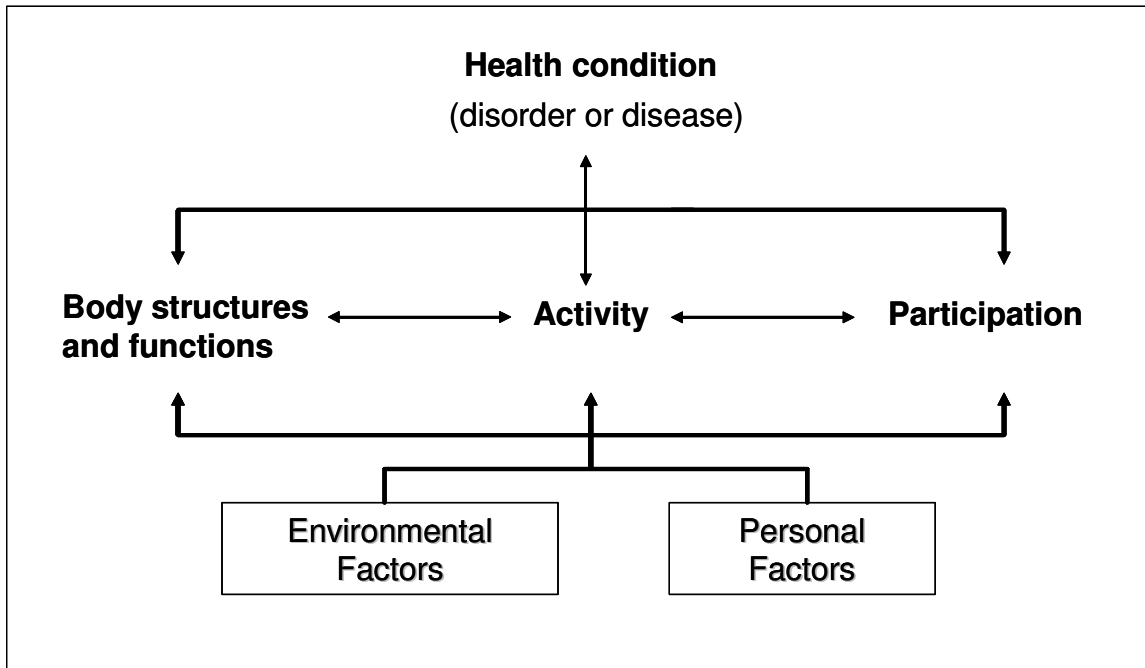


Figure A.1. The World Health Organization’s International Classification of Functioning, Disability and Health (ICF, 2001)

CP describes a collection of disorders “of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain” (Bax et al., 2005). CP is not a disease, per se, but rather, a descriptive term that describes a heterogeneous group of children who often manifest with chronic motor impairment. Although variability exists with respect to the degree of impairments individuals with CP may exhibit, common impairments include loss of selective motor control, spasticity, muscle weakness, co-contraction, and contractures. In turn, these impairments can lead to activity restrictions such as difficulty in walking and other activities of daily living, often leading to worsening disability throughout the lifespan.

Studies over the last fifteen years have documented a gradual onset of newly recognized problems in adults with CP, such as fatigue, musculoskeletal pain, and deterioration of functional skills (Andersson & Mattsson, 2001; Bottos, Feliciangeli, Sciuto, Gericke, & Vianello, 2001;

Cathels & Reddihough, 1993; Gajdosik & Cicirello, 2001; Jahnsen, Villien, Aamodt, Stanghelle, & Holm, 2004; Jahnsen, Villien, Egeland, Stanghelle, & Holm, 2004; Jahnsen, Villien, Stanghelle, & Holm, 2003; Murphy, Molnar, & Lankasky, 1995; Pimm, 1992). These problems manifest in adolescence and early adulthood and have consequences for activities and participation in work and social situations. Furthermore, these studies provide evidence of the progression of certain impairments in CP and the need for targeted interventions throughout the life span, despite the non-progressive brain lesion (Figure A.2).

Physical fatigue, in particular, has been identified as a significant impairment in adults with CP compared with the general population and has been significantly associated with deterioration of functional skills, bodily pain, limitations in physical and emotion role function, and low life satisfaction (Jahnsen et al., 2003) (Figure A.2). In fact, adults with CP report fatigue as a main cause of the deterioration or cessation of their walking ability (Bottos et al., 2001; Jahnsen et al., 2004; Murphy et al., 1995). Murphy et al. (1995) reported that 75% of subjects ceased to walk by the age of 25 due to fatigue and inefficiency of ambulation. Jahnsen et al. (2004) reported that 44% of subjects had deterioration of walking due to fatigue, pain, and lack of adapted physical activity. However, fatigue was assessed subjectively in these studies through the use of questionnaires and interviews.

The term “fatigue” has been subjectively used to describe a multitude of mental and physical symptoms and is often confused with other symptoms, such as weakness (Schwid, Covington, Segal, & Goodman, 2002). Therefore, these self-report questionnaires may not be adequate in the assessment of fatigue. Jahnsen et al. (2003) was the only study to divide the questionnaire into mental and physical fatigue components for separate analysis. Compared to the general population, adults with CP report significantly more physical, but not more mental fatigue. Despite the overwhelming evidence that physical fatigue is a significant impairment in

this population, there are no studies to date that have quantitatively assessed physical fatigue in this population.

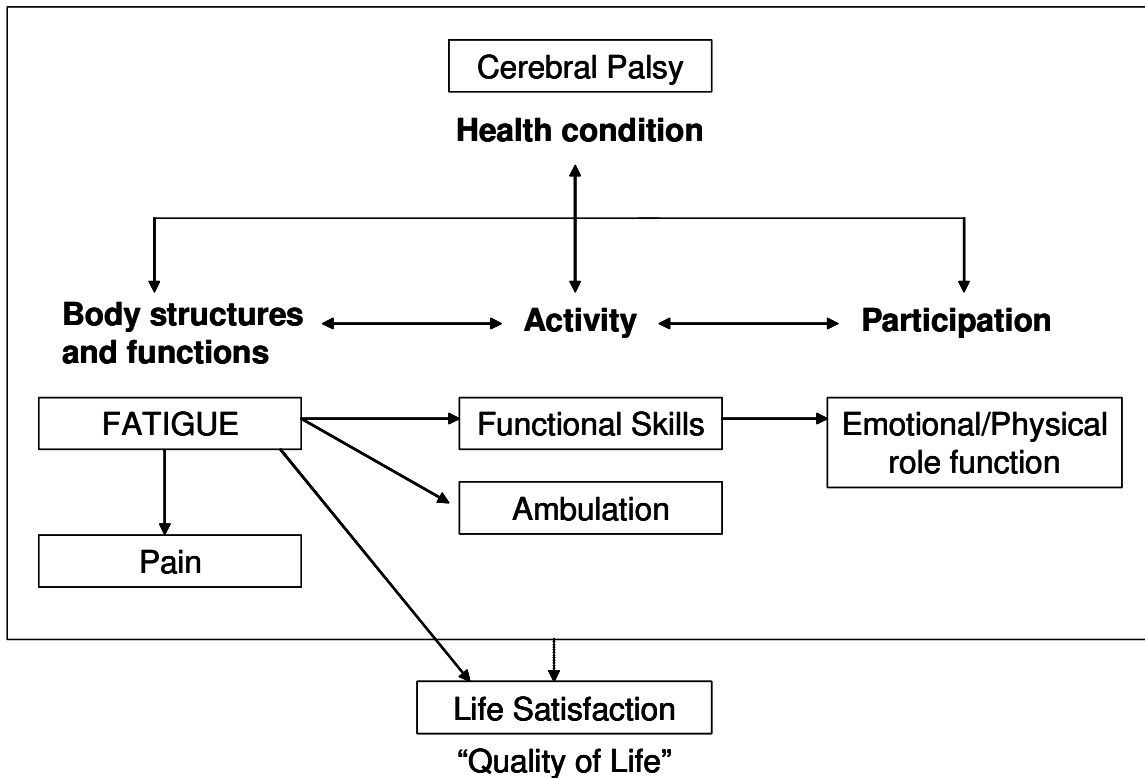


Figure A.2. The World Health Organization’s International Classification of Functioning, Disability and Health (ICF, 2001) illustration of the relationships between fatigue (body function) and activity limitations and participation. The relationship between fatigue and low life satisfaction is also illustrated.

Further support for the existence of muscle fatigue in individuals with CP comes from studies of energy expenditure. Because of the frequent clinical observation of fatigue in children with CP, previous studies have investigated cardiovascular endurance (Lundberg, 1978; Rose, Haskell, & Gamble, 1993; Unnithan, Dowling, Frost, & Bar-Or, 1996). Rose et al. (1993) demonstrated that the cardiorespiratory response to walking at submaximal level of work was not significantly different for children with cerebral palsy as compared to a healthy control group. In

addition, Dahlback and Norlin (1985) reported that children with CP became fatigued while working at levels less than 50-60% of maximal oxygen uptake during treadmill walking, indicating that local muscle fatigue was responsible for the exhaustion. Furthermore, McNevin, Coraci, and Schafer (2000) observed a significant increase in perceived exertion without a concomitant increase in heart rate during an incremental gait speed test. The authors suggest this was possibly due to fatigue. Similar results have been observed in the upper extremities of children with CP. In one study, cardiorespiratory endurance during an arm ergometer test did not differ between subjects with CP and controls at 75% VO_2 and maximum heart rate (Tobimatsu, Nakamura, Kusano, & Iwasaki, 1998). Subjects with CP also stopped the ergometer test prematurely at 75% VO_2 max because of arm muscle fatigue. Collectively, this evidence provides support that local muscle fatigue rather than cardiorespiratory factors may be responsible for the exhaustion observed in submaximal states.

Fatigue has also been studied extensively in other neurological populations with upper motor neuron lesions that present with spasticity and other similar impairments to those seen in CP. Although there are similar documented complaints of fatigue in other neurological populations via questionnaires and fatigue scales (Sharma, Kent-Braun, Mynhier, Weiner, & Miller, 1995; Staub & Bogousslavsky, 2001), objective assessments of fatigue have been measured. Muscle fatigue, in particular, has been quantitatively assessed in MS and spinal cord injury (SCI) (de Haan A., de Ruiter, van der Woude, & Jongen, 2000; Lambert, Archer, & Evans, 2001; Lenman, Tulley, Vrbova, Dimitrijevic, & Towle, 1989; Miller, Green, Moussavi, Carson, & Weiner, 1990). Muscle fatigue as used here is defined as a decline in the force-generating capacity of the neuromuscular system, which occurs during sustained activity (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983). The commonality among these studies is that muscles of individuals with MS and SCI are more fatigable than those without pathology.

Perhaps the most extensive evidence of muscle fatigue in neurological populations is from studies of MS, as fatigue is one of the most common and disabling symptoms in this disease (Schwid et al., 2002). However, unlike CP, MS is a progressive neurological disorder with differing pathology. The most similar upper motor lesion to CP would be cerebrovascular accident (CVA), characterized by unilateral damage to the cerebral cortex. However, studies on this population are limited, and results are equivocal. When comparing the involved to the uninvolved contralateral side, decreased levels of fatigue (Riley & Bilodeau, 2002; Toffola, Sparpaglione, Pistorio, & Buonocore, 2001) and no significant differences (Sunnerhagen, Svantesson, Lonn, Krotkiewski, & Grimby, 1999; Svantesson, Osterberg, Grimby, & Sunnerhagen, 1998; Svantesson, Sunnerhagen, Carlsson, & Grimby, 1999) were observed. The discrepancy among studies may be explained by differing methodology, muscles studied, and subject characteristics. Methodological differences include the use of electrical stimulation techniques (Riley et al., 2002; Toffola et al., 2001), isokinetic dynamometry (Sunnerhagen et al., 1999; Svantesson et al., 1999), and the standing heel-rise test (Svantesson et al., 1998), which may partially explain the different results. In fact, the heel-rise has not been validated as a measure of fatigability. Riley and Bilodeau (2002) studied the upper extremity, where the others studied different lower extremity muscles. Among the studies where no differences were observed, the subjects were ambulatory with only minor motor impairment. In fact, two of the three studies reported that spasticity was absent (0 on the Ashworth Scale) in the studied plantarflexors of all subjects (Svantesson et al., 1998; 1999). The mild impairment level of these subjects may explain why there were no observed differences between the paretic, non-paretic, and control sides. Regardless of the measurement technique utilized, considering that we know the ipsilateral “uninvolved” extremity is often affected in CVA (Baskett, Marshall, Broad, Owen, & Green, 1996), it may not be valid to compare the two sides without a control group. In

summary, CP is a lifelong disorder, which distinguishes it further from these other neurological disorders and as such, these results cannot be extrapolated to CP without further investigation.

Purpose and Clinical Significance

The purpose of this paper is to review the evidence implicating muscle fatigue as a significant impairment in people with CP and to discuss potential contributors of fatigue in this population. Although previous research has focused on the amelioration of spasticity as a primary goal of treatment, current research has shown that other aspects of muscle performance, such as strength, have higher correlations with gross motor function and walking velocity, and are amenable to treatment (Damiano & Abel, 1998; Damiano, Kelly, & Vaughn, 1995; MacPhail & Kramer, 1995). A critical aspect of muscle performance is endurance, or resistance to fatigue, and this area of performance has not been substantiated in individuals with CP. Therefore, a better understanding of muscle fatigue or endurance in this population and its relationship to other impairments and activity limitations will lead to improved treatment programs. Improved treatment aimed at addressing fatigue may ultimately improve the health related quality of life in these individuals, thereby delaying the onset of worsening disability with age.

Muscle Fatigue

Definition

Because of the broad use of the term fatigue, it is important to operationally define fatigue. For purposes of this review, muscle fatigue will be defined as a reduction in the force-generating capacity of the neuromuscular system, which occurs during sustained activity (Bigland-Ritchie et al., 1983). Muscle endurance, on the other hand, is resistance to fatigue or the ability to withstand fatigue. These terms are often used interchangeably throughout the literature with muscle endurance tests often employed to assess muscle fatigue (Jones & Stratton, 2000).

Mechanisms

Fatigue is a common occurrence in the everyday life of individuals with neurological disorders as well as in able-bodied individuals (Sharma et al., 1995; Staub & Bogousslavsky, 2001). The perception of fatigue is very subjective, with complaints such as feelings of weakness, lack of energy, and lassitude. Objectively, however, fatigue has been defined as a reduced capacity to maintain a required physical or mental output (Staub & Bogousslavsky, 2001). Although not the focus of this paper, it is important to mention that fatigue can occur in several different central and peripheral sites, such as the following: 1.) primary motor cortex activation, 2.) central nervous system drive to motor neurons, 3.) muscles and motor units that are activated, 4.) neuromuscular propagation, 5.) excitation-contraction coupling, 6.) the availability of metabolic substrates, 7.) intracellular mechanisms, 8.) contractile apparatus, and 9.) muscle blood flow (Bigland-Ritchie, 1981). Traditionally, fatigue was thought to occur exclusively either in the central nervous system or the peripheral nervous system. However, since muscle activity depends on the integrity of the entire chain of events, fatigue may occur at many sites simultaneously (McComas, Miller, & Gandevia, 1995). Thus, fatigue should be viewed as the result of the interaction of several different processes in both the central and peripheral nervous system.

Contributors to Muscle Fatigue in Individuals with CP

Introduction

Central nervous system lesions may cause impaired central drive to the motoneurons, or central fatigue. However, it is not specific to the underlying disorder. In other words, upper motor neuron lesions do not exclusively induce central fatigue as a consequence of the lesion site. Rather, individuals with upper motor neuron disorders generally demonstrate both central and peripheral fatigue factors (de Haan A. et al., 2000; Lenman et al., 1989; Miller et al., 1990).

The relationships among these factors are usually quite complex and vary among disorders (Figure A.3).

In addition to these factors, CP is a multifaceted disorder and as such, complex interrelationships exist among upper motor neuron lesion impairments. The relationships among muscle fatigue and other impairments are important in the understanding of fatigue, as these impairments may, in fact, contribute directly or indirectly to muscle fatigue. As a result, four contributors to fatigue at the impairment/body function level have been identified and will be discussed: weakness, co-contraction, spasticity, and stiffness. Muscle adaptations in spastic disorders will be also be highlighted, as these factors may play an important role in the process of fatigue (Figure A.3).

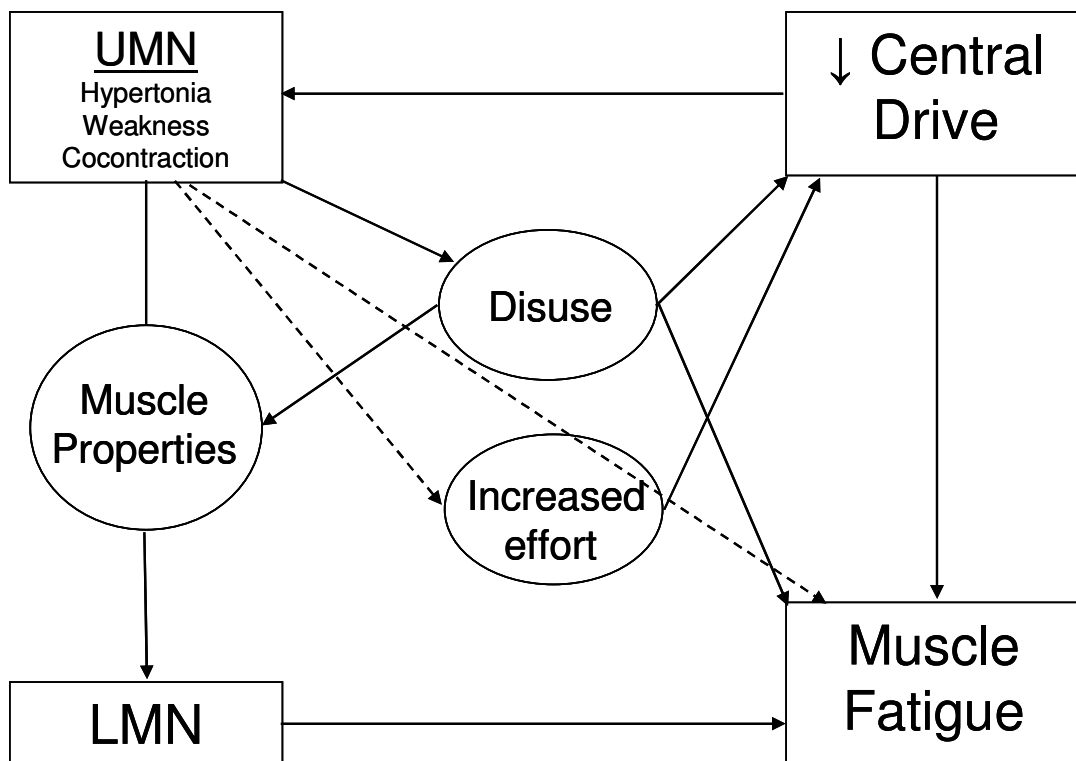


Figure A.3. Diagram illustrating the relationships between central and peripheral factors of muscle fatigue in upper motoneuron (UMN) lesions. (LMN = lower motoneuron). Modified from McComas et al., 1995.

Muscle Adaptation in Spastic Disorders

Definitions

Lesions to the central nervous system, also known as upper motor neuron lesions, result in hypertonia or an increased resistance to passive muscle elongation (Stolov, 1966).

Unfortunately, the term “spasticity”, a component of hypertonia, is frequently and non-specifically used to describe all aspects of hypertonia in addition to other upper motor neuron signs, such as clonus and spasms. Hypertonia is associated with an increased sensitivity of the stretch reflex (reflex component) and with changes in muscle and connective tissue properties (non-reflexive component) (Malouin, Bonneau, Pichard, & Corriveau, 1997). The reflexive component, also known as spasticity, is defined as a velocity-dependent increased resistance to movement due to hyperexcitable stretch reflexes (Lance, 1980). Passive stiffness, on the other hand, denotes the non-reflexive components, such as changes in muscle tissue, joint capsules, and surrounding connective tissue, which are not velocity-dependent (Singer, Dunne, & Allison, 2001). Rather, stiffness is a length-dependent resistance to movement. It should be noted that there is also a non-reflexive, velocity dependent component known as viscosity. However, viscosity has been observed to contribute insignificantly to passive resistance in CP (Damiano, Quinlivan, Owen, Shaffrey, & Abel, 2001). For clarity, the terms spasticity (reflexive) and stiffness (non-reflexive) will be used throughout the review paper as described above.

Introduction

Although the primary lesion of CP is neural, it is important to discuss the properties of spastic muscle. It has been well established that muscle properties adapt to the amount and type of neural stimulation that is imposed upon them. Therefore, investigation of the muscle changes which occur secondary to CP can provide insight into the effects of the disease process on muscle characteristics over an extended period of time (Lieber, Steinman, Barash, & Chambers,

2004). In general, fiber type distribution and muscle fiber size are indicators of the amount and type of activity imposed upon a muscle and as such, are often investigated in spastic muscle in order to determine a muscle's usage pattern (Lenman et al., 1989; Miller et al., 1990; Rose et al., 1994). Predominance of a particular fiber type can influence fatigue, as Type I (slow twitch) fibers are more fatigue-resistant, while Type II (fast twitch) fibers are more fatigable (Burke, Levine, Tsairis, & Zajac, 1973; Thorstensson & Karlsson, 1976). Therefore, the investigation of fiber type predominance in individuals with CP will provide insight into muscle fatigue in this population.

Increased/Decreased Use Models

Two models of muscle usage have been extensively described in the literature and serve as templates to describe the changes that occur in skeletal muscle with either increased or decreased use. Increased use models, such as chronic electrical stimulation or endurance exercise, result in muscle fiber hypertrophy and an increased percentage of type I, slow and oxidative, fibers due to transformation of fast to slow twitch fibers (Eisenberg & Salmons, 1981; Lieber, 1986; Roy, Meadows, Baldwin, & Edgerton, 1982). On the other hand, decreased use models, such as reduced activity, immobilization, and spinal cord isolation or injury, result in muscle fiber atrophy and transformation to a greater proportion of type II, fast and glycolytic, fibers (Booth & Kelso, 1973; Grossman, Roy, Talmadge, Zhong, & Edgerton, 1998; Lieber, Friden, Hargens, & Feringa, 1986a; Lieber, Johansson, Vahlsing, Hargens, & Feringa, 1986b). Two schools of thought have emerged regarding the effect of spasticity on muscle properties. One is that spasticity leads to muscle disuse, while the other purports that spasticity results in chronic muscle overactivity as seen in increased use models (Lieber et al., 2004). Although it appears likely that spasticity represents an increased use model due to chronic over-activity, there has been no consensus on fiber type predominance in spastic disorders. There are biopsy

reports of increased percentages of Type I fibers (Dietz, Ketelsen, Berger, & Quintern, 1986; Ito et al., 1996; Marbini et al., 2002; Rose et al., 1994), increased percentages of Type II fibers (Carroll, Gallagher, Seidle, & Trappe, 2005; Kent-Braun et al., 1997; Ponten, Friden, Thornell, & Lieber, 2005; Sjostrom, Fugl-Meyer, Nordin, & Wahlby, 1980), or no change in fiber type distribution (Booth, Cortina-Borja, & Theologis, 2001; Castle, Reyman, & Schneider, 1979; Romanini, Villani, Meloni, & Calvisi, 1989). As a result, it appears that spastic muscle may not be adequately represented by either model. These conclusions in the literature regarding the effect of spasticity on muscle properties are deduced across a wide range of diagnoses with spasticity (Lieber et al., 2004). Therefore, it is important to discuss the muscle properties in individuals with CP alone, as these other diagnoses (MS and SCI) may present confounding issues, such as adult versus pediatric onset of spasticity.

Muscle Properties in Individuals with CP

Specific to individuals with CP, literature suggests that there may be significant secondary effects of CP on muscle tissue itself. Muscle abnormalities such as changes in muscle fiber size and fiber type distribution, collagen accumulation, and increased stiffness of spastic muscle cells have been extensively reported (Booth et al., 2001; Castle et al., 1979; Friden & Lieber, 2003; Ito et al., 1996; Marbini et al., 2002; Romanini et al., 1989; Rose et al., 1994). A common finding among these studies, however, is an increase in fiber size variability, which is representative of a pathological but non-specific skeletal muscle abnormality (Lieber et al., 2004).

However, there is also no general consensus as to whether spastic muscles in individuals with CP represent an increased or decreased use model. For example, Ito et al., Marbini et al., and Rose et al. identified a predominance of Type I fibers, while Castle et al. and Romanini et al. showed no change. Methodological issues regarding biopsy studies include the number of fibers

sampled, the variability in fiber type and fiber size between muscles, whether different muscles are being used to compare control subjects to those with pathology, and the variability in severity of disease or clinical presentation (Lieber et al., 2004). These studies sampled muscle fibers across numerous different muscles and in a wide range of ages (Castle et al., 1979; Ito et al., 1996; Marbini et al., 2002; Romanini et al., 1989; Rose et al., 1994). In addition, only 200 to 300 fibers per biopsy were sampled (Castle et al., 1979; Ito et al., 1996; Marbini et al., 2002; Romanini et al., 1989; Rose et al., 1994) or no specifics were reported (Marbini et al., 2002; Romanini et al., 1989). Only one study had a control group but examined historical pathological specimens from different muscles (Rose et al., 1994). Therefore, it is not surprising that there is no general consensus as to whether muscles in individuals with CP represent an increased or decreased use model.

An issue that has not been addressed in these biopsy studies of “spastic” muscle is the degree of spasticity present, if any, in the muscles sampled. Both clinically and experimentally, it is common to be unable to detect spasticity in certain muscle groups while detecting it in others (Damiano et al., 2002; Damiano et al., 2001; Katz, Rovai, Brait, & Rymer, 1992). Therefore, if spasticity is believed to result in secondary myopathic changes, the presence and degree of spasticity should be documented for the muscles in question. Until this is documented and investigated experimentally, we cannot accurately say that these findings are representative of “spastic” muscle. Rather, these histopathological results are representative of muscles involved in upper motor neuron lesions. With this in mind, Ponten et al. (2005) indirectly provided insight into the preferential affect of spasticity on muscle properties in CP. The aim of this study was to determine whether different muscle groups in the same individuals with CP are affected differentially by the disease process. Therefore, biopsies of the wrist flexors and extensors were sampled in the same individuals with CP. Furthermore, Ponten et al. addressed some of the

earlier methodological concerns by testing a smaller age range of five years and sampling over a thousand fibers per biopsy. Results revealed increased fiber type variation and decreased fiber size for the wrist flexors as compared to the extensors. More importantly, there was a significantly greater percentage of type IIb, fast fatigable, fibers in the flexors as compared with the extensors. It is well known that spasticity affects the upper extremity flexors greater than the extensors and for this reason, the wrist flexors are often the site of tendon transfers (Friden & Lieber, 2003; Katz et al., 1992). Although spasticity was not measured in this study, all subjects were undergoing tendon transfers or flexor tendon lengthenings. Therefore, we can infer with some degree of confidence that the wrist flexors were spastic and had greater levels of spasticity than the extensors. The authors concluded that the increased percentages of Type IIb fibers and decreased fiber size in the wrist flexors as compared to the extensors provides the most sound evidence that spasticity in CP may represent a decreased-use model. However, further research is needed to verify this assumption.

Weakness

The presence of weakness in muscles of individuals with CP as compared to age-matched controls has been well documented (Damiano, Vaughan, & Abel, 1995; Wiley & Damiano, 1998). The exact nature of the weakness is unclear and is thought to be a result of either decreased central drive to the agonist due to the lesion itself, spasticity, co-contraction, secondary changes in the properties of the muscles fibers, or some combination of the above (Damiano et al., 2001). In fact, leg strength has been observed to be correlated to self-selected walking speed and to the Gross Motor Function Measure (GMFM) in children and adolescents with CP (Damiano & Abel, 1998; Kramer & MacPhail, 1994). As a consequence, weakness is considered one of the primary contributors to motor dysfunction in individuals with CP.

Weakness in upper motor neuron disorders is often accompanied by disuse, as the individual tries to conserve strength by resting or by ceasing to perform tasks that are tiring. Disuse can reduce the ability of the higher motor centers to recruit motoneurons maximally, leading to fatigue (McComas et al., 1995). As discussed previously, muscles respond to the amount and type of activity that is imposed upon them. Disuse, or decreased use models, result in muscle fiber atrophy and transformation to a greater proportion of type II, fast and glycolytic, fibers (Booth & Kelso, 1973; Grossman et al., 1998; Lieber et al., 1986a; Lieber et al., 1986b). Therefore, weakness can also lead to increased numbers of type II fibers, which are more fatigable. As a result, weaker muscles may demonstrate greater levels of fatigability.

A secondary consequence of weakness and muscle atrophy is the recruitment of more motor units or the greater frequency of excitation required to perform a given task (Edgerton, Roy, Allen, & Monti, 2002). Normally, the force of a muscular contraction is determined by both firing rate or rate modulation and the recruitment of additional motor units (DeLuca & Erim, 1994). In addition, smaller motor units are recruited first, followed by larger motor units. This regulation serves to decrease the occurrence of fatigue by ensuring that the larger, more fatigable units are recruited later in the contraction (Calcancie & Bawa, 1990). Recruitment and rate modulation have been shown to be impaired in stroke patients with hemiparesis (Gemperline, Allen, Walk, & Rymer, 1995; Jakobsson, Grimby, & Edstrom, 1992; Rosenfalck & Andreassen, 1980). In particular, Gemperline et al. studied the upper extremity muscles of six subjects with hemiparesis and showed that motor units were recruited at lower thresholds and failed to increase firing rates with increased muscle activation. As a result, additional force was generated primarily through increased recruitment rather than rate modulation. They concluded that the inability to increase firing rates may alter the precise match between the properties of the motoneuron and the mechanical properties of the muscle fibers, leading to fatigue and weakness.

As a consequence of recruiting more motor units, the overall fatigability will increase because increased numbers of upper threshold units will be recruited.

Working at a higher capacity during everyday tasks secondary to weakness was first described by Pimm (1992) as “physiological burn-out” in adults with CP. In other words, working at a greater load relative to maximum on a daily basis can cause the system to become overburdened and physical function to deteriorate (de Haan A. et al., 2000; Pimm, 1992). Deterioration of function leads to disuse. Disuse exacerbates weakness, and a vicious cycle develops. Combined with an increase in perceived effort, fatigue is sure to develop.

Co-contraction

Co-contraction refers to the simultaneous activation of agonist and antagonist muscles during voluntary movement. Although co-contraction occurs normally in everyday activities, it is excessive in individuals with CP. Co-contraction in persons with upper motor neuron lesions is thought to be caused by reciprocal facilitation/excitation of the agonist and antagonist (Myklebust, Gottlieb, Penn, & Agarwal, 1982) or decreased disynaptic or presynaptic reciprocal inhibition of the antagonist muscle during agonist activation (Morita, Crone, Christenhuis, Petersen, & Nielsen, 2001). Co-contraction has been suggested to generate opposing torque throughout the range of motion (Baratta et al., 1988). In addition, it may impair the full activation of the agonist due to reciprocal inhibition (Milner, Cloutier, Leger, & Franklin, 1995; Tyler & Hutton, 1986). Therefore, co-contraction could reduce the efficiency of force output, leading to fatigue. It is of importance to note that neither the antagonistic moment (Kellis, 2003) nor the electromyography (EMG) activity (Kellis & Kellis, 2001) has been shown to change during an isokinetic fatigue task in pubescent boys. Therefore, the contribution of the antagonist co-contraction to the force output should remain constant throughout a fatigue task.

Further support for this hypothesis comes from studies of energy expenditure during gait in children with CP. It has been established that children with CP have a lower maximal oxygen uptake ($VO_{2\text{ max}}$) as compared with able bodied peers during tests of cycling and treadmill walking (Hoofwijk, Unnithan, & Bar-Or, 1995; Lundberg, 1978). On average they also have a three-fold increase in submaximal walking energy expenditure (Campbell & Ball, 1978). Dahlback and Norlin (1985) reported that children with CP became fatigued while working at submaximal levels less than 50-60% of maximal oxygen uptake during treadmill walking. They concluded that local muscle factors rather than cardiopulmonary factors were responsible for the exhaustion. Furthermore, Unnithan et al. (1996) reported a positive relationship between co-contraction of lower extremity muscles in children with CP and the elevated energy cost of treadmill walking at submaximal speeds. Children with CP also complain of fatigue at these submaximal walking intensities considered slow for able-bodied peers (Berg, 1970; Dahlback & Norlin, 1985; Unnithan et al., 1996). Therefore, high levels of co-contraction may be responsible for the early fatigue of muscles, thereby contributing to the reduction in $VO_{2\text{ max}}$ at maximal exercise intensity.

Spasticity

It is well-recognized that many children with CP have spasticity, or a velocity-dependent increased resistance to movement due to hyperexcitable stretch reflexes (Lance, 1980). Although spasticity was once considered the primary cause of motor dysfunction in individuals with CP, it is now believed that other impairments, such as weakness, are more detrimental to function (Damiano & Abel, 1998; Sahrman & Norton, 1977). Furthermore, spasticity has been observed to have a weak to absent relationship to strength (Damiano et al., 2001; Ross & Engsborg, 2002) and only a weak to moderate relationship to function (Damiano et al., 2001). Since muscle endurance, like strength, is also a component of muscle performance, perhaps spasticity will

have a weaker or no relationship to muscle endurance as well. Nevertheless, spasticity is an important component of the upper motor neuron syndrome. Therefore, the potential long-term and short-term effects of spasticity on muscle fatigability are worth investigating.

In regards to long-term muscle adaptation to spasticity in CP, there is no consensus on whether spasticity represents an increased or decreased use model (Booth et al., 2001; Castle et al., 1979; Ito et al., 1996; Marbini et al., 2002; Ponten et al., 2005; Romanini et al., 1989; Rose et al., 1994). If spasticity leads to disuse, then spastic muscles should be more fatigable due to increased numbers of Type II fibers as seen in decreased use models. In turn, if spasticity leads to muscle overactivity, then spastic muscles should be more fatigue-resistant due to increased numbers of Type I fibers as observed in increased use models. Perhaps, fiber type predominance may be dependent upon the muscle studied and the amount of spasticity in that particular muscle. It is well established that different muscles have different fiber type distributions (Edstrom & Nystrom, 1969); however, the relationship of fiber type to the amount of spasticity has not been explored. The first histopathological study in CP reported a variety of patterns of Type I/II atrophy and hypertrophy depending on the muscle biopsied and the degree of spasticity or severity of each subject (Castle et al., 1979). However, a definitive relationship could not be ascertained. Further support for this hypothesis stems from the original work of Ponten et al. (2005). In this study, the presumed spastic wrist flexors were found to have increased amounts of type II, fast fatigable fibers as compared to the less spastic wrist extensors. If the degree of spasticity does indeed play a part in fiber type predominance, then the amount of spasticity should influence the development of fatigue accordingly. Future muscle-specific biopsy studies in conjunction with spasticity assessment are needed to explore this hypothesis.

It is important to note that these muscle fiber changes are the result of long-term spasticity. However, fatigue is not solely determined by muscle fiber type. From a short-term

perspective, spasticity could impair the maximum force output of the agonist, secondary to the hyperexcitable stretch reflex. Therefore, independent of fiber type changes, spasticity could also result in an immediate reduction in the efficiency of force output, which would lead to fatigue.

Stiffness

Literature suggests that the properties of muscles in individuals with CP are very different from normally developed muscles, including collagen accumulation (Booth et al., 2001) and increased stiffness at both the cellular (Friden & Lieber, 2003) and whole muscle level (Hufschmidt & Mauritz, 1985). This is of no surprise, considering the subjective complaints of tightness and stiffness by individuals with CP and the resistance felt upon passive movement of the extremities.

Dietz, Quintern, and Berger (1981) first suggested that that muscle hypertonia is mainly due to secondary changes in spastic muscles and that these altered mechanical properties contribute to muscle stiffness during gait. They observed increased EMG activity of the anterior tibialis without a concomitant increase in ankle dorsiflexion during the swing phase compared to controls. Furthermore, there was no excessive EMG activity of the gastroc/soleus and no evidence of contracture. They concluded that the altered mechanical properties of the gastroc/soleus muscle fibers themselves were responsible for the limited ankle dorsiflexion. This hallmark study spurred numerous investigations into this phenomenon.

It has also been suggested that increased stiffness may be a compensation for weakness, thus allowing better utilization of elastic energy during functional activities, such as gait (Lamontagne, Malouin, & Richards, 2000; Svantesson & Sunnerhagen, 1997). Lamontagne et al. reported that the passive stiffness contribution to the total plantarflexor moment in individuals with CVA was greater on the weaker, affected side as compared to controls during gait. Thus, the affected plantarflexors in subjects with CVA appeared to utilize passive stiffness to

compensate for weakness as compared to the healthy controls. Svantesson & Sunnerhagen (1997) reported a similar observation during controlled stretch-shortening cycles of the plantarflexors in individuals with CVA. Furthermore, in a follow-up study in healthy adults, fatigue, measured as the number of heel-rises performed to exhaustion, was negatively correlated to the amount of stiffness (Svantesson, Carlsson, Takahashi, Thomee, & Grimby, 1998). Increased stiffness was thus suggested to enhance the development of fatigue. Therefore, stiffness, as a compensation for weakness, may be directly related to muscle fatigue. Furthermore, stiffness (quantified as the slope of the torque/angle curve) has been observed to have a stronger relationship to both strength and function as compared to quantitative measures of spasticity (Damiano et al., 2002; Damiano et al., 2001). In accordance, perhaps stiffness will have a stronger relationship to muscle fatigue than spasticity.

Methods of Measurement

Introduction

Muscle fatigue, or muscle endurance, has been studied using a wide variety of exercise protocols and assessment methods. Based on the definition of muscle fatigue as a reduction in the force-generating capacity of the neuromuscular system during sustained activity, the different methods to measure muscle fatigue are discussed. The focus of this review is on voluntary assessment techniques of muscular fatigue rather than electrical stimulation procedures, such as tetanic stimulation and twitch interpolation. These electrical stimulation techniques are used to differentiate between central and peripheral fatigue factors. The reliable assessment of muscle fatigue is highly dependent upon the measurement of maximum force generation and as such, maximal voluntary contraction force is considered the “gold standard” for the assessment of fatigue (Vollestad, 1997). The advantage of using maximal voluntary force is that the output is the result of the total chain of events, including both central and peripheral fatigue factors.

Therefore, voluntary contraction should serve as the first choice of methods before additional methods are employed to examine the possible sites within the central and peripheral systems (Vollestad, 1997).

Fatigue Assessment in Children

Isometric and isokinetic techniques are most commonly employed in the assessment of muscle performance in children. However, the limitations of isometric techniques are that the strength measurements are limited to a fixed joint angle and optimal angles for individual muscle groups in children have not been identified (Gaul, 1996). Despite the expense and complexity of testing, isokinetic dynamometry is currently considered the most valid tool for muscle performance assessment (Jones & Stratton, 2000). It provides a controlled, safe environment where no resistance is applied once the movement has ceased. Although isokinetic testing in children has typically been performed in the range of 0-240 degrees/second, an optimal movement velocity for reliable measurement has not been established (Gaul, 1996; Jones & Stratton, 2000).

Limited information regarding isokinetic muscle endurance testing in children is available in the literature. To the author's knowledge, there is only one study that has utilized isokinetic dynamometry to assess the reliability of muscle fatigue testing in the knee flexors and extensors of children. De Ste Croix, Armstrong, and Welsman (2003) studied 30, 12-year old children on two test sessions separated by 1 week. The subjects performed 50 concentric, reciprocal knee flexions and extensions at 90 degrees/second. A fatigue index was calculated by using the average torque and average work of the first 3 and last 3 repetitions. The percentage difference between these values was used to represent the decline in torque and work. Intra-class correlation coefficients (ICCs) for knee extension torque fatigue and work fatigue were higher (.90 and .85, respectively) than for flexion torque and work fatigue (.36 and .54, respectively). In

addition, all fatigue indices except for knee flexion torque fatigue index (.36), were deemed reliable by high ICC values. After a sufficient recovery period, a second test of endurance was performed consisting of reciprocal knee flexion and extension until the torque fell below 50% of the maximal torque or the subjects reached 80 repetitions. Interestingly, none of the subject's extension or flexion torque fell below 50% of maximum after 80 repetitions. This testing protocol has been frequently used in adults. Therefore, it is unclear as to why the subjects' torque did not fall below the 50% of maximum in the allotted number of repetitions. The authors suggested that it may be a function of the lower initial maximal torque values as compared to adults. This idea is in agreement with Pincivero, Gear, Sterner, and Karunakara (2000) who demonstrated that a faster rate of fatigue was significantly related to the ability to generate a high initial level of torque. Kellis and Kellis (2001) utilized a similar protocol with reciprocal knee flexion and extension at 60 degrees/second for approximately 60 seconds or 22 repetitions. However, intersession reliability was not assessed for this protocol.

Fatigue Assessment in Cerebral Palsy

The first reported test of endurance in children with neuromuscular diseases was published by Hosking, Bhat, Dubowitz, and Edwards (1976). For this test, the length of time the leg could be held straight with the hip flexed to 45 degrees and the head at 45 degrees above the horizontal were recorded with the subject in the supine position. Although this test was able to discriminate between children with and without neuromuscular disease, it did not show sufficient reproducibility to be recommended for future testing.

Other attempts to measure overall endurance in children with CP employed physiological measures of energy expenditure, such as oxygen consumption, heart rate, perceived exertion, and measures of cardiorespiratory function (Dahlback & Norlin, 1985; Hoofwijk et al., 1995; Lundberg, 1976; Rose, Gamble, Burgos, Medeiros, & Haskell, 1990; Rose et al., 1993; Unnithan

et al., 1996). Others have studied endurance from an aerobic (Lundberg, 1978; Tobimatsu et al., 1998) versus anaerobic perspective (Parker, Carriere, Hebestreit, & Bar-Or, 1992; Tirosh, Bar-Or, & Rosenbaum, 1990). However, these are physiological measures of the overall individual and are different from tests of muscle endurance. Proponents of anaerobic testing via the Wingate anaerobic test purport to measure muscle endurance by measuring mean power of the lower extremities (Parker et al., 1992). However, this test cannot differentiate between right and left limb measurements or among muscle groups; therefore, it is a non-specific, gross physiologic measurement of endurance. Isokinetic dynamometry, on the other hand, has the ability to isolate a single muscle group under controlled conditions with stabilization of other joints, thus providing a measure of localized muscle fatigue.

To date, there are no studies that have quantitatively assessed localized muscle fatigue via isokinetic or isometric means in individuals with CP. However, because the basis of fatigue or endurance testing is maximal voluntary contraction (Vollestad, 1997), it is important to discuss the reliability of isokinetic strength testing in children with and without CP.

Isokinetic Strength Testing in Children With and Without CP

Two studies have examined the reliability of isokinetic strength assessments in children and adolescents with CP (Ayalon, Ben-Sira, Hutzler, & Gilad, 2000; Van den Berg-Emons RJ, Van Baak, de, Speth, & Saris, 1996). Both examined isokinetic concentric knee extension and flexion but at different velocities of movement. Van den Berg-Emons et al. (1996) examined the reliability of strength assessments in 12 children with CP (ages 6-12) on two separate tests during the same day. Peak torque of the knee flexors and extensors was assessed over 5 maximum trials at 30, 60, and 120 degrees/second. Results revealed that the only reliable measurement of peak torque for both the knee flexors and extensors was at 30 degrees/second (Spearman rank correlation = $r_s = .71 - .84$). However, it should be noted that knee flexion peak

torque was reliable at 60 and 120 degrees/second as well ($r_s = .75$ and $.65$, respectively). These results are questionable, considering that the two test sessions were performed on the same test day with only an hour and a half break between tests. In addition, only two familiarization trials were given. Therefore, the reliability at 60 and 120 degrees/second may have been significant with a greater number of familiarization trials and increased time between tests.

A more recent study by Ayalon et al. (2000) investigated the reliability of strength measurements in 12 children with CP (ages 9-15) on two separate occasions one week apart. However, Ayalon et al provided 15 to 20 submaximal familiarization trials and utilized only one velocity (90 degrees/second), which was determined to be the most comfortable for the participants during a pilot study. Mean absolute peak torque and mean relative peak torque normalized by body weight were the dependent measures. Results revealed both absolute and relative peak torque measurements to be equally reliable with intrasession ICCs of $.90$ to $.99$ and intersession ICCs of $.95$ to $.99$. In contrast with the Van den Berg-Emons et al study, knee extension and knee flexion tests were both reliable at the faster speed of 90 degrees/second (ICC intersession = $.95$ -. 98 and $.96$ -. 98 , respectively). These results support the use of isokinetic concentric testing at 90 degrees/second in children and adolescents.

Holland, McCubbin, Nelson, and Steadward (1994) were the first to investigate the reliability of isokinetic concentric and eccentric strength testing in adults (ages 17-38) with CP. Reliability of knee flexion and extension at 60 degrees/second was assessed over 3 test sessions conducted every other day. All average torque and peak torque values were reliable except for eccentric knee extension average torque, as determined by generalizability coefficients ($p^2 = .20$). In general, concentric tests were more reliable than eccentric tests ($.69$ -. 91 and $.20$ -. 90 , respectively). Furthermore, the concentric knee flexion test was more reliable than the knee extension test ($.80$ -. 90 and $.69$ -. 91 , respectively). Further support for the use of isokinetic

velocities greater than 30 degrees/second comes from strength testing in individuals with CVA, during which reliability was established in normalized and non-normalized peak torque measures at 90 and 60 degrees, respectively (Hsu, Tang, & Jan, 2002; Pohl, Startzell, Duncan, & Wallace, 2000). Collectively, these studies provide support for the use of higher speeds (60 – 90 degree/second), which have been speculated to mimic more functional speeds encountered in everyday activities (Ayalon et al., 2000).

Studies of reliable strength assessment are more prevalent in healthy children than in children with either neuromuscular or neurological disorders. Nevertheless, an optimal movement velocity for isokinetic strength testing in children has not been established (Gaul, 1996; Jones & Stratton, 2000). However, reliability of strength measurements has been demonstrated at 30, 60, 90, 100, 120, and 180 degrees/second for the knee flexors and extensors in children and adolescents (De Ste Croix, Armstrong, & Welsman, 2003; Deighan, De Ste Croix, & Armstrong, 2003; Kellis, Kellis, Gerodimos, & Manou, 1999; Merlini, Dell'Accio, & Granata, 1995). In general, reliability for able-bodied children is higher for the knee extensors compared to the knee flexors and for concentric versus eccentric testing.

Isokinetic Muscle Fatigue / Endurance Protocols

Adults

No single, reliable test of muscle endurance exists in children with or without CP. Therefore, it is important to discuss endurance protocols in adults. The most widely used protocol consists of a predetermined number of maximal repetitions. The number of maximal repetitions in adults usually varies from 25 to 50 repetitions and is usually performed at 180 degrees/second (Burdett & Van Swearingen, 1987; Gleeson & Mercer, 1992; Manou, Arseniou, Gerodimos, & Kellis, 2002; Pincivero, Gear, & Sterner, 2001; Pincivero, Lephart, & Karunakara, 1997; Thorstensson & Karlsson, 1976). Another common protocol involves the performance of

consecutive repetitions or maximum isometric contractions until the torque, work, or power decreases to 50% of the maximum torque (Emery, Sitler, & Ryan, 1994; Schwendner, Mikesky, Wigglesworth, & Burr, 1995). Other protocols require the subject to perform as many repetitions as possible in a predetermined period of time (Felicetti, Zelaschi, & Di Patrizi, 1994; Montgomery, Douglass, & Deuster, 1989) or repeated contractions until exhaustion (Patton, Hinson, Arnold, Jr., & Lessard, 1978).

The most commonly used measurement parameter is the calculation of the fatigue index (FI) as an indicator of muscle endurance. This idea was first proposed by Thorstensson and Karlsson (1976), where the decline in torque output of the quadriceps after 50 contractions was expressed as a percentage of the highest of the first 3 peak torques to the last 3 peak torques. Although there is no standardized definition for FI, it usually represents the percentage decline in work or torque from the beginning to the end of a predetermined number of repetitions or a certain period of time. Thorstensson and Karlsson also reported a positive correlation between the percentage of Type II fibers and the FI.

Although the most common technique, the FI has been questioned in terms of its reliability (Burdett & Van Swearingen, 1987; Pincivero et al., 2001; Pincivero et al., 1997). With similar protocols of 25 to 30 repetitions at 180 degrees/second, ICC's have been reported from .26 to .82 for knee extension and .52 to .84 for knee flexion. The disadvantages of the FI are that it represents only the initial and final values. Furthermore, the division of one value with error associated with it by another value with error associated with it results in a ratio with even more error (Burdett & Van Swearingen, 1987). Because reductions in torque output over short periods of time (30-60 seconds) have been observed to be linear (Bigland-Ritchie et al., 1983; Lindstrom, Karlsson, & Gerdle, 1995), researchers have suggested the linear slope as an alternative measure of the rate of decrease in work or torque over the testing session (Pincivero,

Gandaio, & Ito, 2003; Pincivero et al., 2001). The slope was found to be more reliable than the FI with ICC's of .78 to .82 (Pincivero et al., 2001). An advantage of using the slope is that it captures the rate of decline over the entire test. However, the data must be linear in order to use this measure of fatigue.

Emery, Sitler, and Ryan (1994) developed another alternative to the FI, in which fatigue was measured by counting the number of repetitions completed in which three consecutive repetitions met the 50% of peak torque deficit. They discovered that the number of repetitions needed at 60 and 150 degrees/second, respectively, was 30 and 46 for knee extension and 36 and 41 for knee flexion. Burdett and Van Swearingen (1987) also calculated the number of contractions until torque fell below 50% of maximum as well as a type of FI in which the ratio of work done during the last 5 repetitions to the first five was measured. They determined that the number of repetitions was more reliable ($r = .85$) than the FI/work ratio ($r = .48$). Similarly, Manou et al. (2002) determined that the number of repetitions was very reliable for the knee extensors and flexors ($r = .82$ and $.90$, respectively). Another measure of fatigability is endurance time, or the time to reach either 50% of maximum or exhaustion (Manou et al., 2002; Patton et al., 1978). The advantage of these two parameters is that they are simple and easy to calculate. On the other hand, they do not provide a measure of the rate of decline. Furthermore, it has been documented that endurance time is not closely related to fatigue (Vollestad, 1997).

Total work, or area under the isokinetic torque curve for all repetitions, is another common measurement in endurance testing that has been determined to be highly reliable (Burdett & Van Swearingen, 1987; Gleeson & Mercer, 1992; Manou et al., 2002). Again, with similar protocols for the knee extensors and knee flexors, ICC's were between .92 and .98 and between .88 and .97, respectively. In fact, Gleeson and Mercer (1992) have proposed that total work should be the recommended index of isokinetic leg muscular endurance. It has also been

suggested that the reliability of total work over all repetitions is a better indicator of similar effort across all repetitions during repeated trials (De Ste Croix et al., 2003).

Neurological Populations

Isokinetic protocols that are similar to those used in adult populations have been employed in studies of individuals with neurological impairments. The majority are studies of fatigue in MS in which either isokinetic concentric (Armstrong et al., 1983; Lambert et al., 2001) or isometric (Surakka et al., 2004) contractions of the knee extensors and flexors were investigated in comparison with a control population. Lambert et al. (2001) measured total work and a FI for three sets of 30 repetitions at 180 degrees/second. Total work was determined to be reliable for the knee flexors and extensors (.80 and .94, respectively) while the FI had low reliability (.51 and .36, respectively). Armstrong et al. (1983) and Sunnerhagen et al. (1999) examined FI in individuals with MS and CVA, respectively, with 50 concentric repetitions at 180 degrees/second; however, reliability was not measured. It is of interest to note that even though higher speeds were employed, the subjects were able to effectively complete the testing, despite the inherent motor control issues associated with upper motor neuron lesions.

Conclusions

Although no single standardized protocol exists for the assessment of muscle endurance in either adult, pediatric, or neurological populations, some conclusions can be drawn from the available literature (See Table A.2 for a list of fatigue protocols). First, utilizing a set number of repetitions between 25 and 50 appears to be most reliable. Secondly, although 180 degrees/second is the most common speed utilized in the adult population, speeds of 100 degrees/second or less may be more reliable in children with and without CP. However, the previous limitation of 30 degrees/second in CP, proposed by Van den Berg-Emons et al. (1996), appears to be unsupported by recent research. For example, the only study to test muscle

Table A.2: Isokinetic Endurance Protocols

Author	Population	Age	N	Protocol	Velocity (deg/s)	Action Type	Limb tested	Measurement	Reliability
De Ste Croix et al., 2003	Children	12.2 (±0.3)	30	Reciprocal KF and KE; 50 maximal reps	90	Isokinetic Concentric	DOM	-FI (MPT) -FI (Avg. Work) -Total Work	(ICC Test-retest -1 wk) KE / KF = .90 / .36 KE / KF = .85 / .54 KE / KF = .95 / .86
Kellis & Kellis, 2001	Adolescents	13.8 (±0.8)	15	Reciprocal KF and KE; 30 maximal reps	60	Isokinetic Concentric	NR	-Joint moment -EMG	NR
Burdett & Van Swearingen, 1987	Adults	NR	36	Reciprocal KF and KE; 25 max reps & the decline of KE torque to 50% of maximum	180 240	Isokinetic Concentric	DOM	-Total Work -Work Ratio -# of reps	(ICC Test-retest) KE(180/240) = .98/.87 KF(180/240) = .91/.83 KE(180/240) = .48/.55 KF(180/240) = .60/.73 KE only = .84/.71
Emery et al., 1994	Adults	21	12	Reciprocal KF and KE; torque decline to 50% of maximum	60 150	Isokinetic Concentric & Eccentric	NR	-# of contractions	NR
Felicetti et al., 1994	Adults	20-30	50	Reciprocal KF and KE for 60seconds	180	Isokinetic Concentric	Both	-# of reps until 20% decline in PT -# of reps until 30% decline in PT -# of reps until 50% decline in PT -Slope -Total Work	(ICC 3 test sessions) KE / KF = .74 / .70 KE / KF = .70 / .69 KE / KF = .77 / .75 KE /KF = .86 / .83 KE / KF = .85 / .82

(table continued)

Author	Population	Age	N	Protocol	Velocity (deg/s)	Action Type	Limb tested	Measurement	Reliability
Gleeson & Mercer, 1992	Adults	28.4 (±3.9)	10	Reciprocal KF and KE; 30 maximal reps	180	Isokinetic Concentric	DOM	-FI (work) -Total Work	(ICC 3 test sessions x 5 days) KE / KF = .84 / .49 KE / KF = .93 / .88
Manou et al., 2002	Adults	27 (±3.8)	12	Reciprocal KF and KE; 40 maximal reps	120	Isokinetic Concentric	DOM	-FI (work) -Total Work -50% fatigue work -50% fatigue time -50% fatigue reps	(Reliability coefficient test-retest - 5days) KE / KF = .90 / .49 KE / KF = .92 / .97 KE / KF = .89 / .96 KE / KF = .88 / .84 KE / KF = .82 / .90
Montgomery et al., 1989	Adults	20-49	32	# of reciprocal KF and KE contractions performed in 45seconds	180	Isokinetic Concentric	R	-Total Work -# of reps -FI #1: (reps 1-5 / reps 21-25) -FI #2: (1 st 5 reps / last 5)	(ICC) KE = .92 KE = .55 Work = .67 MPT = .60 Work = .72 MPT = .74
Patton et al., 1978	Adults	18-24	32	Elbow flexion to exhaustion	60	Isokinetic Concentric	NR	-# of contractions	NR
Pincivero et al., 1997	Adults	22 (±2.2)	21	Reciprocal KF and KE; 30 maximal reps	180	Isokinetic Concentric	DOM & NDOM	-FI (Work) -Total Work	(ICC Test-retest -1wk) KE = .62-.74 KF = .52-.84 KE = .88-.90 KF = .91-.95

(table continued)

Author	Population	Age	N	Protocol	Velocity (deg/s)	Action Type	Limb tested	Measurement	Reliability
Pincivero et al., 2001	Adults	22 (±1.9)	16	Reciprocal KF and KE; 30 maximal reps	180	Isokinetic Concentric	DOM & NDOM	-FI (Work) -Slope	(ICC Test-retest; 1-2wk) KE = .26-.82 KE = .78-.82
Pincivero et al., 2003	Adults	22 (±3.8)	19	Reciprocal KF & KE; 30 max reps	180	Isokinetic Concentric	DOM	-FI (Work) -Slope	NR
Schwendner et al., 1995	Adults	20-40	17	Reciprocal KF & KE until torque declined to 50% of maximum	90	Isokinetic Concentric	DOM & NDOM	-Decline in force output	NR
Thorstensson & Karlsson, 1976	Adults	30 (±2.0)	10	Consecutive KE; 50 max reps	180	Isokinetic Concentric	L	-FI (MPT)	ME = 1.4%
Armstrong et al., 1983	Multiple Sclerosis	MS: ~27-57 C: ~29-58	10 20	Consecutive KE; 50 max reps	190	Isokinetic Concentric	R	-FI (PT)	NR
Lambert et al., 2001	Multiple Sclerosis	MS: 39 (±1.0) C: 33 (±7.6)	15 15	Reciprocal KE and KF; 3 x 30 max reps	180	Isokinetic Concentric	DOM	<u>MS</u> -FI (Work) -Total Work <u>Control</u> -FI (Work) -Total Work	<u>MS (ICC):</u> KE / KF = .36 / .51 KE / KF = .94 / .80 <u>C (ICC):</u> KE / KF = .58 / .38 KE / KF = .92 / .81

(table continued)

Author	Population	Age	N	Protocol	Velocity (deg/s)	Action Type	Limb tested	Measurement	Reliability
Surraka et al., 2004	Multiple Sclerosis	30-54	28	30sec max isometric contractions of KE and KF		Isokinetic Isometric	Both	(See ref.) FI#1 FI#2 FI#3	(ICC test-retest -1wk) KE / KF = .70 / .85 KE / KF = .68 / .81 KE / KF = .68 / .86
Sunnerhagen et al., 1999	CVA	40-65	16	<u>Static</u> : 40% max isometric contraction <u>Dynamic</u> : 50 consecutive KE	180	Isokinetic Isometric Isokinetic Concentric	Both	Endurance time FI	NR

NR = not reported; R = right; L = left; DOM = dominant; NDOM = non-dominant; KF = knee flexion; KE = knee extension; FI = Fatigue index; ICC = Intraclass correlation coefficient; # = number; PT = peak torque; MPT = mean peak torque; ME = methodological error from duplicate determinations and linear correlation coefficient (r); MS = Multiple Sclerosis; CVA = Cerebrovascular accident; C = Control; EMG = electromyography

endurance in children utilized 90 degrees/second with high reliability and increased comfort level for the subjects (De Ste Croix et al., 2003). Speeds of 60, 90, and 100 degrees/second have also been deemed reliable in isokinetic strength testing of children with and without CP (Ayalon et al., 2000; Deighan et al., 2003; Kellis et al., 1999; Merlini et al., 1995). Third, concentric repetitions are more reliable than eccentric, especially in children. Lastly, because there is no consensus on the most reliable measurement of fatigue, several measurements should be made in order to find the best fit for the data. Furthermore, different parameters should be used to capture different aspects of the fatigue process, such as the FI, linear slope, and total work.

Conclusion and Hypotheses

Fatigue has been identified as a significant impairment in adolescents and adults with CP with serious consequences for function and quality of life issues. Further support for the significance of muscle fatigue in individuals with CP comes from studies of energy expenditure, morphological and histopathological changes in spastic muscles, and the presence of muscle fatigue in similar neurological populations (Figure 5).

Despite this evidence, fatigue has not been quantitatively assessed in this population. Therefore, it is important to specifically define the type of fatigue to be studied (i.e. muscle fatigue) and to provide an objective measurement that is more scientifically rigorous. Furthermore, we must understand the contributors to fatigue and their role in the fatigue process. Future research is needed to address the following aims: 1.) quantification of muscle fatigue in individuals with CP and in a control group without motor disability, 2.) examination of the relationships among muscle fatigue and other impairments in order to identify possible contributors to fatigue, 3.) identification of possible consequences (functional limitations) of muscle fatigue and the relationship to severity of disease (disability), and 4.) development of appropriate treatment interventions. Based on the literature presented here regarding the first two

aims, the central hypothesis is that 1.) individuals with CP will experience greater levels of muscle fatigue than those without motor disability and 2.) the amount of fatigue will be related to other impairments of muscle function, such as weakness, co-contraction, stiffness, and spasticity, in unique ways.

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APPENDIX 2: CONSENT FORMS

Louisiana State University
Department of Kinesiology

Consent Form

1. Study Title:

Quantification of Muscle Fatigue in Individuals with Cerebral Palsy

2. Performance Sites:

Data will be collected in the Motor behavior laboratory in Room 2B of the Cox Communication Building at LSU (Gym Armory).

3. Contacts:

Dr. Li Li	phone: 225-578-9146	e-mail: lli3@lsu.edu
Noelle Moreau, PT	phone: 225-202-7854	e-mail: nmorea1@lsu.edu

4. Purpose of the Study:

1.) to measure muscle fatigue in individuals with Cerebral Palsy (CP) compared to able-bodied individuals, 2.) to examine the relationships among muscle fatigue and other impairments in order to identify possible contributors to fatigue in individuals with CP, and 3.) to identify the relationship between muscle fatigue and mobility/functional level.

5. Subjects:

A. Inclusion Criteria

- 1.) Diagnosis of CP for experimental group
- 2.) Age 10-30
- 3.) Willingness to participate in study
- 4.) Ability to follow instructions

B. Exclusion Criteria

- 1.) history of orthopedic surgery (affecting the knee) in the last 9 months
- 2.) residual *knee* pain if surgery greater than 9 months
- 3.) history of knee pain
- 4.) deformity, malalignment, or significant contracture of knees
- 5.) significant cognitive impairments (inability to follow commands)

C. Maximum number of subjects: 100

6. Study Procedures:

Subjects with CP will be classified according to GMFCS (Gross Motor Function Classification System level), a self or parent-report scale. In addition, the parent, adolescent, or adult subject will complete the PODCI (The Pediatric Outcomes Data Collection Instrument) questionnaire, designed to assess function in children with mild to

moderate disability. The PODCI contains 52 short questions and takes about 10-20 minutes to complete. You may already have experience with this questionnaire, as it is commonly used in pediatric practice.

Next, walking speed will be determined by a timed walk test of 25 feet over level ground. Subjects will be allowed to use any assistive devices, such as walkers, they may use in the community. A physical therapist will be administering the test should any assistance be required.

Next, we will use a device known as an isokinetic dynamometer to evaluate muscle function of the knee in individuals with CP compared to individuals who do not have a motor disability. The dynamometer is a device which moves the subject's limb at a preset speed and range of motion (See figure 1). Isokinetic dynamometry provides a safe and controlled environment for children where no resistance is applied once the movement stops. Following familiarization with the isokinetic equipment and explanation of procedures, the subject will be positioned in the device chair in a semireclining sitting position. Both lower extremities will be tested for subjects with bilateral involvement and the involved lower extremity will be tested for subjects with unilateral involvement. The subject's leg will be aligned so that the knee joint center is aligned with the center of rotation of the isokinetic device. The calf will be secured against the knee attachment pad and additional stabilizing straps around the waist, the torso, and over the mid-thigh portion will be used to restrain trunk and hip movement during testing. Following set-up, the complete passive range of motion in knee extension and flexion as designated as "comfortable" by the patient will be determined and this will be used to set the limits of motion. Passive testing will be performed prior to active testing.

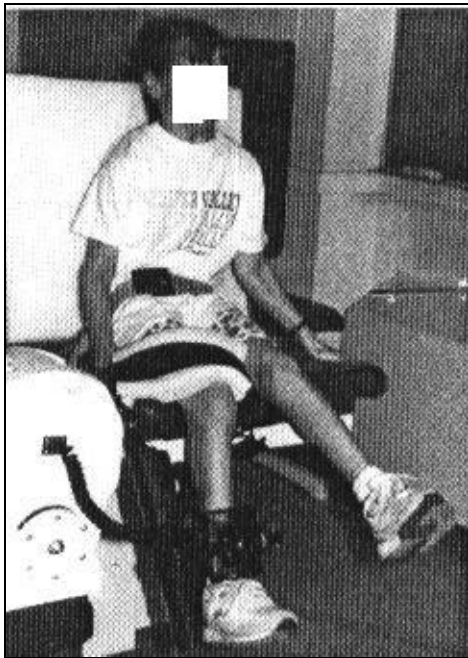


Figure 1: Isokinetic dynamometry testing of the right knee of a child with CP

Passive testing: The passive tests will consist of repetitive flexion and extension of the knee within the preset range of motion (3-5 repetitions each) with a 2 second pause

during the reversal of motion. The subjects will be instructed to relax their muscles and surface electromyography (EMG) will be applied to the quadriceps and hamstrings to verify that the muscles are not active. Surface electromyography is a non-invasive, painless technique of measuring the activity or lack of activity of muscle groups. Repetitions will be performed at various speeds and the torque will be measured.

Active testing: The subjects will perform 5-10 submaximal knee flexion and extension repetitions to familiarize themselves with the procedure. The subject will then perform two maximal exertions for each muscle group at 30 to 60 degrees per second in order to measure the strength of the muscles. The subjects will be instructed to “push” and “pull” their leg against the lever as hard as possible. One minute of rest will be given between exertions to prevent muscle fatigue. After a five minute rest, the fatigue protocol will consist of repeated knee flexion and extension at 30 to 60 degrees per second until the peak torque declines to 50% of the maximum peak torque value for each muscle group (as determined prior to the fatigue test). Again, the subjects will be instructed to “push” and “pull” their leg against the lever as hard as possible.

This is a single testing session. The total time for this process, including explanations and familiarization, is between one and two hours.

7. Benefits:

Although there are no immediate benefits to participation in this study, the goal of this project is to gain a better understanding of muscle endurance in children with CP with the ultimate goal of improving current treatment protocols based on the information gained by this study. Therefore, it is likely that the knowledge gained from this study will benefit the participant in the future. Furthermore, the participants and family will have the self-satisfaction of knowing that they contributed to the future body of knowledge regarding muscle performance in CP.

8. Risks/Discomforts:

Self or Parent-Report Measures: no risks except confidentiality

Gait Velocity: Assessment would involve less risk than that associated with walking during daily activities due to the controlled environment (level ground) and the supervision of a licensed physical therapist.

Passive testing: Assessment should not involve any risk as the subject is relaxed during this portion of the test and will have the ability to terminate the test at any time through a hand-held safety switch.

Active testing: Assessment should involve minimal risk as the strength assessment has been well established by Damiano and colleagues in children with CP. The fatigue assessment, however, may result in temporary mild post-testing soreness, similar to that experienced after a bout of exercise.

9. Measures taken to reduce risk

All tests and measures will be administered and supervised by a licensed physical therapist, who has over 7 years experience in working with children with disabilities.

(Investigator, Noelle Moreau, P.T.). In addition, every effort will be made to maintain the confidentiality of the study records. Participants will be assigned a number for identification in the study (it will not be related to their social security number, birth date, etc) and all collected data will be coded by that number. Files will be kept in a secure room to which only investigators will have access.

Gait Velocity: Two investigators, one of whom is a licensed physical therapist, will be close to the subject to offer additional support should imbalance occur.

Passive testing: The passive range of motion will be predetermined according to what is comfortable for the subject. In addition, the subject will be given a hand-held safety switch which will immediately terminate the test at any point in time. Again, the testing will be supervised and administered by a licensed physical therapist for added safety.

Active testing: The active range of motion will be predetermined according to what is comfortable for the subject. The subject will be also given a hand-held safety switch which will immediately terminate the test at any point in time. Furthermore, isokinetic dynamometry provides a safe and controlled environment for children where no resistance is applied once the movement stops. Therefore, there is minimal risk for injury. The fatigue assessment, however, may result in temporary mild post-testing soreness, similar to that experienced after a bout of exercise. A licensed physical therapist will be available by phone after testing to answer any questions or concerns regarding possible post-testing soreness.

10. Right to Refuse:

Participation in the study is voluntary. You may withdraw from the study at any time without penalty or loss of any benefit to which they may otherwise be entitled.

11. Privacy:

The results of the study may be published, but no names or identifying information will be included in the publication. Your identity will remain confidential unless disclosure is required by law.

12. Financial Information:

Participation in this study is voluntary with no financial compensations.

13. Withdrawal:

There are no consequences if you choose to withdraw from participation at any time during this study.

14. Removal:

The investigators may remove you from the study for any number of reasons, including, but not limited to, the detection of adverse responses and technical difficulties in obtaining information during the testing session. If the investigators elect to remove you from the study they will provide you with the justification for doing so, and you will be given an opportunity to ask questions regarding your removal.

Part 5: Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, LSU Institutional Review Board, (225)578-8692. I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.'

Subject Signature _____ Date _____

Illiterate subjects:

The study subject has indicated to me that he/she is unable to read. I certify that I have read this consent form to the subject and explained that by completing the signature line above, the subject has agreed to participate.

Signature of Reader _____ Date _____

Parental Permission/Consent Form

1. Study Title:

Quantification of Muscle Fatigue in Individuals with Cerebral Palsy

2. Performance Sites:

Data will be collected in the Motor behavior laboratory in Room 2B of the Cox Communication Building at LSU (Gym Armory).

3. Contacts:

Dr. Li Li	phone: 225-578-9146	e-mail: lli3@lsu.edu
Noelle Moreau, PT	phone: 225-202-7854	e-mail: nmorea1@lsu.edu

4. Purpose of the Study:

1.) to measure muscle fatigue in individuals with Cerebral Palsy (CP) compared to able-bodied individuals, 2.) to examine the relationships among muscle fatigue and other impairments in order to identify possible contributors to fatigue in individuals with CP, and 3.) to identify the relationship between muscle fatigue and mobility/functional level.

5. Subjects:

A. Inclusion Criteria

- 5.) Diagnosis of CP for experimental group
- 6.) Age 10-30
- 7.) Willingness to participate in study
- 8.) Ability to follow instructions

B. Exclusion Criteria

- 1.) history of orthopedic surgery (affecting the knee) in the last 9 months
- 6.) residual *knee* pain if surgery greater than 9 months
- 7.) history of knee pain
- 8.) deformity, malalignment, or significant contracture of knees
- 9.) significant cognitive impairments (inability to follow commands)

C. Maximum number of subjects: 100

6. Study Procedures:

Subjects with CP will be classified according to GMFCS (Gross Motor Function Classification System level), a self or parent-report scale. In addition, the parent, adolescent, or adult subject will complete the PODCI (The Pediatric Outcomes Data Collection Instrument) questionnaire, designed to assess function in children with mild to moderate disability. The PODCI contains 52 short questions and takes about 10-20

minutes to complete. You may already have experience with this questionnaire, as it is commonly used in pediatric practice.

Next, walking speed will be determined by a timed walk test of 25 feet over level ground. Subjects will be allowed to use any assistive devices, such as walkers, they may use in the community. A physical therapist will be administering the test should any assistance be required.

Next, we will use a device known as an isokinetic dynamometer to evaluate muscle function of the knee in individuals with CP compared to individuals who do not have a motor disability. The dynamometer is a device which moves the subject's limb at a preset speed and range of motion (See figure 1). Isokinetic dynamometry provides a safe and controlled environment for children where no resistance is applied once the movement stops. Following familiarization with the isokinetic equipment and explanation of procedures, the subject will be positioned in the device chair in a semireclining sitting position. Both lower extremities will be tested for subjects with bilateral involvement and the involved lower extremity will be tested for subjects with unilateral involvement. The subject's leg will be aligned so that the knee joint center is aligned with the center of rotation of the isokinetic device. The calf will be secured against the knee attachment pad and additional stabilizing straps around the waist, the torso, and over the mid-thigh portion will be used to restrain trunk and hip movement during testing. Following set-up, the complete passive range of motion in knee extension and flexion as designated as "comfortable" by the patient will be determined and this will be used to set the limits of motion. Passive testing will be performed prior to active testing.

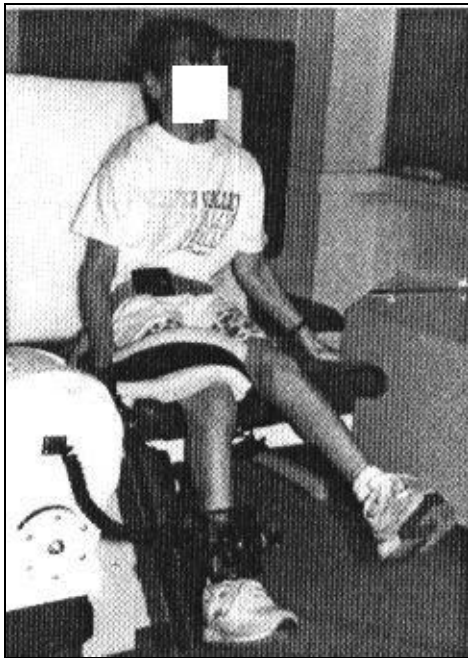


Figure 1: Isokinetic dynamometry testing of the right knee of a child with CP

Passive testing: The passive tests will consist of repetitive flexion and extension of the knee within the preset range of motion (3-5 repetitions each) with a 2 second pause

during the reversal of motion. The subjects will be instructed to relax their muscles and surface electromyography (EMG) will be applied to the quadriceps and hamstrings to verify that the muscles are not active. Surface electromyography is a non-invasive, painless technique of measuring the activity or lack of activity of muscle groups. Repetitions will be performed at various speeds and the torque will be measured.

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This is a single testing session. The total time for this process, including explanations and familiarization, is between one and two hours.

7. Benefits:

Although there are no immediate benefits to participation in this study, the goal of this project is to gain a better understanding of muscle endurance in children with CP with the ultimate goal of improving current treatment protocols based on the information gained by this study. Therefore, it is likely that the knowledge gained from this study will benefit the participant in the future. Furthermore, the participants and family will have the self-satisfaction of knowing that they contributed to the future body of knowledge regarding muscle performance in CP.

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Self or Parent-Report Measures: no risks except confidentiality

Gait Velocity: Assessment would involve less risk than that associated with walking during daily activities due to the controlled environment (level ground) and the supervision of a licensed physical therapist.

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All tests and measures will be administered and supervised by a licensed physical therapist, who has over 7 years experience in working with children with disabilities.

(Investigator, Noelle Moreau, P.T.). In addition, every effort will be made to maintain the confidentiality of the study records. Participants will be assigned a number for identification in the study (it will not be related to their social security number, birth date, etc) and all collected data will be coded by that number. Files will be kept in a secure room to which only investigators will have access.

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Active testing: The active range of motion will be predetermined according to what is comfortable for the subject. The subject will be also given a hand-held safety switch which will immediately terminate the test at any point in time. Furthermore, isokinetic dynamometry provides a safe and controlled environment for children where no resistance is applied once the movement stops. Therefore, there is minimal risk for injury. The fatigue assessment, however, may result in temporary mild post-testing soreness, similar to that experienced after a bout of exercise. A licensed physical therapist will be available by phone after testing to answer any questions or concerns regarding possible post-testing soreness.

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11. Privacy:

The results of the study may be published, but no names or identifying information will be included in the publication. Your identity will remain confidential unless disclosure is required by law.

12. Financial Information:

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13. Withdrawal:

There are no consequences if you choose to withdraw from participation at any time during this study.

14. Removal:

The investigators may remove you from the study for any number of reasons, including, but not limited to, the detection of adverse responses and technical difficulties in obtaining information during the testing session. If the investigators elect to remove you from the study they will provide you with the justification for doing so, and you will be given an opportunity to ask questions regarding your removal.

Part 5: Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, LSU Institutional Review Board, (225)578-8692. I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.'

Parent Signature _____ Date _____

Illiterate subjects:

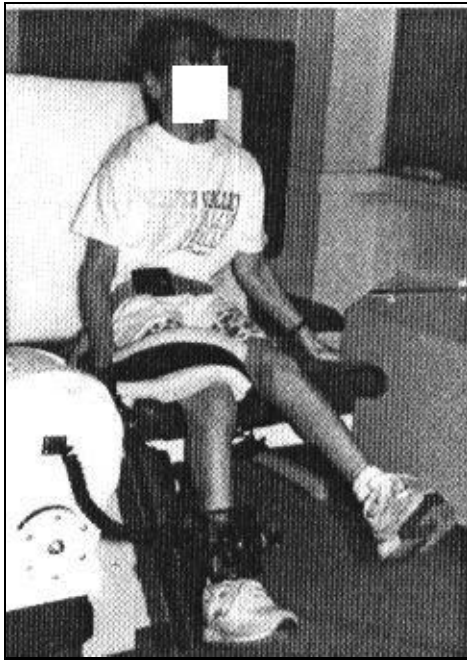
The study subject has indicated to me that he/she is unable to read. I certify that I have read this consent form to the subject and explained that by completing the signature line above, the subject has agreed to participate.

Signature of Reader _____ Date _____

Louisiana State University
Department of Kinesiology

Child Assent Form

I, _____, agree to be in a study to help people better understand how the muscles of the knee work in people with and without Cerebral Palsy. I will be asked to “push” and “pull” my leg against a lever as hard as I can. Other times, I will just relax and the lever will move my leg for me. I will also walk a short distance and be timed. I agree to give my best effort throughout the test and to follow the instructions. **I understand that I will be able to stop the test at any time if I feel pain or discomfort or for any other reason. I will not get in trouble for stopping the test.**



Child's Signature _____ Age _____ Date _____

Witness _____ Date _____

APPENDIX 3: GROSS MOTOR FUNCTION CLASSIFICATION SYSTEM

Palisano, R., Rosenbaum, P., Walter, S., Russell, D., Wood, E., & Galuppi, B. (1997). Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev.Med.Child Neurol.*, 39, 214-223.

LEVEL I--Walks without restrictions; limitations in more advanced gross motor skills.

Before 2nd birthday: Infants move in and out of sitting and floor sit with both hands free to manipulate objects. Infants crawl on hands and knees, pull to stand and take steps holding onto furniture. Infants walk between 18 months and 2 years of age without the need for any assistive mobility device.

From age 2 to 4th birthday: Children floor sit with both hands free to manipulate objects. Movements in and out of floor sitting and standing are performed without adult assistance. Children walk as the preferred method of mobility without the need for any assistive mobility device.

From age 4 to 6th birthday: Children get into and out of, and sit in, a chair without the need for hand support. Children move from the floor and from chair sitting to standing without the need for objects for support. Children walk indoors and outdoors, and climb stairs. Emerging ability to run and jump.

From age 6 to 12: children walk indoors and outdoors, and climb stairs without limitations. Children perform gross motor skills including running and jumping but speed, balance, and coordination are reduced.

LEVEL II--Walks without assistive devices; limitations walking outdoors and in the community.

Before 2nd birthday: Infants maintain floor sitting but may need to use their hands for support to maintain balance. Infants creep on their stomach or crawl on hands and knees. Infants may pull to stand and take steps holding onto furniture.

From age 2 to 4th birthday: Children floor sit but may have difficulty with balance when both hands are free to manipulate objects. Movements in and out of sitting are performed without adult assistance. Children pull to stand on a stable surface. Children crawl on hands and knees with a reciprocal pattern, cruise holding onto furniture and walk using an assistive mobility device as preferred methods of mobility.

From age 4 to 6th birthday: Children sit in a chair with both hands free to manipulate objects. Children move from the floor to standing and from chair sitting to standing but often require a stable surface to push or pull up on with their arms. Children walk without the need for any assistive mobility device indoors and for short distances on level surfaces outdoors. Children climb stairs holding onto a railing but are unable to run or jump.

From age 6 to 12: children walk indoors and outdoors, and climb stairs holding onto a railing but experience limitations walking on uneven surfaces and inclines, and walking in crowds or confined spaces. Children have at best only minimal ability to perform gross motor skills such as running and jumping.

Distinctions between levels I and II:

Compared with children in level I, children in level II have limitations in the ease of performing movement transitions; walking outdoors and in the community; the need for assistive mobility devices when beginning to walk; quality of movement; and the ability to perform gross motor skills such as running and jumping.

LEVEL III--Walks with assistive mobility devices; limitations walking outdoors and in the community.

Before 2nd birthday: Infants maintain floor sitting when the low back is supported. Infants roll and creep forward on their stomachs.

From age 2 to 4th birthday: Children maintain floor sitting often by "W-sitting" (sitting between flexed and internally rotated hips and knees) and may require adult assistance to assume sitting. Children creep on their stomach or crawl on hands and knees (often without reciprocal leg movements) as their primary methods of self-mobility. Children may pull to stand on a stable surface and cruise short distances. Children may walk short distances indoors using an assistive mobility device and adult assistance for steering and turning.

From age 4 to 6th birthday: Children sit on a regular chair but may require pelvic or trunk support to maximize hand function. Children move in and out of chair sitting using a stable surface to push on or pull up with their arms. Children walk with an assistive mobility device on level surfaces and climb stairs with assistance from an adult. Children frequently are transported when travelling for long distances or outdoors on uneven terrain.

From age 6 to 12: children walk indoors or outdoors on a level surface with an assistive mobility device. Children may climb stairs holding onto a railing. Depending on upper limb function, children propel a wheel chair manually or are transported when traveling for long distances or outdoors on uneven terrain.

Distinctions between levels II and III:

Differences are seen in the degree of achievement of functional mobility. Children in level III need assistive mobility devices and frequently orthoses to walk, while children in level II do not require assistive mobility devices after age 4.

LEVEL IV--Self-mobility with limitations; children are transported or use power mobility outdoors and in the community.

Before 2nd birthday: Infants have head control, but trunk support is required for floor sitting. Infants can roll to supine and may roll to prone.

From age 2 to 4th birthday: Children floor sit when placed, but are unable to maintain alignment and balance without use of their hands for support. Children frequently require adaptive equipment for sitting and standing. Self-mobility for short distances (within a room) is achieved through rolling, creeping on stomach, or crawling on hands and knees without reciprocal leg movement.

From age 4 to 6th birthday: Children sit on a chair but need adaptive seating for trunk control and to maximize hand function. Children move in and out of chair sitting with assistance from an adult or a stable surface to push or pull up on with their arms. Children may at best walk short distances with a walker and adult supervision but have difficulty turning and maintaining balance on uneven surfaces. Children are transported in the community. Children may achieve self-mobility using a power wheelchair.

From age 6 to 12: Children may maintain levels of function achieved before age 6 or rely more on wheeled mobility at home, school, and in the community. Children may achieve self-mobility using a power wheelchair.

Distinctions between levels III and IV:

Differences in sitting ability and mobility exist, even allowing for extensive use of assistive technology. Children in level III sit independently, have independent floor mobility, and walk with assistive mobility devices. Children in level IV function in sitting (usually supported), but independent mobility is very limited. Children in level IV are more likely to be transported or use power mobility.

LEVEL V--Self-mobility is severely limited even with the use of assistive technology.

Before 2nd birthday: Physical impairments limit voluntary control of movement. Infants are unable to maintain antigravity head and trunk postures in prone and sitting. Infants require adult assistance to roll.

From age 2 to 12: Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. At level V, children have no means of independent mobility and are transported. Some children achieve self-mobility using a power wheelchair with extensive adaptations.

Distinctions between levels IV and V:

Children in level V lack independence even in basic antigravity postural control. Self mobility is achieved only if the child can learn how to operate an electrically powered wheelchair.

PARENT FORM
(BASELINE)

**TO BE COMPLETED BY THE PARENTS OF
CHILDREN 2-18 YEARS OLD**

We are asking you to complete this questionnaire about your child to better understand his/her health in general and problems related to bone and muscle conditions. Your completion of this questionnaire is voluntary. Your responses will be held in the strictest of confidence. It will take about 15 to 20 minutes to complete.

Please answer every question. Some questions may look like others, but each one is different.

Answer the questions by circling the appropriate number or by writing the answer as requested.

There are no right or wrong answers. If you are not sure how to answer a question, please give the best answer you can and make a comment in the margin. We will read all your comments, so feel free to make as many as you wish.

1. Your Child's Name: _____

2. Today's Date: _____

3. Your Child's Birth Date: _____

OFFICE USE ONLY

Subject ID:

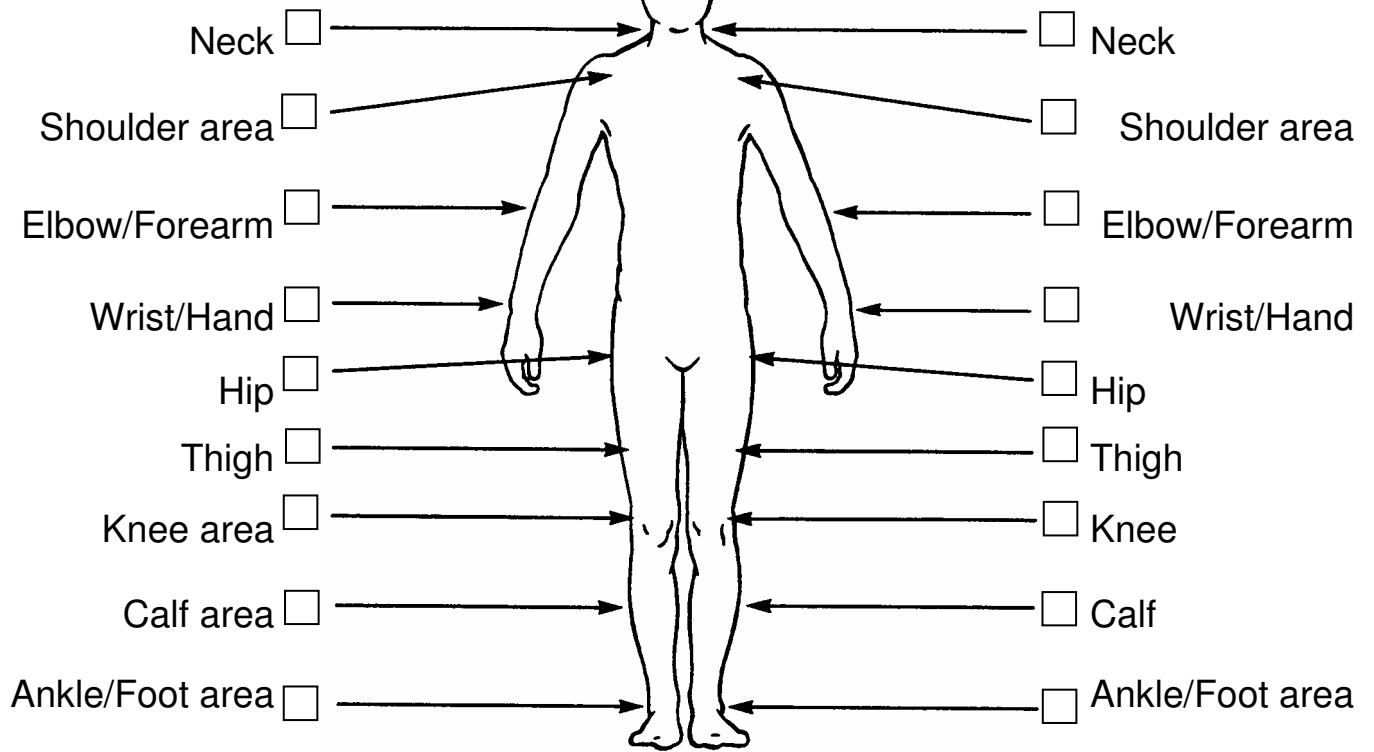
Be sure to fill out both the front and back of all subsequent pages.

OFFICE USE ONLY

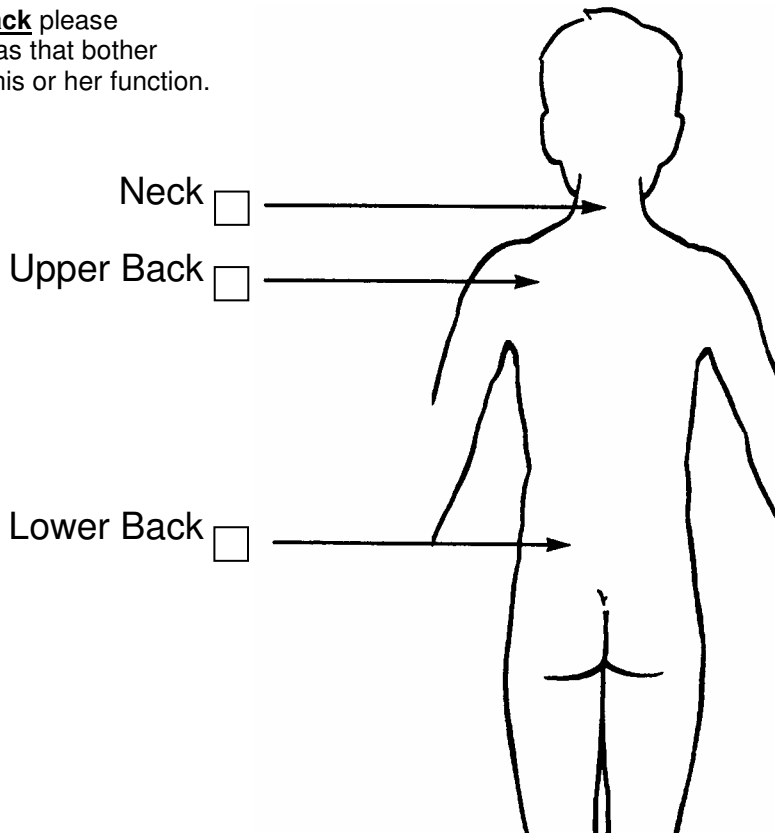
Notes by clinician administering questionnaire:

For your child's **right side** please indicate those areas that bother your child or limit his or her function.

For your child's **left side** please indicate those areas that bother your child or limit his or her function.



For your child's **back** please indicate those areas that bother your child or limit his or her function.



	Excellent	Very Good	Good	Fair	Poor
5. In general, would you say your child's health is: (Circle one number)	1	2	3	4	5

	Much better than one year ago	Somewhat better than one year ago	About the same	Somewhat worse than one year ago	Much worse than one year ago
6. Compared to one year ago , how would you rate your child's health in general now? (Circle one number)	1	2	3	4	5

Have you ever been told by a doctor, nurse, teacher, or other health professional that your child has had any of the following conditions? (Please circle "yes" for all conditions that apply). If yes, indicate if your child is being treated for this condition and if your child is limited by those conditions.

	Has your child <u>ever</u> had it?		Does your child receive treatment for it <u>now</u> ?		Are your child's activities limited by it <u>now</u> ?	
7. Juvenile arthritis (one or two joints).	Yes	No	Yes	No	Yes	No
8. Juvenile arthritis (many joints).	Yes	No	Yes	No	Yes	No
9. Anorexia or bulimia (eating disorders).	Yes	No	Yes	No	Yes	No
10. Asthma.	Yes	No	Yes	No	Yes	No
11. Attention or behavioral problems.	Yes	No	Yes	No	Yes	No
12. Chronic allergies or sinus trouble.	Yes	No	Yes	No	Yes	No
13. Developmental delay.	Yes	No	Yes	No	Yes	No
14. Mental retardation.	Yes	No	Yes	No	Yes	No
15. Diabetes.	Yes	No	Yes	No	Yes	No
16. Epilepsy (seizure disorder).	Yes	No	Yes	No	Yes	No
17. Hearing impairment or deafness.	Yes	No	Yes	No	Yes	No
18. Heart problem.	Yes	No	Yes	No	Yes	No
19. Learning problem.	Yes	No	Yes	No	Yes	No
20. Sleep disturbance.	Yes	No	Yes	No	Yes	No
21. Speech problems.	Yes	No	Yes	No	Yes	No
22. Vision problems.	Yes	No	Yes	No	Yes	No

Some kinds of problems can make it hard to do many activities, such as eating, bathing, school work and playing with friends. We would like to find out how your child is doing.

During the **last week** was it easy or hard for your child to:

	Easy	A little hard	Very hard	Can't do at all	Too young for this activity
23. Lift heavy books?	1	2	3	4	5
24. Pour a half gallon of milk?	1	2	3	4	5
25. Open a jar that has been opened before?	1	2	3	4	5
26. Use a fork and spoon?	1	2	3	4	5
27. Comb his/her hair?	1	2	3	4	5
28. Button buttons?	1	2	3	4	5
29. Put on his/her socks?	1	2	3	4	5
30. Write with a pencil?	1	2	3	4	5

	Rarely	Once a month	Two or three times a month	Once a week	More than once a week	Does not attend school, etc.
31. On average, over the last 12 months , how often did your child miss school (preschool, day care, camp, etc.) because of his/her health?	1	2	3	4	5	6

During the **last week**, how happy has our child been with:

	Very happy	Somewhat happy	Not sure	Somewhat unhappy	Very unhappy	Child is too young
32. How he/she looks?	1	2	3	4	5	6
33. His/her body?	1	2	3	4	5	6
34. What clothes or shoes he/she can wear?	1	2	3	4	5	6
35. His/her ability to do the same things his/her friends do?	1	2	3	4	5	6
36. His/her health in general?	1	2	3	4	5	6

During the **last week**, how much of the time:

	Most of the time	Some of the time	A little of the time	None of the time
37. Did your child feel sick and tired?	1	2	3	4
38. Was your child full of pep and energy?	1	2	3	4
39. Did pain or discomfort interfere with your child's activities?	1	2	3	4

During the **last week**, has it been easy or hard for your child to:

	Easy	A little hard	Very hard	Can't do at all	Too young for this activity
40. Run short distances?	1	2	3	4	5
41. Bicycle or tricycle?	1	2	3	4	5
42. Climb three flights of stairs?	1	2	3	4	5
43. Climb one flight of stairs?	1	2	3	4	5
44. Walk more than a mile?	1	2	3	4	5
45. Walk three blocks?	1	2	3	4	5
46. Walk one block?	1	2	3	4	5
47. Get on and off a bus?	1	2	3	4	5

	Never	Sometimes	About half the time	Often	All the time
48. How often does your child need help from another person for walking and climbing?	1	2	3	4	5

	Never	Sometimes	About half the time	Often	All the time
49. How often does your child use assistive devices (such as braces, crutches, or wheelchair) for walking and climbing?	1	2	3	4	5

During the **last week**, has it been easy or hard for your child to:

	Easy	A little hard	Very hard	Can't do at all	Too young for this activity
50. Stand while washing his/ her hands and face at a sink?	1	2	3	4	5
51. Sit in a regular chair without holding on?	1	2	3	4	5
52. Get on and off a toilet or chair?	1	2	3	4	5
53. Get in and out of bed?	1	2	3	4	5
54. Turn door knobs?	1	2	3	4	5
55. Bend over from a standing position and pick up something off the floor?	1	2	3	4	5

	Never	Sometimes	About half the time	Often	All the time
56. How often does your child need help from another person for sitting and standing?	1	2	3	4	5
57. How often does your child use assistive devices (such as braces, crutches, or wheelchair) for sitting and standing?	1	2	3	4	5

	Yes, easily	Yes, but a little hard	Yes, but very hard	No
58. Can your child participate in recreational outdoor activities with other children the same age? (For example: bicycling, tricycling, skating, hiking, jogging)	1	2	3	4

If you answered "no" to Question 58 above, was your child's activity limited by: (Circle "yes" to all that apply.)

	Yes
59. Pain?	1
60. General Health?	1
61. Doctor or parent instructions?	1
62. Fear the other kids won't like him/ her?	1
63. Dislike of recreational outdoor activities?	1
64. Too young?	1
65. Activity not in season?	1

	Yes, easily	Yes, but a little hard	Yes, but very hard	No
66. Can your child participate in pickup games or sports with other children the same age? (For example: tag, dodge ball, basketball, soccer, catch, jump rope, touch football, hop scotch)	1	2	3	4

If you answered “no” to Question 66 above, was your child’s activity limited by: (Circle “yes” to all that apply.)

	Yes
67. Pain?	1
68. General Health?	1
69. Doctor or parent instructions?	1
70. Fear the other kids won’t like him/ her?	1
71. Dislike of pickup games or sports?	1
72. Too young?	1
73. Activity not in season?	1

	Yes, easily	Yes, but a little hard	Yes, but very hard	No
74. Can your child participate in competitive level sports with other children the same age? (For example: hockey, basketball, soccer, football, baseball, swimming, running [track or cross country], gymnastics, or dance)	1	2	3	4

If you answered “no” to Question 74 above, was your child’s activity limited by: (Circle “yes” to all that apply.)

	Yes
75. Pain?	1
76. General Health?	1
77. Doctor or parent instructions?	1
78. Fear the other kids won’t like him/ her?	1
79. Dislike of competitive level sports?	1
80. Too young?	1
81. Activity not in season?	1

	Often	Sometimes	Never or rarely
82. How often in the past week did your child get together and do things with friends?	1	2	3

If you answered “sometimes” or “never or rarely” to Question 82 above, was your child’s activity limited by:
(Circle “yes” to all that apply.)

	Yes
83. Pain?	1
84. General health?	1
85. Doctor or parent instructions?	1
86. Fear the other kids won’t like him/her?	1
87. Friends not around?	1

	Often	Sometimes	Never or rarely	No gym or recess
88. How often in the past week did your child participate in gym/ recess?	1	2	3	4

If you answered “sometimes” or “never or rarely” to Question 88 above, was your child’s activity limited by:
(Circle “yes” to all that apply.)

	Yes
89. Pain?	1
90. General health?	1
91. Doctor or parent instructions?	1
92. Fear the other kids won’t like him/her?	1
93. Dislike of gym/recess?	1
94. School not in session?	1
95. Does not attend school?	1

	Usually easy	Sometimes easy	Sometimes hard	Usually hard
96. Is it easy or hard for your child to make friends with children his/ her own age?	1	2	3	4

	None	Very mild	Mild	Moderate	Severe	Very severe
97. How much pain has your child had during the last week ?	1	2	3	4	5	6

	Not at all	A little bit	Moderately	Quite a bit	Extremely
98. During the last week, how much did pain interfere with your child's normal activities (including at home, outside of the home, and at school)?	1	2	3	4	5

What expectations do you have for your child's treatment?
As a result of my child's treatment, I expect my child:

	Definitely yes	Probably yes	Not sure	Probably not	Definitely not
99. To have pain relief.	1	2	3	4	5
100. To look better.	1	2	3	4	5
101. To feel better about himself/ herself.	1	2	3	4	5
102. To sleep more comfortably.	1	2	3	4	5
103. To be able to do activities at home.	1	2	3	4	5
104. To be able to do more at school.	1	2	3	4	5
105. To be able to do more play or recreational activities (biking, walking, doing things with friends).	1	2	3	4	5
106. To be able to do more sports.	1	2	3	4	5
107. To be free from pain or disability as an adult.	1	2	3	4	5

	Very satisfied	Somewhat satisfied	Neutral	Somewhat dissatisfied	Very dissatisfied
108. If your child had to spend the rest of his/ her life with his/ her bone and muscle condition as it is right now , how would you feel about it?	1	2	3	4	5

109. What is your child's gender?

Male

Female

110. What is your child's race? (check all that apply)

White

Black or African-American

Hispanic

Asian or Pacific Islander

Native American Indian

Other (please specify)

111. Who lives at home with your child? (check all that apply)

- | | | |
|---|-------------------------------------|--|
| <input type="checkbox"/> Mother | <input type="checkbox"/> Stepmother | <input type="checkbox"/> Foster mother |
| <input type="checkbox"/> Father | <input type="checkbox"/> Stepfather | <input type="checkbox"/> Foster father |
| <input type="checkbox"/> Brothers and/or sisters (How many _____ ?) | | |
| <input type="checkbox"/> Other adults | | |

112. What is your relationship to this child?

- | | | |
|--------------------------------------|-------------------------------------|--|
| <input type="checkbox"/> Mother | <input type="checkbox"/> Stepmother | <input type="checkbox"/> Foster mother |
| <input type="checkbox"/> Father | <input type="checkbox"/> Stepfather | <input type="checkbox"/> Foster father |
| <input type="checkbox"/> Brother | <input type="checkbox"/> Sister | <input type="checkbox"/> Grandmother |
| <input type="checkbox"/> Grandfather | | |
| <input type="checkbox"/> Aunt | <input type="checkbox"/> Uncle | <input type="checkbox"/> Guardian |
| <input type="checkbox"/> Other _____ | | |

Please answer the next two questions about **your health (not your child's)**:

113. In general, would you say your health is:

- | | | |
|------------------------------------|------------------------------------|-------------------------------|
| <input type="checkbox"/> Excellent | <input type="checkbox"/> Very good | <input type="checkbox"/> Good |
| <input type="checkbox"/> Fair | <input type="checkbox"/> Poor | |

114. Compared to **one year ago**, how would you rate **your health** in general now?

- Much better now than 1 year ago
- Somewhat better now than 1 year ago
- About the same as 1 year ago
- Somewhat worse now than 1 year ago
- Much worse now than 1 year ago

ADOLESCENT / PATIENT FORM

(BASELINE)

TO BE COMPLETED BY ADOLESCENTS 11-18 YEARS OLD

We are asking you to complete this questionnaire about you to better understand your health in general and problems related to bone and muscle conditions. Your completion of this questionnaire is voluntary. Your responses will be held in the strictest of confidence. It will take about 15 to 20 minutes to complete.

Please answer every question. Some questions may look like others, but each one is different.

Answer the questions by circling the appropriate number or by writing the answer as requested.

There are no right or wrong answers. If you are not sure how to answer a question, please give the best answer you can and make a comment in the margin. We will read all your comments, so feel free to make as many as you wish.

1. Your Name:

2. Today's Date:

3. Your Birth Date:

OFFICE USE ONLY

Subject ID:

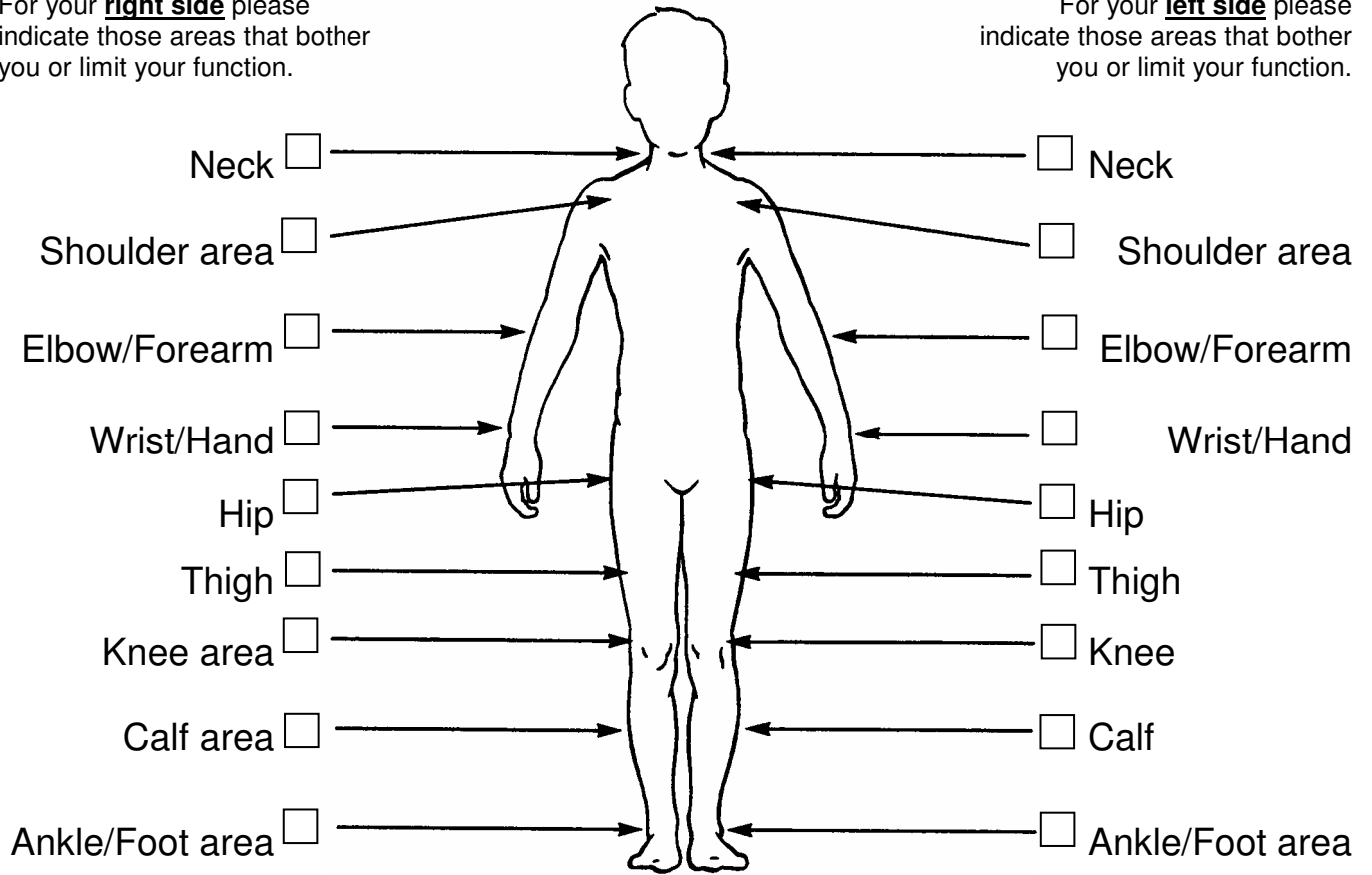
Be sure to fill out both the front and back of all subsequent pages.

OFFICE USE ONLY

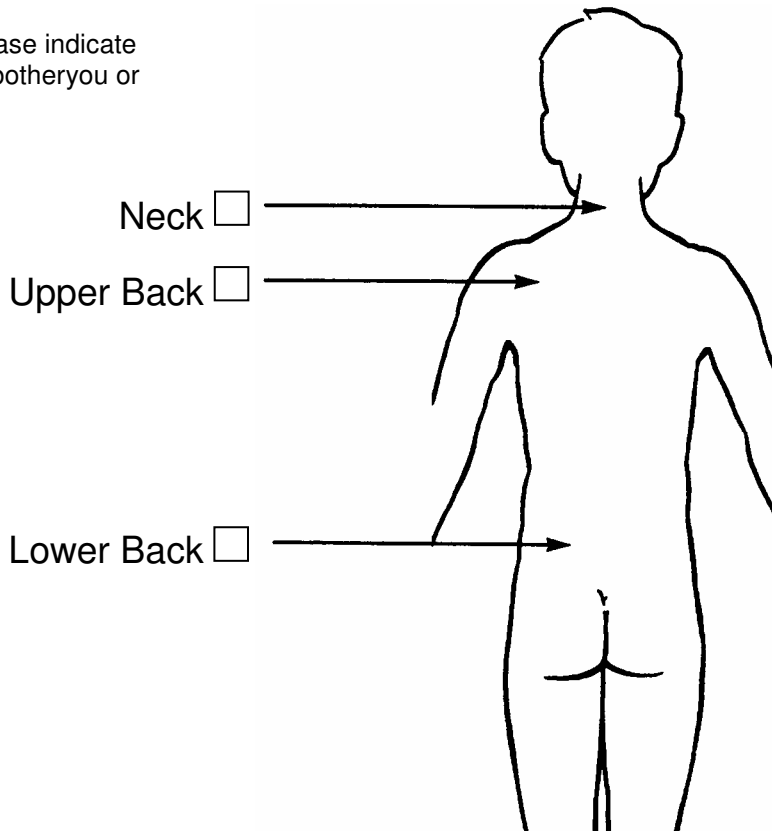
Notes by clinician administering questionnaire:

For your **right side** please indicate those areas that bother you or limit your function.

For your **left side** please indicate those areas that bother you or limit your function.



For your **back** please indicate those areas that bother you or limit your function.



	Excellent	Very Good	Good	Fair	Poor
5. In general, would you say your health is: (Circle one number) <input type="checkbox"/>	1	2	3	4 <input type="checkbox"/>	5

	Much better than one year ago	Somewhat better than one year ago	About the same	Somewhat worse than one year ago	Much worse than one year ago
6. Compared to one year ago , how would you rate your health in general now? (Circle one number)	1	2	3	4	5

Have you ever been told by a doctor, nurse, teacher, or other health professional that you have had any of the following conditions? (Please circle "yes" for all conditions that apply). If yes, indicate if you are being treated for this condition and if you are limited by those conditions.

	Have you <u>ever</u> had it?		Do you receive treatment for it <u>now</u> ?		Are your activities limited by it <u>now</u> ?	
7. Juvenile arthritis (one or two joints).	Yes	No	Yes	No	Yes	No
8. Juvenile arthritis (many joints).	Yes	No	Yes	No	Yes	No
9. Anorexia or bulimia (eating disorders).	Yes	No	Yes	No	Yes	No
10. Asthma.	Yes	No	Yes	No	Yes	No
11. Attention or behavioral problems.	Yes	No	Yes	No	Yes	No
12. Chronic allergies or sinus trouble.	Yes	No	Yes	No	Yes	No
13. Developmental delay.	Yes	No	Yes	No	Yes	No
14. Mental retardation.	Yes	No	Yes	No	Yes	No
15. Diabetes.	Yes	No	Yes	No	Yes	No
16. Epilepsy (seizure disorder).	Yes	No	Yes	No	Yes	No
17. Hearing impairment or deafness.	Yes	No	Yes	No	Yes	No
18. Heart problem.	Yes	No	Yes	No	Yes	No
19. Learning problem.	Yes	No	Yes	No	Yes	No
20. Sleep disturbance.	Yes	No	Yes	No	Yes	No
21. Speech problems.	Yes	No	Yes	No	Yes	No
22. Vision problems.	Yes	No	Yes	No	Yes	No

Some kinds of problems can make it hard to do many activities, such as eating, bathing, school work and playing with friends. We would like to find out how you are doing.

During the **last week** was it easy or hard for you to:

	Easy	A little hard	Very hard	Can't do at all
23. Lift heavy books?	1	2	3	4
24. Pour a half gallon of milk?	1	2	3	4
25. Open a jar that has been opened before?	1	2	3	4
26. Use a fork and spoon?	1	2	3	4
27. Comb your hair?	1	2	3	4
28. Button buttons?	1	2	3	4
29. Put on your socks?	1	2	3	4
30. Write with a pencil?	1	2	3	4

	Rarely	Once a month	Two or three times a month	Once a week	More than once a week	Do not attend school, etc.
31. On average, over the last 12 months , how often did you miss school (camp, etc.) because of your health?	1	2	3	4	5	6

During the **last week**, how happy have you been with:

	Very happy	Somewhat happy	Not sure	Somewhat unhappy	Very unhappy
32. How you look?	1	2	3	4	5
33. Your body?	1	2	3	4	5
34. What clothes or shoes you can wear?	1	2	3	4	5
35. Your ability to do the same things your friends do?	1	2	3	4	5
36. Your health in general?	1	2	3	4	5

During the **last week**, how much of the time:

	Most of the time	Some of the time	A little of the time	None of the time
37. Did you feel sick and tired?	1	2	3	4
38. Were you full of pep and energy?	1	2	3	4
39. Did pain or discomfort interfere with your activities?	1	2	3	4

During the **last week**, has it been easy or hard for you to:

	Easy	A little hard	Very hard	Can't do at all
40. Run short distances?	1	2	3	4
41. Bicycle or tricycle?	1	2	3	4
42. Climb three flights of stairs?	1	2	3	4
43. Climb one flight of stairs?	1	2	3	4
44. Walk more than a mile?	1	2	3	4
45. Walk three blocks?	1	2	3	4
46. Walk one block?	1	2	3	4
47. Get on and off a bus?	1	2	3	4

	Never	Sometimes	About half the time	Often	All the time
48. How often do you need help from another person for walking and climbing?	1	2	3	4	5

	Never	Sometimes	About half the time	Often	All the time
49. How often do you use assistive devices (such as braces, crutches, or wheelchair) for walking and climbing?	1	2	3	4	5

During the **last week**, has it been easy or hard for you to:

	Easy	A little hard	Very hard	Can't do at all
50. Stand while washing your hands and face at a sink?	1	2	3	4
51. Sit in a regular chair without holding on?	1	2	3	4
52. Get on and off a toilet or chair?	1	2	3	4
53. Get in and out of bed?	1	2	3	4
54. Turn door knobs?	1	2	3	4
55. Bend over from a standing position and pick up something off the floor?	1	2	3	4

	Never	Sometimes	About half the time	Often	All the time
56. How often do you need help from another person for sitting and standing?	1	2	3	4	5
57. How often do you use assistive devices (such as braces, crutches, or wheelchair) for sitting and standing?	1	2	3	4	5

	Yes, easily	Yes, but a little hard	Yes, but very hard	No
58. Can you participate in recreational outdoor activities with other kids the same age? (For example: bicycling, tricycling, skating, hiking, jogging)	1	2	3	4

If you answered "no" to Question 58 above, was your activity limited by: (Circle "yes" to all that apply.)

	Yes
59. Pain?	1
60. General Health?	1
61. Doctor or parent instructions?	1
62. Fear the other kids won't like you?	1
63. Dislike of recreational outdoor activities?	1
64. Activity not in season?	1

	Yes, easily	Yes, but a little hard	Yes, but very hard	No
65. Can you participate in pickup games or sports with other kids the same age? (For example: tag, dodge ball, basketball, soccer, catch, jump rope, touch football, hop scotch)	1	2	3	4

If you answered “no” to Question 65 above, was your activity limited by: (Circle “yes” to all that apply.)

	Yes
66. Pain?	1
67. General Health?	1
68. Doctor or parent instructions?	1
69. Fear the other kids won't like you?	1
70. Dislike of pickup games or sports?	1
71. Activity not in season?	1

	Yes, easily	Yes, but a little hard	Yes, but very hard	No
72. Can you participate in competitive level sports with other kids the same age? (For example: hockey, basketball, soccer, football, baseball, swimming, running [track or cross country], gymnastics, or dance)	1	2	3	4

If you answered “no” to Question 72 above, was your activity limited by: (Circle “yes” to all that apply.)

	Yes
73. Pain?	1
74. General Health?	1
75. Doctor or parent instructions?	1
76. Fear the other kids won't like you?	1
77. Dislike of competitive level sports?	1
78. Activity not in season?	1

	Often	Sometimes	Never or rarely
79. How often in the past week did you get together and do things with friends?	1	2	3

If you answered “sometimes” or “never or rarely” to Question 79 above, was your activity limited by: (Circle “yes” to all that apply.)

	Yes
80. Pain?	1
81. General health?	1
82. Doctor or parent instructions?	1
83. Fear the other kids won't like you?	1
84. Friends not around?	1

	Often	Sometimes	Never or rarely	No gym or recess
85. How often in the past week did you participate in gym/ recess?	1	2	3	4

If you answered “sometimes” or “never or rarely” to Question 85 above, was your activity limited by: (Circle “yes” to all that apply.)

	Yes
86. Pain?	1
87. General health?	1
88. Doctor or parent instructions?	1
89. Fear the other kids won't like you?	1
90. Dislike of gym/recess?	1
91. School not in session?	1
92. Does not attend school?	1

	Usually easy	Sometimes easy	Sometimes hard	Usually hard
93. Is it easy or hard for you to make friends with kids your own age?	1	2	3	4

	None	Very mild	Mild	Moderate	Severe	Very severe
94. How much pain have you had during the last week ?	1	2	3	4	5	6

	Not at all	A little bit	Moderately	Quite a bit	Extremely
95. During the last week, how much did pain interfere with your normal activities (including at home, outside of the home, and at school)?	1	2	3	4	5

What expectations do you have for your treatment?
As a result of my treatment, I expect:

	Definitely yes	Probably yes	Not sure	Probably not	Definitely not
96. To have pain relief.	1	2	3	4	5
97. To look better.	1	2	3	4	5
98. To feel better about myself.	1	2	3	4	5
99. To sleep more comfortably.	1	2	3	4	5
100. To be able to do activities at home.	1	2	3	4	5
101. To be able to do more at school.	1	2	3	4	5
102. To be able to do more play or recreational activities (biking, walking, doing things with friends).	1	2	3	4	5
103. To be able to do more sports.	1	2	3	4	5
104. To be free from pain or disability as an adult.	1	2	3	4	5

	Very satisfied	Somewhat satisfied	Neutral	Somewhat dissatisfied	Very dissatisfied
105. If you had to spend the rest of your life with your bone and muscle condition as it is right now , how would you feel about it?	1	2	3	4	5

106. What is your gender?

Male

Female

107. What is your race? (check all that apply)

- White
 Black or African-American Hispanic
 Asian or Pacific Islander Native American Indian
 Other (please specify)

108. Who lives at home with you? (check all that apply)

- Mother Stepmother Foster
 mother Father Stepfather
 Foster father Brothers and/or sisters (How many _____ ?)
 Other adults

APPENDIX 5: INSTITUTIONAL REVIEW BOARD APPROVAL



Institutional Review Board
203 B-1 David Boyd Hall
Louisiana State University and A&M College
Baton Rouge LA 70803

(225) 578-8692
FAX: 578-6792
irb@lsu.edu

INSTITUTIONAL REVIEW BOARD

ACTION ON PROTOCOL APPROVAL REQUEST

TO: Li Li
Department of Kinesiology
FROM: Robert C. Mathews
Chair, Institutional Review Board for Research with Human Subjects
DATE: August 22, 2005
RE: IRB# 2546 Titled: "Quantification of Muscle Fatigue in Individuals with Cerebral Palsy"

New Protocol/Modification/Continuation :N

Review type: Full X Expedited Review date: 08/19/2005

Approved X* Disapproved Developmentally Approved

Approval Date: 08/19/2005 Approval Expiration Date: 08/19/2006

Risk Assessment: Minimal X Uncertain Greater than Minimal

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 100

By: Robert C. Mathews, Chairman [Signature]

* Approval is conditional on the following changes:
1. Mark in bold the sentence in the consent form saying person can quit at any time.

- PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING - Continuing approval is CONDITIONAL on:
1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects"
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

*All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/osp/irb

APPENDIX 6: COMPUTER PROGRAMS

Fatigue Data Programs

```
Sub ENDHeader()  
,  
    Name = "" 'manipulate name for different subjects  
    Num = "" 'manipulate trial #  
  
    ChDir "C:\TestData\Process"  
    Workbooks.OpenText Filename:="C:\TestData\Process\" + Name + "ISOKBREP_END60"  
+ Num + ".txt" _  
    , Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _  
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _  
    Comma:=True, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _  
    Array(2, 1), Array(3, 1), Array(4, 1), Array(5, 1), Array(6, 1), Array(7, 1), Array(8, 1), _  
    Array(9, 1), Array(10, 1), Array(11, 1), Array(12, 1), Array(13, 1), Array(14, 1), Array(15, _  
    , 1), Array(16, 1), Array(17, 1), Array(18, 1), Array(19, 1)), TrailingMinusNumbers:= _  
    True  
  
    Rows("3:5").Select  
    Selection.Insert Shift:=xlDown  
    ChDir "C:\TestData"  
    Workbooks.Open Filename:="C:\TestData\Export_Rep_Headers.xls"  
    Rows("3:5").Select  
    Range("AK3").Activate  
    Selection.Copy  
    Windows(Name + "ISOKBREP_END60" + Num + ".txt").Activate  
    Rows("3:5").Select  
    ActiveSheet.Paste  
    Application.CutCopyMode = False  
    'ChDir "C:\TestData\Process"  
    ActiveWorkbook.SaveAs Filename:= _  
    "C:\TestData\Process\" + Name + "ISOKBREP_END60" + Num + ".xls",  
FileFormat:=xlNormal, _  
    Password:="", WriteResPassword:="", ReadOnlyRecommended:=False, _  
    CreateBackup:=False  
    Windows("Export_Rep_Headers.xls").Activate  
    ActiveWindow.Close  
  
End Sub  
  
Sub ConvertToNm()  
'copy Repnum over to new column  
  
N = 39 'N = # of reps + 4*****  
For I = 5 To N
```

```

Cells(I + 1, 22) = Cells(I + 1, 1)
Next I

'convert ft-lb to N-m
K = 1.355 'conversion factor to N-m

For J = 1 To 2 'for KE and KF
  For I = 5 To N
    PT = Cells(I + 1, J + 1) * K 'PT = PTKE and PTKF
    'place PT in the columns for KE and KF
    Cells(I + 1, J + 22) = PT
  Next I
Next J

For L = 1 To 2 'for WKE and WKF
  For I = 5 To N
    W = Cells(I + 1, L + 11) * K 'W = Peak Work for KE and KF
    'place W in the columns for WKE and WKF
    Cells(I + 1, L + 24) = W
  Next I
Next L

'Sub Normalize()
'normalize PT and Work by mass in kg

'convert BW(body wt)to kg
BW = Cells(1, 11) * 0.4526
Cells(6, 21) = BW

'N = 104 'N = # of reps + 4*****
m = Cells(6, 21) 'm = mass in kg

For J = 1 To 4
  For I = 5 To N
    Norm = Cells(I + 1, J + 22) / m * 100 'Norm = normalized data x 100%
    'place normalized values in the appropriate columns
    Cells(I + 1, J + 26) = Norm
  Next I
Next J

'Sub Max()
'max in N-m for PTKE,PTKF,TWKE,TWKF
ReDim Max(4)
ReDim MaxC(4)

'N = 104 'N = # of reps + 4*****

```

```

For J = 1 To 4
  Max(J) = 0
  For I = 5 To N
    If Cells(I + 1, J + 22) > Max(J) Then
      Max(J) = Cells(I + 1, J + 22)
      MaxC(J) = (I + 1) - 5
    End If
  Next I
  'place max in appropriate column
  Cells(6, J * 2 + 30) = Max(J)
  'place rep # in column
  Cells(6, J * 2 + 31) = MaxC(J)
Next J

```

```

' Three Reps Fifty percent
'max in N-m for PTKE,PTKF,TWKE,TWKF

```

```

For J = 1 To 4
  For I = 5 To N - 2
    If Cells(I + 1, J + 22) < 0.5 * Max(J) Then
      If Cells(I + 2, J + 22) < 0.5 * Max(J) Then
        If Cells(I + 3, J + 22) < 0.5 * Max(J) Then
          Cells(6, J + 39) = (I + 3) - 5
          Exit For
        End If
      End If
    End If
  Next I
Next J

```

```

'Two REPS Fiftypercent
'max in N-m for PTKE,PTKF,TWKE,TWKF

```

```

For J = 1 To 4
  For I = 5 To N - 2
    If Cells(I + 1, J + 22) < 0.5 * Max(J) Then
      If Cells(I + 2, J + 22) < 0.5 * Max(J) Then
        'If Cells(I + 3, J + 22) < 0.5 * Max(J) Then
          Cells(8, J + 39) = (I + 2) - 5
          Exit For
        End If
      End If
    End If
  Next I
Next J

```

```

'One REP Fiftypercent
'max in N-m for PTKE,PTKF,TWKE,TWKF

```

```

For J = 1 To 4
  For I = 5 To N - 2
    If Cells(I + 1, J + 22) < 0.5 * Max(J) Then
      'If Cells(I + 2, J + 22) < 0.5 * Max(J) Then
        'If Cells(I + 3, J + 22) < 0.5 * Max(J) Then
          Cells(9, J + 39) = (I + 1) - 5
          Exit For
        End If
      End If
    Next I
  Next J

'Sub NormalizedMax()
'max in N-m/kg for NORMALIZED VALUES of PTKE,PTKF,TWKE,TWKF
ReDim Max(4)
ReDim MaxC(4)

'N = 104 'N = # of reps + 4****
Cells(3, 26) = "MaxNORM"
Range("Z3").Select
  Selection.Font.Bold = True

For J = 1 To 4
  Max(J) = 0
  For I = 5 To N
    If Cells(I + 1, J + 26) > Max(J) Then
      Max(J) = Cells(I + 1, J + 26)
      MaxC(J) = (I + 1) - 5
    End If
  Next I
  'place max in appropriate column
  Cells(3, J + 26) = Max(J)
  'place rep # in column
  'Cells(6, J * 2 + 31) = MaxC(J)
Next J

End Sub

Sub NEWFiftypercent()
'Use if altered range is needed
'max in N-m for PTKE,PTKF,TWKE,TWKF
ReDim Max(4)
ReDim MaxC(4)

N = 39 'N = # of Reps + 4 *****
For J = 1 To 4
  Max(J) = 0
  For I = 5 To N
    If Cells(I + 1, J + 22) > Max(J) Then

```

```

        Max(J) = Cells(I + 1, J + 22)
        MaxC(J) = (I + 1) - 5
    End If
Next I
'place max in appropriate column
Cells(7, J * 2 + 30) = Max(J)
'place rep # in column
Cells(7, J * 2 + 31) = MaxC(J)
Next J

For J = 1 To 4
    For I = 5 To N - 2 '*****alter range here *****
        If Cells(I + 1, J + 22) < 0.5 * Max(J) Then
            If Cells(I + 2, J + 22) < 0.5 * Max(J) Then
                If Cells(I + 3, J + 22) < 0.5 * Max(J) Then
                    Cells(7, J + 39) = (I + 3) - 5
                    Exit For
                End If
            End If
        End If
    End If
Next I
Next J
End Sub

```

```

Sub TotalFatigueIndex()

```

```

Cells(26, 53) = "Last5avgReps/BW" 'Labels for new rows
Cells(28, 53) = "AvgLast5/Peak"
Cells(30, 53) = "First5avgReps/BW"

```

```

ReDim Startt(4)
ReDim Stopp(4)
ReDim First(5)
ReDim Last(5)

```

```

For J = 1 To 4

```

```

    'get start/stop data from spreadsheet - ****far right data column where 35 reps lies
    Startt(J) = Cells(6, J * 2 + 51)
    Stopp(J) = Cells(6, J * 2 + 52)

```

```

For I = 1 To 5 '5 numbers

```

```

    'get data - don't change
    First(I) = Cells(Startt(J) + I + 4, J + 22)
    Last(I) = Cells(Stopp(J) + I, J + 22) 'Stop(number) + 5 -1 = + 1
    'place numbers in columns
    Cells(37 + I, J * 2 + 51) = First(I)
    Cells(37 + I, J * 2 + 52) = Last(I)

```

Next I
Next J

For J = 1 To 4

'add 1 to Cells(37 ..) above

'First5 = first five values added together for FI calculation

First5 = Cells(38, J * 2 + 51) + Cells(39, J * 2 + 51) + Cells(40, J * 2 + 51) + Cells(41, J * 2 + 51) + Cells(42, J * 2 + 51)

Cells(9, J * 2 + 52) = First5

'NEW: Avg of first 5 divided by BW in kg for 35 Reps method

First5avgbyBW = (First5 / 5 / Cells(6, 21)) * 100

Cells(30, J * 2 + 52) = First5avgbyBW

'Last5 = last five values added together for FI calculation

Last5 = Cells(38, J * 2 + 52) + Cells(39, J * 2 + 52) + Cells(40, J * 2 + 52) + Cells(41, J * 2 + 52) + Cells(42, J * 2 + 52)

Cells(10, J * 2 + 52) = Last5

'NEW: Avg of last 5 divided by Peak value

Last5avgbyMax = (Last5 / 5 / Cells(6, J * 2 + 30)) * 100

Cells(28, J * 2 + 52) = Last5avgbyMax

'NEW: Avg of last 5 divided by BW in kg for 35 Reps method

Last5avgbyBW = (Last5 / 5 / Cells(6, 21)) * 100

Cells(26, J * 2 + 52) = Last5avgbyBW

'Fatigue Index

FI = 100 - ((Last5 / First5) * 100)

Cells(11, J * 2 + 52) = FI

Next J

Range("BA26:BA31").Select

Selection.Font.Bold = True

End Sub

Sub FiftyPercentFatigueIndex()

Cells(27, 53) = "Last5avg50%/BW"

Cells(31, 53) = "First5avg50%/BW"

ReDim Startt(4)

ReDim Stopp(4)

ReDim First(5)

ReDim Last(5)

For J = 1 To 4

'get start/stop data from spreadsheet - **left lower data column where 50% of max data lies

Startt(J) = Cells(17, J * 2 + 42)

Stopp(J) = Cells(17, J * 2 + 43)

```

For I = 1 To 5 '5 numbers
  First(I) = Cells(Startt(J) + I + 4, J + 22)
  Last(I) = Cells(Stopp(J) + I, J + 22) 'Stop(number) + 5 -1 = + 1
  'place numbers in columns
  Cells(31 + I, J * 2 + 42) = First(I)
  Cells(31 + I, J * 2 + 43) = Last(I)
Next I
Next J

For J = 1 To 4

'add 1 to Cells(31 ..) above
First5 = Cells(32, J * 2 + 42) + Cells(33, J * 2 + 42) + Cells(34, J * 2 + 42) + Cells(35, J * 2 +
42) + Cells(36, J * 2 + 42)
  Cells(20, J * 2 + 43) = First5
'NEW: Avg of first 5 divided by BW in kg for 50% of max method
First5avg50byBW = (First5 / 5 / Cells(6, 21)) * 100
  Cells(31, J * 2 + 52) = First5avg50byBW

Last5 = Cells(32, J * 2 + 43) + Cells(33, J * 2 + 43) + Cells(34, J * 2 + 43) + Cells(35, J * 2 +
43) + Cells(36, J * 2 + 43)
  Cells(21, J * 2 + 43) = Last5
'NEW: Avg of last 5 divided by BW in kg for 50% of max method
Last5avg50byBW = (Last5 / 5 / Cells(6, 21)) * 100
  Cells(27, J * 2 + 52) = Last5avg50byBW

'Fatigue Index
FI = 100 - ((Last5 / First5) * 100)
Cells(22, J * 2 + 43) = FI

Next J

*****MACRO to Place ALL CP ENDURANCE data in spreadsheet*****
*****DATA must end in numerical format, ie, subject# 1,2,3.....
Sub ENDCPdata()
'
'Macro for CP subjects ENDURANCE files
'EXCEL Files to process must be in the Process folder

ChDir "C:\TestData"
  Workbooks.OpenText Filename:="C:\TestData\CP_data.xls"

For N = 1 To 17 'N = 1 to the # of subjects to process*****CHANGE AS NEEDED*****

'Macro to Process CP ENDURANCE STRENGTH DATA
'Sub ENDCPStrengthdata()

```

```
ChDir "C:\TestData\Process\Endurance_REP"  
Workbooks.OpenText  
Filename:="C:\TestData\Process\Endurance_REP\ISOKBREP_END60_CP" + Trim(Str(N)) +  
.xls"
```

'End strength data

```
Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate  
Range("AF6,AH6,AJ6,AL6").Select  
Range("AL6").Activate  
Selection.Copy  
Windows("CP_data.xls").Activate  
Range("AB55").Select  
ActiveSheet.Paste
```

'End Normalized strength data

```
Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate  
Range("AA3:AD3").Select  
Application.CutCopyMode = False  
Selection.Copy  
Windows("CP_data.xls").Activate  
Range("AF55").Select  
ActiveSheet.Paste
```

'FI35Reps data

```
Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate  
Range("BB11,BD11,BF11,BH11").Select  
Range("BH11").Activate  
Selection.Copy  
Windows("CP_data.xls").Activate  
Range("AJ55").Select  
ActiveSheet.Paste
```

'FI50% data

```
Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate  
Range("AS22,AU22,AW22,AY22").Select  
Range("AY22").Activate  
Selection.Copy  
Windows("CP_data.xls").Activate  
Range("AN55").Select  
ActiveSheet.Paste
```

'AvgLast5 data

```
Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate  
Range("BB26,BD26,BF26,BH26").Select  
Range("BH26").Activate  
Selection.Copy  
Windows("CP_data.xls").Activate  
Range("AR55").Select
```

ActiveSheet.Paste

'AvgLast5 50% data

Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate

Range("BB27,BD27,BF27,BH27").Select

Range("BH27").Activate

Selection.Copy

Windows("CP_data.xls").Activate

Range("AV55").Select

ActiveSheet.Paste

'Max Rep #'s

Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate

Range("AG6,AI6,AK6,AM6").Select

Range("AM6").Activate

Selection.Copy

Windows("CP_data.xls").Activate

Range("AZ55").Select

ActiveSheet.Paste

'AVGLast5 Norm by PT

Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate

Range("BB28,BD28,BF28,BH28").Select

Range("BH28").Activate

Selection.Copy

Windows("CP_data.xls").Activate

Range("BD55").Select

ActiveSheet.Paste

'move ENDMax(s),FI(s),AvgLast5(s), and MaxRep#'s in row 55 to columns in data.xls file

For J = 1 To 32

Cells(N + 3, J + 27) = Cells(55, J + 27)

Next J

Windows("CP_data.xls").Activate

Range("AB55:BG55").Select

Selection.ClearContents 'clear temp placement holder row55

ActiveWorkbook.Save

Windows("ISOKBREP_END60_CP" + Trim(Str(N)) + ".xls").Activate

ActiveWindow.Close

Next N 'For loop to next subjectN

End Sub

*****MACRO to Place ALL CONTROL(Normal) ENDURANCE data in spreadsheet*****

*****DATA must end in numerical format, ie, subject# 1,2,3.....

Sub ENDNdata()
,

"Macro for CONTROL(Normal) subjects ENDURANCE files

'EXCEL Files to process must be in the Process folder

ChDir "C:\TestData"

Workbooks.OpenText Filename:="C:\TestData\Control_data.xls"

For N = 1 To 16 'N = 1 to the # of subjects to process*****CHANGE AS NEEDED*****

'Macro to Process CONTROL ENDURANCE STRENGTH DATA

'Sub ENDNStrengthdata()

ChDir "C:\TestData\Process\Endurance_REP"

Workbooks.OpenText

Filename:="C:\TestData\Process\Endurance_REP\ISOKBREP_END60_N" + Trim(Str(N)) + ".xls"

'End strength data

Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate

Range("AF6,AH6,AJ6,AL6").Select

Range("AL6").Activate

Selection.Copy

Windows("Control_data.xls").Activate

Range("AB55").Select

ActiveSheet.Paste

'End Normalized strength data

Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate

Range("AA3:AD3").Select

Application.CutCopyMode = False

Selection.Copy

Windows("Control_data.xls").Activate

Range("AF55").Select

ActiveSheet.Paste

'FI35Reps data

Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate

Range("BB11,BD11,BF11,BH11").Select

Range("BH11").Activate

Selection.Copy

Windows("Control_data.xls").Activate

Range("AJ55").Select

ActiveSheet.Paste

'FI50% data

```
Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate  
Range("AS22,AU22,AW22,AY22").Select  
Range("AY22").Activate  
Selection.Copy  
Windows("Control_data.xls").Activate  
Range("AN55").Select  
ActiveSheet.Paste
```

'AvgLast5 data

```
Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate  
Range("BB26,BD26,BF26,BH26").Select  
Range("BH26").Activate  
Selection.Copy  
Windows("Control_data.xls").Activate  
Range("AR55").Select  
ActiveSheet.Paste
```

'AvgLast5 50% data

```
Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate  
Range("BB27,BD27,BF27,BH27").Select  
Range("BH27").Activate  
Selection.Copy  
Windows("Control_data.xls").Activate  
Range("AV55").Select  
ActiveSheet.Paste
```

'Max Rep #'s

```
Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate  
Range("AG6,AI6,AK6,AM6").Select  
Range("AM6").Activate  
Selection.Copy  
Windows("Control_data.xls").Activate  
Range("AZ55").Select  
ActiveSheet.Paste
```

'AVGLast5 Norm by PT

```
Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate  
Range("BB28,BD28,BF28,BH28").Select  
Range("BH28").Activate  
Selection.Copy  
Windows("Control_data.xls").Activate  
Range("BD55").Select  
ActiveSheet.Paste
```

```
'move ENDMax(s),FI(s),AvgLast5(s), and MaxRep#'s in row 55 to columns in data.xls file  
For J = 1 To 32  
Cells(N + 3, J + 27) = Cells(55, J + 27)
```

Next J

```
Windows("Control_data.xls").Activate  
Range("AB55:BG55").Select  
Selection.ClearContents 'clear temp placement holder row55  
ActiveWorkbook.Save
```

```
Windows("ISOKBREP_END60_N" + Trim(Str(N)) + ".xls").Activate  
ActiveWindow.Close
```

Next N 'For loop to next subjectN

End Sub

Strength Data Programs

```
*****MACRO to Process ALL CP Strength Files*****
*****DATA must end in numerical format, ie, subject# 1,2,3.....
Sub CPSTRHeader()
'Macro for CP subjects Strength files
'Files to process must be in the Process folder

ChDir "C:\TestData"
    Workbooks.OpenText Filename:="C:\TestData\CP_data.xls"

For N = 1 To 15 'N = 1 to the # of subjects to process*****CHANGE AS NEEDED*****
,
'SHeader Macro
'Macro recorded 11/8/2005 by Noelle Moreau
,

    ChDir "C:\TestData\Process\Strength_REP"
        Workbooks.OpenText
Filename:="C:\TestData\Process\Strength_REP\ISOKBREP_ST60_CP" + Trim(Str(N)) + ".txt"
    , Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=True, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1), Array(4, 1), Array(5, 1), Array(6, 1), Array(7, 1), Array(8, 1), _
    Array(9, 1), Array(10, 1), Array(11, 1), Array(12, 1), Array(13, 1), Array(14, 1), Array(15 _
    , 1), Array(16, 1), Array(17, 1), Array(18, 1), Array(19, 1)), TrailingMinusNumbers:= _
    True

Rows("3:5").Select
Selection.Insert Shift:=xlDown
ChDir "C:\TestData"
Workbooks.Open Filename:="C:\TestData\Export_RepSTR_Headers.xls"
Rows("3:5").Select
Range("AK3").Activate
Selection.Copy
'Windows(Name + "ISOKBREP_ST60_CP" + Num + ".txt").Activate
Windows("ISOKBREP_ST60_CP" + Trim(Str(N)) + ".txt").Activate
Rows("3:5").Select
ActiveSheet.Paste
Application.CutCopyMode = False
'ChDir "C:\TestData\Process"
,
'Windows(Name + "ISOKBREP_ST60_CP" + Num + ".txt").Activate
Windows("ISOKBREP_ST60_CP" + Trim(Str(N)) + ".txt").Activate
Rows("7:7").Select
Selection.Delete Shift:=xlUp
Rows("8:8").Select
```

```
Selection.Delete Shift:=xlUp
Range("F15").Select
```

```
' Change rep #'s to 1,2,3
```

```
'Windows(Name + "ISOKBREP_ST60_CP" + Num + ".txt").Activate
Windows("ISOKBREP_ST60_CP" + Trim(Str(N)) + ".txt").Activate
Range("A7").Select
ActiveCell.FormulaR1C1 = "2"
Range("A8").Select
ActiveCell.FormulaR1C1 = "3"
Range("V7").Select
```

```
'Autofit columns
```

```
ActiveWindow.ScrollColumn = 26
ActiveWindow.ScrollColumn = 25
ActiveWindow.ScrollColumn = 24
ActiveWindow.ScrollColumn = 23
ActiveWindow.ScrollColumn = 22
ActiveWindow.ScrollColumn = 21
ActiveWindow.ScrollColumn = 20
ActiveWindow.ScrollColumn = 18
ActiveWindow.ScrollColumn = 17
ActiveWindow.ScrollColumn = 16
ActiveWindow.ScrollColumn = 15
ActiveWindow.ScrollColumn = 14
ActiveWindow.ScrollColumn = 13
ActiveWindow.ScrollColumn = 12
ActiveWindow.ScrollColumn = 11
ActiveWindow.ScrollColumn = 10
ActiveWindow.ScrollColumn = 9
ActiveWindow.ScrollColumn = 8
ActiveWindow.ScrollColumn = 7
ActiveWindow.ScrollColumn = 6
ActiveWindow.ScrollColumn = 5
ActiveWindow.ScrollColumn = 4
ActiveWindow.ScrollColumn = 3
ActiveWindow.ScrollColumn = 2
ActiveWindow.ScrollColumn = 1
Cells.Select
Selection.Columns.AutoFit
Range("I18").Select
```

```
ActiveWorkbook.SaveAs Filename:= _
"C:\TestData\Process\Strength_REP\ISOKBREP_ST60_CP" + Trim(Str(N)) + ".xls",
FileFormat:=xlNormal, _
Password:="", WriteResPassword:="", ReadOnlyRecommended:=False, _
CreateBackup:=False
```

```

'Sub ConvertToNm()
'copy Repnum over to new column
Windows("ISOKBREP_ST60_CP" + Trim(Str(N)) + ".xls").Activate

For I = 5 To 7
    Cells(I + 1, 22) = Cells(I + 1, 1)
Next I

'Convert ft-lb to N-m
K = 1.355 'conversion factor to N-m

For J = 1 To 2 'for KE and KF
    For I = 5 To 7
        PT = Cells(I + 1, J + 1) * K    'PT = PTKE and PTKF
        'place PT in the columns for KE and KF
        Cells(I + 1, J + 22) = PT
    Next I
Next J

For L = 1 To 2 'for WKE and WKF
    For I = 5 To 7
        W = Cells(I + 1, L + 11) * K    'W = Peak Work for KE and KF
        'place W in the columns for WKE and WKF
        Cells(I + 1, L + 24) = W
    Next I
Next L

'Sub Normalize()
'normalize PT and Work by mass in kg

'convert BW(body wt)to kg
BW = Cells(1, 11) * 0.4526
Cells(6, 21) = BW

m = Cells(6, 21) 'm = mass in kg

For J = 1 To 4
    For I = 5 To 7
        Norm = Cells(I + 1, J + 22) / m * 100 'Norm = normalized data x 100%
        'place normalized values in the appropriate columns
        Cells(I + 1, J + 26) = Norm
    Next I
Next J

'Sub Max()
'max in N-m for PTKE,PTKF,TWKE,TWKF and Norm values

```

```
ReDim Max(8)
ReDim MaxC(8)
```

```
For J = 1 To 8
    Max(J) = 0
    For I = 5 To 7
        If Cells(I + 1, J + 22) > Max(J) Then
            Max(J) = Cells(I + 1, J + 22)
            MaxC(J) = (I + 1) - 5
        End If
    Next I
    'place max in appropriate column
    Cells(6, J * 2 + 30) = Max(J)
    'place rep # in column
    Cells(6, J * 2 + 31) = MaxC(J)
Next J
```

```
' PlaceMAXinspreadsheet Macro
```

```
Windows("ISOKBREP_ST60_CP" + Trim(Str(N)) + ".xls").Activate
Range("AF6,AH6,AJ6,AL6").Select
Range("AL6").Activate
Selection.Copy
'ChDir "C:\TestData"
'Workbooks.Open Filename:="C:\TestData\CP_data.xls"
Windows("CP_data.xls").Activate
Range("T45").Select
ActiveSheet.Paste
```

```
Windows("ISOKBREP_ST60_CP" + Trim(Str(N)) + ".xls").Activate
Range("AN6,AP6,AR6,AT6").Select
Range("AT6").Activate
Selection.Copy
Windows("CP_data.xls").Activate
Range("X45").Select
ActiveSheet.Paste
```

```
'move Max(s) in row 45 to columns in data.xls file
```

```
For J = 1 To 8
    Cells(N + 3, J + 19) = Cells(45, J + 19)
Next J
```

```
'Save and close file
```

```
Windows("ISOKBREP_ST60_CP" + Trim(Str(N)) + ".xls").Activate
ActiveWorkbook.Save
ActiveWindow.Close
```

Next N 'Loop to next subject

```
Windows("CP_data.xls").Activate
Range("T45:AA45").Select
Selection.ClearContents 'clear temp placement holder row45
ActiveWorkbook.Save
```

```
Windows("Export_RepSTR_Headers.xls").Activate
ActiveWindow.Close
```

End Sub

*****MACRO to Process ALL CONTROL(Normal) Strength Files*****

*****DATA must end in numerical format, ie, subject# 1,2,3.....

```
Sub CONTROLSTRHeader()
'Macro for CONTROL(Normal)Strength files
'Files to process must be in the Process folder
```

```
ChDir "C:\TestData"
Workbooks.OpenText Filename:="C:\TestData\Control_data.xls"
```

For N = 1 To 16 'N = 1 to the # of subjects to process*****CHANGE AS NEEDED*****

' STHeader Macro

```
ChDir "C:\TestData\Process\Strength_REP"
Workbooks.OpenText
Filename:="C:\TestData\Process\Strength_REP\ISOKBREP_ST60_N" + Trim(Str(N)) + ".txt" _
, Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=True, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1), Array(4, 1), Array(5, 1), Array(6, 1), Array(7, 1), Array(8, 1), _
Array(9, 1), Array(10, 1), Array(11, 1), Array(12, 1), Array(13, 1), Array(14, 1), Array(15 _
, 1), Array(16, 1), Array(17, 1), Array(18, 1), Array(19, 1)), TrailingMinusNumbers:= _
True
```

```
Rows("3:5").Select
Selection.Insert Shift:=xlDown
ChDir "C:\TestData"
Workbooks.Open Filename:="C:\TestData\Export_RepSTR_Headers.xls"
Rows("3:5").Select
Range("AK3").Activate
Selection.Copy
'Windows(Name + "ISOKBREP_ST60_N" + Num + ".txt").Activate
Windows("ISOKBREP_ST60_N" + Trim(Str(N)) + ".txt").Activate
Rows("3:5").Select
```

```
ActiveSheet.Paste
Application.CutCopyMode = False
'ChDir "C:\TestData\Process"
```

```
'Windows(Name + "ISOKBREP_ST60_N" + Num + ".txt").Activate
Windows("ISOKBREP_ST60_N" + Trim(Str(N)) + ".txt").Activate
Rows("7:7").Select
Selection.Delete Shift:=xlUp
Rows("8:8").Select
Selection.Delete Shift:=xlUp
Range("F15").Select
```

```
' Change rep #'s to 1,2,3
```

```
'Windows(Name + "ISOKBREP_ST60_N" + Num + ".txt").Activate
Windows("ISOKBREP_ST60_N" + Trim(Str(N)) + ".txt").Activate
Range("A7").Select
ActiveCell.FormulaR1C1 = "2"
Range("A8").Select
ActiveCell.FormulaR1C1 = "3"
Range("V7").Select
```

```
'Autofit columns
```

```
ActiveWindow.ScrollColumn = 26
ActiveWindow.ScrollColumn = 25
ActiveWindow.ScrollColumn = 24
ActiveWindow.ScrollColumn = 23
ActiveWindow.ScrollColumn = 22
ActiveWindow.ScrollColumn = 21
ActiveWindow.ScrollColumn = 20
ActiveWindow.ScrollColumn = 18
ActiveWindow.ScrollColumn = 17
ActiveWindow.ScrollColumn = 16
ActiveWindow.ScrollColumn = 15
ActiveWindow.ScrollColumn = 14
ActiveWindow.ScrollColumn = 13
ActiveWindow.ScrollColumn = 12
ActiveWindow.ScrollColumn = 11
ActiveWindow.ScrollColumn = 10
ActiveWindow.ScrollColumn = 9
ActiveWindow.ScrollColumn = 8
ActiveWindow.ScrollColumn = 7
ActiveWindow.ScrollColumn = 6
ActiveWindow.ScrollColumn = 5
ActiveWindow.ScrollColumn = 4
ActiveWindow.ScrollColumn = 3
ActiveWindow.ScrollColumn = 2
ActiveWindow.ScrollColumn = 1
Cells.Select
```

```
Selection.Columns.AutoFit
Range("I18").Select
```

```
ActiveWorkbook.SaveAs Filename:= _
"C:\TestData\Process\Strength_REP\ISOKBREP_ST60_N" + Trim(Str(N)) + ".xls",
FileFormat:=xlNormal, _
Password:="", WriteResPassword:"", ReadOnlyRecommended:=False, _
CreateBackup:=False
'Sub ConvertToNm()
'copy Repnum over to new column
```

```
Windows("ISOKBREP_ST60_N" + Trim(Str(N)) + ".xls").Activate
```

```
For I = 5 To 7
Cells(I + 1, 22) = Cells(I + 1, 1)
Next I
```

```
'Convert ft-lb to N-m
K = 1.355 'conversion factor to N-m
```

```
For J = 1 To 2 'for KE and KF
For I = 5 To 7
PT = Cells(I + 1, J + 1) * K 'PT = PTKE and PTKF
'place PT in the columns for KE and KF
Cells(I + 1, J + 22) = PT
Next I
Next J
```

```
For L = 1 To 2 'for WKE and WKF
For I = 5 To 7
W = Cells(I + 1, L + 11) * K 'W = Peak Work for KE and KF
'place W in the columns for WKE and WKF
Cells(I + 1, L + 24) = W
Next I
Next L
```

```
'Sub Normalize()
'normalize PT and Work by mass in kg
```

```
'convert BW(body wt)to kg
BW = Cells(1, 11) * 0.4526
Cells(6, 21) = BW
```

```
m = Cells(6, 21) 'm = mass in kg
```

```
For J = 1 To 4
For I = 5 To 7
Norm = Cells(I + 1, J + 22) / m * 100 'Norm = normalized data x 100%
```

```

        'place normalized values in the appropriate columns
        Cells(I + 1, J + 26) = Norm
    Next I
Next J

'Sub Max()
'max in N-m for PTKE,PTKF,TWKE,TWKF and Norm values
ReDim Max(8)
ReDim MaxC(8)

For J = 1 To 8
    Max(J) = 0
    For I = 5 To 7
        If Cells(I + 1, J + 22) > Max(J) Then
            Max(J) = Cells(I + 1, J + 22)
            MaxC(J) = (I + 1) - 5
        End If
    Next I
    'place max in appropriate column
    Cells(6, J * 2 + 30) = Max(J)
    'place rep # in column
    Cells(6, J * 2 + 31) = MaxC(J)
Next J

' PlaceMAXinspreadsheet Macro

Windows("ISOKBREP_ST60_N" + Trim(Str(N)) + ".xls").Activate
Range("AF6,AH6,AJ6,AL6").Select
Range("AL6").Activate
Selection.Copy
'ChDir "C:\TestData"
'Workbooks.Open Filename:="C:\TestData\Control_data.xls"
Windows("Control_data.xls").Activate
Range("T45").Select
ActiveSheet.Paste

Windows("ISOKBREP_ST60_N" + Trim(Str(N)) + ".xls").Activate
Range("AN6,AP6,AR6,AT6").Select
Range("AT6").Activate
Selection.Copy
Windows("Control_data.xls").Activate
Range("X45").Select
ActiveSheet.Paste

'move Max(s) in row 45 to columns in data.xls file
For J = 1 To 8
    Cells(N + 3, J + 19) = Cells(45, J + 19)
Next J

```

```
'Save and close file  
Windows("ISOKBREP_ST60_N" + Trim(Str(N)) + ".xls").Activate  
ActiveWorkbook.Save  
ActiveWindow.Close
```

```
Next N 'Loop to next subject
```

```
Windows("Control_data.xls").Activate  
Range("T45:AA45").Select  
Selection.ClearContents 'clear temp placement holder row45  
ActiveWorkbook.Save
```

```
Windows("Export_RepSTR_Headers.xls").Activate  
ActiveWindow.Close
```

```
End Sub
```

EMG Program: EMG Mean Removal, Rectification, Low Pass Filtering, Rescaling separately for knee extension and flexion, and calculation of cocontraction

Sub emg()

*****Individual Parameters*****

Group = "N" 'CP or N

Num = "3" 'Subject #

For N = 1 To 3

Workbooks.OpenText Filename:= _

"C:\TestData\Process\EMG\" + Group + "\" + Group + Num + "\ST60_" + Trim(Str(N)) + ".xls", Origin:=437, _

StartRow:=1, DataType:=xlFixedWidth, FieldInfo:=Array(Array(0, 1), Array(6, _
1), Array(18, 1), Array(27, 1), Array(42, 1)), TrailingMinusNumbers:=True

'find total # of points

For I = 1 To 8000

If Cells(I + 4, 1) = "" Then Exit For

Next I

ttlptnt = I - 1 'Total # of points

'read in data

For I = 1 To 4

'define the array

ReDim dat(ttlptnt) 'column/row

dat(0) = Cells(4, I + 1)

For J = 1 To ttlptnt

dat(J) = Cells(J + 4, I + 1)

Next J

'replace the title of each channel

Cells(4, I + 10) = dat(0)

'calculate means

dat(0) = 0

For J = 1 To ttlptnt

dat(0) = dat(0) + dat(J) 'all all the emg values together

Next J

dat(0) = dat(0) / ttlptnt 'divided by # of data points

For J = 1 To ttlptnt

'full wave rectification and subtract the mean

dat(J) = Abs(dat(J) - dat(0))

Next J

*****Filter*****

'Following are the variables needed to be defined outside

'of the sub in order to get the sub "DFilter" to operate

DFNumptnt = ttlptnt ' Number of points in the set of data being passed in

Const DFPi = 3.1415926

Const DFcutoff = 6 ' Cutoff frequency for either a hi-pass or a low-pass

```

Const DFfiltertype = "lp" ' can be either "lp" for low pass or "hp" for high pass
Const DFSrate = 1000 'Sampling rate of the original date
Const DFtypef = "Butterworth"
Dim DFti ' time interval (period) of the original data, 1/sampling rate
Dim DFpcut
Dim DFWC
Dim DFk1, DFk2, DFk3
Dim DFa0, DFa1, DFa2
Dim DFb1, DFb2
Dim DFfiltoption As String
ReDim DFdata(DFNumpnt) ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 1 To DFNumpnt
    DFdata(DFi) = dat(DFi)
Next DFi
'Fourth order, zero lag filter
'correction to cutoff for high-pass filter
DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
    DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
    DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)
'Wc need to be corrected for the dual pass
'Murphy and Robertson (1994),
'J. of Applied Biomechanics, 10:374-381
'And also, Robertson, Barden and Dowling
'NACOB II, 1992
If DFtypef = "Butterworth" Then
    DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
    DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
    DFk1 = Sqr(2) * DFWC
Else
    DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3

```

```

DFb2 = 1 - (2 * DFa0) - DFk3
'correction to coefficients for high-pass filter
If DFfiltoption = "hp" Then
    DFa1 = -DFa1
    DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) - DFdata(DFNumpnt -
1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) - DFdata(DFNumpnt -
2))
For DFi = 1 To DFNumpnt
    DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
    DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
    DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 * DFTemp(DFi -
2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
    DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
    DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 * DFTemp(DFi
+ 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
    dat(DFi) = DFprime(DFi + 2)
Next DFi
*****Filter*****
    For J = 1 To ttlpnt
        'print rectified data back to the spread sheet
        Cells(J + 4, I + 10) = dat(J)
    Next J
Next I

Cells(1, 10) = ttlpnt

Next N

End Sub
*****Program for the RightLE where ext motion is (+)velocity and flex motion (-)velocity
Sub RIGHTConstantVelocity()

```

```

For N = 1 To 3

    sheetname = "ST60_" + Trim(Str(N))
    Windows(sheetname + ".xls").Activate

    'Format velocity into numerical format
    Range("F5").Select
        Range(Selection, Selection.End(xlDown)).Select
        Selection.NumberFormat = "0.00"
    Range("S1").Select

th = 1.9 'threshold Change as needed*****
Speed = 60
Speed = Speed - th
'read in numbers and find total # of data points
ReDim dat(6, 7000)
For I = 1 To 7000
    If Cells(I + 4, 1) = "" Then Exit For
    dat(1, I) = Cells(I + 4, 1) 'Time (ms)
    dat(2, I) = Cells(I + 4, 6) 'Velocity
    dat(3, I) = Cells(I + 4, 11) 'Rectus Femoris EMG
    dat(4, I) = Cells(I + 4, 12) 'Vastus Medialis EMG
    dat(5, I) = Cells(I + 4, 13) 'Lat. Hamstrings EMG
    dat(6, I) = Cells(I + 4, 14) 'Med. Hamstrings EMG
Next I
ttlpt = I - 1 'ttlpt = total # of data points
'++++++
'find the extension phase
ReDim est(1) 'starting of the extension phase
ReDim eend(1) 'end of the extension phase
For I = 1 To ttlpt
    If dat(2, I) > Speed And dat(2, I + 1) > Speed And dat(2, I + 2) > Speed And dat(2, I + 3) > Speed Then
        est(1) = I
        Exit For
    End If
Next I
For I = est(1) To ttlpt
    If dat(2, I) < Speed And dat(2, I + 1) < Speed And dat(2, I + 2) < Speed And dat(2, I + 3) < Speed And dat(2, I + 4) < Speed Then
        eend(1) = I - 1
        Exit For
    End If
Next I
'++++++
'find the flexion phase
ReDim fst(1) 'starting of the flexion phase
ReDim fend(1) 'end of the flexion phase
For I = eend(1) To ttlpt

```

```

If dat(2, I) < -Speed And dat(2, I + 1) < -Speed And dat(2, I + 2) Then
    fst(1) = I
    Exit For
End If
Next I
For I = fst(1) To ttlpnt
    If dat(2, I) > -Speed And dat(2, I + 1) > -Speed And dat(2, I + 2) > -Speed And dat(2, I + 3)
Then
    fend(1) = I - 1
    Exit For
    End If
Next I

```

'Print data to spread sheet and :calculate the sum of each EMG channel for Extension

aRFe = 0: aVMe = 0: aLHe = 0: aMHe = 0

aRFf = 0: aVMf = 0: aLHf = 0: aMHf = 0

For I = 1 To eend(1) - est(1) + 1

Cells(I + 4, 16) = dat(1, I + est(1) - 1) - dat(1, est(1)) 'correct time to start at 0

Cells(I + 4, 17) = dat(2, I + est(1) - 1)

Cells(I + 4, 18) = dat(3, I + est(1) - 1): aRFe = aRFe + dat(3, I + est(1) - 1)

Cells(I + 4, 19) = dat(4, I + est(1) - 1): aVMe = aVMe + dat(4, I + est(1) - 1)

Cells(I + 4, 20) = dat(5, I + est(1) - 1): aLHe = aLHe + dat(5, I + est(1) - 1)

Cells(I + 4, 21) = dat(6, I + est(1) - 1): aMHe = aMHe + dat(6, I + est(1) - 1)

Next I

'Calculate averages of each EMG channel for Extension phase

'aRFe = Avg of the RF EMG acting in extension (agonist)

'aVMe = Avg of the VM EMG acting in extension (agonist)

'aLHe = Avg of the LH EMG acting in extension (antagonist)

'aMHe = Avg of the MH EMG acting in extension (antagonist)

aRFe = aRFe / (eend(1) - est(1) + 1)

aVMe = aVMe / (eend(1) - est(1) + 1)

aLHe = aLHe / (eend(1) - est(1) + 1)

aMHe = aMHe / (eend(1) - est(1) + 1)

'Print data to spread sheet and :calculate the sum of each EMG channel for Flexion

For I = 1 To fend(1) - fst(1) + 1

Cells(I + 4, 23) = dat(1, I + fst(1) - 1) - dat(1, fst(1))

Cells(I + 4, 24) = dat(2, I + fst(1) - 1)

Cells(I + 4, 25) = dat(3, I + fst(1) - 1): aRFf = aRFf + dat(3, I + fst(1) - 1)

Cells(I + 4, 26) = dat(4, I + fst(1) - 1): aVMf = aVMf + dat(4, I + fst(1) - 1)

Cells(I + 4, 27) = dat(5, I + fst(1) - 1): aLHf = aLHf + dat(5, I + fst(1) - 1)

Cells(I + 4, 28) = dat(6, I + fst(1) - 1): aMHf = aMHf + dat(6, I + fst(1) - 1)

Next I

'Calculate averages of each EMG channel for Flexion phase

'aRFf = Avg of the RF EMG acting in flexion (antagonist)

'aVMf = Avg of the VM EMG acting in flexion (antagonist)

'aLHf = Avg of the LH EMG acting in flexion (agonist)

'aMHf = Avg of the MH EMG acting in flexion (agonist)

aRFf = aRFf / (fend(1) - fst(1) + 1)

```

aVMf = aVMf / (fend(1) - fst(1) + 1)
aLHf = aLHf / (fend(1) - fst(1) + 1)
aMHf = aMHf / (fend(1) - fst(1) + 1)
'Print Avg values to spreadsheet
Cells(2, 18) = aRFe
Cells(2, 19) = aVMe
Cells(2, 20) = aLHe
Cells(2, 21) = aMHe
Cells(2, 25) = aRFf
Cells(2, 26) = aVMf
Cells(2, 27) = aLHf
Cells(2, 28) = aMHf
'Print Normalized Cocontraction data (antagonist/agonist) to spreadsheet in % format
Cells(1, 20) = Int(0.5 + 1000 * aLHe / aLHf) / 10 'Cocontraction of LH during Extension
Cells(1, 21) = Int(0.5 + 1000 * aMHe / aMHf) / 10 'Cocontraction of MH during Extension
Cells(1, 25) = Int(0.5 + 1000 * aRFf / aRFe) / 10 'Cocontraction of RF during Flexion
Cells(1, 26) = Int(0.5 + 1000 * aVMf / aVMe) / 10 'Cocontraction of VM during Flexion
'Print ttpnt and start/stop points to spreadsheet
Cells(1, 10) = ttpnt
Cells(1, 11) = est(1) + 4
Cells(1, 12) = eend(1) + 4
Cells(2, 11) = fst(1) + 4
Cells(2, 12) = fend(1) + 4
'Print headers
Cells(4, 16) = Cells(4, 1)
Cells(4, 23) = Cells(4, 1)
Cells(4, 17) = Cells(4, 6)
Cells(4, 24) = Cells(4, 6)
Cells(4, 18) = Cells(4, 2)
Cells(4, 25) = Cells(4, 2)
Cells(4, 19) = Cells(4, 3)
Cells(4, 26) = Cells(4, 3)
Cells(4, 20) = Cells(4, 4)
Cells(4, 27) = Cells(4, 4)
Cells(4, 21) = Cells(4, 5)
Cells(4, 28) = Cells(4, 5)
Cells(3, 16) = "Extension motion"
Cells(3, 23) = "Flexion motion"

```

```

Next N
End Sub

```

```

*****Program for Left sided trials to make ext motion (+)velocity and flex motion (-)velocity
Sub LEFTMultiplyVelocity()

```

```

For N = 1 To 3

```

```

    sheetname = "ST60_" + Trim(Str(N))

```

```

Windows(sheetname + ".xls").Activate

'Format velocity into numerical format
Range("F5").Select
    Range(Selection, Selection.End(xlDown)).Select
    Selection.NumberFormat = "0.00"
Range("S1").Select

' Multiply velocity cells by -1 to make ext motion (+)velocity and flex motion (-)velocity
Cells(1, 5) = -1
Range("E1").Select
Application.CutCopyMode = False
Selection.Copy
Range("F5").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.PasteSpecial Paste:=xlPasteAll, Operation:=xlMultiply, _
    SkipBlanks:=False, Transpose:=False
Range("E1").Select
Selection.ClearContents
Next N
End Sub

*****Program for the RightLE where ext motion is (+)velocity and flex motion (-)velocity
Sub MANUALRightConstantVelocity()

For N = 1 To 3    'ST60_ trial #

    sheetname = "ST60_" + Trim(Str(N))
    Windows(sheetname + ".xls").Activate

'Format velocity into numerical format
Range("F5").Select
    Range(Selection, Selection.End(xlDown)).Select
    Selection.NumberFormat = "0.00"
Range("S1").Select

*****MANUAL - Change Start/Stop data points on spreadsheet*****
est = Cells(1, 11)    'start of extension phase
end = Cells(1, 12)    'end of extension phase
fst = Cells(2, 11)    'start of flexion phase
fend = Cells(2, 12)    'end of flexion phase
*****
'read in numbers and find total # of data points
ReDim dat(6, 7000)
For I = 1 To 7000
    If Cells(I + 4, 1) = "" Then Exit For
    dat(1, I) = Cells(I + 4, 1) 'Time (ms)
    dat(2, I) = Cells(I + 4, 6) 'Velocity

```

```

dat(3, I) = Cells(I + 4, 11) 'Rectus Femoris EMG
dat(4, I) = Cells(I + 4, 12) 'Vastus Medialis EMG
dat(5, I) = Cells(I + 4, 13) 'Lat. Hamstrings EMG
dat(6, I) = Cells(I + 4, 14) 'Med. Hamstrings EMG
Next I
ttlpt = I - 1 'ttlpt = total # of data points
'+++++
'Print data to spread sheet and :calculate the sum of each EMG channel for Extension
aRFe = 0: aVMe = 0: aLHe = 0: aMHe = 0
aRFf = 0: aVMf = 0: aLHf = 0: aMHf = 0
For I = 1 To eend - est + 1
    Cells(I + 4, 16) = dat(1, I + est - 1) - dat(1, est) 'correct time to start at 0
    Cells(I + 4, 17) = dat(2, I + est - 1)
    Cells(I + 4, 18) = dat(3, I + est - 1): aRFe = aRFe + dat(3, I + est - 1)
    Cells(I + 4, 19) = dat(4, I + est - 1): aVMe = aVMe + dat(4, I + est - 1)
    Cells(I + 4, 20) = dat(5, I + est - 1): aLHe = aLHe + dat(5, I + est - 1)
    Cells(I + 4, 21) = dat(6, I + est - 1): aMHe = aMHe + dat(6, I + est - 1)
Next I
'Calculate averages of each EMG channel for Extension phase
'aRFe = Avg of the RF EMG acting in extension (agonist)
'aVMe = Avg of the VM EMG acting in extension (agonist)
'aLHe = Avg of the LH EMG acting in extension (antagonist)
'aMHe = Avg of the MH EMG acting in extension (antagonist)
aRFe = aRFe / (eend - est + 1)
aVMe = aVMe / (eend - est + 1)
aLHe = aLHe / (eend - est + 1)
aMHe = aMHe / (eend - est + 1)
'Print data to spread sheet and :calculate the sum of each EMG channel for Flexion
For I = 1 To fend - fst + 1
    Cells(I + 4, 23) = dat(1, I + fst - 1) - dat(1, fst)
    Cells(I + 4, 24) = dat(2, I + fst - 1)
    Cells(I + 4, 25) = dat(3, I + fst - 1): aRFf = aRFf + dat(3, I + fst - 1)
    Cells(I + 4, 26) = dat(4, I + fst - 1): aVMf = aVMf + dat(4, I + fst - 1)
    Cells(I + 4, 27) = dat(5, I + fst - 1): aLHf = aLHf + dat(5, I + fst - 1)
    Cells(I + 4, 28) = dat(6, I + fst - 1): aMHf = aMHf + dat(6, I + fst - 1)
Next I
'Calculate averages of each EMG channel for Flexion phase
'aRFf = Avg of the RF EMG acting in flexion (antagonist)
'aVMf = Avg of the VM EMG acting in flexion (antagonist)
'aLHf = Avg of the LH EMG acting in flexion (agonist)
'aMHf = Avg of the MH EMG acting in flexion (agonist)
aRFf = aRFf / (fend - fst + 1)
aVMf = aVMf / (fend - fst + 1)
aLHf = aLHf / (fend - fst + 1)
aMHf = aMHf / (fend - fst + 1)
'Print Avg values to spreadsheet
Cells(2, 18) = aRFe
Cells(2, 19) = aVMe

```

```

Cells(2, 20) = aLHe
Cells(2, 21) = aMHe
Cells(2, 25) = aRFf
Cells(2, 26) = aVMf
Cells(2, 27) = aLHf
Cells(2, 28) = aMHf
'Print Normalized Cocontraction data (antagonist/agonist) to spreadsheet in % format
Cells(1, 20) = Int(0.5 + 1000 * aLHe / aLHf) / 10 'Cocontraction of LH during Extension
Cells(1, 21) = Int(0.5 + 1000 * aMHe / aMHf) / 10 'Cocontraction of MH during Extension
Cells(1, 25) = Int(0.5 + 1000 * aRFf / aRFe) / 10 'Cocontraction of RF during Flexion
Cells(1, 26) = Int(0.5 + 1000 * aVMf / aVMe) / 10 'Cocontraction of VM during Flexion
Cells(1, 10) = ttlpnt
'Print headers
Cells(4, 16) = Cells(4, 1)
Cells(4, 23) = Cells(4, 1)
Cells(4, 17) = Cells(4, 6)
Cells(4, 24) = Cells(4, 6)
Cells(4, 18) = Cells(4, 2)
Cells(4, 25) = Cells(4, 2)
Cells(4, 19) = Cells(4, 3)
Cells(4, 26) = Cells(4, 3)
Cells(4, 20) = Cells(4, 4)
Cells(4, 27) = Cells(4, 4)
Cells(4, 21) = Cells(4, 5)
Cells(4, 28) = Cells(4, 5)
Cells(3, 16) = "Extension motion"
Cells(3, 23) = "Flexion motion"

```

```

Next N
End Sub

```

Passive Data Programs: Resistance torque (spasticity) and stiffness

```
Sub openfileP5()
'+++++++For P5 - To determine Gravity Correction+++++++

'*****Individual Parameters*****
Group = "CP" 'CP or N
Num = "4" 'Subject #
Speed = "5" 'Speed
'*****

Workbooks.OpenText Filename:= _
"C:\TestData\Process\Passive_Log to\" + Group + "\" + Group + Num + "\" + Group + Num
+ "_P" + Speed + ".txt", Origin:=437, _
StartRow:=1, DataType:=xlFixedWidth, FieldInfo:=Array(Array(0, 1), Array(6, _
1), Array(18, 1), Array(27, 1), Array(42, 1)), TrailingMinusNumbers:=True

ActiveWorkbook.saveas Filename:= _
"C:\TestData\Process\Passive_Log to\" + Group + "\" + Group + Num + "\" + Group + Num
+ "_P" + Speed + ".xls", FileFormat:=xlNormal _
, Password:="", WriteResPassword:="", ReadOnlyRecommended:=False, _
CreateBackup:=False

'Sub graf()
sheetname = Group + Num + "_P" + Speed
Windows(sheetname + ".xls").Activate
Charts.Add
ActiveChart.ChartType = xlXYScatterLinesNoMarkers
ActiveChart.SetSourceData Source:=Sheets(sheetname).Range("F18")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(1).XValues = Sheets(sheetname).Range("D7:D12199")
ActiveChart.SeriesCollection(1).Values = Sheets(sheetname).Range("B7:B12199")
ActiveChart.Location Where:=xlLocationAsObject, Name:=sheetname
With ActiveChart.Axes(xlCategory)
.HasMajorGridlines = False
.HasMinorGridlines = False
End With
With ActiveChart.Axes(xlValue)
.HasMajorGridlines = False
.HasMinorGridlines = False
End With
ActiveChart.HasLegend = False
ActiveChart.PlotArea.Select
Selection.ClearFormats

Range("E11").Select
Select Case Speed
Case 5
```

```

    th = 0.5
Case Else
    th = 1.1
End Select

Cells(3, 7) = "Extension motion"
Cells(3, 14) = "Flexion motion"

Speed = Speed - th
'read in numbers
ReDim dat(4, 13000)
For I = 1 To 13000
    If Cells(I + 6, 1) = "" Then Exit For
    dat(1, I) = Cells(I + 6, 1) 'Time (ms)
    dat(2, I) = Cells(I + 6, 2) 'Torque (Nm)
    dat(3, I) = Cells(I + 6, 4) 'Position (Anatonical, degree)
    dat(4, I) = Cells(I + 6, 5) 'Velocity (deg/sec)
Next I
ttlpt = I - 1
'find the three extension trials
ReDim est(3) 'starting of the extension phase
ReDim eend(3) 'end of the extension phase
'first extension
For I = 1 To ttlpt
    If dat(4, I) > Speed And dat(4, I + 1) > Speed And dat(4, I + 2) > Speed Then
        est(1) = I
        Exit For
    End If
Next I
For I = est(1) To ttlpt
    If dat(4, I) < Speed And dat(4, I + 1) < Speed And dat(4, I + 2) < Speed Then
        eend(1) = I - 1
        Exit For
    End If
Next I
'second extension
*****find the beginning of the next extension phase
For I = eend(1) To ttlpt
    If dat(4, I) < 0 Then Exit For
Next I
nst = I 'new starting point
For I = nst To ttlpt
    If dat(4, I) > 0 Then Exit For
Next I
nst = I
*****
For I = nst To ttlpt
    If dat(4, I) > Speed And dat(4, I + 1) > Speed And dat(4, I + 2) > Speed Then

```

```

        est(2) = I
        Exit For
    End If
Next I
For I = est(2) To ttlpnt
    If dat(4, I) < Speed And dat(4, I + 1) < Speed And dat(4, I + 2) < Speed Then
        eend(2) = I - 1
        Exit For
    End If
Next I
'Third extension
*****find the beginning of the next extension phase
For I = eend(2) To ttlpnt
    If dat(4, I) < 0 Then Exit For
Next I
nst = I 'new starting point
For I = nst To ttlpnt
    If dat(4, I) > 0 Then Exit For
Next I
nst = I
*****
For I = nst To ttlpnt
    If dat(4, I) > Speed And dat(4, I + 1) > Speed And dat(4, I + 2) > Speed Then
        est(3) = I
        Exit For
    End If
Next I
For I = est(3) To ttlpnt
    If dat(4, I) < Speed And dat(4, I + 1) < Speed And dat(4, I + 2) < Speed Then
        eend(3) = I - 1
        Exit For
    End If
Next I
'++++++++'
'find the three flexion trials
ReDim fst(3) 'starting of the flexion phase
ReDim fend(3) 'end of the flexion phase
'first flexion
For I = eend(1) To ttlpnt
    If dat(4, I) < -Speed And dat(4, I + 1) < -Speed And dat(4, I + 2) < -Speed Then
        fst(1) = I
        Exit For
    End If
Next I
For I = fst(1) To ttlpnt
    If dat(4, I) > -Speed And dat(4, I + 1) > -Speed And dat(4, I + 2) > -Speed Then
        fend(1) = I - 1
        Exit For

```

```

    End If
Next I
'second flexion
For I = eend(2) To ttlpnt
    If dat(4, I) < -Speed And dat(4, I + 1) < -Speed And dat(4, I + 2) < -Speed Then
        fst(2) = I
        Exit For
    End If
Next I
For I = fst(2) To ttlpnt
    If dat(4, I) > -Speed And dat(4, I + 1) > -Speed And dat(4, I + 2) > -Speed Then
        fend(2) = I - 1
        Exit For
    End If
Next I
'Third flexion
For I = eend(3) To ttlpnt
    If dat(4, I) < -Speed And dat(4, I + 1) < -Speed And dat(4, I + 2) < -Speed Then
        fst(3) = I
        Exit For
    End If
Next I
For I = fst(3) To ttlpnt
    If dat(4, I) > -Speed And dat(4, I + 1) > -Speed And dat(4, I + 2) > -Speed Then
        fend(3) = I - 1
        Exit For
    End If
Next I
'Export trials into new array
'find max number of data points in all six trials
maxp = 0
For I = 1 To 3
    If maxp < eend(I) - est(I) + 1 Then maxp = eend(I) - est(I) + 1
    If maxp < fend(I) - fst(I) + 1 Then maxp = fend(I) - fst(I) + 1
Next I
ReDim newdat(2, 2, 3, maxp) '2-exten(1)/flex(2); 2-angle(1)/torque(2); 3-three trials; and maxp -
maxnumber in all trials
For J = 1 To 3
    For I = est(J) To eend(J)
        newdat(1, 1, J, I - est(J) + 1) = dat(3, I)
        'without gravity correction
        newdat(1, 2, J, I - est(J) + 1) = dat(2, I)
        'with gravity correction
        newdat(1, 2, J, I - est(J) + 1) = dat(2, I) + gc * Cos((dat(3, I) - 0) * 3.14 / 180) / Cos(cosgc *
3.14 / 180)
        'gravity correction by itself
        newdat(1, 2, J, I - est(J) + 1) = gc * Cos(dat(3, I) * 3.14 / 180) / Cos(cosgc * 3.14 / 180)
    Next I

```

```

Next J
For J = 1 To 3
  For I = fst(J) To fend(J)
    newdat(2, 1, J, I - fst(J) + 1) = dat(3, I)
    'without gravity correction
    newdat(2, 2, J, I - fst(J) + 1) = dat(2, I)
    'with gravity correction
    newdat(2, 2, J, I - fst(J) + 1) = dat(2, I) + gc * Cos((dat(3, I) - 0) * 3.14 / 180) / Cos(cosgc *
3.14 / 180)
    'gravity correction by itself
    newdat(2, 2, J, I - fst(J) + 1) = gc * Cos(dat(3, I) * 3.14 / 180) / Cos(cosgc * 3.14 / 180)
  Next I
Next J
'find minimum torque (@angle) during extension motion
ReDim minT(2, 3) '2- angle(1)/torque(2); 3- three trials
For J = 1 To 3
  minT(2, J) = 1000
  For I = 1 To eend(J) - est(J) + 1
    If minT(2, J) > newdat(1, 2, J, I) Then
      minT(2, J) = newdat(1, 2, J, I) 'find the minimum torque
      minT(1, J) = newdat(1, 1, J, I) 'find the angle with it
    End If
  Next I
Next J
'find maximum torque (@angle) during flexion motion
ReDim maxT(2, 3)
For J = 1 To 3
  maxT(2, J) = -1000
  For I = 1 To fend(J) - fst(J) + 1
    If maxT(2, J) < newdat(2, 2, J, I) Then
      maxT(2, J) = newdat(2, 2, J, I) 'find the maximum torque
      maxT(1, J) = newdat(2, 1, J, I) 'find the angle with it
    End If
  Next I
Next J
'Print data to spread sheet
For J = 1 To 3
  For I = 1 To eend(J) - est(J) + 1
    Cells(I + 6, 7 + (J - 1) * 2) = newdat(1, 1, J, I)
    Cells(I + 6, 8 + (J - 1) * 2) = newdat(1, 2, J, I)
  Next I
Next J
For J = 1 To 3
  For I = 1 To fend(J) - fst(J) + 1
    Cells(I + 6, 14 + (J - 1) * 2) = newdat(2, 1, J, I)
    Cells(I + 6, 15 + (J - 1) * 2) = newdat(2, 2, J, I)
  Next I
Next J

```

```

Cells(1, 7) = ttlpnt
Cells(1, 8) = est(1) + 6
Cells(1, 9) = eend(1) + 6
Cells(1, 10) = est(2) + 6
Cells(1, 11) = eend(2) + 6
Cells(1, 12) = est(3) + 6
Cells(1, 13) = eend(3) + 6
Cells(2, 8) = fst(1) + 6
Cells(2, 9) = fend(1) + 6
Cells(2, 10) = fst(2) + 6
Cells(2, 11) = fend(2) + 6
Cells(2, 12) = fst(3) + 6
Cells(2, 13) = fend(3) + 6
'For J = 1 To 3
    'Cells(5, 7 + (J - 1) * 2) = minT(1, J)
    'Cells(5, 8 + (J - 1) * 2) = minT(2, J)
    'Cells(5, 14 + (J - 1) * 2) = maxT(1, J)
    'Cells(5, 15 + (J - 1) * 2) = maxT(2, J)
'Next J
'End Sub
*****
'Sub graf2() 'Extension movement

    'sheetname = Group + Num + "_P" + Speed
    Windows(sheetname + ".xls").Activate
    Charts.Add
    ActiveChart.ChartType = xlXYScatterLinesNoMarkers
    ActiveChart.SetSourceData Source:=Sheets(sheetname).Range("I18")
    ActiveChart.SeriesCollection.NewSeries
    ActiveChart.SeriesCollection(1).XValues = Sheets(sheetname).Range("G7:G2863")
    ActiveChart.SeriesCollection(1).Values = Sheets(sheetname).Range("H7:H2863")
    ActiveChart.SeriesCollection(2).XValues = Sheets(sheetname).Range("I7:I2863")
    ActiveChart.SeriesCollection(2).Values = Sheets(sheetname).Range("J7:J2863")
    ActiveChart.SeriesCollection.NewSeries
    ActiveChart.SeriesCollection(3).XValues = Sheets(sheetname).Range("K7:K2863")
    ActiveChart.SeriesCollection(3).Values = Sheets(sheetname).Range("L7:L2863")
    ActiveChart.Location Where:=xlLocationAsObject, Name:=sheetname
    With ActiveChart
        .HasTitle = True
        .ChartTitle.Characters.Text = "Knee extension movement"
        .Axes(xlCategory, xlPrimary).HasTitle = False
        .Axes(xlValue, xlPrimary).HasTitle = False
    End With
    With ActiveChart.Axes(xlCategory)
        .HasMajorGridlines = False
        .HasMinorGridlines = False
    End With
    With ActiveChart.Axes(xlValue)

```

```

        .HasMajorGridlines = False
        .HasMinorGridlines = False
    End With
    With ActiveChart.Axes(xlCategory)
        .HasMajorGridlines = False
        .HasMinorGridlines = False
    End With
    With ActiveChart.Axes(xlValue)
        .HasMajorGridlines = False
        .HasMinorGridlines = False
    End With
    ActiveChart.HasLegend = False
    ActiveChart.PlotArea.Select
    Selection.ClearFormats
'End Sub

```

```

'Sub graf3() 'Flexion movement
'sheetname = "P5"
Windows(sheetname + ".xls").Activate

```

```

Charts.Add
ActiveChart.ChartType = xlXYScatterLinesNoMarkers
ActiveChart.SetSourceData Source:=Sheets(sheetname).Range("Q18")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(1).XValues = Sheets(sheetname).Range("N7:N2863")
ActiveChart.SeriesCollection(1).Values = Sheets(sheetname).Range("O7:O2863")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(2).XValues = Sheets(sheetname).Range("P7:P2863")
ActiveChart.SeriesCollection(2).Values = Sheets(sheetname).Range("Q7:Q2863")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(3).XValues = Sheets(sheetname).Range("R7:R2863")
ActiveChart.SeriesCollection(3).Values = Sheets(sheetname).Range("S7:S2863")
ActiveChart.Location Where:=xlLocationAsObject, Name:=sheetname
With ActiveChart
    .HasTitle = True
    .ChartTitle.Characters.Text = "Knee flexion movement"
    .Axes(xlCategory, xlPrimary).HasTitle = False
    .Axes(xlValue, xlPrimary).HasTitle = False
End With
With ActiveChart.Axes(xlCategory)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
With ActiveChart.Axes(xlValue)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
With ActiveChart.Axes(xlCategory)

```

```

        .HasMajorGridlines = False
        .HasMinorGridlines = False
    End With
    With ActiveChart.Axes(xIValue)
        .HasMajorGridlines = False
        .HasMinorGridlines = False
    End With
    ActiveChart.HasLegend = False
    ActiveChart.PlotArea.Select
    Selection.ClearFormats
End Sub

```

```
Sub openfile()
```

```
'+++++++++After Gravity Correction has been determined+++++++++
```

```
'*****Individual Parameters*****
```

```

Group = "CP" 'CP or N
Num = "4" 'Subject #
GC = 12 'gravity correction in NM
cosgc = 30 'Angle of the GC was measured
minAext = 17 'angle to measure torque for all Extension trials determined from 120deg/s
maxAflx = 86 'angle to measure torque for all Flexion trials determined from 120deg/s

```

```
Speed = "120" 'Change Speed for each trial!!!!!!
```

```
'*****
```

```
Workbooks.OpenText Filename:= _
```

```

"C:\TestData\Process\Passive_Log to\" + Group + "\" + Group + Num + "\" + Group + Num
+ "_P" + Speed + ".txt", Origin:=437, _
StartRow:=1, DataType:=xlFixedWidth, FieldInfo:=Array(Array(0, 1), Array(6, _
1), Array(18, 1), Array(27, 1), Array(42, 1)), TrailingMinusNumbers:=True

```

```
ActiveWorkbook.saveas Filename:= _
```

```

"C:\TestData\Process\Passive_Log to\" + Group + "\" + Group + Num + "\" + Group + Num
+ "_P" + Speed + ".xls", FileFormat:=xlNormal _
, Password:="", WriteResPassword:="", ReadOnlyRecommended:=False, _
CreateBackup:=False

```

```
Cells(3, 7) = "Extension motion"
```

```
Cells(3, 14) = "Flexion motion"
```

```
'Sub graf() 'Raw data
```

```
sheetname = Group + Num + "_P" + Speed
```

```
Windows(sheetname + ".xls").Activate
```

```
Charts.Add
```

```
ActiveChart.ChartType = xlXYScatterLinesNoMarkers
```

```
ActiveChart.SetSourceData Source:=Sheets(sheetname).Range("F18")
```

```
ActiveChart.SeriesCollection.NewSeries
```

```

ActiveChart.SeriesCollection(1).XValues = Sheets(sheetname).Range("D7:D12199")
ActiveChart.SeriesCollection(1).Values = Sheets(sheetname).Range("B7:B12199")
ActiveChart.Location Where:=xlLocationAsObject, Name:=sheetname
With ActiveChart.Axes(xlCategory)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
With ActiveChart.Axes(xlValue)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
ActiveChart.HasLegend = False
ActiveChart.PlotArea.Select
Selection.ClearFormats

Range("E11").Select
'End Sub

```

```
'Sub GCtrialid()
```

```

Cells(1, 15) = "GC(Nm)" 'Gravity correction in Nm
Cells(2, 15) = GC
Cells(1, 16) = "Angle"
Cells(2, 16) = cosgc
Cells(1, 17) = "SlopeExt"
Cells(1, 18) = "SlopeFlex"

```

```
Select Case Speed
```

```

Case 5
    th = 0.5
Case Else
    th = 1.1

```

```
End Select
```

```
Speed = Speed - th
```

```
'read in numbers
```

```
ReDim dat(4, 13000)
```

```
For I = 1 To 13000
```

```

If Cells(I + 6, 1) = "" Then Exit For
dat(1, I) = Cells(I + 6, 1) 'Time (ms)
dat(2, I) = Cells(I + 6, 2) 'Torque (Nm)
dat(3, I) = Cells(I + 6, 4) 'Position (Anatomical, degree)
dat(4, I) = Cells(I + 6, 5) 'Velocity (deg/sec)

```

```
Next I
```

```
ttlpt = I - 1
```

```
'find the three extension trials
```

```
ReDim est(3) 'starting of the extension phase
```

```
ReDim eend(3) 'end of the extension phase
```

```

'first extension
For I = 1 To ttlpnt
  If dat(4, I) > Speed And dat(4, I + 1) > Speed And dat(4, I + 2) > Speed Then
    est(1) = I
    Exit For
  End If
Next I
For I = est(1) To ttlpnt
  If dat(4, I) < Speed And dat(4, I + 1) < Speed And dat(4, I + 2) < Speed Then
    eend(1) = I - 1
    Exit For
  End If
Next I
'second extension
*****find the beginning of the next extension phase
For I = eend(1) To ttlpnt
  If dat(4, I) < 0 Then Exit For
Next I
nst = I 'new starting point
For I = nst To ttlpnt
  If dat(4, I) > 0 Then Exit For
Next I
nst = I
*****
For I = nst To ttlpnt
  If dat(4, I) > Speed And dat(4, I + 1) > Speed And dat(4, I + 2) > Speed Then
    est(2) = I
    Exit For
  End If
Next I
For I = est(2) To ttlpnt
  If dat(4, I) < Speed And dat(4, I + 1) < Speed And dat(4, I + 2) < Speed Then
    eend(2) = I - 1
    Exit For
  End If
Next I
'Third extension
*****find the beginning of the next extension phase
For I = eend(2) To ttlpnt
  If dat(4, I) < 0 Then Exit For
Next I
nst = I 'new starting point
For I = nst To ttlpnt
  If dat(4, I) > 0 Then Exit For
Next I
nst = I
*****
For I = nst To ttlpnt

```

```

    If dat(4, I) > Speed And dat(4, I + 1) > Speed And dat(4, I + 2) > Speed Then
        est(3) = I
        Exit For
    End If
Next I
For I = est(3) To ttlpnt
    If dat(4, I) < Speed And dat(4, I + 1) < Speed And dat(4, I + 2) < Speed Then
        eend(3) = I - 1
        Exit For
    End If
Next I
'+++++
'find the three flexion trials
ReDim fst(3) 'starting of the flexion phase
ReDim fend(3) 'end of the flexion phase
'first flexion
For I = eend(1) To ttlpnt
    If dat(4, I) < -Speed And dat(4, I + 1) < -Speed And dat(4, I + 2) < -Speed Then
        fst(1) = I
        Exit For
    End If
Next I
For I = fst(1) To ttlpnt
    If dat(4, I) > -Speed And dat(4, I + 1) > -Speed And dat(4, I + 2) > -Speed Then
        fend(1) = I - 1
        Exit For
    End If
Next I
'second flexion
For I = eend(2) To ttlpnt
    If dat(4, I) < -Speed And dat(4, I + 1) < -Speed And dat(4, I + 2) < -Speed Then
        fst(2) = I
        Exit For
    End If
Next I
For I = fst(2) To ttlpnt
    If dat(4, I) > -Speed And dat(4, I + 1) > -Speed And dat(4, I + 2) > -Speed Then
        fend(2) = I - 1
        Exit For
    End If
Next I
'Third flexion
For I = eend(3) To ttlpnt
    If dat(4, I) < -Speed And dat(4, I + 1) < -Speed And dat(4, I + 2) < -Speed Then
        fst(3) = I
        Exit For
    End If
Next I

```

```

For I = fst(3) To ttlpnt
  If dat(4, I) > -Speed And dat(4, I + 1) > -Speed And dat(4, I + 2) > -Speed Then
    fend(3) = I - 1
  Exit For
End If
Next I
'Export trials into new array
'find max number of data points in all six trials
maxp = 0
For I = 1 To 3
  If maxp < eend(I) - est(I) + 1 Then maxp = eend(I) - est(I) + 1
  If maxp < fend(I) - fst(I) + 1 Then maxp = fend(I) - fst(I) + 1
Next I
ReDim newdat(2, 2, 3, maxp) '2-exten(1)/flex(2); 2-angle(1)/torque(2); 3-three trials; and maxp -
maxnumber in all trials
For J = 1 To 3
  For I = est(J) To eend(J)
    newdat(1, 1, J, I - est(J) + 1) = dat(3, I)
    'without gravity correction
    newdat(1, 2, J, I - est(J) + 1) = dat(2, I)
    'with gravity correction
    newdat(1, 2, J, I - est(J) + 1) = dat(2, I) + GC * Cos((dat(3, I) - 0) * 3.14 / 180) / Cos(cosgc
* 3.14 / 180)
    'gravity correction by itself
    newdat(1, 2, J, I - est(J) + 1) = gc * Cos(dat(3, I) * 3.14 / 180) / Cos(cosgc * 3.14 / 180)
  Next I
Next J
For J = 1 To 3
  For I = fst(J) To fend(J)
    newdat(2, 1, J, I - fst(J) + 1) = dat(3, I)
    'without gravity correction
    newdat(2, 2, J, I - fst(J) + 1) = dat(2, I)
    'with gravity correction
    newdat(2, 2, J, I - fst(J) + 1) = dat(2, I) + GC * Cos((dat(3, I) - 0) * 3.14 / 180) / Cos(cosgc
* 3.14 / 180)
    'gravity correction by itself
    newdat(2, 2, J, I - fst(J) + 1) = gc * Cos(dat(3, I) * 3.14 / 180) / Cos(cosgc * 3.14 / 180)
  Next I
Next J
'find minimum torque (@angle) during extension motion
ReDim minT(2, 3) '2- angle(1)/torque(2); 3- three trials
For J = 1 To 3
  minT(2, J) = 1000
  For I = 1 To eend(J) - est(J) + 1
    If minT(2, J) > newdat(1, 2, J, I) Then
      minT(2, J) = newdat(1, 2, J, I) 'find the minimum torque
      minT(1, J) = newdat(1, 1, J, I) 'find the angle with it
    End If
  Next I
Next J

```

```

Next I
Next J
'find maximum torque (@angle) during flexion motion
ReDim maxT(2, 3)
For J = 1 To 3
    maxT(2, J) = -1000
    For I = 1 To fend(J) - fst(J) + 1
        If maxT(2, J) < newdat(2, 2, J, I) Then
            maxT(2, J) = newdat(2, 2, J, I) 'find the maximum torque
            maxT(1, J) = newdat(2, 1, J, I) 'find the angle with it
        End If
    Next I
Next J
'find torque associated with the minimum angle during extension motion
ReDim minA(2, 3) '2- angle(1)/torque(2); 3- three trials
For J = 1 To 3
    For I = 1 To eend(J) - est(J) + 1
        If newdat(1, 1, J, I) = minAext Then
            minA(1, J) = newdat(1, 1, J, I)
            minA(2, J) = newdat(1, 2, J, I)
        End If
    Next I
Next J
'find torque associated with the maximum angle during flexion motion
ReDim maxA(2, 3)
For J = 1 To 3
    For I = 1 To fend(J) - fst(J) + 1
        If newdat(2, 1, J, I) = maxAflx Then
            maxA(1, J) = newdat(2, 1, J, I)
            maxA(2, J) = newdat(2, 2, J, I)
        End If
    Next I
Next J
'Print data to spread sheet
For J = 1 To 3
    For I = 1 To eend(J) - est(J) + 1
        Cells(I + 6, 7 + (J - 1) * 2) = newdat(1, 1, J, I)
        Cells(I + 6, 8 + (J - 1) * 2) = newdat(1, 2, J, I)
    Next I
Next J
For J = 1 To 3
    For I = 1 To fend(J) - fst(J) + 1
        Cells(I + 6, 14 + (J - 1) * 2) = newdat(2, 1, J, I)
        Cells(I + 6, 15 + (J - 1) * 2) = newdat(2, 2, J, I)
    Next I
Next J
Cells(1, 7) = ttpnt
Cells(1, 8) = est(1) + 6

```

```

Cells(1, 9) = eend(1) + 6
Cells(1, 10) = est(2) + 6
Cells(1, 11) = eend(2) + 6
Cells(1, 12) = est(3) + 6
Cells(1, 13) = eend(3) + 6
Cells(2, 8) = fst(1) + 6
Cells(2, 9) = fend(1) + 6
Cells(2, 10) = fst(2) + 6
Cells(2, 11) = fend(2) + 6
Cells(2, 12) = fst(3) + 6
Cells(2, 13) = fend(3) + 6
For J = 1 To 3
    Cells(5, 7 + (J - 1) * 2) = minT(1, J)
    Cells(5, 8 + (J - 1) * 2) = minT(2, J)
    Cells(5, 14 + (J - 1) * 2) = maxT(1, J)
    Cells(5, 15 + (J - 1) * 2) = maxT(2, J)
    Cells(4, 7 + (J - 1) * 2) = minA(1, J)
    Cells(4, 8 + (J - 1) * 2) = minA(2, J)
    Cells(4, 14 + (J - 1) * 2) = maxA(1, J)
    Cells(4, 15 + (J - 1) * 2) = maxA(2, J)
Next J
'End Sub
*****
'Sub graf2() 'Extension movement

'sheetname = Group + Num + "_P" + Speed
Windows(sheetname + ".xls").Activate
Charts.Add
ActiveChart.ChartType = xlXYScatterLinesNoMarkers
ActiveChart.SetSourceData Source:=Sheets(sheetname).Range("I18")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(1).XValues = Sheets(sheetname).Range("G7:G2863")
ActiveChart.SeriesCollection(1).Values = Sheets(sheetname).Range("H7:H2863")
ActiveChart.SeriesCollection(2).XValues = Sheets(sheetname).Range("I7:I2863")
ActiveChart.SeriesCollection(2).Values = Sheets(sheetname).Range("J7:J2863")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(3).XValues = Sheets(sheetname).Range("K7:K2863")
ActiveChart.SeriesCollection(3).Values = Sheets(sheetname).Range("L7:L2863")
ActiveChart.Location Where:=xlLocationAsObject, Name:=sheetname
With ActiveChart
    .HasTitle = True
    .ChartTitle.Characters.Text = "Knee extension movement"
    .Axes(xlCategory, xlPrimary).HasTitle = False
    .Axes(xlValue, xlPrimary).HasTitle = False
End With
With ActiveChart.Axes(xlCategory)
    .HasMajorGridlines = False
    .HasMinorGridlines = False

```

```

End With
With ActiveChart.Axes(xlValue)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
With ActiveChart.Axes(xlCategory)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
With ActiveChart.Axes(xlValue)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
ActiveChart.HasLegend = False
ActiveChart.PlotArea.Select
Selection.ClearFormats
'End Sub

```

```

'Sub graf3() 'Flexion movement
'sheetname = "P5"
Windows(sheetname + ".xls").Activate

```

```

Charts.Add
ActiveChart.ChartType = xlXYScatterLinesNoMarkers
ActiveChart.SetSourceData Source:=Sheets(sheetname).Range("Q18")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(1).XValues = Sheets(sheetname).Range("N7:N2863")
ActiveChart.SeriesCollection(1).Values = Sheets(sheetname).Range("O7:O2863")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(2).XValues = Sheets(sheetname).Range("P7:P2863")
ActiveChart.SeriesCollection(2).Values = Sheets(sheetname).Range("Q7:Q2863")
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(3).XValues = Sheets(sheetname).Range("R7:R2863")
ActiveChart.SeriesCollection(3).Values = Sheets(sheetname).Range("S7:S2863")
ActiveChart.Location Where:=xlLocationAsObject, Name:=sheetname
With ActiveChart
    .HasTitle = True
    .ChartTitle.Characters.Text = "Knee flexion movement"
    .Axes(xlCategory, xlPrimary).HasTitle = False
    .Axes(xlValue, xlPrimary).HasTitle = False
End With
With ActiveChart.Axes(xlCategory)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
With ActiveChart.Axes(xlValue)
    .HasMajorGridlines = False
    .HasMinorGridlines = False

```

```

End With
With ActiveChart.Axes(xlCategory)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
With ActiveChart.Axes(xlValue)
    .HasMajorGridlines = False
    .HasMinorGridlines = False
End With
ActiveChart.HasLegend = False
ActiveChart.PlotArea.Select
Selection.ClearFormats
End Sub

```

Sub openfiles() '*****Program to Place Slope data in one spreadsheet

Group = "CP" 'CP or N *****Change for each group

For J = 1 To 17 'Number of subjects

For I = 1 To 6

Select Case I

Case 1

Speed = "5"

Case 2

Speed = "10"

Case 3

Speed = "30"

Case 4

Speed = "60"

Case 5

Speed = "90"

Case 6

Speed = "120"

End Select

Workbooks.OpenText Filename:= _

"C:\TestData\Process\Passive_Log to\" + Group + "\" + Group + Trim(Str(J)) + "\" + Group
+ Trim(Str(J)) + "_P" + Speed + ".xls"

slopeext = Cells(2, 17)

slopeflex = Cells(2, 18)

ActiveWindow.Close

'Place data in data spreadsheet

Windows(Group + "_SlopeData.xls").Activate

Cells(J + 1, I + 1) = slopeext

Cells(J + 1, 7 + I + 1) = slopeflex

Cells(J + 1, 1) = J

Next I

```
Next J
End Sub
```

```
Sub openfiles() '*****Program to Place Peak Resistance Torque data in one spreadsheet
Group = "CP" 'CP or N *****Change for each group
```

```
For J = 1 To 17 'Number of subjects
```

```
  For I = 1 To 6
```

```
    Select Case I
```

```
      Case 1
```

```
        Speed = "5"
```

```
      Case 2
```

```
        Speed = "10"
```

```
      Case 3
```

```
        Speed = "30"
```

```
      Case 4
```

```
        Speed = "60"
```

```
      Case 5
```

```
        Speed = "90"
```

```
      Case 6
```

```
        Speed = "120"
```

```
    End Select
```

```
Workbooks.OpenText Filename:= _
```

```
  "C:\TestData\Process\Passive_Log to\" + Group + "\" + Group + Trim(Str(J)) + "\" + Group
+ Trim(Str(J)) + "_P" + Speed + ".xls"
```

```
'Find Minimum Resistive torque over the 3 trials for Extension because negative numbers
```

```
Minext = 1000
```

```
  For K = 1 To 3
```

```
    If Minext > Cells(5, 6 + K * 2) Then
```

```
      Minext = Cells(5, 6 + K * 2)
```

```
    End If
```

```
  Next K
```

```
'Find Maximum Resistive torque over the 3 trials for Flexion
```

```
Maxflx = 0.0005
```

```
  For K = 1 To 3
```

```
    If Cells(5, 13 + K * 2) > Maxflx Then
```

```
      Maxflx = Cells(5, 13 + K * 2)
```

```
    End If
```

```
  Next K
```

```
  ActiveWindow.Close
```

```
'Place data in data spreadsheet
```

```
Windows(Group + "_ResistanceTorqueData.xls").Activate
```

```
'place max in appropriate column
```

```
Cells(J + 1, I + 1) = Minext
```

```
Cells(J + 1, I + 8) = Maxflx
```

```
Next I
```

```
Next J
```

```
End Sub
```

VITA

Noelle Gerise Moreau was born on December 16, 1973 in Cottonport, Louisiana. She graduated from St. Joseph High School in Plaquemine, Louisiana, in 1992. In 1996 Noelle graduated summa cum laude with a Bachelor of Science degree in physical therapy from Louisiana State University Medical Center in Shreveport, Louisiana. After graduation, Noelle worked in both hospital and outpatient centers as a physical therapist treating a variety of adult neurological and orthopedic patients. In 1998, Noelle was hired by Shriners Hospital for Children in Shreveport, Louisiana, and was trained in computerized, 3-D gait analysis technology for children with cerebral palsy. She soon became an instructor at her alma mater, Louisiana State University Medical Center, teaching gait analysis to students in the physical therapy program. Shortly thereafter, Noelle spearheaded a research agenda between Shriners Hospital and the physical therapy department and thus, began her love of research and teaching. In 2002 Noelle moved to Baton Rouge, Louisiana, to attend Louisiana State University in order to pursue her doctoral degree on a full-time basis. While at Louisiana State University, Noelle was the recipient of the Louisiana Board of Regents Fellowship, College of Education Lilian Olson Scholarship, the American Physical Therapy Association Mary McMillan Doctoral Scholarship, Section on Pediatrics Clinical Research Grant, and the Louisiana State University Dissertation Year Fellowship. Recently, Noelle has accepted a post-doctoral research position at Washington University School of Medicine in St. Louis, Missouri.