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An Exploration of the Underlying Mechanisms Causing Spasticity in Young People with Cerebral Palsy

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AN EXPLORATION OF THE UNDERLYING MECHANISMS CAUSING SPASTICITY IN YOUNG PEOPLE WITH CEREBRAL PALSY

by

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(Under the Direction of Li Li)

ABSTRACT

Background and Objective(s): Spasticity is a common symptom experienced by individuals with cerebral palsy (CP). Spastic CP is often accompanied by hypertonia. Currently, there is a limited understanding of the contributions of spasticity to hypertonia which can in turn hinder the development of new rehabilitative measure to improve these conditions. Additionally, clinical evaluation of spasticity is limited to observational techniques such as the Ashworth scale. The purpose of this study was to compare differences in passive joint torque in the upper extremity between individuals with severe, spastic CP (MACS III-V) and healthy, age-matched controls at different speeds during passive stretching.

Study Participants & Setting: Six children (M_{age} = 15.0; SD =2.28) had been previously diagnosed with cerebral palsy, and the remaining six were age-matched controls (M_{age} =14.2; SD =1.32). The children with CP were classified as high CP (level III-V) based off the Manual Ability Classification System (MACS) scale.

Materials/Methods: Passive stretch torque during elbow flexion and extension were obtained using the Biodex (Biodex Medical Systems Incorporated, Shirley, NY) System 4 isokinetic dynamometer. Each participant went through five repetitions of passive stretch for both arms at four different speeds (90, 120, 150, and 180 deg/s). A comfortable range of motion was set for each participant and they were asked to stay relaxed throughout the entire testing period. Peak and average elbow passive torque due to extension (PTE / ATE) and flexion (PTF / ATF) movement during different stretching speeds were recorded as the outcome variables.

Results: This study observed significant PTF (group X velocity interaction, $F_{(3, 15)}$= 4.60, $p < .05$), where the control group had increasing torque values as the velocity increased and the CP group had decreasing torque values as the velocity increased. Average torque during flexion significantly affected by passive stretching velocity in a linear fashion ($p < .05$) without group by speed interaction ($p > .05$). We also observed significant group X speed interaction ($F_{(3, 15)}$= 5.11, $p < .05$) for ATE, where both the control and participants with CP had increasing torque values as stretching velocity increased, but participants with CP had a greater increase. Peak torque during extension had no significant interactions to change of stretching velocity between the two groups of participants, but did display a significant linear trend by passive stretching velocity ($p < .05$).

Conclusions/Significance: Our observations indicate that young people with severe, spastic CP exhibit different joint torque values at different speeds. A more effective rehabilitation plan can be based off the observations in this study. More resistive torque occurred at slower stretching speeds for young people with lower upper extremity function and severe spasticity. For children at higher levels on the MACS, higher speeds appeared to provide less of a hypertonic response, which suggests that power training can be done at faster speeds in order to see improvements.

INDEX WORDS: Cerebral palsy, Spasticity, Hypertonia, Elbow, Passive stretching

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CHAPTER 1

INTRODUCTION

Cerebral palsy (CP) is a group of neurological disorders that hinders the progression of motor skills by affecting body movement, muscle coordination, reflexes, postural control, balance, and muscle tone (U. S. Department of Health and Human Services, National Institutes of Health [NIH], National Institute of Neurological Disorders and Stroke [NINDS], 2013). Each year, approximately 1 in 323 infants are diagnosed with CP caused by damage to the developing brain (Christensen et al., 2014). Spasticity is one of the most common symptoms associated with CP and has been observed in up to 77.4% of the individuals with the disorder (Christensen et al., 2014). Spasticity is caused by damage of central neuron pathways above T12, which induces muscle weakness, contracture, and muscle over activity (McGuire, 2016). Spasticity can be defined as "hypertonia in which 1 or both of the following signs are present: 1) resistance to externally imposed movement increases with increasing speed of stretch and varies with the direction of joint movement, and/or 2) resistance to externally imposed movement rises rapidly above stretching speed or joint angle thresholds" (Sanger, et al., 2003, p. e89). Spasticity is caused by disruptions within motor neurons that result in a speed dependent stretch reflex that is 'hyper-excited' resulting in stiffness, cramping, or spasms (Brashear, 2015; Elovic, 2016; Hughes & Howard, 2013; Rush & Kumbhare, 2015).

Spasticity can negatively affect function, which can in turn affect quality of life (QOL) and participation in daily activities (Orlin et al. 2010). Orlin et al. (2010) observed

that children and young people with CP who possessed greater function were more likely to participate in recreational activities, but not as much in formal or physical activities such as team sports. They also observed that those with more severe symptoms associated with CP did not participate in most activities. When upper extremity function is impaired due to spasticity, functional tasks such as reaching, grasping, pointing, releasing and manipulating objects are affected (Boyd, Morris, & Graham, 2001). Most children with spastic CP do not have use of their affected limb(s) (Boyd, Morris, & Graham, 2001). Muscular weakness resulting from spasticity and disuse can in turn lead to pain, fatigue, and depression (Opheim, et al., 2009, Van Der Slot, et al., 2012).

A major limitation of previous studies examining treatments for spasticity in the upper extremity is a lack of precise assessments to measure the effectiveness of these interventions. Clinical settings often employ the Ashworth Scale, where the limb is manually moved to passively stretch specific muscle groups through a range of motion (Bohannon & Smith, 1987). The clinician then grades spasticity based on resistance felt during passive stretch from numbers 0-4. The Ashworth Scale offers a qualitative assessment of resistance and is subject to the interpretation of the clinician. Although a feasible clinical tool, the Ashworth scale is has limitations (Patrick & Ada, 2006). For example, the Ashworth scale is not sensitive enough to differentiate contracture from spasticity (Patrick & Ada, 2006). Due to its subjectivity and generalized rating scale, the test is precisely measure any changes in 'hyper-excitability' and cannot detect any improvements through therapeutic modalities such as stretching or strengthening exercises. Due to the limitations of the Ashworth Scale, a more precise method is needed to measure spasticity in rehabilitation settings to monitor progression of symptoms over

time and then provide accurate data points to measure the effectiveness of rehabilitative protocols (Ansari, et al., 2005).

However, both spasticity and hypertonia can be difficult to quantify due to their varied presence influenced by level of consciousness, emotional state, and external stimuli (e.g. temperature or noise) (Lebiedowska, Gaebler-Spira, Burns, & Fisk, 2004). Hypertonia may also be caused by dystonia, a condition of continuous muscle contractions that can cause repetitive movements or abnormal postures, often exacerbated during voluntary movement (Fahn, Bressman, & Marsden, 1998). Although the increase in stiffness is similar, dystonia and spasticity have different physiological mechanisms and are caused by different disorders within the larger classification of CP. Stretching during passive movement at various speeds results in a spastic 'catch' during a particular range of motion (Levitt, 2010). These muscles experience hypertonia, where muscles are improperly activated and reflexes are amplified, albeit at patterns that widely differ within each individual. Lebiedowska et al. (2004) observed multiple patterns of antagonist muscle activation in the legs associated with hypertonia in children with CP, with speed-dependent activation to be the most common. The second most prevalent pattern was position-dependent in which resistance and activation were greatest once a position threshold was met.

Currently, few studies have measured torque values of spasticity in the upper extremity among children with CP. Many studies, like that of Patten et al. (2013), studied populations of older adults who have experienced a stroke. A feasible and precise clinical methodology to measure spasticity in the upper extremity could greatly enhance diagnosis and progress monitoring in clinical settings.

Based on the literature, spasticity in the upper extremity should result in corresponding increases in both peak and average torque with increasing passive stretching speed during elbow flexion and extension (Lebiedowska et al., 2004). Due to the hypertonic nature of CP, the purpose of this study was to compare differences in passive joint torque in the upper extremity between individuals with severe, spastic CP (MACS III-V) and healthy, age-matched controls at different speeds during passive stretching. We hypothesize that both average and peak torque for each muscle group will be greater in CP participants than control participants, especially at higher stretching speeds. Due to differing underlying mechanisms causing spasticity and the potential for higher speeds to produce changes in these mechanisms (Moreau et al., 2013), we also hypothesize that young people with spastic CP will reach a stretching speed threshold after which resistive torque will be reduced with increased stretching speed.

CHAPTER 2

METHODS

Participants

Twelve children were recruited to participate in this study. Six children had been previously diagnosed with cerebral palsy, and the remaining six were age-matched healthy controls. All participants were recruited using rolling recruitment in the local school system and through support services. Participants in the CP group were eligible for the study if they met the following requirements: (1) within levels III-V of the Manual Ability Classification System for Children with Cerebral Palsy (MACS), (2) between ages 10-21 years and (3) cleared by a medical professional for physical activity. Control participants were eligible for the study if they (1) had limitations in handling objects and therefore were not eligible for scoring according to the MACS, (2) were within two years of age and matched the sex of their corresponding participant with CP, (3) had never been diagnosed with a developmental disorder. Testing took place in the Biomechanics Lab at Georgia Southern University. Parental consent and minor assent was obtained prior to the participant's involvement in the study. The study was approved by the university's Institutional Review Board.

Procedures

Each participant was given an overview of the testing protocol and verbal explanation and demonstration before starting data collection. Elbow flexion and extension torque during passive stretching were obtained using the Biodex System 4 isokinetic dynamometer (Biodex Medical Systems Incorporated, Shirley, NY). Participants were set up comfortably in the Biodex chair and strapped in for safety with

two straps crossing their chest and one lying across their lap like a seat belt. Each participant picked out a movie on Netflix, which was played throughout the testing period to serve as a passive distractor (Dahlquist, et al., 2007). Participants were instructed to hold on to the arm of a Biodex elbow attachment with a pronated grip and remain completely relaxed for all repetitions of extension/flexion. The medial epicondyle of the humerus was aligned as the axis of rotation of the dynamometer. A comfortable range of motion (ROM) was set as the movement limits for each test. Limb weight was calibrated while setting ROM and used to account for gravity during torque testing. Each participant went through five repetitions of passive stretch for both arms at four different stretching speeds (90, 120, 150, and 180 deg/s). Peak and average torque values for each repetition at each speed trial were calculated by determining the constant speed period for each cycle and time spent in constant speed.

Instrumentation

Peak and average elbow passive torque due to extension (PTE / ATE) and flexion (PTF / ATF) movement during different stretching speeds were recorded as the outcome variables. Peak and average torque values for each repetition at each speed trial were identified and calculated within the constant speed period of each cycle. Time periods in constant speed were different between participants and showed greater variance in participants with CP due to the hypertonic nature of their CP. Those participants could not maintain constant speed as long as the control participants. Average and peak torque calculations for a participant in the control group at 90 deg/s are shown on Figure 1.

Statistical Analysis

Differences of MACS scores between groups were examined using t-tests. Three-

factor analysis (Left/Right X Speed X Group) of variance (ANOVA) with repeated measures was used to analyze peak and average torque during passive elbow flexion and extension. Alpha level was set at 0.05. All statistical analyses were run using Statistix 10 (Statistix Data Analysis Software, Tallahassee, FL).

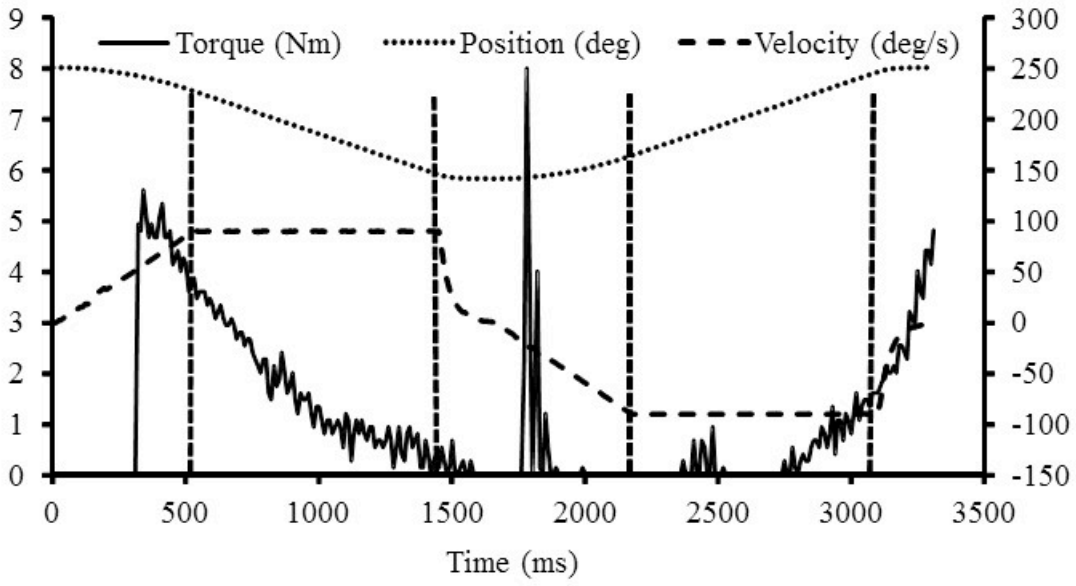

Figure 1. Exemplar angle, speed, and torque time profile for a typical data cycle of a participant in the control group at 90 deg/s stretching speed. Constant speed period identified with two adjacent vertical dash lines.

CHAPTER 3

RESULTS

Basic participant information is presented in Table 1. The anthropometric data shows no significant differences between groups for height, body mass, age, and sex ($p > .05$). Between the two groups, the MACS scores were significantly different ($p < .05$). We failed to observe any left / right differences and influences on any of our outcome variables, therefore the following results only reported the two factor (speed X group) with the combined results of left and right elbows. We have observed significant PTF (group X velocity interaction, $F_{(3, 15)} = 4.60$, $p < .05$), where the control group had increasing torque values as the velocity increased and the CP group had decreasing torque values as the velocity increased (see Figure 2, upper-left). Average torque during flexion (Figure 2, lower-left) significantly affected by passive stretching velocity in a linear fashion ($p < .05$) without group by speed interaction ($p > .05$). We also observed significant group X speed interaction ($F_{(3, 15)} = 5.11$, $p < .05$) for ATE (Figure 2, lower right), where both the control and participants with CP had increasing torque values as stretching velocity increased, but participants with CP had a greater increase. Peak torque during extension (Figure 2, upper right) had no significant interactions to change of stretching velocity between the two groups of participants, but did display a significant linear trend by passive stretching velocity ($p < .05$).**.**

Table 1

Participant Characteristics by Group with Means and Standard Deviation (SD)

Group	Subject Number	Height (m)	Body Mass (kg)	Age (yrs)	Sex	MACS
1	1	1.6	50.0	12	Female	3
1	2	1.5	50.0	17	Female	3
1	3	1.5	53.2	15	Male	3
1	4	1.6	45.5	18	Male	5
1	5	1.6	101.8	13	Female	4
1	6	1.5	42.3	15	Female	4
Mean		1.6	57.1	15.0		3.7
SD		0.1	22.2	2.3		0.8
2	1	1.7	43.6	13	Female	0
2	2	1.5	42.7	13	Female	0
2	3	1.6	52.3	13	Male	0
2	4	1.6	47.7	15	Female	0
2	5	1.9	77.3	15	Male	0
2	6	1.6	56.8	16	Female	0
Mean		1.6	53.4	14.2		0
SD		0.1	12.8	1.3		0

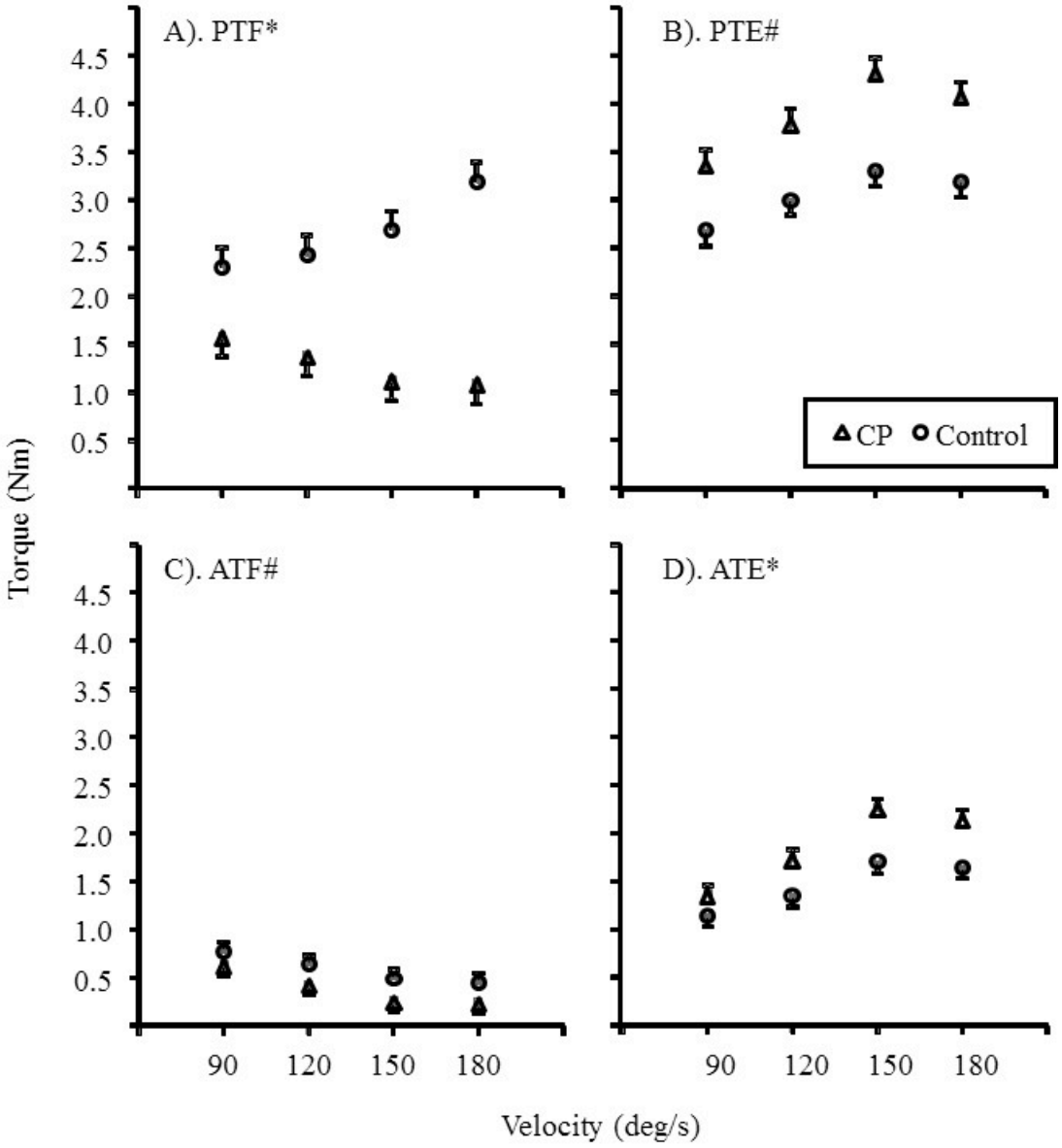

Figure 2. Significant groups X speed interactions observed for PTF* and ATE*, where ATF decreased and PTE increased with stretching speed at a linear fashion without group difference.

CHAPTER 4

DISCUSSION

The purpose of this study was to investigate levels of passive joint torque between individuals with severe CP at different stretching speeds to determine the capability of using dynamometry to assess spasticity at the elbow joint. This study has shown that spasticity can be measured by resistance to passive stretching of the upper extremity in young people with CP. Resistance was quantified using peak and average torque at constant speeds. In using an isokinetic dynamometer, we were able to stretch a group of muscles at a constant and consistent speed, which was needed to reliably measure resistance. Due to the Biodex operating system, we were able to remove the gravity effect since limb weight was calibrated for each trial, therefore showing only pure muscle torque during constant speeds. These passive stretching tests were precise and easy to perform in a clinical setting. This testing method is suitable for individuals of varying ages.

Our results show that control participants tended to have an increasing trend of resistance as speed increased in all conditions except for average torque collected during passive stretching of the elbow flexors. Participants with CP exhibited a trend in which torque values decreased as speed increased during passive stretching of the flexors and torque values increased as speed increased during passive stretching of the extensors. Hypertonia appeared to be more severe at lower speeds and less severe at higher speeds for participants with CP during passive stretching of the elbow flexors. In our results, we did not observe a significant interference of hypertonia with hyper-reflexia. According to

other literature (Patten et al., 2013), higher levels of hyper-reflexia should be seen at higher speeds. Therefore, our results do not support the hypothesis that peak and average torque in both elbow flexion and extension will increase as stretching speed increases in all participants in a linear fashion as observed when Engsberg, Ross, Olree, and Park (2000) compared spasticity in the lower extremity among youth with CP and age-matched controls. We observed varying levels of torque resistance at different speeds among young people with CP.

Any resistive torque observed during a passive elbow extension stretching should be observed in the biceps from the elbow flexors. That is not always the case due to agonist or antagonist muscle group spasms. The underlying mechanisms responsible for the stretch reflex could provide insight into our observations. Both average and peak torque could have been influenced by any of part of the 3-component model of stretch reflex. The underlying causes for spastic contractures in individuals with CP is very complex and no theory has provided enough evidence to be definitive (Wiart et al., 2008). It is assumed that the mechanism of spastic muscle contractions can be attributed to the reduction in number of in-series sarcomeres, muscle fiber atrophy, and the reduction of in-parallel sarcomeres (Mohagheghi et al., 2007, Shortland et al., 2002, Tardieu et al., 1982, Wiart et al., 2008).

Another potential explanation is the strength difference and overall torque production capabilities among young people with CP and control participants. Young people with CP are much weaker and have less muscle tone than typically developing children. The control group produced higher resistive torque values, especially at higher speeds opposed to participants with CP. This could explain differences in torque

magnitude seen; controls will be able to produce higher resistive torques or will be able to produce a great stretch reflex due to their greater muscle tone. Moreau et al. (2008) had young people with CP and age-matched controls perform fatigue tests and observed that the maximum peak torque values obtained during the beginning of the test were 50% lower among young people with CP compared to control participants.

In a healthy individual, a stretch reflex is the rapid response to an unexpected increase in length or speed (Enoka, 2008). There are two components of this reflex, short-latency response to increases in speed and long-latency response to increases in muscle length. In young people with CP, the long-latency response to changes in length is usually effected (Hallet et al., 1994). Our data shows that the long-latency stretch response is being activated after constant speed has ceased. Due to that observation and the abnormal long-latency response in young people with CP, our peak and average torque values during constant speed may not be associated with a full stretch reflex, but are in fact showing the resistive torque produced by spastic muscle contractures. The muscle contractures may be responsible for the majority of the discrepancies seen in the peak and average torque during an individual's trial of constant speed. Spastic muscle contractures happen quickly, whereby the peak is somewhat high, but the average torque is low due to less muscle activity and reduced muscle tone in young people with CP. The peak torque of the muscle contracture, in most cases, will be of a lesser magnitude than the peak torque produced by a normal stretch reflex in a healthy control due to the weakness and atrophied muscle tone of a young person with CP as Moreau et al. (2008) previously observed.

Torque measurements are frequently used and are straightforward to obtain.

Condliffe, Clark, and Patten (2005) calculated average torque over a 100ms window centered at a fixed position and observed increases in torque as speed increased among participants with post-stroke hemiparesis. About two-thirds of individuals post-stroke experience the same type of spastic hypertonia as children with CP (Condliffe et al., 2005). Those results are similar to our observations with participants with CP who have higher with more severe symptoms therefore have more spasticity. Unlike their methodology, we were able to identify torque values during constant speed and find the average during that period. The time periods of constant speed were different for each participant due to the hypertonic nature of spastic CP where they could not maintain constant speed as long as other or as long as the control participants which was also observed in Gordon et al. (2006). Outside of constant speed periods, higher resistance torque values were observed. Lebiedowska et al. (2004) observed resistance torque values during slow, passive flexion and saw a significant increase in torque at the beginning of motion in participants with dystonia over those with spasticity.

Peak torque has long been seen as the ideal measure of strength among young people with CP. Damiano, Martellotta, Quinlivan, and Abel (2001) explained that peak torque allowed the observation of isokinetic eccentric voluntary force production. For the purpose of our study, peak torque was important in determining the peak resistive value through a passive range of motion at different speeds.

Since we observed hypertonia as being more severe at low speeds and less severe at high speeds, we can conclude that therapeutics to improve strength and flexibility among individuals with spastic CP be done at the highest possible stretching speed. This is consistent with a previous study by Moreau, Holthaus, and Marlow (2013). More

research should be conducted, especially to confirm that stretching at faster speeds for young people with CP may be advantageous due to our observations of less passive resistance at higher speeds which can lead to better training of the agonist muscles.

Another important implication of this study is the presentation of quantitative and objective data. Clinical tools such as the Ashworth Scale provide important categorical measures of spasticity, but specific torque values at various speeds can be used to better measure changes in spasticity over time. Quantitative data can also be used to identify eligible populations for research studies, deliver therapeutic interventions in clinical setting, and establish the efficacy of medical treatments (Gordon et al., 2006).

As with all small, pilot studies, our study had multiple limitations. We did not randomize the speed between trials and participants like Condliffe et al. (2005) did, but we had our participants focus on something other than their arm passively moving so they were unaware of the stretching speed at which the dynamometer arm was moving. However, due to the repeated stretching, non-randomization, and fewer and shorter rest periods, we possibly have desensitized the high-sensitivity stretch reflex in this population. With that knowledge, we can apply this to training modalities and potentially overcome the stretch reflex with repetitive stretching at higher speeds.

CHAPTER 5

CONCLUSION

Despite the small number of participants, our observations indicate that young people with severe, spastic CP exhibit different joint torque values at different speeds. The underlying causes of hypertonia are still complex, but a better understanding of the relationship between resistive torque at different speeds and an objective measure of spasticity can build a foundation for more research and improvements in rehabilitation techniques. A more effective rehabilitation plan can be based off the observations in this study. More resistive torque occurred at slower stretching speeds for young people with lower upper extremity function and severe spasticity. For children at higher levels on the MACS, higher speeds appeared to provide less of a hypertonic response, which suggests that power training can be done at faster speeds in order to see improvements. This also suggests that power training may be more advantageous for this population opposed to strength training. Increasing stretching speed in children with hypertonia can provide fewer spastic muscle contractions while improving muscle strength.

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APPENDIX A

IRB PROPOSAL

Personnel. Please list any individuals who will be participating in the research beyond the PI and advisor. Also please detail the experience, level of involvement in the process and the access to information that each may have.

Principal Investigator: Alexis Carnes

Graduate Student

School of Health and Kinesiology

Involvement in all phases of the study

Co-Investigator: Dr. Li Li

Research Professor

School of Health and Kinesiology

Experience: Expert in Biomechanics and electromyography. Has been involved in research project, funding, and publications that focused on the movement characteristics of people with Cerebral Palsy.

Level of Involvement: Involvement of all phases of the study

Access to Information: Full access to information obtained

during the project.

Co-Investigator: Dr. Gavin Colquitt

Associate Professor

School of Health and Kinesiology

Certified Adapted Physical Educator

Certified Strength and Conditioning Specialist

Fellow, American Academy of Cerebral Palsy and Developmental Medicine

Experience conducting research in K-12 setting

Involvement in all phases of the study, primarily participant recruitment

Co-Investigator: Dr. Manuela Caciula

Assistant Professor

School of Heath and Kinesiology

AFAAGroup Exercise Certification

Expertise in conducting research in neurological disorders

Involvement in all phases of the study

Co-Investigator: Jordan Nourse

Undergraduate Student

School of Health and Kinesiology

Assist with data collection and processing

Purpose. 1. Briefly describe in one or two sentences the purpose of your research. 2. What questions are you trying to answer in this experiment? Please include your hypothesis in this section. The jurisdiction of the IRB requires that we ensure the appropriateness of research. It is unethical to put participants at risk without the possibility of sound scientific result. For this reason, you should be very clear on how participants and others will benefit from knowledge gained in this project.

1. Based on the literature, we believe that we can determine differences in hypertonia and hyperreflexia and identify the contributions of these underlying mechanics to spastic responses to movement. We will examine these differences and explore such

mechanisms by syncing Biodex and surface electromyography measures during functional testing in in the upper and lower extremity.

2. Based on the literature, we hypothesize:

    Primary hypothesis: After controlling for age and Gross Motor Function Classification System (GMFCs) level, we will be better able to determine the relationships and characteristics of spasticity with hypertonia and hyperreflexia during different velocities of passive stretching.

Literature Review. Provide a brief description of how this study fits into the current literature. Have the research procedures been used before? How were similar risks controlled for and documented in the literature? Have your instruments been validated with this audience? Include citations in the description. Do not include dissertation or thesis chapters.

Cerebral palsy (CP) is classified as a group of developmental disorders that limit movement and affect posture and is associated with Limitations in areas such as cognition, perception, and communication (Rosenbaum, 2007). Symptoms of CP include: ataxia, spasticity, weakness, toe-walking, “variations in muscle tone”, shaking, motor skill development delays, difficulty with fine movements (NINDS, 2016). Spastic cerebral palsy is the most common type of CP affecting 70-80% of all CP cases (Thanda, Soe, & Thaingi, 2016). Damage to the central nervous system affects the motor impairments that characterize CP one of which is Spasticity. Damage to central neuron pathways above T12 induces muscle weakness, contracture, and muscle over activity associated with spasticity (McGuire, 2016). Spasticity is caused by disruptions within motor neurons that result in a velocity

dependent stretch reflex that is ‘hyper-excited’ and is characterized by stiffness, cramping”, or spasms, (Brashear, 2015; Elovic, 2016; (Hughes & Howard, 2013; Rush & Kumbhare, 2015).

Stretching during passive movement at various speeds result in a spastic ‘catch’ during a particular range of motion (Levitt, 2010). These muscles experience hypertonia, where muscles are improperly activated or hyperreflexia where muscles reflexes are exaggerated. The contracture of muscles in spasticity are influenced by the functioning capabilities of the spinal neurons and motor subsystems along with the supraspinal and suprasegmental mechanisms where the tendon compliance alters, muscle fibers change and affect the functionality of muscles, and the spinal reflexes that regulate the excitability of a muscle lose the ability to inhibit causing hyperexcitability in the muscles (Mukherjee & Chakravarty, 2010). Furthermore, the effects of supraspinal and spinal mechanisms result in a loss of normal functioning motor units which in turn causes a decline in motor neuron firing rate and muscle contraction efficiency (Thibaut et al., 2013).

The underlying mechanisms of hypertonia and hyperreflexia are complex and the specific contribution of each mechanism to spastic response to passive movement is unknown. Therefore, we will employ a modified version of Patten et al.’s measurement battery, employing a non-invasive methodology using surface electromyography (sEMG) and dynamometry to examine underlying mechanisms related to spasticity, including hypertonia and hyperreflexia (2013). The faculty involved in this study have previously conducted two studies examining the effects of power training on individuals with CP. The purpose of this study is mechanistic in

nature and will seek to elucidate these underlying mechanisms through a similar testing protocol developed by the faculty advisor.

Participants with CP will engage in two passive and dynamic functional testing sessions and healthy aged-matched controls will participate in one testing session. These will occur in the Biomechanics lab at Georgia Southern University.

Outcome. Please state what results you expect to achieve? Who will benefit from this study? How will the participants benefit (if at all). Remember that the participants do not necessarily have to benefit directly. The results of your study may have broadly stated outcomes for a large number of people or society in general.

After controlling for age and Gross Motor Function Classification System (GMFCs) level, we hypothesize there will be a decrease in spasticity levels of individuals with CP after passive and high velocity knee and elbow extension. To determine a decrease in spasticity, we also hypothesize that there will be a relationship between hypertonia and hyperreflexia and a clear depiction of the onset during passive knee and elbow extensions at multiple velocities. This study has to potential to provide additional evidence to support therapies that involve higher velocities and inform clinical practice in the fields of occupational and physical therapy.

Describe your subjects. Give number of participants, approximate ages, gender requirements (if any).

Describe how they will be recruited, how data will be collected (i.e., will names or social security numbers be collected, or will there be any other identification process used that might jeopardize confidentiality?), and/or describe any inducement (payment, etc.) that will be used to recruit subjects. Please use this section to justify how limits and

inclusions to the population are going to be used and how they might affect the result (in general).

30 youth or adults (7 - 21) with cerebral palsy, 30 youth or adults (age-matched) without cerebral palsy or any other neurological disorders

Gender requirements – none

Inclusion/Exclusion Criteria

The following selection criteria are based on similar research on the strength, functional capacity, and physical activity of individuals with CP. Individuals with CP will be included if they are a) between the ages of 7 and 21 years old, b) within levels I through III of the Gross Motor Classification System (GMFCS; see attached), c) cleared by a medical professional for physical activity, and d) able perform coordinated tasks of daily living with one lower and upper limb. The diagnosis of CP will be accepted from the student's individualized education program (IEP) document.

Recruitment

Dr. Colquitt has established strong relationships with the Bulloch County School District (BCSD) and B&B Care Services who also support this study (see attached letters of support). He has assisted in planning and implementing school-based health fairs, supervising adapted physical education programming, and has currently collaborated with Statesboro High School to provide comprehensive health education to students with disabilities beginning in the spring of 2013. He will work with Don Garrick, Adapted Physical Education Teacher in the BCSD, Tina Rigdon, Physical Therapist in the BCSD, and Pauline Shaw, Family Support Coordinator for B&B Care Services. Mr. Garrick, Mrs. Rigdon, and Mrs. Shaw will contact potential participants and provide an overview

of the study. If interested and providing permission for contact, either Mr. Garrick, Mrs. Rigdon, or Mrs. Shaw will forward their contact information to the research team.

Each family will be compensated $50 each time they come to campus for data collection. Paying families $50 for each data collection session will increase participation dramatically, reduce attrition, and compensate them for their time and transportation. Many potential participants are of low socioeconomic status and/or live in remote, rural areas in the Bulloch County, making transportation difficult. An incentive of $50 will cover all potential costs and promote attendance to data collection. The last four digits of the recipient's social security number will be collected as well as the last four digits of the gift card during both data collection periods in the biomechanics laboratory at GSU. Numbers will be entered into the Human Subject Payment Control log and kept separate from all other data.

Research Procedures and Timeline: Enumerate specifically what will you be doing in this study, what kind of experimental manipulations you will use, what kinds of questions or recording of behavior you will use. Focus on the interactions you will have with the human subjects. (Where applicable, attach a questionnaire, focus group outline, interview question set, etc.) Describe in detail any physical procedures you may be performing. Hypertonia and hyperreflexia responses will be elicited using passive elbow and knee extensions applied using a dynamometer. Surface EMG will be recorded from the brachioradialis, biceps brachii, triceps brachii muscles, vastus lateralis, vastus medialis, and rectus femoris using pre-amplified electrodes. A surface EMG will also be placed on the wrist and the ankle to act as a position gathering sensor. Acceleration and surface EMG signals will be sampled from a wireless EMG system with acceleration sensors

embedded in the EMG electrodes. Elbow joint and knee joint angle and torque signals will be sampled from the dynamometer. Raw EMG, acceleration, position, and torque data from the same trial will be exported and merged into one data file and synchronized based the onset of the movement detected from the acceleration and position data.

For each test session, participants will be seated in the dynamometer chair with the back angled at 85º, the trunk stabilized using waist and trunk straps, and the feet supported using the leg rest. The testing arm will be positioned with the shoulder in 0º abduction, and 0º flexion with the lateral epicondyle of the humerus aligned with the dynamometer rotational axis. The testing leg will be positioned with the knee in 0º abduction, 0º flexion with the lateral epicondyle of the femur aligned with the dynamometer rotational axis. Passive elbow and knee extensions will cover the participant's full anatomical available range of motion. The anatomical position will be determined using a handheld goniometer and reported in degrees of elbow and knee flexion (i.e., full extension = 0º). Anatomical angles will be used to report subject-specific joint angles for the onset of hypertonia and hyperreflexia activity.

Velocity-dependent hypertonia and hyperreflexia responses will be tested by operating the dynamometer in passive mode. Each trial will have four phases: i) 10 second static hold in elbow and knee flexion; ii) passive elbow and knee extension at criterion speed; iii) 5 second static hold in full extension; iv) passive return to elbow and knee flexion at 30º/s. During all movement phases, participants will be instructed to relax as the limb was moved through the full range of elbow and knee motion by the dynamometer. Torque, position, acceleration, and EMG data will be collected before and during passive elbow and knee extension stretches. Passive stretches will be delivered at seven criterion

speeds (i.e., 5,10, 30, 60, 90, 120, and 180º/s). After every third trial the test speed will be incremented by 30º/s to obtain three trials at each criterion. Two additional trials were obtained at 10º/s to quantify passive joint torques.

Data Analysis: Briefly describe how you will analyze and report the collected data. Include an explanation of how will the data be maintained after the study is complete and anticipated destruction date or method used to render it anonymous for future use.

All data collection will take place in the Human Performance and Biomechanics Laboratories at Georgia Southern University. The data collected will be pulled from the Delsys EMG and Biodex systems. A macro in excel written by Dr. Li Li will run the EMG and torque data in a synchronization. A MANCOVA will be employed to analyze relationships between torque, position, acceleration, and EMG response between subjects treating functional classification as a covariate.

Risk. Is there greater than minimal risk from physical, mental or social discomfort? Describe the risks and the steps taken to minimize them. Justify the risk undertaken by outlining any benefits that might result from the study, both on a participant and societal level. Even minor discomfort in answering questions on a survey may pose some risk to subjects. Carefully consider how the subjects will react and address ANY potential risks. Do not simply state that no risk exists, until you have carefully examined possible subject reactions.

Functional tests using dynamometer involve potential risks associated with the exercise. These include dizziness, shortness of breath, increased blood pressure and heart rate, and muscle soreness. Every effort will be made to minimize these risks by having the PI and Co-PIs evaluate preliminary health information prior to testing. Additionally,

each participant must obtain physician's clearance before enrolling in the study. Furthermore, all testing sessions will be monitored closely by qualified professionals to minimize injury risk. Dr. Colquitt is a certified strength and conditioning specialist, and Dr. Li has years of experience conducting functional testing in this population.

Additionally, functioning testing using dynamometry are common examinations in clinics and during research. These tests pose minimum risk to the participant's muscular system. The passive testing period can serve as warm up sessions for the active muscle contraction that followed. Warm up has the effect of reduce the potential of short term muscle soreness. To further reduce the effect of exhaustion and potential muscle sourness, the participant will be instructed to rest and drink plenty of fluid after each of the testing session.

In the event of emergency, the activation of an emergency response will be initiated by dialing 911.

Data Storage and Security: All data will be collected and held under confidentiality by the PI and Co-PIs, with numerical coding to identify participants objectively. Participants' names, addresses, telephone numbers, and email addresses will be recorded in order to contract participants to remind them of their scheduled appointments. All participants will be given an ID number that has no relationship to their recorded identifiers. All participant-related material and data will be held confidential and stored in the PI or Co-PIs database. Databases will be stored on the PI and Co-PI's password protected computers for a period of three years. At which time, assuming data are no longer needed for grant writing and publication efforts; data will be deleted permanently from both computers. Only qualified research personnel and Georgia Southern University

Institutional Review Board (IRB) will have access to the database containing study information. All study data that are entered into statistical analyses and publication reports will refer to group mean data. No individual or group, other than the research team, will be given information unless specifically requested by the IRB. All primary data sources will be kept in the locked file cabinet located in the PI's office.

Special Conditions:

Research involving minors. Describe how the details of your study will be communicated to parents/guardians. If part of an in-school study (elementary, middle, or high school), describe how permission will be obtained from school officials/teachers, and indicate whether the study will be a part of the normal curriculum/school process. Please provide both *parental consent* letters and *child assent* letters (or processes for children too young to read).

Bulloch County School District (BCSD) personnel will contact the parent/guardians of potential participants. Those parents/guardians who express interest will provide consent to BCSD personnel to forward personal contact information to the research team. The research team will arrange a time to meet with the potential participants and parents (if minors) to provide an overview of the study. Participants who agree to participate and whose parents provide consent (if minors) will be enrolled in the study. Parents will provide letters of informed consent. Minor participants will be given an assent letter to be signed and to be read aloud if necessary.

Deception. Describe the deception and how the subject will be debriefed. Briefly address the rationale for using deception. Be sure to review the *deception disclaimer*

language required in the informed consent. **Note:** All research in which deception will be used is required to be reviewed by the full Board.

None.

Medical procedures. Describe your procedures, including safeguards. If appropriate, briefly describe the necessity for employing a medical procedure in this study. Be sure to review the *medical disclaimer* language required in the informed consent.

None.

Cover page checklist. Please provide additional information concerning these risk elements. If none, please state "none of the items listed on the cover page checklist apply." *Click here* to go to cover page for completion.

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Thibaut, A., Chatelle, C., Ziegler, E., Bruno, M.-A. l., Laureys, S., & Gosseries, O. (2013). Spasticity after stroke: Physiology, assessment and treatment. *Brain Inj., 27*(10), 1093-1105.

APPPENDIX B

CONSENT FORMS

COLLEGE: Health and Human Sciences
DEPARTMENT: Health & Kinesiology

MINOR ASSENT (to be read aloud if necessary)

Dear Student:

My name is Alexis Carnes and I am student studying the science of exercise at Georgia Southern University. I am doing research to look at the differences between young people with and without cerebral palsy (CP).

The tests to see how your muscles work and how strong you are will take about one hour to complete and will take place in a lab at Georgia Southern University.

You may feel dizzy, have trouble catching your breath, your heart may beat really fast, and your muscles may be sore. The tests in the lab will be given by people with lots of experience administering these tests to young people with CP. These tests pose minimum risk to your muscles. One of the tests could make you very tired and make your muscles sore for a little while. We will try to prevent this by doing another test first. The first test can serve as warm up sessions for the other tests that may make you tired or sore. Warm up can keep your muscles from getting sore. To keep you from getting really tired or sore, we will remind you to rest and drink plenty of fluids after each of the testing

session.

In order to be sure no one sees your information, a number and not a name will appear in place of your information. All the information will be stored a password-protected computer at Georgia Southern University for a period of three years. After three years, all the information will be deleted permanently from the computers.

You can ask questions of me at any time and if your or your parents have any questions or concerns, please call me at (912) 478-0889. You do not have to participate in this research and may end your participation at any time by telling the individual collecting the data. You do not have to answer any questions you do not want to answer. There is no penalty if you decide not to participate in the study. However, participants who drop out of at any stage of the study cannot reenter the study at any time.

People in the lab will help you to answer the following questions if needed. To contact someone where I work about this study, you may call the Office of Research Services and Sponsored Programs. You and your parents can also ask for answers to questions about your rights about answering my questions by emailing IRB@georgiasouthern.edu or calling call (912) 478-6545.

Your legal guardian will be compensated by a $50 gift card each time you come to Georgia Southern University for testing. Each family will be compensated $50 each time they come to campus for data collection. The $50 incentive will only be associated with trips to Georgia Southern University.

By signing on the line below, you are saying that you understand what you just read or what was read and explained to you.

You will be given a copy of this form to keep for your records. This project has been

reviewed and approved by the GSU Institutional Review Board under tracking number H1712**.**

Title of Project: *An Exploration of the Underlying Mechanisms Causing Spasticity among Young People with Cerebral Palsy*

Principal Investigator: Alexis Carnes, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460, ac05656@georgiasouthern.edu, 770-883-2814.

Other Investigator(s):

Dr. Li Li, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460, lili@georgiasouthern.edu, 912-478-8015

_____

Minor Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

_____

Investigator Signature Date

COLLEGE: Health and Human Sciences
DEPARTMENT: Health & Kinesiology

ADULT INFORMED CONSENT

Dear Sir or Madam:

My name is Alexis Carnes and I am second year Exercise Science Master's student at Georgia Southern University. Here at GSU, where I received my undergraduate degree in Kinesiology, I have been an anatomy and physiology lab instructor and currently serve as a research assistant. Under the supervision of my thesis advisor, Dr. Li Li, I am conducting a study for my Master's Thesis, which will examine the relationship between hypertonia and hyperreflexia in young people with cerebral palsy (CP) in Bulloch County.

I am asking for your permission to participate in this study. Participation in this research will include non-invasive tests in laboratories at Georgia Southern University. These tests will examine some of your the functional capacities. You will participate in 1-2 testing sessions.

All testing sessions will be monitored closely by qualified professionals to minimize injury risk. Functional tests using a dynamometer are common examinations in clinics and during research, which pose minimum risk to your muscular system. These include dizziness, shortness of breath, increased blood pressure and heart rate, and muscle soreness. Every effort will be made to minimize these risks by having the PI and Co-PIs

evaluate preliminary health information prior to testing. Additionally, each participant must obtain physician's clearance before enrolling in the study. To further reduce the effect of exhaustion and potential muscle soreness, you will be instructed to rest and drink plenty of fluids after each of the testing sessions.

The study will further the line of inquiry for effective physical rehabilitation programs to overcome muscle spasticity for individuals with cerebral palsy and possibly improve the practice of occupational and physical therapists.

All data will be collected and held under confidentiality by the PI and Co-PIs, with numerical coding to identify participants objectively. Your name, address, telephone numbers, and email address will be recorded in order to contract you to remind you of your scheduled testing appointments. You will be given an ID number that has no relationship to your recorded identifiers. All material and data related to your participation in this study will be held confidential and stored in the PI or Co-PIs database. Data will be coded and your personal data will not be linked to any database. Databases will be stored on the PI and Co-PI's password protected computers for a period of three years. At which time, assuming data are no longer needed for grant writing and publication efforts; data will be deleted permanently from both computers. Only qualified research personnel and Georgia Southern University Institutional Review Board (IRB) will have access to the database containing study information. All study data that are entered into statistical analyses and publication reports will refer to group mean data. No individual or group, other than the research team, will be given information unless specifically requested by the IRB. All primary data sources will be kept in the locked file cabinet located in the PI's office.

You have the right to ask questions and have those questions answered. If you have any questions or concerns regarding this study at any time, please feel free to contact Alexis Carnes (770) 883-2814 or Dr. Li Li (912) 478-8015.

To contact the Office of Research Services and Sponsored Programs for answers to questions about the rights of research participants please email IRB@georgiasouthern.edu or call (912) 478-6545.

You will be compensated by a $50 gift card each time you come to campus for data collection. The $50 incentive will only be associated with trips to Georgia Southern University.

You do not have to participate in this research and may end your participation at any time by telling the individual collecting the data. You do not have to answer any questions you do not want to answer. There is no penalty if you decide not to participate in the study. However, participants who drop out of at any stage of the study cannot reenter the study at any time.

Please note that you do not have to sign this Authorization, but if you do not, you may not participate in this research study.

Please note that you may change your mind and revoke (take back) this Authorization at any time. Even if you revoke this Authorization, my colleagues and I may still use or disclose health information they already have obtained about you as necessary to maintain the integrity or reliability of the current research. To revoke this Authorization, you must write to: Alexis Carnes, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460

This Authorization does not have an expiration date.

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number H1712**.**

Title of Project: *An Exploration of the Underlying Mechanisms Causing Spasticity among Young People with Cerebral Palsy*

Principal Investigator: Alexis Carnes, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460, ac05656@georgiasouthern.edu, 770-883-2814

Other Investigator(s):

Dr. Li Li, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460, lili@georgiasouthern.edu, 912-478-8015

_____

Participant Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

_____

Investigator Signature Date

COLLEGE: Health and Human Sciences
DEPARTMENT: Health & Kinesiology

PARENT INFORMED CONSENT

Dear Parent or Guardian:

My name is Alexis Carnes and I am second year Exercise Science Master's student at Georgia Southern University. Here at GSU, where I received my undergraduate degree in Kinesiology, I have been an anatomy and physiology lab instructor and currently serve as a research assistant. Under the supervision of my thesis advisor, Dr. Li Li, I am conducting a study for my Master's Thesis which will examine the relationship between hypertonia and hyperreflexia in young people with cerebral palsy (CP) in Bulloch County.

I am asking for permission for your child to participate in this study. Participation in this research will include non-invasive tests in laboratories at Georgia Southern University. These tests will examine some of the functional capacities of your child. Your child will participate in one to two testing sessions.

All testing sessions will be monitored closely by qualified professionals to minimize injury risk. Functional tests using a dynamometer are common examinations in clinics and during research, which pose minimum risk to your child's muscular system. These include dizziness, shortness of breath, increased blood pressure and heart rate, and muscle soreness. Every effort will be made to minimize these risks by having the PI and

Co-PIs evaluate preliminary health information prior to testing. Additionally, each participant must obtain physician's clearance before enrolling in the study. To further reduce the effect of exhaustion and potential muscle soreness, your child will be instructed to rest and drink plenty of fluids after each of the testing sessions.

The study will further the line of inquiry for effective physical rehabilitation programs to overcome muscle spasticity for individuals with cerebral palsy and possibly improve the practice of occupational and physical therapists.

All data will be collected and held under confidentiality by the PI and Co-PIs, with numerical coding to identify participants objectively. You and your child's names, addresses, telephone numbers, and email addresses will be recorded in order to contract you to remind you of your scheduled testing appointments. You and your child will be given an ID number that has no relationship to your recorded identifiers. All material and data related to your participation in this study will be held confidential and stored in the PI or Co-PIs database. Data will be coded and your personal data will not be linked to any database. Databases will be stored on the PI and Co-PI's password protected computers for a period of three years. At which time, assuming data are no longer needed for grant writing and publication efforts; data will be deleted permanently from both computers. Only qualified research personnel and Georgia Southern University Institutional Review Board (IRB) will have access to the database containing study information. All study data that are entered into statistical analyses and publication reports will refer to group mean data. No individual or group, other than the research team, will be given information unless specifically requested by the IRB. All primary data sources will be kept in the locked file cabinet located in the PI's office.

You and your child have the right to ask questions and have those questions answered. If you have any questions or concerns regarding this study at any time, please feel free to contact Alexis Carnes (770) 883-2814 or Dr. Li Li (912) 478-8015.

To contact the Office of Research Services and Sponsored Programs for answers to questions about the rights of research participants please email IRB@georgiasouthern.edu or call (912) 478-6545.

Each family will be compensated by a $50 gift card each time they come to campus for data collection. The $50 incentive will only be associated with trips to Georgia Southern University.

Your child does not have to participate in this research and may end their participation at any time by telling the individual collecting the data. There is no penalty for your child for deciding not to participate in the study. However, participants who drop out of at any stage of the study cannot reenter the study at any time.

Please note that you do not have to sign this Authorization, but if you do not, you may not participate in this research study.

Please note that you may change your mind and revoke (take back) this Authorization at any time. Even if you revoke this Authorization, my colleagues and I may still use or disclose health information they already have obtained about you as necessary to maintain the integrity or reliability of the current research. To revoke this Authorization, you must write to: Alexis Carnes, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460

This Authorization does not have an expiration date.

I am asking your permission for your child to participate in this study, and will provide

him/her with a simplified "assent" letter/verbal description before enrolling them in this study.

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number H1712**.**

Title of Project: *An Exploration of the Underlying Mechanisms Causing Spasticity among Young People with Cerebral Palsy*

Principal Investigator: Alexis Carnes, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460, ac05656@georgiasouthern.edu, 770-883-2814

Other Investigator(s):

Dr. Li Li, Georgia Southern University, PO Box 8076, Statesboro, GA, 30460, lili@georgiasouthern.edu, 912-478-8015

_____

Participant Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

_____

Investigator Signature Date

APPPENDIX C

STATISTICS

Statistix 10.0 5/4/2017, 10:31:19 AM

Analysis of Variance Table for AET

Source	DF	SS	MS	F	P
Subject	5	36.529	7.3058	1.19	0.4274
GROUP	1	21.806	21.8061	3.55	0.1184
Error Subject*GROUP	5	30.755	6.1509		
Velocity	3	7.771	2.5904	2.26	0.1234
Error Subject*Velocity	15	17.194	1.1463		
GROUP*Velocity	3	0.637	0.2123	0.35	0.7871
Error Subject*GROUP*Velocity	15	9.000	0.6000		
Error	432	68.794	0.1592		
Total	479	192.486			

Grand Mean	0.5849
CV(Subject*GROUP)	424.03
CV(Subject*Velocity)	183.05
CV(Subject*GROUP*Velocity)	132.43
CV(Error)	68.23

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Polynomial Contrasts of AET by Velocity

Degree = 1, Linear Trend

Contrast	-0.2487	SS (Contrast)	7.4209
Scheffe's F	2.16	P (Scheffe's F)	0.1356
T-Statistic	-2.54	P (T-Statistic)	0.0224

SE (Contrast) 0.0977

Degree = 2, Quadradic Trend

Contrast	0.0458	SS (Contrast)	0.2518
Scheffe's F	0.07	P (Scheffe's F)	0.9734
T-Statistic	0.47	P (T-Statistic)	0.6460
SE (Contrast)	0.0977		

Degree = 3, Cubic Trend

Contrast	0.0287	SS (Contrast)	0.0986
Scheffe's F	0.03	P (Scheffe's F)	0.9932
T-Statistic	0.29	P (T-Statistic)	0.7734
SE (Contrast)	0.0977		

Error term used: Subject*Velocity, 15 DF

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Means of AET for Velocity

Velocity	**Mean**
90	0.7682
120	0.6368
150	0.4872
180	0.4474

Observations per Mean	120
Standard Error of a Mean	0.0977
Std Error (Diff of 2 Means)	0.1382

Error term used: Subject*Velocity, 15 DF

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Analysis of Variance Table for PET

Source	DF	SS	MS	F	P
Subject	5	61.891	12.378	1.54	0.3227
GROUP	1	226.810	226.810	28.29	0.0031
Error Subject*GROUP	5	40.090	8.018		
Velocity	3	4.614	1.538	0.67	0.5848
Error Subject*Velocity	15	34.549	2.303		
GROUP*Velocity	3	32.671	10.890	4.60	0.0178
Error Subject*GROUP*Velocity	15	35.504	2.367		
Error	432	344.832	0.798		
Total	479	780.961			

Grand Mean	1.9684
CV(Subject*GROUP)	143.85
CV(Subject*Velocity)	77.10
CV(Subject*GROUP*Velocity)	78.16
CV(Error)	45.39

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Tukey HSD All-Pairwise Comparisons Test of PET for GROUP*Velocity

GROUP	Velocity	Mean	Homogeneous Groups
2	180	3.1947	A
2	150	2.6886	AB
2	120	2.4333	ABC
2	90	2.3068	ABC
1	90	1.5680	BC
1	120	1.3646	BC
1	150	1.1139	C
1	180	1.0777	C

Comparisons of means for the same level of GROUP

Alpha	0.05	Standard Error for Comparison	0.2790
Critical Q Value	4.942	Critical Value for Comparison	0.9750

Error terms used: Subject*Velocity and Subject*GROUP*Velocity

Comparisons of means for the same level of Velocity

Alpha	0.05	Standard Error for Comparison	0.3549
Critical Q Value	5.812	Critical Value for Comparison	1.4588

Error terms used: Subject*GROUP and Subject*GROUP*Velocity

Comparisons of means for different levels of GROUP and Velocity

Alpha	0.05	Standard Error for Comparison	0.3535
Critical Q Value	5.820	Critical Value for Comparison	1.4545

Error terms used: Subject*GROUP and Subject*Velocity and Subject*GROUP*Velocity

There are 3 groups (A, B, etc.) in which the means are not significantly different from one another.

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Polynomial Contrasts of PET by Velocity

Degree = 1, Linear Trend

Contrast	0.1339	SS (Contrast)	2.1508
Scheffe's F	0.31	P (Scheffe's F)	0.8169
T-Statistic	0.97	P (T-Statistic)	0.3492
SE (Contrast)	0.1385		

Degree = 2, Quadradic Trend

Contrast	0.1367	SS (Contrast)	2.2421
Scheffe's F	0.32	P (Scheffe's F)	0.8076
T-Statistic	0.99	P (T-Statistic)	0.3395
SE (Contrast)	0.1385		

Degree = 3, Cubic Trend

Contrast	0.0429	SS (Contrast)	0.2213
Scheffe's F	0.03	P (Scheffe's F)	0.9920
T-Statistic	0.31	P (T-Statistic)	0.7609
SE (Contrast)	0.1385		

Error term used: Subject*Velocity, 15 DF

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Means of PET for GROUP*Velocity

GROUP	Velocity	Mean
1	90	1.5680
1	120	1.3646
1	150	1.1139

1	180	1.0777
2	90	2.3068
2	120	2.4333
2	150	2.6886
2	180	3.1947

Observations per Mean 60
Standard Error of a Mean 0.1986
Error term used: Subject*GROUP*Velocity, 15 DF

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Analysis of Variance Table for AFT

Source	DF	SS	MS	F	P
Subject	5	86.884	17.3769	0.55	0.7343
GROUP	1	76.408	76.4085	2.43	0.1797
Error Subject*GROUP	5	157.114	31.4228		
Velocity	3	24.125	8.0418	5.11	0.0124
Error Subject*Velocity	15	23.625	1.5750		
GROUP*Velocity	3	8.254	2.7514	1.42	0.2759
Error Subject*GROUP*Velocity	15	29.059	1.9373		
Error	432	235.284	0.5446		
Total	479	640.754			

Grand Mean	1.4574
CV(Subject*GROUP)	384.63
CV(Subject*Velocity)	86.11
CV(Subject*GROUP*Velocity)	95.50
CV(Error)	50.64

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Polynomial Contrasts of AFT by Velocity

Degree = 1, Linear Trend

Contrast	0.4106	SS (Contrast)	20.235
Scheffe's F	4.28	P (Scheffe's F)	0.0226
T-Statistic	3.58	P (T-Statistic)	0.0027
SE (Contrast)	0.1146		

Degree = 2, Quadradic Trend

Contrast	-0.1317	SS (Contrast)	2.0825
Scheffe's F	0.44	P (Scheffe's F)	0.7273
T-Statistic	-1.15	P (T-Statistic)	0.2682
SE (Contrast)	0.1146		

Degree = 3, Cubic Trend

Contrast	-0.1227	SS (Contrast)	1.8075
Scheffe's F	0.38	P (Scheffe's F)	0.7671
T-Statistic	-1.07	P (T-Statistic)	0.3010

SE (Contrast) 0.1146

Error term used: Subject*Velocity, 15 DF

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Means of AFT for Velocity

Velocity	**Mean**
90	1.1435
120	1.3491
150	1.6974
180	1.6396

Observations per Mean	120
Standard Error of a Mean	0.1146
Std Error (Diff of 2 Means)	0.1620

Error term used: Subject*Velocity, 15 DF

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Analysis of Variance Table for PFT

Source	DF	SS	MS	F	P
Subject	5	367.18	73.437	0.60	0.7081
GROUP	1	332.04	332.042	2.69	0.1616
Error Subject*GROUP	5	616.13	123.226		
Velocity	3	26.58	8.861	2.72	0.0813
Error Subject*Velocity	15	48.83	3.255		
GROUP*Velocity	3	7.24	2.414	0.65	0.5964
Error Subject*GROUP*Velocity	15	55.89	3.726		
Error	432	855.36	1.980		
Total	479	2309.26			

Grand Mean	3.0538
CV(Subject*GROUP)	363.51
CV(Subject*Velocity)	59.08
CV(Subject*GROUP*Velocity)	63.21
CV(Error)	46.08

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Polynomial Contrasts of PFT by Velocity

Degree = 1, Linear Trend

Contrast	0.4074	SS (Contrast)	19.921
Scheffe's F	2.04	P (Scheffe's F)	0.1515
T-Statistic	2.47	P (T-Statistic)	0.0258
SE (Contrast)	0.1647		

Degree = 2, Quadradic Trend

Contrast	-0.2175	SS (Contrast)	5.6747
Scheffe's F	0.58	P (Scheffe's F)	0.6365
T-Statistic	-1.32	P (T-Statistic)	0.2065
SE (Contrast)	0.1647		

Degree = 3, Cubic Trend

Contrast	-0.0907	SS (Contrast)	0.9868
Scheffe's F	0.10	P (Scheffe's F)	0.9582
T-Statistic	-0.55	P (T-Statistic)	0.5900

SE (Contrast) 0.1647

Error term used: Subject*Velocity, 15 DF

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Means of PFT for Velocity

Velocity	**Mean**
90	2.6920
120	3.0106
150	3.3144
180	3.1981

Observations per Mean 120
Standard Error of a Mean 0.1647
Std Error (Diff of 2 Means) 0.2329
Error term used: Subject*Velocity, 15 DF