HAND FUNCTION DEFICITS IN INDIVIDUALS WITH SPASTIC DIPLEGIA

by

David R. Clizbe

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Exercise Science

Spring 2011

HAND FUNCTION DEFICITS IN INDIVIDUALS WITH SPASTIC DIPLEGIA

by
David R. Clizbe

Approved: ____
Nancy Getchell, PhD.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: ____
Todd Royer, PhD.
Chair of the Department of Kinesiology and Applied Physiology

Approved: ____
Kathleen S. Matt, PhD.
Dean of the College of Health Sciences

Approved: ____
Charles G. Riordan, Ph.D.
Vice Provost for Graduate and Professional Education

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Nancy Getchell, whose guidance, patience, and support has been indispensable. I would also like to thank my committee, Dr. Slobodan Jaric, Dr. Christopher Knight, and Dr. Sam Lee. During my graduate career, my relationship with my committee members and advisor, in matters related to my thesis as well as other scholastic matters, has provided the means for an environment that strongly benefited me by providing me an education equal to what I had received in the classroom.

This thesis would not have been possible without the generous help of certain individuals to whom I also owe a great deal of gratitude. I would like to thank Dr. Paulo de Freitas and Mehmet Uygur, who lent their time and energy for my benefit during the preparation and implementation of this project. Additionally, I would like to give my thanks to Dr. Freeman Miller of A.I. DuPont Hospital for Children and United Cerebral Palsy of Delaware. These people gave their time to provide me with the knowledge and insight for the benefit of this study. I would also like to thank those who were participants in this study. It is because of them and others like them that we know what we do about cerebral palsy as well as other neurological conditions. Participation in research, while living with a condition that may make your life more difficult is admirable and not always easy. It is the only way that the future generations, similarly affected, will live healthier, fuller lives. Therefore, they deserve to be recognized.

On a more personal note, I would like to thank those who have supported me while I worked through this master's thesis. To Lindsay, my wife, your love, support, and understanding was the best that anyone could ask for. Thank you. To my brothers, both of whom live happily and productively with spastic diplegia, I want to thank you, not just for providing me with the inspiration for this study, but also for providing a great example of integrity and hard work that anyone could learn from. Finally, I would like to thank my parents. They have supported my academic efforts ever since I was young and always encouraged me to do my best. I would especially like to recognize my mother, who encouraged my brothers' participation in research throughout their lives, which indirectly introduced me to the world of medically related research. This involvement is something that has definitely had an influence on my perspective of science as well as my career. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Cerebral Palsy (CP) is a neurological condition caused by a non-progressive pre/perinatal lesion to brain that impedes one's motor behavior. Two positively correlated (Himmelmann, et al, 2006), commonly used methods to describe motor behavior in CP are the Gross Motor Function Classification System (GMFCS) (Palisano, et al, 1997) and the Bimanual Fine Motor Function (BFMF) scale (Himmelmann, et al, 2006). This raises questions on the origins of this poor performance in hand function as it pertains to individuals with the type of CP, spastic diplegia. It is a type of CP where spasticity does not significantly influence the hands.

Prior to this study, most of the study on hand function in individuals with CP focused on the subtype of CP, spastic hemiplegia (SH) (Hadders-Algra, et al, 1999; Hirschfeld, 2007; Steenbergen & Gordon, 2006). These studies suggest that dysfunction may be global in CP. This idea may explain possible hand function deficits in individuals with the SD.

Three tests were performed to investigate how SD affects hand function. There were 6 people in the SD group and 6 age/gender-matched individuals in a typically developing (TD) group with no neurological conditions. We used the Jebsen Taylor test to examine functional motor deficits in every day tasks. The SD group significantly differed from the TD group. The other two tasks, a task in the end task comfort (ETC) paradigm and a task measuring the coordination of grip forces were used to determine where this deficit might originate.

There were no group differences in performance of the ETC test. This suggested that anticipatory motor planning may not cause the deficits seen in the Jebsen Taylor test. However, repeated examination may yield more polarizing results. It still may be possible that motor planning deficits exist but they were unable to be described in this study.

Differences were found in variables indicating poor task performance and poor ability to modulate grip force relative to load force. There was excessive gripping and higher variability in hand force production. This may explain the deficit seen in the Jebsen Taylor test. This suggested that any deficits in hand function in people with SD might result from an inability to properly execute force sequencing.

Keywords: Cerebral Palsy, Spastic Diplegia, hand function, grip force load force modulation, Jebsen Taylor Test, End Task Comfort, non-spastic deficits

Chapter 1

INTRODUCTION

Cerebral palsy (CP) is a common neuromuscular condition characterized by a non-progressive lesion that has occurred at or near birth. The prevalence rate in the United States is currently estimated at 2.4 per 1000 people (Hirtz et al, 2007). CP typically results in abnormal muscle tone properties. Spastic diplegia (SD) is a specific classification of CP where the muscle tone properties are presented as spasticity and are located primarily in the legs. Despite there being comparably little spasticity in the hands, this group still has deficits in hand function (Himmelman et al, 2006). Hand function deficits could result in difficulty typing, carrying delicate objects, and having legible handwriting. These are examples of skills needed to allow efficient integration into the workplace. Deficits in these areas may result in the inability to fully participate in society, which can significantly influence a person's quality of life (Schenker et al, 2005).

To understand these types of deficits, more investigation into SD is needed. Currently, almost all of the studies dedicated to hand function in CP focus exclusively on spastic hemiplegia (SH). This type of CP is characterized by a predominantly unilateral distribution of spasticity and dysfunction caused by a unilateral lesion to the motor cortex (Miller, 2005). Many studies have looked at this group to compare the more involved limb with the less involved limb (Eliasson et al, 1995; Mustaarts et al, 2006) or comparing individuals with SH to typically developing (TD) individuals (Eliasson et al, 1995; Mustaarts et al, 2006; Rosenbaum et al, 1996). There has also been comparison to individuals with hemiparesis due to a stroke (Hirschfeld, 2007). These findings have indicated that the population with SH has specific deficits in fingertip force scaling during grasping tasks (Eliasson et al, 1995), motor planning to allow for task appropriate end task comfort (Mustaarts et al, 2006), and making appropriate postural adjustments in support of a task (Hirschfeld, 2007). Each of these deficits was not found in either the TD participants or the participants who have had a stroke. However since this was predominantly the only type of CP examined under these conditions, it is not known if these types of deficits are exclusive to SH or if they are a trait of CP in general.

A relationship exists between gross motor function and fine motor function in individuals with CP including SD (Himmelman et al, 2006). The deficits described in studies examining hand coordination in individuals with SH, reveal methodological considerations that can also be used to better understand any hand deficits found in individuals with SD. Fingertip force scaling, end task comfort decision-making, and postural adjustments are all related to anticipatory motor planning, and motor control. It is in these areas that non-spastic motor deficits were expected.

This study intends to quantify the hand function deficits exhibited by individuals with SD. The goal is to then, try to explain the cause of those deficits by having participants with SD perform hand function tasks similar to what had been used to quantify the non-spastic deficits found in participants with SH.

Specific Aim 1: Quantify the hand function deficit for people with spastic diplegia. This will be determined with a standardized hand function test known as the Jebsen Taylor Test, a timed test that involves a participant manipulating different common objects as quickly as possible. The faster the performance on the test the more a performance is correlated with proficient function in activities of daily living.

H1: The typically developing group (TD) will perform significantly faster at each subtest in the Jebsen Taylor Test than the spastic diplegia (SD) group

Specific Aims 2 and 3 are designed to explain the cause of any deficits that might be found in the application of Specific Aim 1. If deficits are found the next two aims are designed to determine the origin of the deficits. By using similar tasks previously done with individuals with SH, we will analyze the two of the main hierarchies of motor behavior, the motor control portion and the motor planning portion and determine their role in the deficit.

Specific Aim 2: Determine if hand function deficits in people with SD originate from deficits in cognitive aspects of motor behavior. To test this idea a procedure that analyzes anticipatory motor planning, a context based area of motor behavior, was used. It is based on the idea that successful motor planning will result in a phenomenon known as end task comfort. The End Task Comfort (ETC) paradigm is based on the idea that typically developing people will sacrifice initial task comfort for end task comfort which typically leaves the biomechanics of the system in a comfortable state and ready for another task. (Rosenbaum, van Heugten, & Caldwell, 1996)

H2: The TD group will sacrifice initial task comfort for end task comfort, during the task within the ETC paradigm, more frequently than the SD group.

Specific Aim 3: Determine if there are aspects of force coordination and control that quantify any hand function deficit in individuals with SD. This would possibly describe the cause of deficits specifically having to do with motor control aspects of motor behavior. This will be done by analyzing results from a device designed to measure the gripping force and loading force expressed whenever an object is grasped. The gripping force acts normal to an object's surface and creates the friction needed to prevent the object being held from falling out of grasp. The loading force is the force that acts tangentially to the surface on which the gripping force is being applied. This force is necessary to lift an object or move it in different directions. A balance between the grip force and load force is considered to be a healthy characteristic of the human nervous system. Different variables can help determine how proficient an individual is at a given task as well as how well that individual coordinates the grip force and the load force. These variables have indicated in differences in performance and technique in previous studies examining hand function in people with neurological conditions.

H3.1: Task performance variables such as coefficient of variation (CV), and root mean square error (RMSE), will be lower in the TD group than in the SD group.

H3.2: The coordination of grip force (GF) and load force (LF) as determined by the safety margin (GF/LF ratio), and gain (slope of the plot of GF vs. LF) will be better in the TD group than the SD group for all the tasks performed within this paradigm

Chapter 2

LITERATURE REVIEW

Introduction

Cerebral palsy (CP) is a neurological condition originating from a non-progressive lesion in the brain resulting from an injury occurring at or near the time of birth (Miller, 2005). Despite there being a great deal of research on some aspects of CP, there is a lot that can still be learned. A review of the scientific literature has revealed an insufficient definition of certain motor behavioral deficits in individuals with CP. The source of these deficits in skills pertaining to activities of daily living (ADL) are not yet understood and it is possible that learning more about them will give people living with CP access to a better life.

For example, people with CP have shown to have varying scores related to quality of life that are correlated with function. Individuals with CP who have shown higher scores pertaining to function have also shown to have higher self-reported and parent reported scores related to quality of life (Davis et al, 2008; Viehweger et al, 2008). This could be related to the fact that, in other studies, high correlations were found between function and education, social relationships, and lack of participation restrictions (Beckung & Hagberg, 2002; Wright et al, 2008). These findings are supported by another study showing that an increase in successful participation in mainstreamed schools was highly correlated with a decrease in neurological impairments related to CP (Shenker, Coster, & Parush, 2005). These facts show that improving function in people with neurological conditions such as CP will in fact provide a benefit to a person's life who is living with CP.

Like many neurological conditions, CP is a complex condition. Therefore understanding motor behavior resulting from it requires a thorough understanding of the condition itself. CP is an umbrella term for a set of neurological conditions caused by brain damage to the developing brain (Shevell, Majnemer, Morin, 2003). This damage takes place at or near the time of birth, so much of how it affects the brain, also affects how the brain develops from then on. It results in motor control deficits, irregularities in muscle tone, and can cause mild to severe dysfunction in different ADL. The cause of the brain damage can come from different etiologies, and, because brain damage can come in irregular patterns, the associated dysfunctions can also come in different varieties.

Beyond the general etiologies, we know little about the nature of motor deficiencies. That is to say, the majority of the research has involved only a very specific subtype of CP, spastic hemiplegia (SH). It is possible that the motor deficits seen with SH may also occur in other types of CP. After a review of the neurology and known motor behavior of CP and its subtypes, it should become clear that analyzing another subtype of CP, spastic diplegia (SD), could assist in accurately describing characteristics of functional motor deficits that individuals with CP have.

Cerebral Palsy in General

The best way to understand the deficits a person with CP may experience is to first understand CP. As mentioned earlier, CP is an umbrella neurological condition stemming from damage to the brain at or near the time of birth that can result in motor dysfunction. This is not very specific and to properly interpret neuromuscular data a more specific understanding of the condition should be provided. Understanding how the injury takes place and the lesion patterns created by the injury can clarify how the condition is presented in an individual's body and motor behavior that can be expressed. As the research will show, how much damage takes place in certain regions of the brain influences the amount and type of motor dysfunction seen peripherally.

One of the most influential characteristics of the damage causing CP is the timing of when it occurs. The lesion is only produced in the developing brain. After a few months of development in the term-born infant, the window allowing for damage to cause CP begins to close (Kulak et al, 2006; Shevell, Majnemer, & Morin, 2003). Any other types of injury to the brain may result in the same symptoms as CP, such as spasticity and poor motor control, but the condition may not properly be classified as CP. At that point the condition would considered a non-progressive injury to the brain as a result of trauma of some kind. This difference in the environment of the injury may be subtle but may also be significant. For example, a stroke that results in hemiparesis, outside this time window, while even at a young age, is not hemiparetic CP and sometimes presents different traits (Ada et al, 2007).

There are several mechanisms that can cause the various types of lesion patterns that are categorized as CP. Some of the mechanisms would be considered more common in people with CP and typically resulting in common traits seen in CP, while others are not. These differences, as will be discussed later on, help classify the subtypes of CP. There can be a single or several etiologies for an individual with CP (Shevell, Majnemmer, & Morin, 2003). Each case for CP is very individualized and can vary from person to person, resulting in a neurologically heterogeneous population. Researchers must take careful consideration of this fact when making generalizations about the differences in function between the different subtypes of CP as well as when comparing individuals with CP with typically developing individuals.

The most common etiology is white matter irregularities from damage to oligodendrocyte progenitor cells (Riddle et al, 2006). This damage is often due to ischemia and depending on the circumstance can result in the neurological condition, periventricular leukomalacia (PVL) (Riddle et al, 2006) or periventricular gliosis (PVG) (Krageloh-Mann, 2007). According to a bovine model, these conditions are usually a result of lowered basal blood flow to the periventricular area of the motor cortex during the time period between 24 and 28 weeks gestation (Riddle et al, 2006).

When blood flow to the brain is lowered globally it significantly affects this region, denying it necessary blood supply to support the tissue. After at least 30 minutes of ischemia there is damage to the oligodendrocyte progenitor cells and with prolonged ischemia the individual will be more significantly affected. Once the brain has been experiencing this type of ischemia for 45 minutes, extensive damage has taken place resulting in grey matter damage that could affect the cortical pathways, the basal ganglia, thalamus, or the cerebellum (Riddle et al, 2006).

While it is one of the best understood etiologies of CP, the cause of CP is not restricted simply to ischemic circumstances. The one constant is damage to the brain that significantly affects the health of the nervous tissue enough to result in, among other things, motor impairment. It is not unusual to see CP also come as a result of a specifically vascular condition such as a prenatal hemorrhage or a stroke (Shevell, Majnemer, & Morin, 2003; Takanashi et al, 2005). This type of damage would result in a pattern more specific to the individual and its severity would also depend on the individual circumstance, so information on the subtype of CP resulting from a situation like this can be difficult to generalize to other subtypes of CP. This is true of other causes of CP. These include but may not be limited to cerebral dysgenesis and neural damage due to exposure to toxins (Shevell, Majnemer, & Morin, 2003). This heterogeneity may also result in comorbid conditions less characteristic of CP. Examples of comorbid conditions are varying degrees of learning disabilities, epilepsy, visual and hearing difficulties, and sensory deficits (Pirila et al, 2007; Himmelman et al, 2006; Beckung & Hagberg, 2002)

Several general characteristics of CP exist. The commonality between them is that the condition affects the motor system. There are three major classifications of CP: spastic, athetoid, and ataxic (there are other classifications however, they involve a very intricate understandings of the movement disorders presented. This narrows the discussion to the most basic types of CP to present the best description of the condition). Each one is classified by the way that its most prominent traits affect the motor system. Spastic CP is noted by hypertonia exhibited in the muscles of the regions that correlate with the affected areas of the brain (Miller, 2005). Hypertonia is best described by excessive muscle tone, and, in the case of CP, comes from an excess in excitatory stimulus from the upper motor system in the central nervous system and is often referred to in this situation as spasticity (Granata, Ikeda, & Abel, 2000). Athetoid CP is noted by significant deficits in motor control characterized by dyskinesia, involuntary movement, and a variety of presentations of muscle tone, either hyper or hypo tonic (Miller, 2005). Finally, ataxic CP is noted by significant difficulties in coordination (Miller, 2005)

These different classification subtypes of CP very often refer to specific areas of neurological damage, however, something to consider for any individual who has experienced significant brain damage is that this damage could present itself in ways that do not stick to classification standards. This is shown by the fact that many people with CP exhibit different subtypes of CP simultaneously, although this is not common for CP (Shevell, Majnemer, & Morin, 2003). For most individuals with CP their type and where it affects them can be correlated with where the condition affects the brain and often times the etiology causing it. The most common type of CP is spastic CP and is generally related to unilateral or bilateral damage to the periventricular area of the motor cortex (Shevell, Majnemer, & Morin, 2003). The athetoid type of CP has been related to more damage to thalamus and basal ganglia of the motor pathway (Miller, 2005). This type of damage was seen after excessive ischemia of an hour or more in the bovine model previously mentioned (Riddle et al 2006), but dysgenesis and other etiologies, such as toxins, have also been seen to contribute towards this type of CP (Shevell, Majnemer, & Morin, 2003). Also, ataxic CP can be caused by those particular etiologies (Shevell, Majnemer, & Morin, 2003), but location of the damage is specifically very different. Ataxic CP occurs after there is damage to the cerebellum resulting in coordination problems (Miller, 2005; Shevell, Majnemer, & Morin, 2003).

Athetoid and Ataxic CP generally affect the body globally and are not specific to a given area while spastic CP (SCP) is often further classified based on what parts of the body are affected. This description continues to correlate with the region of the brain affected. Just as damage to the brain can be unilateral or bilateral in nature so can be the expression of CP characteristics. When an individual is affected unilaterally, the hypertonicity or spasticity is generally only present unilaterally as well. When this occurs, the subtype of CP would be considered spastic hemiplegia (SH). Classification is similar when there is bilateral affectation as well. When spasticity generally only presents itself in the lower half of the body this is known as spastic diplegia (SD) and when it takes place in all four limbs it is spastic quadriplegia (SQ). Sometimes there is spasticity in other areas than these when this occurs in addition to the areas presented in SQ it may often be referred to as spastic tetraplegia (ST) (Krageloh-Mann, 2007).

It is important to consider the neurological causes of CP as well as to see the relationship between the brain and the body. CP may often be viewed as a neuromuscular condition, but the differences between the subtypes of CP originate in the brain. It is with this understanding that an investigator may generate insightful new hypotheses about the motor behavior and various functional deficits that an individual with CP has.

Motor Behavior in Individuals with Spastic Cerebral Palsy

One of the most difficult parts of doing research on CP is making representative conclusions by comparing and contrasting findings in previous studies. This is especially difficult because of the way it is defined, as an umbrella term for many different neurological conditions. The neurology that results in three subtypes previously mentioned is very heterogeneous and it may be much easier to draw conclusions if the focus was on the one that is the most neurologically consistent. Therefore the attention will be focused in on SCP. As summarized in Table 2.1, the most common causes of spastic types of CP are very similar and are mostly due to PVL or similar types of white matter damage while other types of CP are caused by less predictable means.

Table 2.1: Summary of top etiologies for the four most typically occurring subtypes of CP according to to Shevell, Majnemer, & Morin, 2003. In this case, Ataxic CP and what was referred to in this paper as Athetoid CP have been combined into one category.

ETIOLOGY	#1	#2	#3
SPASTIC QUADRIPLEGIA	Asphyxia (32.5%)	PVL (29.9%)	Dysgenesis (18.2)
SPASTIC HEMIPLEGIA	Vascular (26.5%)	PVL/Intracranial hemorrhage (14.7%)	Dysgenesis (13.2%)
SPASTIC DIPLEGIA	PVL (53.9%)	Intracranial hemorrgage (15.4%)	Asphyxia (12.8%)
MIXED	Asphyxia (50%)	Toxins (16.7%)	-
ATAXIC-HYPOTONIA	Dysgenesis (91.7%)	-	-

ETIOLOGY	#4	UNKOWN
SPASTIC QUADRIPLEGIA	Intracranial hemorrhage/infection (14.3%)	9.10%
SPASTIC HEMIPLEGIA	Asphyxia (11.8%)	19.10%
SPASTIC DIPLEGIA	Toxins (7.7%)	41%
MIXED	-	-
ATAXIC-HYPOTONIA	-	8.30%

One of the most definitive characteristics of SCP is inherent in its name, spasticity. As mentioned earlier, spasticity is over active muscle tone caused by excessive excitatory signal from the upper motor neuron system, which can present several difficulties to proficient motor performance. One thing that is especially difficult is that spasticity can morphologically change the biomechanics of movement (Mohagheghi et al, 2008). This has been simulated in vitro with excessive electrical input given to a neuromuscular model in order to recreate an excess of endurance activity in a short amount of time. In a relatively short time the muscle changes in composition and becomes less powerful allowing it to resist fatigue (Gardner, 2001). This morphological change leaves it less capable of forceful muscular contractions and becomes more of a tight spring (Fonseca et al, 2004). Therefore, spasticity appears to affect motor behavior by changing the biomechanics that the neuro-motor system has to work with.

However, it is not simply biomechanics that are affected by the spasticity. The motor neurons adapt over time as well allowing for a much shorter electromechanical delay (Granata, Ikeda, & Abel, 2000). This indicates that spastic muscles have much faster reflexes than what would otherwise be, which may or may not be a useful. Because the spasticity can affect both agonist and antagonist muscle groups the resulting reflex may not be biomechanically effective (O'Sullivan et al, 1998). While this may explain some issues with motor behavior in SCP, research has shown that there may to it.

In fact, examples in the literature show that the biomechanical traits caused by spasticity are not responsible for some problems in motor behavior. Studies analyzing gait in individuals with SCP have shown some interesting findings that may be related to those individual's ability to coordinate their movements. It is typical that adjustments need to be made for an individual with lower limb spasticity to be able to ambulate effectively. An example of this is how some individuals with SCP adjust movement strategies for their upper body to make up for their lower body's mechanical differences (Bennett et al, 2005; Russell et al, 2006). Some interpretations may assume that because there are differences in gait strategy, it is caused by the mechanics induced by lower limb spasticity. This concept comes into question when looking at individuals who have spasticity in their lower limbs due to different neurological conditions.

When comparing individuals with spasticity due to a hemiparetic stroke with individuals with spasticity due to hemiplegic SCP, what was seen was that, despite having similar biomechanical systems, each group elicited a different movement strategy (Ada et al, 1998). This could mean that the motor control system in an individual with SCP does not necessarily function the same as that of an individual who has developed without the influence of SCP throughout life. There are examples where the system costs the user energy by being economically costly (Johnston et al, 2004). However, though the motor control system of an individual with SCP may only work with what it is given, there is still evidence that it capable of learning how to work well considering its parameters.

After examining the gait of individuals with SCP, there is evidence to show that the individuals with spasticity in their lower limbs utilized it the same way an individual would recognize the value of different mechanical properties of a tool (Fonseca et al, 2004; Law & Webb 2005). There is one example, however, that shows that SCP significantly affects coordination. In a study examining the effectiveness of a surgical procedure known as a dorsal rhizotomy, the over-active motor neuron leading to an affected limb is severed, which removes the spasticity from that muscle, participants before and after the intervention did not show significant changes in synergy patterns of movement despite the removal of the spasticity's influence (Olree et al, 2000). Focus on why this may be could help researchers understand more about the motor behavior for people with SCP. There is currently a lot known about the management and effects of spasticity for people with SCP (Tilton, 2006) but, what is not known is why, when the spasticity is removed, there are still motor behavior deficits.

It is quite possible that, because of the damage to the motor cortex, there may be differences in sensorimotor integration. The studies that intentionally try to determine the role of sensorimotor integration in movement deficits for people with SCP use different types of coordination to provide explanations. This research perspective has lead investigators to new ideas about SCP that continue to teach us about the condition as well as therapeutic options for the people living with it by helping to explain the functional deficits that the neurology creates.

Something important to consider is that sensorimotor integration and the motor behavior associated with it should not be affected by spasticity or other peripheral conditions. Theoretically, though the motor output would still be affected by spasticity, if the motor control system had developed properly, it would make adaptations in order to form the most efficient output given the constraints of the neuromuscular system. As will be discussed later, this does not seem to be the case, which could explain the less tangible motor behavior characteristics in people with SCP. The research on SCP shows that these motor behavior problems may come from two general categorical ideas in motor behavior, 1) understanding spatial relationships of the world around an individual and adjusting movements appropriately and 2) controlling movements appropriately throughout a task and making necessary adjustments when necessary.

Motor imagery is an important idea when considering how proficient an individual might be when deciding the most appropriate movement given a specific environment. To investigate this idea a paradigm known as end task comfort (ETC) was used to determine how proficient individuals with SH were when it came to utilizing motor imagery to perform a task (Mutsaarts, Steenbergen, & Bekkering, 2007). ETC is based on the idea that, given a healthy neuromuscular system, an individual would perform a task with consideration of finishing the task in a position that is both biomechanically comfortable as well as allows for future movements to be performed (Rosenbaum, van Heugten, & Caldwell, 1996). If an individual can proficiently imagine the mechanics of a given motor behavior, such as grasping an object in the ETC paradigm, that individual would be proficient at anticipatory motor planning. Anticipatory motor planning, which requires motor imagery, is a necessary constituent of the ETC paradigm. A study designed to look at this aspect of motor behavior in individuals with SH was able to show that those individuals were unable to proficiently plan their motor actions appropriately in the ETC paradigm (Mutsaarts, Steenbergen, & Bekkering, 2007). Support that this could be a result of a deficit comes from a study looking at knowledge of performance in people with SCP. A group of physical therapists were investigating whether or not showing the participants their movements would help them perform a task they were already having difficulty with despite practice. They found that the participants performed much better when they were shown what they did compared to what they needed to do (Thorpe, 2002). The individuals with SCP seem to have needed supplementation to their motor imagery and planning of a task that they were already familiar with in order to perform better.

Motor imagery may not be the only explanation, however, for coordination difficulties associated with SCP.

Visual perception has been found to provide similar difficulties for individuals with SCP. Visual perception is essential to many tasks involving motor control in which visual feedback is crucial to proficient task performance. When considering motor control, the visual information is processed by what is known as the dorsal pathway leading to parietal lobe near where motor information is processed (Purves, Augustine, Fitzpatrick, et al, 2008). This area is responsible for interpreting the temporal-spatial information needed to determine the kinematics of objects around the observer and determine what they may do relative to the observer (Schmidt & Lee, 2005). It has been shown that this area can affect the visual perception of certain individuals with SCP (Kozeis et al, 2007). In a study analyzing coordination relying on visual feedback it was shown that this could be responsible for poor hand-eye coordination in individuals with SH (Verrel, Bekkering,& Steenbergen, 2007). It is difficult to differentiate the role that visual perception has in the motor behavior of someone with SCP from the role that motor imagery and anticipatory planning play.

A possible clue may come from studies that have analyzed another approach towards hand based coordination, reaching. Reaching is an important task for everyone from adults to babies because it allows utilization of resources in the environment as well as simple exploration of objects that are unfamiliar. This is another area where the SCP seems to affect the individuals living with it. It has been shown that there is a developmental delay in reaching motor milestones in individuals with CP (Hadders-Algra et al, 1999). Reaching involves similar temporal-spatial awareness required for anticipatory motor planning in ETC in order to decide how to reach and grasp an object. Visual perception is also useful because it is used to gather the information necessary to make any anticipatory motor planning decisions. It was found that when observing individuals with SH reaching for an object, the posture they used was different from typically developing controls (Hirschfeld, 2007). The authors also compared to individuals with hemiparesis due to a stroke, who also showed differences from the group with SH. This shows that, despite having a similar motor system peripherally, unilateral spasticity, the individuals with SH planned a completely different coordination strategy (Hirschfeld, 2007). This suggests that individuals with SCP have difficulty producing motor behavior most appropriate for a given task. The fact that their whole body is moving differently is worth noting. Differences in postural adjustment in reaching development studies, resulting in what was considered to be a developmental delay, showed that TD participants utilized more effective postural adjustments as apart of execution of more effective reaching strategies (Hadders-Algra et al, 1999).

There is another possibility that could explain these inappropriate movements relative to a given task. If an individual with SCP were deficient at making an appropriate output relative to a given input, it would be reasonable to expect that coordination deficits in individuals with SCP could be due to an inability to perform proficient sensorimotor integration.

There are several examples where researchers have investigated sensorimotor integration and its relationship with motor behavior in people with SCP. Many of the examples were used to investigate hand grip force coordination. When examining the coordination of the forces used for gripping there is a specific paradigm used to interpret performance. The force applied normal to an object's surface to allow enough friction between the skin of the fingers and the object required to keep the object from slipping from the individual's fingers is conventionally called the grip force (GF). The force applied tangentially to the object's surface that allows for the object's manipulation is conventionally called the load force (LF). When grasping tasks are performed, there is a specific coordination between the GF and the LF. For example, when holding an object up, the LF is equal to the force of gravity, and the GF is the required normal force when considering the skin's coefficient of friction to keep the object from slipping from the grasp. In addition to this minimum required there is often what is termed a safety margin. This is auxiliary GF used to ensure that any perturbations to the system will not disturb the task of grasping the object. When the object being held is moved upwards for example, the LF is increased in order to supply a vertical force on the object that will result in an acceleration in the vertical direction. When this occurs an appropriate coordination of the GF is to increase. When the object comes to rest in the new position and the LF is allowed to return back to the force of gravity the GF is then returned to its original value as well (Johansson & Westling, 1991).

For some reason in individuals with neurological conditions, there is an excess in application of GF. This has been thought to be true as well for individuals with SCP. In a study designed to assess the grasping coordination of individuals with SH, it was found that there is an excess of GF or over gripping. From analysis of how the forces were exerted the researchers concluded that the participants with SH had more difficulty in sensorimotor integration for these forces when compared to data collected with typically developing participants (Gordon & Duff, 1999). Another study involving participants who had SH provided results that indicated some grasping deficits may be due to difficulty in sensing tactile changes. They determined that these individuals with SH had deficits in finger tactile sensibility (Krumlinde-Sundholm & Eliasson, 2002).

To answer the question on whether individuals with SCP were able to proficiently detect tactile sensory information, a study was conducted to determine their response to changes in object surfaces (Gordon et al, 2006). In neurologically healthy patients, there is a relatively quick adjustment period in which the individual grasping the object with a new surface will behave as if it were the previous surface and then change strategies to adapt to the new surface (Gordon et al, 2006; Johansson & Westling, 1991). When this model was used with participants who had SH, the results indicated that they were able to adapt to new surfaces. However, they were not able to adapt as quickly as the neurologically healthy control participants (Gordon et al, 2006). This indicates that individuals with SCP can detect small tactile differences and relate them to their strategies in applying forces for a given task, but not as proficiently as TD participants. This means that understanding how forces are coordinated in an individual with CP could explain more about the deficiencies in the ability to perform tasks.

Unfortunately, despite all this knowledge about the motor behavior of individuals with SCP, there is still insufficient knowledge regarding how these characteristics affect function in ADL. This is because currently most of the investigations that have lead to the present knowledge have been by comparing participants with SH to TD controls. SH is neurologically different in its lesion pattern as well as how and where it affects the body peripherally. Because of this, it is difficult to make accurate generalizations from this data to bilateral forms of SCP such as SD and SQ. This is because historically it seems that the focus of investigators has been to compare the more affected side of individuals with SH to their less affected side. These designs have provided a great deal of information about CP but similar designs have yet to be conducted to determine if these traits described in participants with unilateral CP are also found in participants with bilateral CP.

Functional Deficits in individuals with Spastic Cerebral Palsy

It was already shown that success in main stream environments is directly correlated with proficiency in functional tasks (Viehweger et al, 2008). In order to see where these functions are affected by the motor behavior found in CP, a description of motor function for individuals with CP must be done.

One method in which this is done is the Gross Motor Function Classification System (GMFCS). This is a system that classifies individuals with CP based on their ability to do everyday tasks (Palisano, et al, 1997). These tasks are often related to their ambulatory ability (Beckung & Hagberg, 2002). Individuals may score a I, II, III, IV, or V with I meaning individuals are able to move without much difficulty and with V meaning that individuals are very restricted in their mobility and have difficulty despite use of assistive technology.

An individual with any type of CP could be classified in any category within the system so long as their motor proficiency is accurately described by the qualifications of that category. This means individuals with unilateral SH or bilateral SD could be either a I or a V depending on their gross motor abilities. However, there is a correlation between brain damage and gross motor classification. It was found that individuals with more neurological damage also recorded higher classifications on the

GMFCS (Himmelman, et al, 2006). For example, in a study designed to to assess the gross and fine motor control associated with CP in 353 participants, it was determined that 15% of the participants with SH were categorized at a level II or higher. It was also found that 32% and 100% of the participants classified as having SD and spastic tetraplegia (ST) respectively were categorized as having a gross motor function at II or higher (Himmelman, Beckung, Hagberg, & Uvebrant, 2006).

Therefore, it seems that, since it requires more neurological damage to have a case of ST than a case of SD (Riddle et al, 2006), that there is also a negative correlation between gross motor function and neurological damage. There is also a correlation found between poor function and poor function in mainstream situations (Beckung & Hagberg, 2002; Schenker, Coster, & Parush, 2005).

This could be explained by the additional spasticity found in cases with more neurological damage. The added spasticity would make movement and coordination more difficult. But, just as there is evidence in motor behavior that certain characteristics exist independently of the presences of spasticity, there is also evidence that spasticity does not dictate proficiency in function. After comparing the GMFCS with the bimanual fine motor function system (BFMF), it was found that there is a strong correlation between performance in the GMFCS and the BFMF (Beckung & Hagberg, 2002; Himmelman, Beckung, Hagberg, & Uvebrant, 2006). This is an interesting finding because it means that individuals with SD, who have little to no spasticity in the upper limbs, would perform similarly on a fine motor performance test as on a gross motor performance test. This suggests that non-spastic aspects of coordination in people who have CP must be severe enough to still influence bimanual performance.

There are fewer instances when data can be interpreted to determine how function is affected in ways not affected by spasticity. Some studies have been done when comparing function in the more affected side to that of the less affected side of participants with SH. They have found that anticipatory motor planning, a skill required for successful grasping techniques, can be negatively affected in these participants (Steenbergen, Meulenbroek, & Rosenbaum, 2004; Steenbergen, Hulstjin, & Dortmans, 2000). This would result in less efficient functional manipulation of tools and other objects in the environment of an individual with CP. Also found was that individuals with SH develop a different technique for reaching, even in their less affected side (Hadders-Algra et al, 1999; Hirschfeld, 2007). This could be a functional deficit in the ability to understand one's movements throughout the environment in general. If this were the case, this would be a very difficult deficit to overcome and may explain some of the non-spastic deficits in individuals with SCP.

If these were also the case in bilaterally affected individuals with CP, this could help explain why individuals with SD have similar functional deficits in gross motor performance as with fine motor performance. The only example in the literature that could provide and example of function is a study of fine motor development in people with SCP (Eliasson, Frosburg, Hung, & Gordon, 2006). They use a test, known as the Jebsen Taylor Test, specifically designed to approximate skills required for everyday activities in order to evaluate proficiency in fine motor skills (Jebsen, et al, 1969). This study had both participant types, with either SH or with SD. They determined that there was a delay in fine motor development and that there were functional deficits between the CP group and typically developing control group (Eliasson, Frosburg, Hung, & Gordon, 2006).

This is an example of the fact that, even though the majority of non-spastic coordination research is done with participants who have SH, there are quite possibly similar fine motor function deficits in individuals with bilateral SCP. There, however, has not been enough research to determine the differences between fine motor function in individuals with bilateral SCP and what has already been found for unilateral SCP. In fact hand function and coordination may be an area that researchers, clinicians, and therapists can use to further explore functional differences between individuals with neurological differences and can also be an area where more can be learned about the characteristics of CP in general.

Conclusions

Because of the heterogeneity of its neurological configuration, the condition, CP can be difficult to study and understand. Spasticity and motor deficits are often highly correlated with the size and location of the lesion. However, lesions and the neuroplasticity following their presentation are highly individualized based on situational experience creating scenarios that are difficult for generalization. The ideas that have proven difficult for generalization are where some of the biggest improvements in understanding CP can be made. One place to start is comparing and contrasting the similarities and differences between subtypes of CP and the corresponding motor behavior that is related to the neurological pattern of those subtypes.

When gross motor function was compared to bimanual fine motor function across different subtypes, researchers found that there was a high correlation between gross motor performance and fine motor performance in each subtype of CP analyzed (Beckung & Hagberg, 2002; Himmelman, Beckung, Hagberg, & Uvebrant, 2006). This raises questions when considering the subtype SD. SD involves spasticity generally in the lower limbs so any upper limb motor deficits would be difficult to be described by the influence of spasticity. Therefore more investigation of nonspastic coordination should be done for individuals with CP to help explain examples like this.

Currently there are some studies that have engaged these subjects but none of which have used individuals with SD or even bilateral CP. They have only used SH, a unilateral form of CP. Most of these studies were designed to compare performance of the more affected side to that of the less affected side. Regardless of intent, these experiments have revealed that there are some motor behavior characteristics that exist globally in the participants. These studies indicated there are grip related sensorimotor integration deficits, anticipatory planning deficits, and postural adjustments deficits in participants with SH.

Investigation of sensorimotor integration, anticipatory motor planning, and postural adjustments in bilateral CP could possibly explain poor upper limb motor performance in individuals with SD. Through understanding this, a better understanding of CP in general could be reached as well as better therapeutic techniques to improve the skills of individuals with SD or other types of CP. Since it has been shown that a higher quality of life is highly correlated with lack of motor deficiencies and lack of restrictions, investigation of nonspastic coordination in individuals with SCP is worth further analysis and may explain some of the motor behavior of CP that has yet to be explained.

Chapter 3

GENERAL METHODOLOGY

Two groups participated in this study. The first group was made up of individuals with spastic diplegia (SD) and the second group consisted of age and gender matched typically developing control group participants (TD). SD is a subtype of cerebral palsy where spasticity or over active muscle tone is predominately located in the lower half of the body (Kulak et al, 2006). The participants performed different tasks to help provide information about hand function in people with SD. The information may also be used to compare with data from participants with spastic hemiplegia (SH), a subtype of CP characterized by unilateral spasticity that can be found in both upper and lower regions of the body (Wood, 2006). Comparisons to other types of CP, neurological conditions, and TD participants may provide new understandings about SD.

Participants

Participants were recruited from the areas of eastern Maryland and New Castle County of Delaware. Recruitment was done through word of mouth as well as advertising at A.I. DuPont Hospital for Children's cerebral palsy clinic, the University of Delaware's Center for Disability Studies, and United Cerebral Palsy of Delaware.

There were a total of 12 participants, including 6 participants in the spastic diplegia (SD) group and 6 age and gender matched participants in the typically developing (TD) group. The average age of the participants was 25.33 $\pm$.52 years old; See Table 3.1 for demographic data on the participants of this study.

To qualify for the SD group the participants had to have been previously diagnosed with SD by a medical doctor. This diagnosis could be supported by the presence of bilateral form of CP with minimal spasticity in their hands mostly affecting the individual in his or her legs.

If an individual were unable to understand the instructions and then perform the tasks according to those instructions, that person would have to be excluded. Otherwise using that individual's performance would make it difficult make conclusions based on task. Also, if there were any visual acuity problems, the participant would have been instructed to wear any corrective eyewear prescribed by his or her doctor. Any evidence of peripheral neuropathies or any other motor control issues not associated with CP would result in exclusion since they would suggest a presence of a different neurological condition.

Table 3.1: Age, gender, and dominant hand (DH) of each participant of this study

Group	Participant	age	Gender	DH
	1	25	M	L
	2	25	M	R
SD Group	3	25	F	L
	4	26	M	L
	5	25	M	L
	6	26	M	R
	1	25	M	L
	2	25	M	R
TD Group	3	25	F	R
	4	26	M	R
	5	25	M	R
	6	26	M	R

Equipment

One standardized test that has a kit of different pieces of equipment used to show hand function with everyday objects is the Jebsen Taylor test (Sammons Preston, Patterson Medical Products Inc., www.sammonspreston.com). This test involves timed manipulation of everyday objects performed as quickly as the participant can manage. The participants performed subtests 2 through 6: simulated page turning, picking up everyday objects, simulated feeding, stacking checkers, lifting large heavy objects, and lifting large light objects (Eliasson et al, 2006 see figure 3.1).

Figure 3.1: The Jebsen Taylor Hand Function Test, used to examine hand function in every day tasks
http://www.sammonspreston.com/images/products/8063L.JPG

To test motor planning contributions an end task comfort protocol was used. This design was based on the type of handle found in a study performed by Rosenbaum (Rosenbaum et al, 1996). The device (see figure 3.2) used in this protocol has a 1ft x 10in handle attached to a 1ft diameter rotating wheel. The wheel is attached to a backboard that is 2 x 1.5ft. The axle was created through fastening the handle through the wheel to the back of the backboard. This is done with a bolt, a washer in between the wheel and the backboard to supply spacing and reduce friction, and another washer on the back of the backboard all tightened with a nut. There are numbers attached in a clocklike fashion from 1 to 8 on the face of the backboard with an arrow on the handle allowing the user to rotate the wheel in order to designate a target number. The stand that erects the device upright allows for four different angles so that maximal reaching comfort can be provided to a variety of participants and their seating positions.

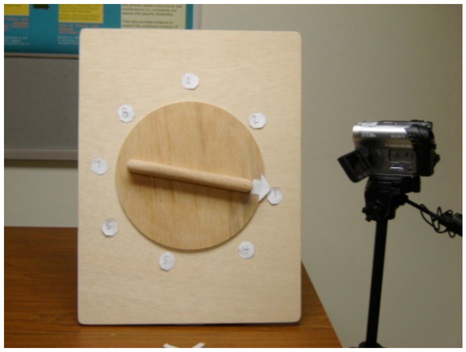

Figure 3.2: This is a picture of the end-task comfort device used in this study. The participants are instructed to move the arrow from one designated number to another. The grip selection is of interest to the researcher

To perform the tests in this study that measure grip and load forces, a device and some accessories were used. The device mostly consists of handles (8.5 cm x 2.5 cm) with grasping surfaces covered in black rubber and a total weight of 1.5 N with a force transducer (Model 484B06, Piezotronics Inc.) between the grasping surfaces of the handles. This force transducer was used to measure any forces normal to the gripping surface or grip forces (GF). Another force transducer is located at the bottom of the handles to measure any vertical or load forces (LF) which was calculated as being the force tangential to the surface of the handle. A series of additional masses were available to adjust the overall weight of the device. These masses increased in increments of 100g. The device has its force transducers connected to a nearby computer where custom software in Labview 8.2 (National Instruments, 2009) was used to record the data and provide the participants with the necessary feedback for the tasks they were asked to perform along with a monitor positioned in front of the participant and one in front of the investigator.

To ensure that results that were obtained in this study were not from a sensory perception problem, each participant went through a peripheral neuropathy test. To do this, Test Touch filaments of different widths were used to test finger sensitivity. Filaments used to apply a pressure equivalent to .07g and .16g were used. These sizes are generally detectable by the average person with no neurological conditions affecting their peripheral sensory perception. All participants in this study were able to detect at least the .16g filament and some participants regardless of group were able to detect even the lighter more sensitive filament.

Figure 3.4: Grip/Load force device. Participants hold vertical handles which record isometric force. Feedback is provided on the monitor

Protocol

When the participants first arrived at the laboratory, they were given an informed consent sheet. They signed the sheet and if they were under the age of 18 their parent/guardian signed while they signed the informed assent sheet. At this point if the participants did not have any more questions they moved on to testing.

For the Jebsen Taylor Hand Function Test, each participant was read the script supplied in the test kit. The participant was expected to perform the instructed task as fast as he or she could. These tasks were timed with a stop watch by the investigator.

Each participant was seated at a table directly in front of the test already set up for the first subtest. The participants performed subtests 2 through 6 one at a time.

For the end task comfort task, the participants were seated at a table with the device positioned in front of them in such a manner that when he or she flexed his or her shoulder and fully extends the elbow the handle was easily and comfortably reached in either their dominant or non-dominant hand. The participant had his or her hand on an “X” marked on the table called the starting place. When told a number the participant moved his or her hand from the “X” to another tape marking located at the center of the handle overtop the point of rotation of the wheel called the grasping place. See Figure 3.1 for a picture of the device.

Table 3.2: Spreadsheet view of trials and corresponding Target Numbers for the End Task Comfort protocol

Trial	1	2	3	4	5	6	7	8	9	10	11
Target Numbers	1 to 3	3 to 7	7 to 2	2 to 6	6 to 1	1 to 5	5 to 8	8 to 4	4 to 7	7 to 3	3 to 6

The participant then moved the arrow located at the end of the handle to a target number as instructed by the researcher and immediately returned his or her hand back to the starting place. As soon as the participant had returned his or her hand to the starting place the participant was told another target number to begin the cycle again. The target numbers that the participants were told were (with a starting position of 1 for the first trial) 3, 7, 2, 6, 1, 5, 8, 4, 7, 3, and 6 (These will be known as trials 1 through 11 respectively. See the Table 3.2).

These target numbers provide a variety of rotations to test the participant's ability to effectively plan the proper end task comfort. The participants did this with each hand and for instruction had the same script read to everyone. This was done intentionally to diminish the possible effects of the investigator accidentally biasing the performance of the participants through his instructions.

While the participants were performing this end task comfort test, they were filmed from behind. This provided a record of what the participants had done without slowing down the cadence of the instructions, which would have allowed them to think about where they would be moving their hand. The filming also aided in the prevention of accidental bias being given to the participant as he or she performed the task.

The hand-force device was used to see how the TD group modulates grip and load forces compared to that of the group with SD and under a couple different conditions. The participants performed a Simple Lifting task and a Ramp & Hold task while seated in front of the hand-force device. Before either of the tasks the maximum voluntary grip force (MVGF) was measured and evaluated as the average of three trials. This will be used to scale the required load force used to perform the rest of the tasks relative to the participant's hand strength. The percentage used for this study was 10% of the MVGF with a maximum used of 10 N.

For the simple lifting task the hand-force device was detached and attached to a weight equivalent to the 10% MVGF in grams up until 10 N. Since the entire device per hand each has a mass of 300 g, a person who obtained a MVGF of 10 N will have for example, 700 g of mass attached to the device. At the sound of a beep the participant was instructed to simply lift the detached device a couple inches off of the table and hold it still in mid air until he or she heard another beep signaling them to then gently place it back down on the table. They were instructed to act naturally as if the device were a glass of water. This was repeated for three trials in each hand and three trials both hands at the same time (or RH, LH, and LHR respectively).

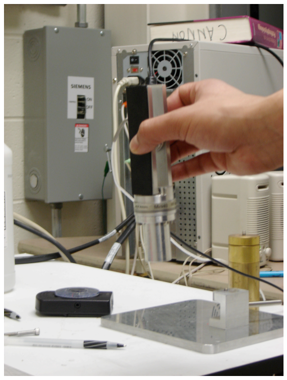

Figure 3.4: A participant performing a right handed lifting task

The ramp and hold task is an isometric task divided into thirds in which the participant uses visual feedback to trace a cursor representing load force on a line representing a force profile based off of percentages of MVGF. For the first third the participant was to be relaxed applying no load force but still being in contact with the device. When the second third began the force profile went from a horizontal line at 0% MVGF to a linear increase such that when the second third was complete the profile was at 10% their MVGF. For the last third the profile was a horizontal line held consistently at 10% MVGF. The participants were first introduced to this task with a demonstration and explanation of how the task works. The participant then was given an opportunity to practice the task until it had become clear that the participant was familiar with the task that he or she was being asked to do and could complete it as best as he or she could. Once this point had been reached the participant performed the task for three trials with each hand unimanually and three trials with both hands (RH, LH, and LHR respectively).

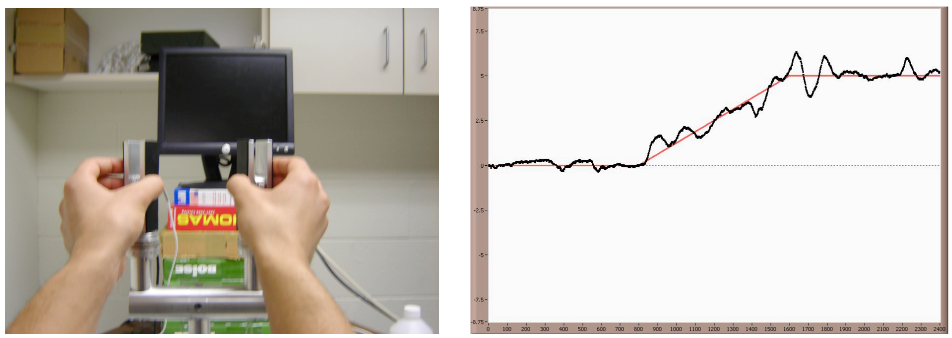

Figure 3.5: Above is a staged example of what it would look like to perform the Ramp and Hold Task. The participant on the left is applying force to the device and on the right you can see the feedback that he would see. Darker line showing the load force applied to the device and a lighter line that is the force profile that is to be traced

Data Analysis and Statistics

The data was entered into Predictive Analytics SoftWare (SPSS 17 from SPSS Inc. of IBM) for statistical analysis. When deciding on an appropriate statistical analysis to perform for these variables, the fact that there was not a large participant pool to work with and that data obtained contained a notable amount of variability, at least with the SD group, were considered. Because of these conditions, it was decided that a nonparametric approach would provide the most accurate results without misrepresenting the data. The assumptions in parametric statistics like a normal distribution of variability just could not be determined with this data set.

To analyze the participants' performance at the Jebsen Taylor test the data for each subtest was entered into SPSS and separated by group. Then for each subtest a Mann-Whitney *U* test was performed to determine if there were significant differences in the performance of each subtest by the SD group and the TD group.

When reviewing the data of each participant for the end task comfort task the primary researcher reviewed the video records. For every rotation the participant had the option of choosing a end task comfortable and an end task uncomfortable grip of the handle to perform the task. A comfortable grasp is considered to be when the participant grips with his or her thumb and fingers pointing up. This grip can be done in the beginning of the task or at the end of the task. If the participant chose to end the task in the position that would represent end task comfort it was recorded as end task comfortable and if not it was recorded as end task uncomfortable. Previous research has shown that this represents a participant's unconscious ability to perform motor planning in a given task (Rosenbaum et al, 1996).

Once this was done for each target number rotation and each participant the data was arranged by target number rotation and by group, either SD group or TD group, and by hand, dominant or non-dominant. From this arrangement a Chi square analysis was performed for each rotation for each group. This was done to allow us to determine how often per target number rotation the participants in each group chose either a biomechanically comfortable or uncomfortable grasp. From this analysis we were able to make decisions on how the conditions having SD, using the dominant or non-dominant hand, or how the participant rotated the handle of the device.

For each condition, the Simple Lift (for LH, RH, LHR) and the Ramp & Hold (for LH, RH, LHR), a Kruskal-Wallis *H* Test was conducted to compare the outcome of the task and force related variables by group, either TD or SD. During the review of the analysis it may be helpful to know the most analogous parametric test is a one-way ANOVA.

Chapter 4

QUANTIFYING HAND DEFICITS IN INDIVIDUALS WITH SPASTIC DIPLEGIA: PERFORMANCE ON THE JEBSEN TAYLOR AND END TASK COMFORT TESTS

Introduction

In any movement no matter how simple or complex there is some form of planning involved to allow it to be successful. One example of such a movement is using a utensil to pick up food so that it can be eaten. While being a task that is so casually, quickly, and easily thought through it involves a lot of anticipatory planning to be successful and proficient. This task requires the correct grasping of the utensil to allow for its proper use throughout the movement as well as the decisions necessary to properly plan to use the utensil to pick up the desired food and take that food to the person's mouth without spilling it. Planning like this is involved in almost every coordinated movement.

This aspect of motor behavior is considered to be purely cognitive. A person with an otherwise healthy motor control system if not paying close attention to his or her movements could easily make mistakes if motor planning is not taken into consideration. But not everyone has such a healthy motor control system. A person with a neurological disorder may not process information the same and therefore may not have optimum motor planning abilities. This may be exhibited in showing deficits in skills like the one mentioned above. Currently the literature indicates that cerebral palsy (CP) may be an example of one of these types of neurological disorders but this is not completely understood at this moment. This is precisely what this study is designed to evaluate.

People who have CP, a neurological condition involving a non-progressive lesion in the brain often leading to muscle spasticity and generalized poor motor control (Miller, 2005), have been shown to have deficits in areas that are not easy to define. Physical therapists and orthopedic surgeons are often forced to deal with the issues stemming from the muscle spasticity which in significant cases of CP is, without a doubt, a very serious concern. But spasticity is not the only answer to the question regarding why there is motor dysfunction. Previous studies examining motor behavior in people with CP have indicated a more global motor control issue that cannot be related to the dysfunction caused by spasticity.

It has been shown that that people with hemiplegic CP affecting the left hemisphere of the brain have impaired motor imagery (Mutsaarts, Steenbergen, & Bekkering, 2006). Physical therapists have found it necessary in some ways to take cognition related to motor performance into account when designing techniques to teach new motor skills (Thorpe & Valvano, 2002, Thrombly, 1993). There are other examples as well. Anticipatory motor planning seems to be affected in some people with CP. This has been found to result in deficits in postural adjustment during movements (Hadders-Algra et al, 1999; Hirschfeld, 2007; van Roon, Steenbergen, & Meulenbroek, 2005), grasping control (Duff & Gordon, 2003; Steenbergen & Gordon, 2006), and grip selection (Mutsaarts, Steenbergen, & Bekkering, 2006; Steenbergen, Hulstijn, & Dortmans, 2000). Each of these studies in some different way has shown that there are deficits in these areas related to motor cognition in people with hemiplegic cerebral palsy. What they do not definitively answer is whether or not this is due to CP in general or if this is due to the unique lesion pattern associated with certain types of hemiplegic CP.

To try and help answer this question, this study looks specifically at a form of bilateral CP known as spastic diplegia. This type of CP is characterized by spasticity primarily in the lower limbs with both the right and left sides generally affected in a very similar magnitude. We asked them to perform a motor cognition task found in some of the previously mentioned literature regarding grip selection in hemiplegic CP, (Mutsaarts, Steenbergen, & Bekkering, 2006; Steenbergen, Hulstijn, & Dortmans, 2000), known as end task comfort (ETC). We also had them perform a standardized hand function test known as the Jebsen Taylor Test to assess the participants' abilities in every day scenarios.

To better understand the concepts analyzed in this study, it is important to understand the paradigm of ETC. End task comfort is an idea that biomechanical comfort as defined for an individual task is reserved for typically the end of a task. This has been shown to be the behavioral response in many individuals with healthy motor control systems (Rosenbaum, van Heugten, & Caldwell, 1996). Generally even under different task contexts this paradigm holds true and is representative of thorough anticipatory motor planning skills being put to use. A lot of research has been put towards this idea to ensure that this is the case and time after time this paradigm seems to be upheld (Cohen & Rosenbaum 2004; Rosenbaum, Halloran & Cohen, 2006; Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001).

It is important to investigate using the ETC paradigm to determine whether or not cognitive motor deficits exist in the form of deficient motor planning skills in people with CP. This will assist us in determining if the globalized coordination deficits that have been seen in previous studies with hemiplegic CP exist in other types of CP as well. This possibility could prove useful for clinicians trying to help people with CP achieve the best quality of life possible.

It is hypothesized that people with CP will perform more poorly according to the ETC paradigm than typically developing controls in both hands. This is because brain damage is bilateral in this type of CP and therefore we predict similar results to those found by those with left brain damaged hemiplegic CP mentioned before (Mutsaarts, Steenbergen, & Bekkering, 2006). It is also hypothesized that the participants with CP will perform worse at the Jebsen Taylor Hand Function Test than their typically developing controls. This is based on anecdotal in the literature and pilot testing showing that there is still a deficit in hand function in people with spastic diplegia despite a lack of significant spasticity in the hands. This also might help quantify this deficit to some degree. If there is a correlation between the Jebsen Taylor Test and the ETC test results then it may be reasonable to hypothesize that the hand function deficits in people with spastic diplegia may be impart due to deficits in anticipatory motor planning and other motor cognition skills. If this turns out to be the case it would provide evidence that there are significant coordination deficits unrelated to spasticity that need to be addressed in the treatment of individuals with CP.

Method

Participants

Participants were recruited from the areas of eastern Maryland and New Castle County of Delaware. Recruitment was done through word of mouth as well as advertising at A.I. DuPont Hospital for Children's cerebral palsy clinic, the University of Delaware's Center for Disability Studies, and United Cerebral Palsy of Delaware. There were a total of 12 participants, 6 participants with cerebral palsy (CP) group and 6 in the typically developing (TD) group. The TD group was age and gender matched with the participants in the CP group. The average age was 23.5 years of age however, 5 out of 6 participants had an average age of 25.2 because the sixth participant's age was 15 years old. This participant was directly age matched with his twin who does not have CP.

Table 4.1: Shows the age, gender, and dominant hand (DH) of each participant of this study

Group	Participant	age	Gender	DH
	1	25	M	L
	2	25	M	R
SD Group	3	25	F	L
	4	26	M	L
	5	25	M	L
	6	26	M	R
	1	25	M	L
	2	25	M	R
TD Group	3	25	F	R
	4	26	M	R
	5	25	M	R
	6	26	M	R

To qualify for the CP group the participants had to meet a range of criteria. They were required to have bilateral form of CP with minimal spasticity in their hands mostly affecting them in their legs. This diagnosis is generally called spastic diplegia. This subtype of CP was chosen because of the end task comfort task and Jebsen Taylor test in the protocol. This would allow testing of non-spastic coordination in people with CP.

People with CP would be excluded if they had any cognitive deficits significant enough to prevent them from understanding the tasks or follow directions. If there were any visual acuity problems the participant would be instructed to wear any corrective eyewear prescribed by his or her doctor. Any evidence of peripheral neuropathies or any other motor control issues not associated with CP would result in exclusion.

Equipment

To test motor planning contributions an end task comfort protocol was used. This design is based on the type of handle found in a study performed by Rosenbaum (Rosenbaum et al, 1996). The device (see figure 4.1) used in this protocol has a 1ft x 10in handle attached to a 1ft diameter rotating wheel. The wheel is attached to a backboard that is 2 x 1.5ft. The axle was created through fastening the handle through the wheel to the back of the backboard. This is done with a bolt, a washer in between the wheel and the backboard to supply spacing and reduce friction, and another washer on the back of the backboard all tightened with a nut. There are numbers painted in a clocklike fashion from 1 to 8 on the face of the backboard with an arrow on the handle allowing the user to rotate the wheel in order to designate a target number. The stand that erects the device upright allows for four different angles so that maximal reaching comfort was provided to a variety of subjects and seating positions.

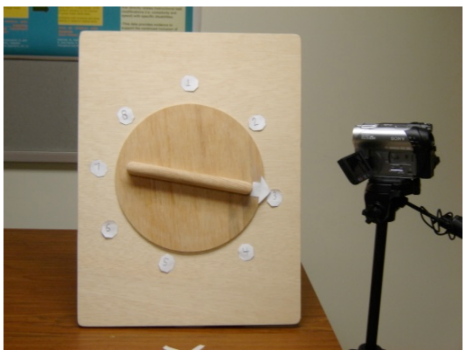

Figure 4.1: This is a picture of the end-task comfort device used in this study. The subjects are instructed to move the arrow from one designated number to another. The grip selection is of interest to the researcher

One standardized test that has a kit of different pieces of equipment used to show hand function with everyday objects is the Jebsen Taylor test (Sammons Preston, Patterson Medical Products Inc., www.sammonspreston.com). This test involves timed manipulation of everyday objects performed as quickly as the subject can manage. The participants performed subtests 2 through 6: simulated page turning, picking up everyday objects, simulated feeding, stacking checkers, lifting large heavy objects, and lifting large light objects (Eliasson et al, 2006), (see Figure 4.2).

Figure 4.2: Picture of the Jebsen-Taylor Hand Function Test that is used to get an idea of how adept a subject is at manipulating everyday objects quickly http://www.sammonspreston.com/images/products/8063L.JPG

Protocol

When the subjects first came into the lab they were given an informed consent sheet. They signed the sheet and if they were under the age of 18 their parents/guardians signed while they signed the informed assent sheet. At this point if the participants did not have any more questions they moved on to testing.

For the end task comfort task the participants were seated at a table with the device sitting on the table centered in front of them in such a manner that when he or she flexed his or her shoulder and fully extends the elbow the handle is easily and comfortably reached in either their dominant or non-dominant. The participant had his or her hand on an “X” marked on the table called the starting place. When told a number the participant moved his or her hand from the “X” to another tape marking located at the center of the handle overtop the point of rotation called the grasping place. The participant then moved the arrow located at the end of the handle to the number as instructed by the researcher and immediately return his or her hand back to the starting place. As soon as the participant returned his or her hand to the starting place, the participant was told another target number to begin the cycle again. The target numbers that the participant were told are (with a starting position of 1) 3, 7, 2, 6, 1, 5, 8, 4, 7, 3, and 6. These target numbers provide a variety of rotations to test the participant’s ability to effectively plan the proper biomechanically comfort. The participants did this twice with each hand.

While the participants were performing this end task comfort test they were filmed from behind revealing to the camera what they had done. This was the best way to record exactly what the participants had done without slowing down the cadence of the instructions to allow them to think about where they would be moving their hand as well as prevent the researcher from accidentally biasing the participant as he or she performed the task.

Performing the Jebsen-Taylor Hand Function Test is a fairly simple procedure. There is a set of instructions for set up as well as for each subtest's protocol as well as a script to read to the participants that comes with each test kit. This script was read to the participant and then the participant was expected to perform the instructed task as fast as he or she could. These tasks were timed with a stopwatch by the investigator. Each subject was seated at a table directly in front of the test already set up for the first subtest. The participants performed subtests 2 through 6 one at a time. In addition to times written down for each task different notes about how each participant performed each task and why were taken to allow for data analysis to be more easily interpreted.

Analysis

When reviewing the data of each participant for the end task comfort task the primary researcher reviewed the video records. For every rotation the participant had the option of choosing a biomechanically comfortable and a biomechanically uncomfortable grip of the handle to perform the task. A comfortable grasp is considered to be when the participant grips with his thumb and fingers pointing up. This grip can be done in the beginning of the task or at the end of the task. If the subject chose to end the task in the position that would represent end task comfort it was recorded as end task comfortable and if not it was recorded as end task uncomfortable. Previous research has shown that this represents a participant's unconscious ability to perform motor planning in a given task (Rosenbaum, et al, 2006).

Once this was done for each target number rotation and each participant the data was arranged by target number rotation and by group, either CP group or TD group, and by hand, dominant or non-dominant. From this arrangement a Chi square analysis was performed for each rotation for each group. This was done to allow us to determine how often per target number rotation the participants in each group chose either a biomechanically comfortable or uncomfortable grasp. From this analysis we were able to make decisions on how the conditions having CP, using the dominant or non-dominant hand, or how the participant rotated the handle of the device.

To analyze the participants' performance at the Jebsen Taylor test the data for each subtest was entered into SPSS and separated by group. Then for each subtest, a Mann-Whitney *U* Test was performed to determine if there were significant differences in the performance of each subtest between the CP group and the TD group.

Statistics

For all the Jebsen Taylor Test subtests, both the dominant hand (DH) and the non-dominant hand (NDH) distributions in the two groups, the CP group and the TD group, differed significantly based on group (Mann–Whitney $U = 0$, $n_1 = n_2 = 7$, $P < 0.05$ two-tailed for both the DH and NDH for subtests 1, 2, 3, 4, 6, & 7 and for the

NDH in subtest 5; Mann-Whitney U =1, $n_1 = n_2 = 7$, $P < 0.05$ two-tailed for DH in subtest 5) (see Table 4.2)

Table 4.2: The statistical results of comparing the performance in the Jebsen Taylor Test across group.

Subtest	Hand	U	p Value
2	DH	0	< .01
2	NDH	0	< .01
3	DH	0	< .01
3	NDH	0	< .01
4	DH	0	< .01
4	NDH	0	< .01
5	DH	1	0.01
5	NDH	0	< .01
6	DH	0	< .01
6	NDH	0	< .01
7	DH	0	< .01
7	NDH	0	< .01

The proper statistical test required for data found in the End Task Comfort test is a Chi Square test. However, because of the small number of participants in this study, this statistical test would have been unreliable and therefore no statistical analysis could be performed on the End Task Comfort test data. All of the analysis of this data can be found in the results section.

Results

The SD group was significantly slower in performing each task than the TD group. Also, for many of the subtests the TD group's dominant hand (TDD) was significantly faster than their non-dominant hand (TDND), where in the SD group, it was not. This was the case for subtests 2, 3, and 5. The rest of the subtests were still significantly different by group but for those subtests the dominant hand of the people in the SD (SDD) group performed significantly different than the non-dominant hand (SDND). This took place during subtests 4, 6, and 7. In 4 and 7 the dominant hand was significantly faster than the non-dominant hand. But, for subtest 6, the non-dominant hand of people in the SD group performed significantly faster than the dominant hand. It was only in subtest 6 that the SD group did this where the people in the TD group was consistently faster with their non-dominant hand for every subtest.

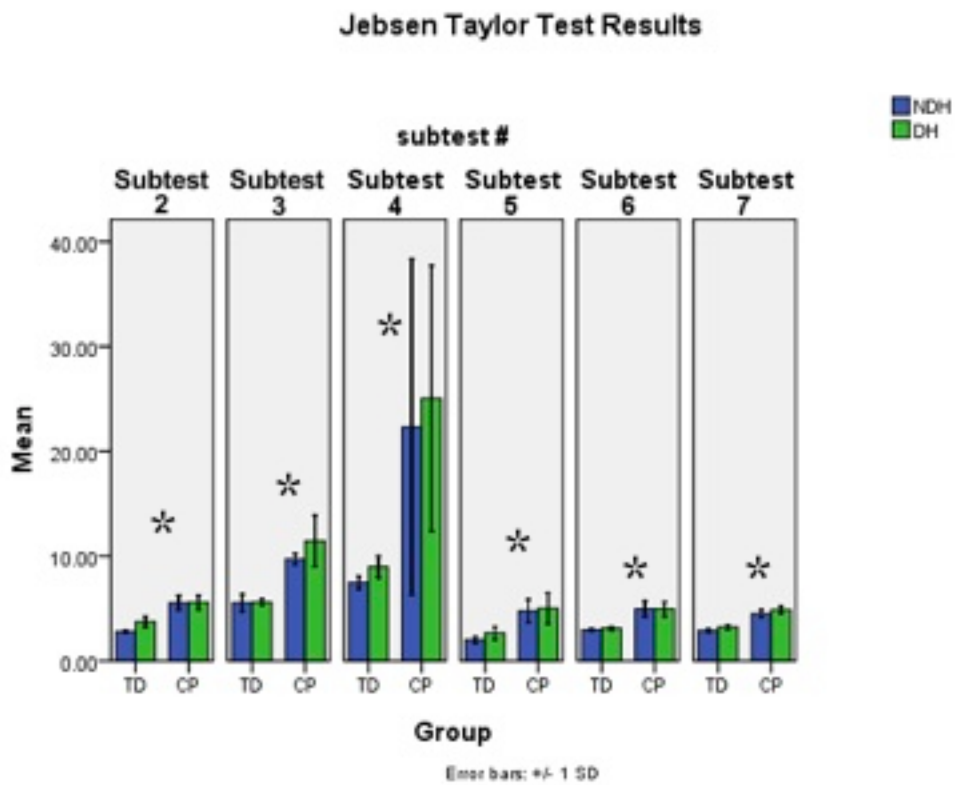

Figure 4.3: Shows group averages and standard deviations of time (s) for each subtest for the Jebsen Taylor Test for both the dominant (DH) and non-dominant (NDH) hands. The "*" signifies where significant differences across group were found for both the DH and NDH.

It was not as simple when analyzing the ETC Test results. One way to view the data can be found in Table 4.3. This is a table listing the frequency that a comfortable position was chosen for each of the 11 different trials. Since biomechanically uncomfortable was recorded as a 0 and biomechanically comfortable was recorded as a 1, the values for each trial were averaged across participants resulting the average amount that a person chose a biomechanically comfortable position. So the closer to 1 this table shows the more likely that a person using that hand for that trial chose a biomechanically comfortable grasp.

It was determined that the most appropriate method to fully analyze this data statistically was a chi square analysis. It takes the heterogeneity of the SD group into consideration. However, because of the small participant pool, a chi square test by itself cannot be properly run. We can only qualitatively compare the data with the frequencies to determine if differences may or may not have occurred and if they were within or between groups. The data was analyzed to determine if there were differences between groups for the dominant hand and then again separately for the non-dominant hand.

Table 4.3: Frequency of how often end task comfort was chosen for each individual trial.

Trial	1	2	3	4	5	6	7	8	9	10	11
CPD	0.83	0.50	0.83	0.67	0.83	0.50	0.67	0.33	0.67	0.67	0.83
TDD	1.00	0.17	0.83	0.33	0.67	1.00	0.33	1.00	0.83	0.50	0.83
CPND	1.00	0.50	1.00	0.50	0.83	0.67	0.50	0.33	0.50	0.67	1.00
TDND	0.83	0.83	0.67	0.67	1.00	0.33	0.67	0.50	1.00	1.00	0.67

There were two occasions where the SD group and TD group both chose a comfortable grasp the same frequency with the dominant hand, trial 3 and 11, and zero occasions where this took place with the non-dominant hand. There were some trials in which the chi square analysis indicates that with higher numbers there may have been a significant difference between groups. This was seen in trials 6 and 8 in the dominant hand and trials, 3 and 9 with the non-dominant hand. These potential differences were compared to that of the frequency measurements found in Table 4.3. In the dominant hand the people in the TD group selected a biomechanically comfortable grasp twice as often as the people in the SD group did for trial 6.

There was an even larger difference for trial 8 where only a third of the people in the SD group chose a comfortable grasp with their dominant hand compared to the

TD group where all the participants chose a biomechanically comfortable grasp. The non-dominant hand's results can also be verified by the table of results. In trial 3 all of the participants in the SD group chose a comfortable grasp with their non-dominant hand while only two thirds of the participants in the TD group did. Also in trial 9 half the SD group chose a comfortable grasp with their non-dominant hand while all of the participants from the TD group did.

There were not a lot of detectable differences between the groups regardless of the hand used. Also any of the possible differences did not indicate a particular grasp selection. For some of the trials the people in the SD group chose a comfortable and some trials and uncomfortable. The same occurred with the TD group indicating a lack of significance regarding the differences found specifically when comparing group, SD versus TD, and grip selection.

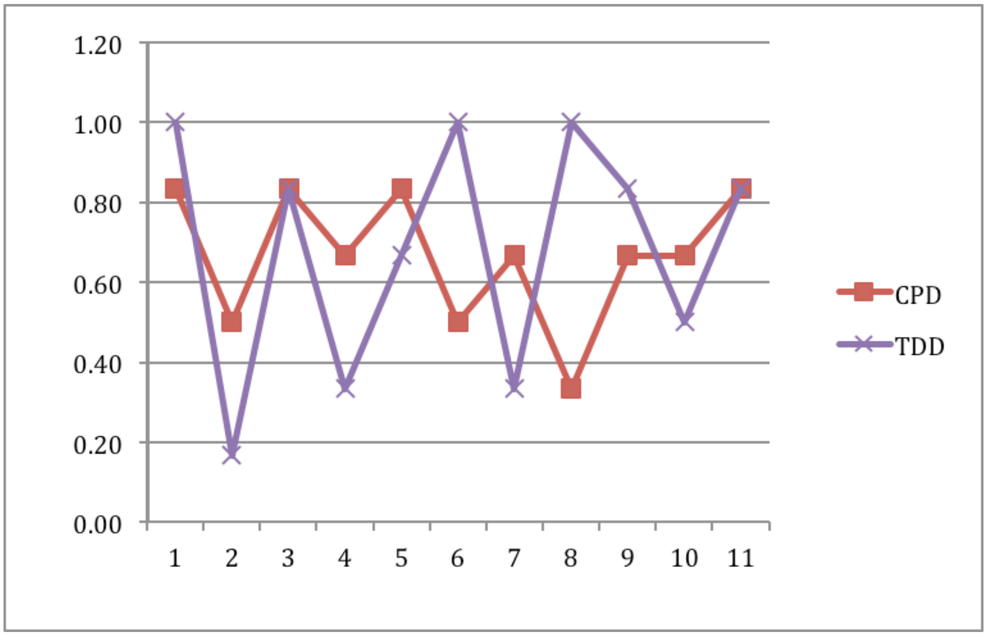

Figure 4.4: A chart displaying the results for the End Task Comfort Test from the CP group's dominant hand (CPD) and the typically developing group's dominant hand (TDD)

Discussion

As mentioned before, cerebral palsy (CP), the neuromuscular condition caused by an insult to the brain that results in a lesion in the motor cortex, is a condition that affects many people. CP can influence many parts of a person's life, which can make it difficult for people who live with it to reach what may be their full potential (Schenker et al, 2005). Lacking proficient hand function is something that can be additionally detrimental to success. Since much of the research prior to this study focused on the hand function of individuals with spastic hemiplegia (SH), it was important to further analyze hand function in CP by examining a neurologically different type of CP, spastic diplegia (SD). The goal of this would be to better understand CP as a whole.

The first hypothesis predicted in this study involved a standardized hand function test, known as the Jebsen Taylor test. In performing the subtests of the Jebsen Taylor test, the participants indicated, according to previous research using the technique (Elliason, et al., 2006), what their fine motor proficiency was during simple everyday tasks. This test is a timed test in which the fastest time indicates the best performance. Therefore it was hypothesized that the SD group would perform significantly slower than the typically developing (TD) group. This hypothesis was upheld.

The fact that the people with SD moved significantly slower while performing the Jebsen Taylor test indicates a certain level of hand function deficiency related to performing tasks associated with activities of daily living. Essentially this means that there is a hand deficit in individuals with SD. This is a more interesting finding when considering the fact that people who have SD do not tend to have significant spasticity in their hands. This deficit is therefore unrelated to spasticity. This supports the findings of Mackenzie et al who had people with SH perform the Jebsen Taylor test and had similar findings. (Mackenzie et al, 2009)

The fact that this study and a previous study with SH had similar differences across groups in the performance of the Jebsen Taylor test, suggests that there may be more to CP than the location of spasticity. This might be due to the possible similarities in neurology between the way one side is affected in individuals with SH and the way the two hemispheres are affected in individuals with SD. Further attention related to these deficits involving activities of daily living should be investigated with particular attention paid to lesion pattern so that a proper comparison between neurological structure and non-spastic function can be made.

One method used to evaluate individuals with SH offered a possible explanation for some of the similarities with SD that were found. This method, the end task comfort (ETC) test, was also used in this study to try to pinpoint the cause of any deficits. This technique is a measure of the ability that an individual has to utilize movement context and integrate it with a new movement to continue to be successful and proficient. Participants in previous research with SH who have performed this task showed a deficit in performance when compared to typically developing (TD) controls. It was therefore hypothesized that the SD group would perform with significantly less ETC than TD controls. However, this hypothesis was not upheld.

After analyzing the data, no pattern arose that could separate the performance of the SD group from the TD group. Though individual significant differences were observed, they were sometimes counter intuitive and may just represent the variability of the task. At no point were there differences that indicated that any particular group or hand usage (either dominant or non-dominant) was representative of performing more successfully at the ETC test.

Despite not being able to confirm the hypothesis, the results of this study still provide information. It is important to still consider what these results mean in relation to activities of daily living and the origins of any deficits in those areas. The fact that there was no pattern that distinguished the SD group from the TD group indicates that anticipatory motor planning, as it pertains to the ETC test, does not have a significant effect on performing tasks like the Jebsen Taylor test.

Since the ability to perform this task was affected in people with SH, something that may possibly explain this situation is the differences between SD and SH. It has been shown that side can have an effect on performance on the ETC test. Research has shown that the left hemisphere is more responsible for proficiency on this task. (Mutsaarts, Steenbergen, & Bekkering, 2006) This idea may shed light on the reason for the difference in performance between people with SD and people with SH. The lesion that causes SH is unilateral in nature and is often caused by different means than that of the lesion responsible for SD. The primary etiology responsible for

SH is vascular in nature while the one responsible for SD is periventricular leukomalacia (PVL) (Shevell, Majnemer, & Morin, 2003).

The more lateralized neurological condition proves to be worse at the ETC task. This seems to indicate that conditions that result in unilateral brain damage, especially on the left hemisphere, will most likely result in poor performance of tasks where context and anticipatory motor planning play a key role, such as the ETC test. Whether or not a lesion is located in a certain area may also explain why this trait was not seen in this study's SD group. There may be a critical difference in the left hemisphere neurology that can functionally distinguish between SD and SH. Further analysis of the idea that the different neurological aspects of the different types of CP could be functionally meaningful should be conducted.

After considering the results of this study and the neurology of SH and SD, some general conclusions can be made about CP and hand function. In general it can be stated that there are functional deficits in CP not associated with spasticity that are of concern. It is equally important to state that as far as can be determined from this study, anticipatory motor planning is not responsible for poor performance of people with SD on the Jebsen Taylor test. In fact, with the SD group performing as proficiently as the TD group, it could be interpreted that significant damage to the left hemisphere, something that is not as inclusive to the definition of SD as it is for diagnosis of right side SH (left brain hemiparesis), was more responsible. A few things can be inferred from this. One is that the poor performance in the ETC task is not associated with generalized CP and happens to be a comorbid condition for people with right side SH that affects their left hemisphere significantly enough to create a deficit. The other is that CP may represent a variety of deficits not associated with spasticity and that these types of deficits may be highly reliant on where the lesions to the brain present themselves This would result in every type of CP having different characteristics of motor performance depending on the lesion creating the condition.

There are a few limitations to the interpretations of this study. The number of participants for this study was low. This means that the statistical methods able to be used were limited in their power. For example the data analysis of the ETC data was qualitative in nature because there were too few participants and therefore too few data points to properly use the chi square test of independence. Since this was the case, further study on CP and ETC should be conducted with more participants prior to making conclusions on how people with SD perform. It is possible that, with a larger number of participants, statistical differences between groups might be seen. Other possible limitations may have come from the methods used during the ETC test. Though the design used in this study was based on the techniques used in previous studies (Rosenbaum, van Heugten, & Caldwell, 1996), they had to be reproduced. In case this was not done properly, it is also a good idea to perform this test using some of the other techniques for ETC testing available in the literature.

Chapter 5

GRIP FORCE COORDINATION IN INDIVIDUALS WITH SPASTIC DIPLEGIA

Introduction

Proficient hand function is important in order for someone to have a high quality of life. Many of the most basic skills required for someone to make it through school and work involve hand function. Additionally skills that allow a person to sufficiently care for his or herself like eating and carrying objects involve generalized motor control of the hand.

While there are many examples of measures for hand function and coordination such as the 9 hole peg test and the Jebsen Taylor test however, those tests are rather qualitative since they only measure the time it takes to perform the task. They do not provide information on how the individual hand forces are coordinated. This study uses a more quantitative approach used to analyze the coordination of gripping forces with loading forces. To best understand this paradigm, one should consider the following example. A person wishes to take a drink out of water out of a paper cup. The person must apply enough load force (LF, force applied tangential to the cup's surface) to counteract the force of gravity. This must be balanced with the proper amount of grip fore (GF, force perpendicular to the object's surface) to allow the necessary amount of frictional force to hold the object up. This is a delicate balance that is performed all of the time. Too much force will crush the cup while too little force will allow the cup to drop spilling the liquid everywhere.

This type of coordination is not just applied in situations where objects can break or be spilled. This coordination is applied in nearly every type of hand gripping situation but, in situations where delicacy is less of an issue, fatigue may become one. These are just some small examples of why proper hand force coordination is necessary.

These characteristics of poor GF and LF coordination can be especially problematic in people with neurological problems. For example people with even mild cases of multiple sclerosis (MS) tend to over-grip or apply unnecessarily high amounts of grip force compared to that which is required to perform the task (Krishnan & Jaric, 2008). Other neurological conditions also present similar dysfunctions in GF LF coordination. People with cerebellar atrophy also have higher than usual amounts of grip force as well as poor coordination between GF and LF (Rost, Nowak, Timmann, & Hermsdörfer, 2005). People with Huntington's disease also have trouble coordinating these forces and use an atypically large amount of GF as well (Serrien , Burgunder, & Wiesendanger, 2002).

Cerebral palsy (CP) is a neurological condition that presents itself significantly as a motor control issue and previous studies indicate that people with CP exhibit similar gripping behavior as other neurological conditions resulting in poor GF LF coordination (Gordon & Duff, 1999; Eliasson & Gordon, 2000) which contributes to poor anticipatory force scaling. What is not known is whether this type of behavior is a CP condition or one specific to a particular type of CP known as hemiplegic CP. To explain the uncertainty surrounding this topic one must better understand what CP is and what the causes of different types of CP are.

In a lot of ways CP can be considered an umbrella term for brain damage resulting in a neuromuscular dysfunction. However, some forms of brain damage are inherently different than others and would therefore result in different outcomes regarding motor behavior. Previous studies involving CP and hand function have focused on the type of CP known as spastic hemiplegia (SH). This type of CP is characterized by unilateral spasticity on either the left or right side. These studies had also been focused on the comparison of the more involved limb to the less involved limb. The focus was never on whether or not the less involved limb had any problems when compared to typically developing populations. But these studies did provide evidence that would inspire new questions about CP. What hand function studies have not yet focused on is examining the different types of CP under the same conditions to ensure that these coordinative traits being found are either traits for people with CP in general or only associated with hemiplegic CP.

The reason this is important is because of the different types of lesions occurring in different people with CP. In an etiological study examining CP (see Table 5.1), the number one etiology for hemiplegic CP was vascular whereas the number one etiology for the form of bilateral CP used in this study, spastic diplegia (SD), had a primary etiology of periventricular leukomalacia. (Shevell, Majnemer, & Morin, 2003)

Table 5.1: Shevell, Majnemer, & Morin, 2003. Page 355

ETIOLOGY	#1	#2	#3
SPASTIC QUADRIPLEGIA	Asphyxia (32.5%)	PVL (29.9%)	Dysgenesis (18.2)
SPASTIC HEMIPLEGIA	Vascular (26.5%)	PVL/Intracranial hemorrhage (14.7%)	Dysgenesis (13.2%)
SPASTIC DIPLEGIA	PVL (53.9%)	Intracranial hemorrgage (15.4%)	Asphyxia (12.8%)
MIXED	Asphyxia (50%)	Toxins (16.7%)	-
ATAXIC-HYPOTONIA	Dysgenesis (91.7%)	-	-

ETIOLOGY	#4	UNKOWN
SPASTIC QUADRIPLEGIA	Intracranial hemorrhage/infection (14.3%)	9.10%
SPASTIC HEMIPLEGIA	Asphyxia (11.8%)	19.10%
SPASTIC DIPLEGIA	Toxins (7.7%)	41%
MIXED	-	-
ATAXIC-HYPOTONIA	-	8.30%

These differences in etiology result in different neurological presentations. SH, the subtype of CP that has been the focus of most CP hand function investigation is unilateral in nature while SD is bilateral. SH has spasticity primarily affecting one side of the body while SD has it affecting both sides, primarily in the lower limbs. By comparing the more affected side to the less affected side of participants with SH, previous research has given reason to look further. One study using SH noted that when the participants used the less involved hand there was some abnormal GF LF sequencing (Gordon, Charles, & Duff, 1999). This indicates the possibility of a deficit in an area of the body that should be minimally affected by the brain lesion. Hand function deficits in individuals with SD have not been adequately described. A similar perspective when applied to SD, could explain where these deficits originate, but so far, until this study, any research with this intent has yet to be performed.

The device in this study measures GF and LF and the analysis performed on that data determines task proficiency and describes force coordination behavior. It was hypothesized that, when compared to a typically developing (TD) control group, the SD group would perform significantly worse at task proficiency. It was also hypothesized that there would be significant differences across group in the measures describing GF LF coordination. If there are deficits in task proficiency we may be describing a new functional deficit in individuals with SD. If the second hypothesis is upheld showing differences in the areas of force sequencing and coordination of grip forces, it may provide new insight into the motor behavior of SD or CP in general.

Methods

Participants

Participants were recruited from the areas of eastern Maryland and New Castle County of Delaware. Recruitment was done through word of mouth as well as advertising at A.I. DuPont Hospital for Children's cerebral palsy clinic, the University of Delaware's Center for Disability Studies, and United Cerebral Palsy of Delaware. There were a total of 12 participants, 6 participants with cerebral palsy (CP) group and 6 in the typically developing (TD) group. The TD group was age and gender matched with the participants in the CP group. The average age was 23.5 years of age however, 5 out of 6 participants had an average age of 25.2 because the sixth participant's age was 15 years old. This participant was directly age matched with his twin who does not have CP. To qualify for the CP group the participants had to meet a range of criteria. They were required to have been previously diagnosed by a physician as having SD.

People with CP were excluded if they had any cognitive deficits significant enough to prevent them from understanding and completing the tasks. One participant's data was not included for these reasons and therefore was not one of the six. If there were any visual acuity problems the participant were instructed to wear any corrective eyewear prescribed by his or her doctor. Any evidence of peripheral neuropathies or any other motor control issues not associated with CP would also have resulted in exclusion.

Table 5.2: Shows the age, gender, and dominant hand (DH) of each participant of this study

Group	Participant	age	Gender	DH
	1	25	M	L
	2	25	M	R
CP Group	3	25	F	L
	4	26	M	L
	5	25	M	L
	6	26	M	R
	1	25	M	L
	2	25	M	R
TD Group	3	25	F	R
	4	26	M	R
	5	25	M	R
	6	26	M	R

Equipment

To perform the tests in this study that measure grip and load forces, a hand grip device and some accessories were used. The device mostly consists of handles (8.5 cm x 2.5 cm) with grasping surfaces covered in black rubber and a total weight of 1.5 N with a force transducer (Model 484B06, Piezotronics Inc.) between the grasping surfaces of the handles. This force transducer was used to measure any forces normal to the gripping surface or grip forces (G). Another force transducer is located at the bottom of the handles to measure any vertical or load forces (L). A series of additional masses were available to adjust the overall weight of the device. These masses increased in increments of 100g. The device has its force transducers connected to a nearby computer where custom software in Labview (National Instruments) was used to record the data and provide the participants with the necessary feedback for the tasks they were asked to perform along with a monitor positioned in front of the participant and one in front of the researcher (For more details see Jaric et al, 2005).

To ensure that results that were obtained in this study were not from a sensory perception problem, each participant went through a peripheral neuropathy test. To do this, Touch Test Sensory Evaluators or filaments of different widths were used to test finger sensitivity (North Coast Medical). Filaments used to apply a pressure equivalent to .07g and .16g were used. These sizes are generally detectable by the average person with no neurological conditions affecting their peripheral sensory perception. All participants in this study were able to detect at least the .16g filament and some participants regardless of group were able to detect even the lighter more sensitive filament.

Figure: 5.1 This is a picture of the set up of the device used. From left to right you will see a screen used for feedback for the participant, the two handles of the device attached to their holder for isometric force recording, and on the right the computer and monitor used by the researcher.

Protocol

When the participants first came into the lab they were given an informed consent sheet. They signed the sheet and if they were under the age of 18 their parents/guarsdians signed while they signed the informed assent sheet. At this point if the participants did not have any more questions, they moved on to testing.

The hand-force device was used to see how the TD group modulates grip and load forces compared to that of the group with CP and under a couple different conditions. The participants performed a simple lifting task and a ramp and hold task while seated in front of the hand-force device. Before either of the tasks the maximum voluntary grip force (MVGF) was measured and evaluated as the average of three trials. This was used to scale the required load force used to perform the rest of the tasks based on the individual's muscular strength. The percentage used for this study is 10% of the MVGF with a maximum used of 10 N. This was used for the ramp and hold task.

For the simple lifting task the hand-force device was detached and attached to a weight equivalent to the 10% MVGF in grams up until 10 N. Since the entire device per hand each has a mass of 300 g a person who obtained a MVGF of 10 N had, for example, 700 g of mass attached to the device. At the sound of a beep the subject was instructed to simply lift the detached device a couple inches off of the table and hold it still in mid air until he or she heard another beep signaling them to then gently place it back down on the table. They were instructed to act naturally as if the device were a glass of water. This was repeated for three trials in each hand and three trials bimanually.

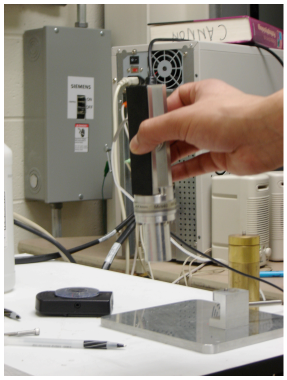

Figure 5.2: A picture of a participant performing a right handed simple lifting task

The ramp and hold task is an isometric task divided into thirds in which the subject uses feedback to trace a cursor representing load force on a line representing a force profile based off percentages of MVGF. For the first third the subject was to be relaxed applying no load force but still being in contact with the device. When the second third begins the force profile went from a horizontal line at 0% MVGF to a linear increase such that when the second third is complete the profile will be at 10% their MVGF. For the last third the profile was a horizontal line at 10% MVGF. The participants were first introduced to this task with a demonstration and explanation of how the task works. The participant was then given an opportunity to practice the task until it had become clear that the participant was familiar with the task that he or she was being asked to do and could complete it as best as he or she could. Once this point had been reached the participant performed the task for three trials with each hand unimanually and three trials bimanually.

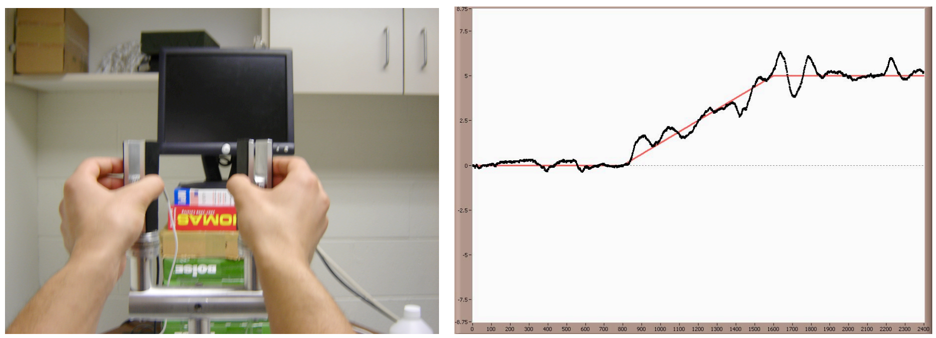

Figure 5.3: Above is a staged example of what it would look like to perform the Ramp and Hold Task. The participant on the left is applying force to the device and on the right you can see the feedback that he would see. Darker line showing the load force applied to the device and a lighter line that is the force profile that is to be traced

Statistics

The Kruskal-Wallis H-Test, a nonparametric one way analysis of variance, was used to detect differences in performance across group. Due to the low numbers of participants and high variability, there was difficulty finding statistically significant differences.

Simple Lift

There were no statistically significant differences detected in the variables related to task performance. However, for the LF during the hold portion of the simple lift task, the coefficient of variation was found to be approaching significance ($H = 3.433$, $df = 1$, $p = .064$) but not significant ($p \leq .05$) (see Table 5.3).

Table 5.3: The Kruskal-Wallace H-test results for the coefficient of variation (CV) for the load force (LF) and the grip force (GF) when performed unimanually (Uni) or bimanually (Bi) in either the dominant (DH) or nondominant hand (NDH)

Task Performance	CV LF Hold		CV GF Hold	
	Uni	Bi	Uni	Bi
Test Stats	DH (NDH)	DH (NDH)	DH (NDH)	DH (NDH)
H	3.433 (1.18)	1.8 (1.8)	.494 (2.551)	1.8 (1.473)
df	1 (1)	1 (1)	1 (1)	1 (1)
p value	.064 (.277)	0.18 (0.18)	.482 (.142)	.18 (.225)

In the variables related to hand grip force coordination of the simple lift task, significant differences across group were found. The GF/LF ratio of the DH during the hold portion of the task was found to differ significantly across group when the task was performed bimanually ($H = 4.445$, $df = 1$, $p = 0.035$). When the task was performed unimanually, significant differences in the r value were seen in the DH ($H = 6.861$, $df = 1$, $p = 0.008$) and the NDH ($H = 9.016$, $df = 1$, $p = 0.002$). When performed bimanually, significant differences were only detected in the DH ($H = 6.876$, $df = 1$, $p = 0.008$).

Under the bimanual condition, the differences in the r value of the NDH were close to significant ($H = 3.682$, $df = 1$, $p = 0.055$). There were several other variables showing that the group differences were close to significance. These variables as well as the significant ones are available in Table 5.4.

Table 5.4: The Kruskal-Wallace H-test results for the grip force load force ratio (G/L) from the lift and hold portions of the Simple Lift task as well as the gain, the offset, and the r value. The tasks were performed unimanually (Uni) and bimanually (Bi) with both the dominant (DH) and nondominant hands (NDH)

Measure	Hand	H value	df	p value
G/L lift	Unimanual	5 (2.976)	1 (1)	.142 (.085)
	Bimanual	3.433 (1.18)	1 (1)	.064 (.277)
G/L hold	Unimanual	2.159 (2.976)	1 (1)	0.142 (.085)
	Bimanual	4.445 (.2)	1 (1)	0.035 (.655)
Gain	Unimanual	3.433 (1.18)	1 (1)	.064 (.277)
	Bimanual	0.918 (.102)	1 (1)	0.338 (.749)
Offset	Unimanual	2.551 (.69)	1 (1)	.11 (.406)
	Bimanual	0.918 (1.473)	1 (1)	0.338 (.225)
r Value	Unimanual	6.861 (9.016)	1 (1)	.008 (.002)
	Bimanual	6.876 (3.682)	1 (1)	.008 (.055)

Ramp and Hold

The measures defining task performance in the Ramp and Hold test had several examples of statistically significant group differences. The total root mean square error (RMSE total) showed that under the unimanual condition the NDH differed (H =

3.922, df = 1, p = 0.048), as well as when performed bimanually (H = 5, df = 1, 0.025). The RMSE total was broken down into RMSE ramp and RMSE hold. In the ramp portion of the task, the RMSE differed significantly in the NDH when the task was performed unimanually (H = 0.0142, df = 1, p = 0.0142). In the hold portion of the task, the RMSE was significantly different in both the DH and NDH when performed unimanually (H = 5.588, df = 1, p = .018 each). When the task was performed bimanually, the RMSE of the hold portion of the task was significant across group (H = 6.208, df = 1, p = 0.013).

The coefficient of variation of the GF and LF (CV GF, CV LF) during the hold portion of the task also had significant differences across group. When performed unimanually, the CV LF and the CV GF differed in the DH and NDH (For CV LF, H = 9.8, df = 1, p = 0.001, H = 6.861, df = 1, p = 0.008 respectively; For CV GF, H = 9.8, df = 1, p = 0.001 for each). When the task was performed bimanually, both the CV LF and the CV GF were found to be significantly different (H = 7.547, df = 1, p = 0.001, H = 9.8, df = 1, p = 0.001). In this case, only the RMSE total of the DH during the unimanual portion of the test was found to be close to significant (see Table 5.5).

Table 5.5: The Kruskal-Wallace H-test results for the root mean square error (RMSE) for the total task as well as the ramp and hold portions, the coefficient of variation (CV) for the load force (LF) and the grip force (GF) when performed unimanually (Uni) or bimanually (Bi) in either the dominant (DH) or nondominant hand (NDH) during the hold portion of the Ramp and Hold task

Measure	Hand	H value	df	p value
RMSE Total	Unimanual	2.976 (3.922)	1 (1)	.085 (.048)
	Bimanual	5	1	0.025
RMSE ramp	Unimanual	1.18 (2.159)	1 (1)	.277 (.0142)
	Bimanual	2.551	1	0.11
RMSE hold	Unimanual	5.588 (5.588)	1 (1)	.018 (.018)
	Bimanual	6.208	1	0.013
CV LF hold	Unimanual	9.8 (6.861)	1 (1)	.001 (.008)
	Bimanual	7.547	1	0.006
CV GF hold	Unimanual	9.8 (9.8)	1 (1)	.001 (.001)
	Bimanual	9.8	1	0.001

There were also several variables related to hand grip force coordination that were statistically significant across group. The GF/LF ratio of the DH during the hold portion differed significantly (H = 3.922, df = 1, p = 0.048) when the task was performed unimanually. The offset of the DH was also was significantly differed across group when performed both unimanually and bimanually (H = 3.922, df = 1, p = 0.48, H = 4.445, df = 1, p = 0.035 respectively). The r value was found to be significantly different across group for both the DH and NDH both unimanually and bimanually (see Table 5.6). Also, listed in Table 5.6, there were several values that had group differences close being statistically significant.

Table 5.6: The Kruskal-Wallace H-test results for the grip force load force ratio (G/L) from the ramp and hold portions of the Ramp and Hold task as well as the gain, the offset, and the r value. The tasks were performed unimanually (Uni) and bimanually (Bi) with both the dominant (DH) and nondominant (NDH) hands

Measure	Hand	H value	df	p value
G/L ramp	Unimanual	2.976 (3.433)	1 (1)	.085 (.064)
	Bimanual	2.551 (2.551)	1 (1)	.11 (.11)
G/L hold	Unimanual	3.922 (2.976)	1 (1)	.048 (.085)
	Bimanual	2.551 (2.976)	1 (1)	.11 (.085)
Gain ramp	Unimanual	.494 (.2)	1 (1)	.482 (.655)
	Bimanual	.2 (.2)	1 (1)	.655 (.655)
Offset ramp	Unimanual	3.922 (2.976)	1 (1)	.048 (.085)
	Bimanual	4.445 (.331)	1 (1)	.035 (.565)
r Value	Unimanual	5.011 (6.545)	1 (1)	.025 (.011)
	Bimanual	4.824 (6.545)	1 (1)	.028 (.011)

Results

Simple Lift

Task Related Variables

The difference across groups of the coefficient of variation (CV) of the LF during the holding portion of the simple lift was approaching statistical significance in the DH when performed unimanually. In this case, the participants in the CP group exhibited a LF while trying to hold the object still with close to significantly higher variance than participants in the TD group. Further observation of the data shows that, while not approaching statistical significance, the rest of the task related data for the simple lift may also show similar behavior (see Figures 5.4 and 5.5).

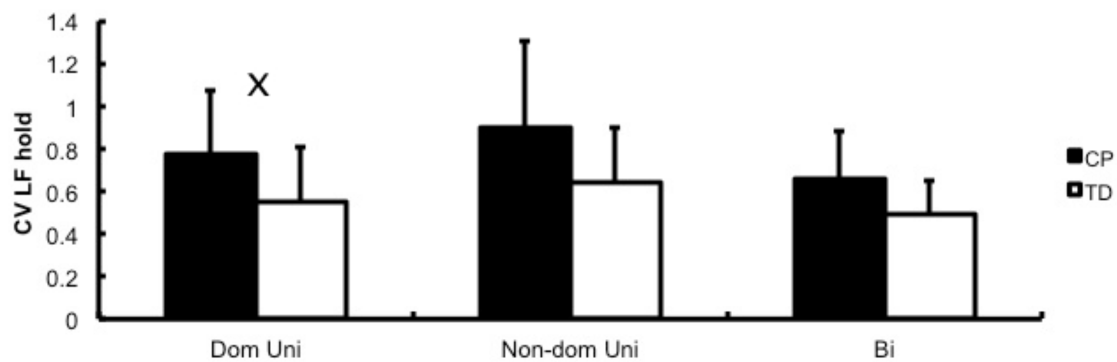

Figure 5.4: The coefficient of variation of the load force (LF) from the hold portion of the Simple Lift task for the dominant hand (Dom) and nondominant hand (Non-dom) when performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1

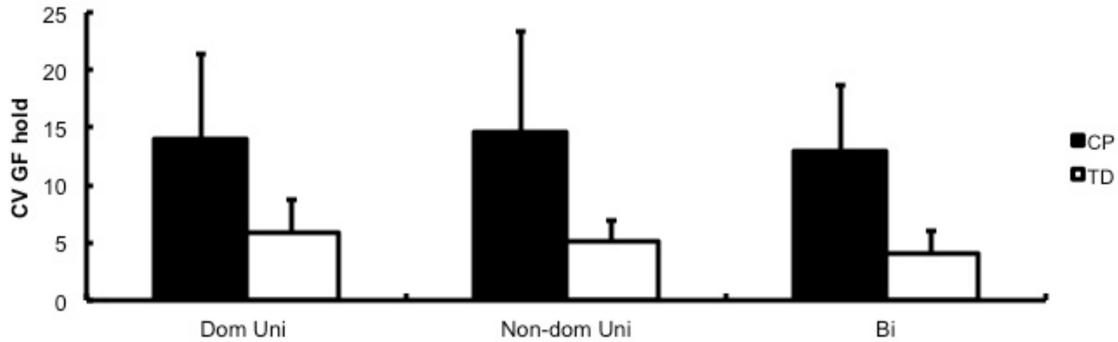

Figure 5.5: The coefficient of variation of the grip force (GF) from the hold portion of the Simple Lift task for the dominant hand (Dom) and nondominant hand (Non-dom) when performed unimanually (Uni) and bimanually (Bi).

Force Coordination Variables

In the force coordination variables, there were also examples where the differences across group were approaching significance as well as some instances where the differences were statistically significant. Where these differences were either significant or approaching significance in the GF/LF ratio during both the lifting and the holding portions of the simple lift task, the CP group performed with a higher ratio as well as with higher variability (see Figures 5.6 and 5.7). This means that for every amount of LF applied during the task there was a higher amount of GF applied to the device by the participants in the CP group than those in the TD group.

The gain, a measure calculated as the slope of a line fitted from the data plotted as the GF vs LF, was approaching significance across group in the DH when performed the simple lift was performed unimanually (see Figure 5.8). In this case, the

CP participants performed with a higher gain. A higher gain is a higher slope. The offset, the GF vs. LF plot's y - intercept, did not have any significant differences (see Figure 5.9)

The r value, the correlation between the GF and the LF, had three statistically significant differences across group with the fourth approaching significance (see Table 5.7). In this case, the CP group had lower values than the TD group showing that the LF was not as strongly correlated with the GF for the CP group as the TD group.

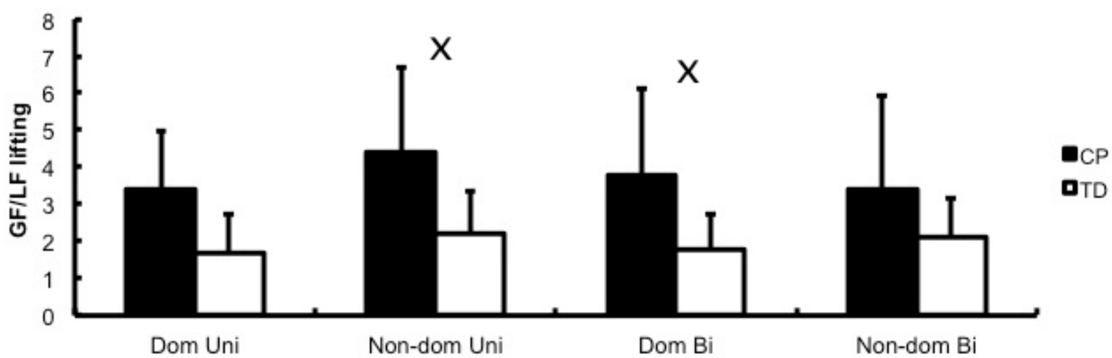

Figure 5.6: The grip force to load force ratio (G/L) for the lifting portion of the Simple Lift task with both the dominant (Dom) and nondominant (Non-dom) hands performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1

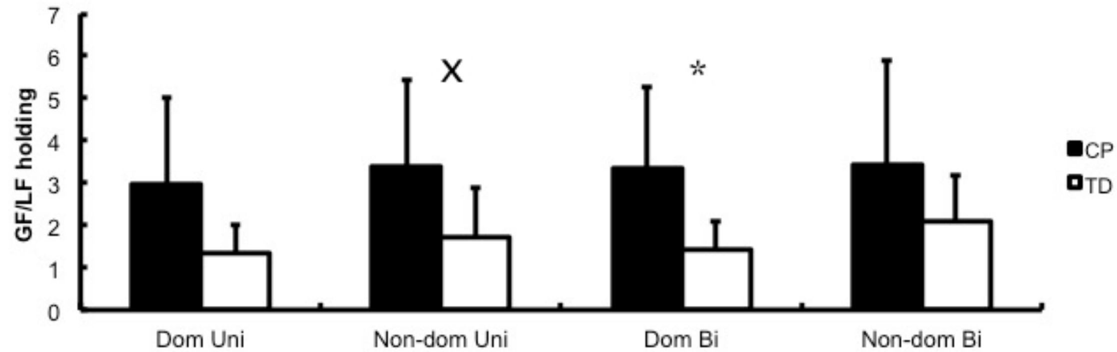

Figure 5.7: The grip force to load force ratio (G/L) for the holding portion of the Simple Lift task with both the dominant (Dom) and nondominant (Non-dom) hands performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1 and "*" indicates significant with a p value ≤ .05

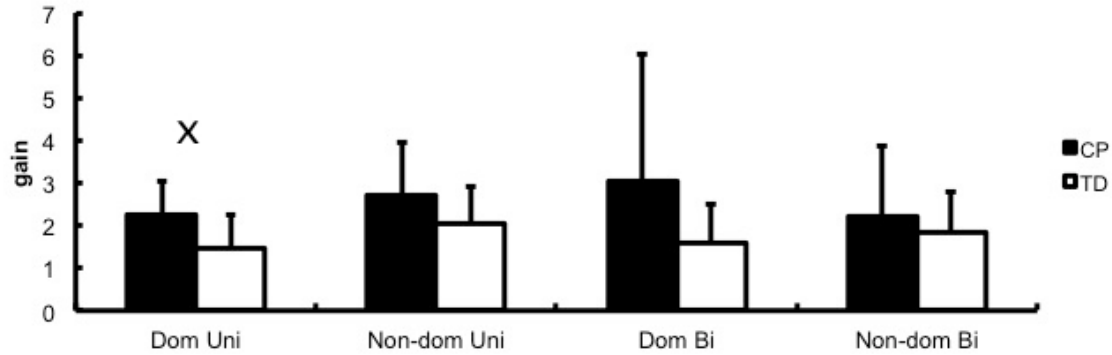

Figure 5.8: The gain from the Simple Lift task with both the dominant (Dom) and nondominant (Non-dom) hands when performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1

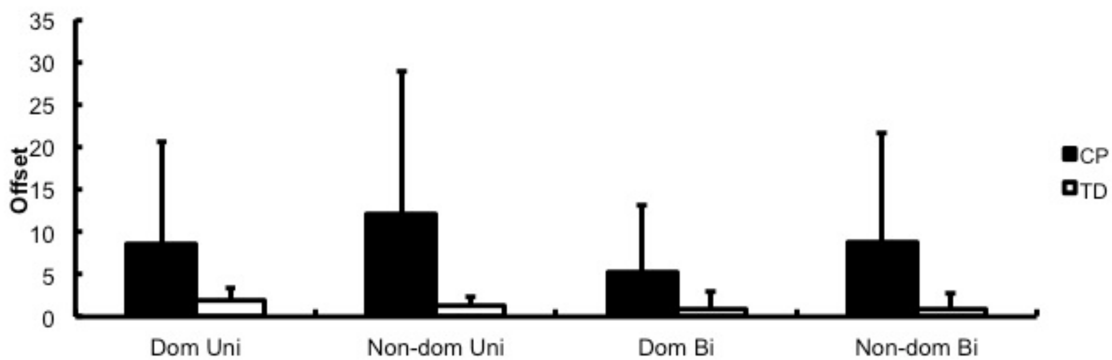

Figure 5.9: The offset from Simple Lift task with both the dominant (Dom) and nondominant (Non-dom) hands when performed unimanually (Uni) and bimanually (Bi).

Table 5.7: The r value from the Simple Lift task with both the dominant (DH) and nondominant (NDH) hands performed unimanually (Uni) and bimanually (Bi) along with the p value across group.

r	DH		NDH	
	Uni	Bi	Uni	Bi
CP	0.853	0.815	0.703	0.859
TD	0.961	0.932	0.955	0.953
p value	0.009	0.003	0.009	0.055

Ramp and Hold

Task Related Variables

The CP group performed the Ramp and Hold task with more error than the TD group. The total error for the task either differed significantly or was approaching statistical significance (see Figure 5.11). When the task was partitioned into ramp and hold portions of the task, few significant differences were detected in the RMSE of the ramp portion than the hold portion (see Figures 5.12 and 5.13). However, they exhibited similar behaviors in error. The CP group performed with significantly more error during the hold portion for either hand unimanually or bimanually as well as in the NDH for the ramp portion when it was performed unimanually.

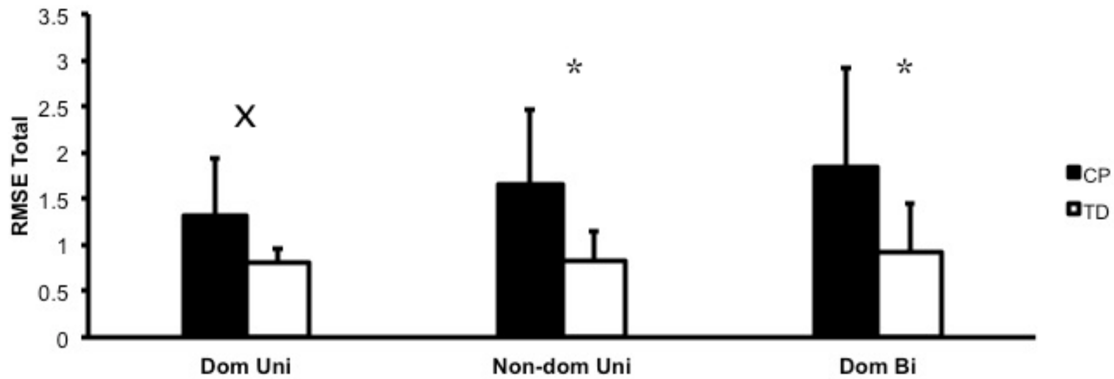

Figure 5.10: The root mean square error (RMSE) for the entirety of the Ramp and Hold task with both the dominant (Dom) and nondominant (Non-dom) hands performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1 and "*" indicates significant with a p value ≤ .05

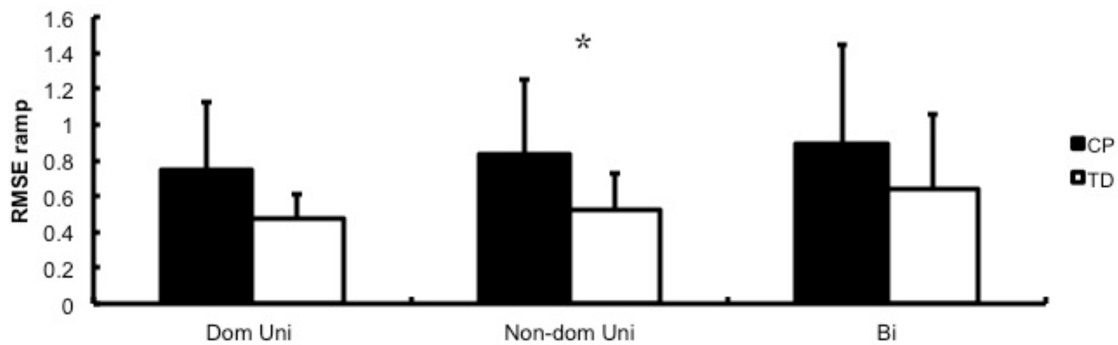

Figure 5.11: The root mean squre error (RMSE) of the ramp portion of the Ramp and Hold task with both the dominant (Dom) and nondominant (Non-dom) hands performed unimanually (Uni) and bimanually (Bi). "*" indicates significant with a p value < .05

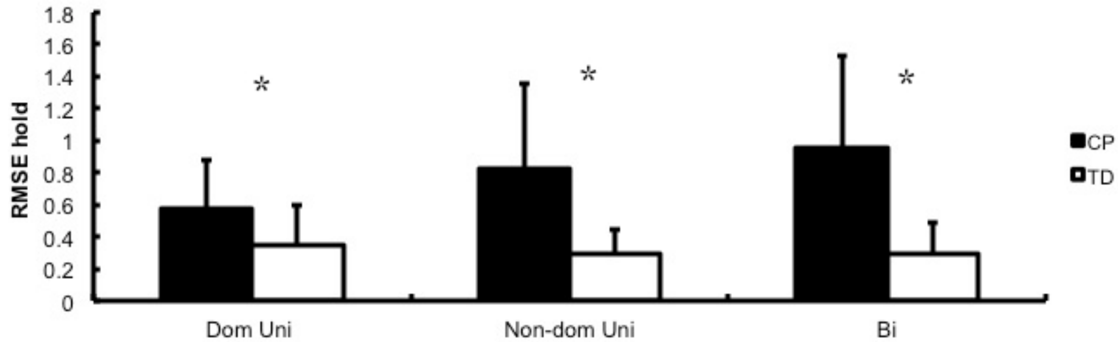

Figure 5.12: The root mean square error (RMSE) for the hold portion of the Ramp and Hold task with both the dominant (Dom) and nondominant (Non-dom) hands performed unimanually (Uni) and bimanually (Bi). "*" indicates significant with a p value $\leq .05$

The CV for the LF and the GF during the hold portion of the task were all significantly higher, unimanually, bimanually, DH, or NDH (see Figures 5.14 and 5.15). In each case the CP group performed with more variance than the participants in the TD group.

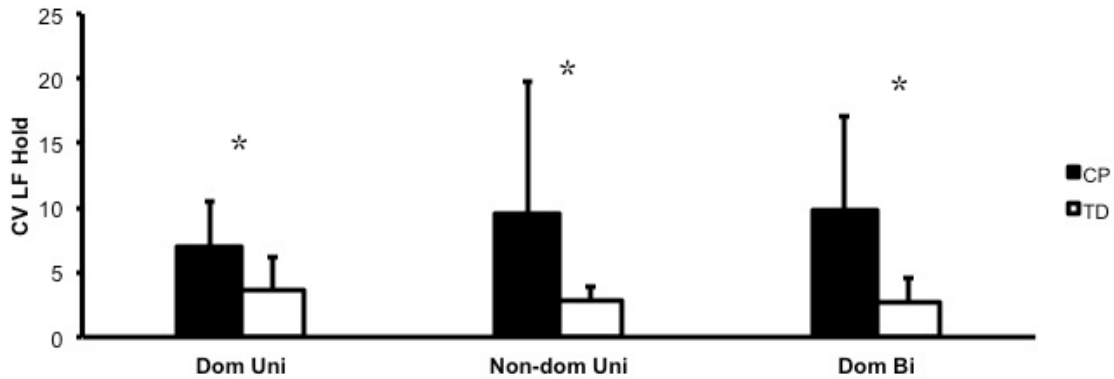

Figure 5.13: The coefficient of variation (CV) of the load force (LF) from the hold portion of the Ramp and Hold task for the dominant hand (Dom) and nondominant hand (Non-dom) when performed unimanually (Uni) and bimanually (Bi). "*" indicates significant with a p value ≤ .05

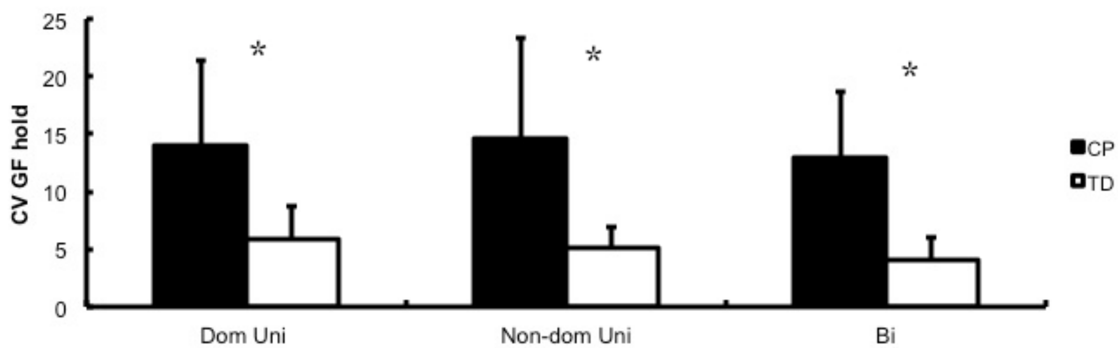

Figure 5.14: The coefficient of variation (CV) of the grip force (GF) from the hold portion of the Ramp and Hold task for the dominant hand (Dom) and nondominant hand (Non-dom) when performed unimanually (Uni) and bimanually (Bi). "*" indicates significant with a p value ≤ .05

Force Coordination Variables

The GF/LF ratio showed the DH to differ significantly during the hold portion of the task when performed unimanually. However, there were other instances where the ratio in which the performance were approaching significance (see Figures 5.16 and 5.17). In all these cases, the GF/LF ratio of the CP group was higher and had more variability than the TD group.

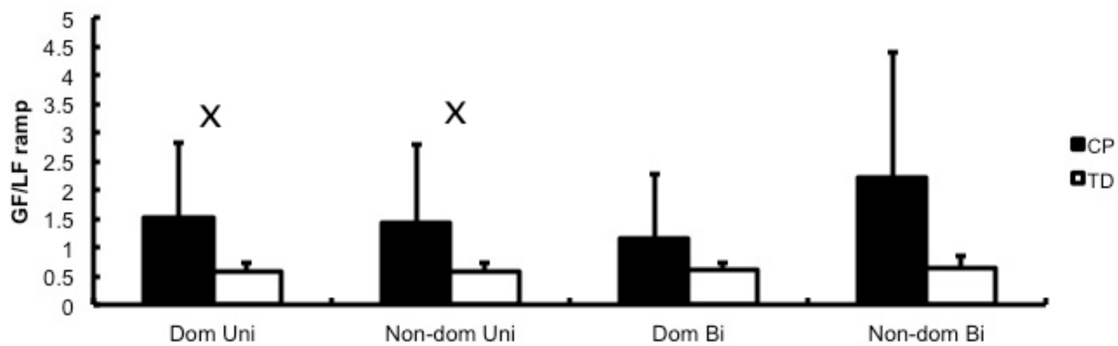

Figure 5.15: The grip force to load force ratio (G/L) for the ramp portion of the Ramp and Hold task with both the dominant (Dom) and nondominant (Non-dom) hands performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1

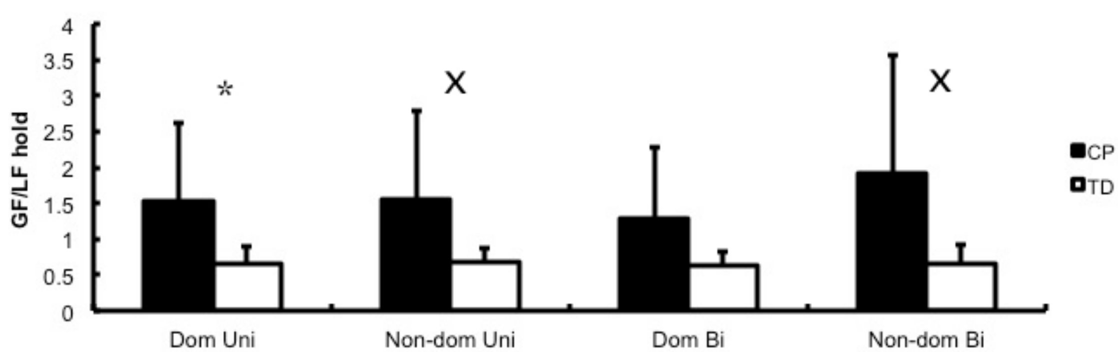

Figure 5.16: The grip force to load force ratio (G/L) for the holding portion of the Ramp and Hold task with both the dominant (Dom) and nondominant (Non-dom) hands performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1 and "*" indicates significant with a p value < .05

When the GF is plotted versus the LF, the slope and the y - intercept can be calculated from the linear fit of the data points. Just as in the Simple Lift task these are considered the gain and the offset. There were no differences detected in the gain. However, the offset in this case did show some differences across group. The DH when performing the task unimanually and bimanually were significantly different while the NDH was only approaching significance when performed unimanually. They not only differed in average value but also show a great deal of variance in comparison to the TD group.

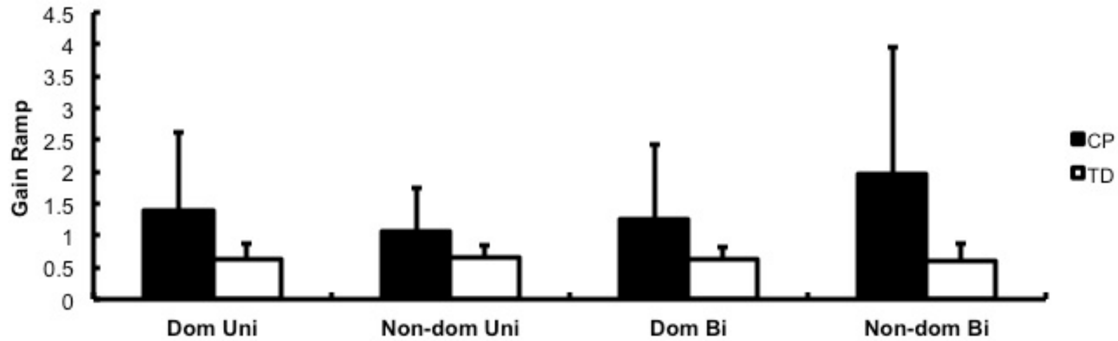

Figure 5.17: The gain from the Ramp and Hold task with both the dominant (Dom) and nondominant (Non-dom) hands when performed unimanually (Uni) and bimanually (Bi).

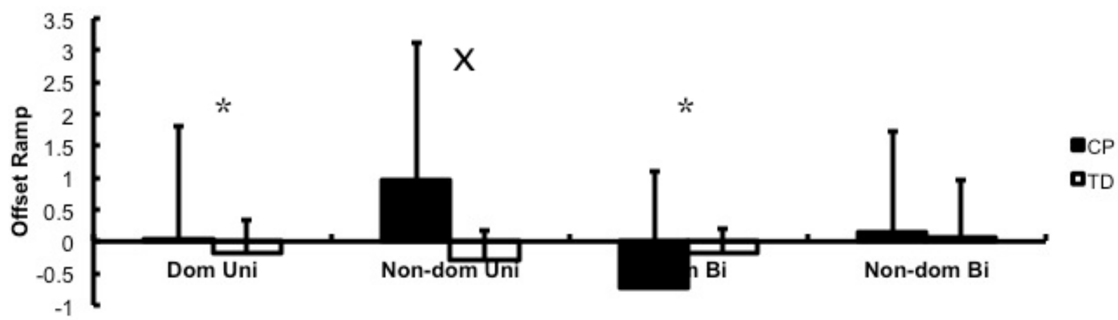

Figure 5.18: The offset from Ramp and Hold task with both the dominant (Dom) and nondominant (Non-dom) hands when performed unimanually (Uni) and bimanually (Bi). "x" indicates approaching significance with a p value < .1 and "*" indicates significant with a p value $\leq$ .05

The r value, showing the amount of correlation between the GF and the LF, differed significantly across group for the DH and NDH unimanually and bimanually (see Table 5.8). In each case, the CP group showed a smaller amount of correlation between the GF and LF than the TD group. In the case of the NDH when performing the task bimanually, there seems to be a much greater difference between groups.

Table 5.8: The r value from the Ramp and Hold task with both the dominant (DH) and nondominant (NDH) hands performed unimanually (Uni) and bimanually (Bi) along with the p value across group.

r	DH		NDH	
	Uni	Bi	Uni	Bi
CP	0.986	0.975	0.955	0.831
TD	0.992	0.989	0.991	0.994
p value	0.025	0.011	0.028	0.011

Discussion

Tasks requiring precise hand function may seem simple to someone who does not have any dysfunction. But for someone with a neurological condition, like cerebral palsy (CP), the dysfunction may be the difference between success and failure. Outside of the findings of this study there are limited amounts of information pertaining to the motor control of hand function in people with the CP subtype, spastic diplegia (SD). Since hand dysfunction can be a problem for people with SD (an idea that was verified in the previous chapter) and the bulk of the research on the topic focuses on the subtype of CP known as spastic hemiplegia (SH), some focus on learning more about hand function in individuals with SD would be beneficial for the people who live with it.

After examining the differences between the SD group and the typically-developing (TD) group in gripping force coordination as well as task proficiency, one can easily come to the conclusion that there is something different pertaining to hand function in people with SD. In the GF/LF paradigm, considerations are made to analyze how well the tasks are performed. This supplies more information to consider when interpreting the gripping force coordination that devices like the one in this study were designed to measure. Because of the high amount of variability and small number of participants in this study, some of the statistical techniques lacked the ability to detect differences. Despite these difficulties some significant differences and trends were observed.

There were two tasks performed for this study that involve the coordination of GF with LF, the Simple Lift task and the Ramp & Hold. A review of the data shows that the CP group performed differently from the TD group. The variables used to determine task completeness for the Simple Lift are used to measure the timing between forces as well as the amount of variability expressed by the individual during different portions of the task. The coefficient of variation (CV) of both the LF and GF in the Simple Lift did not show significant differences. However, they did show that there was a trend approaching significance. This indicates that it could be possible that people with SD have trouble holding the device still while waiting for the instruction to place it back down. This variability could also be interpreted as a lack of precision in holding an object still.

Difficulties related to task performance also seem to be supported by the data from when the participants performed the Ramp & Hold task. The differences between groups related to task performance also showed differences related to amount of error and variability. In the Ramp & Hold, people with SD performed with significantly more error and significantly more variability than people in the TD group. This task is performed with what seems to be more difficulty and less success. After looking over all the task related data for the Ramp & Hold, it can be determined that the movements that people who are TD may take for granted are probably more difficult to coordinate for people with SD.

The fact that coordination might be more difficult for people with SD supports evidence that there is a hand function deficit in individuals with SD. The task related performances and the group differences might assist in determining the cause of poor performance at the Jebsen Taylor Test (Chapter 4: Hand Function Deficits in Individuals with Spastic Diplegia). These results may also be related to results seen when, in a previous study, poor performance on the Jebsen Taylor test coincided with similar amounts of variability and error when the tasks were performed by individuals with SH (Mackenzie et al, 2009). It seems that, regardless of the presence of upper limb spasticity, there are deficits related to everyday tasks which seem to be able to be correlated to poor task performance in tasks related to grip force coordination. Maybe with further investigation in this area a more detailed description of the source of these deficits can be made.

In what could only be described as a difficult comparison due to the high variability and low participant numbers, a few traits regarding group differences in grip force variables during the tasks arose. It was hypothesized that the people in the CP group would exhibit high GF/LF ratios and gain. These hypotheses were somewhat upheld. The differences seen were approaching significance except in one example where groups did indeed differ significantly. However, based off of the trends the data showed, it is likely that with enough participants, all of these differences would have been detected despite the large amounts of variability.

Since the participants in the CP group exhibited a higher GF/LF ratio, it can be determined that they gripped unnecessarily high for each task they were asked to perform. This matches previous research on motor control characteristics in people with SH. (Gordon & Duff, 1999; Gordon, Charles, & Duff, 1999; Mackenzie, 2009) The unnecessarily high GF may represent an inability to distinguish the difference between a reasonable amount of force and an unnecessarily high amount of force for a given task. This might explain the large of amount of task related error and variability. If there were a difficulty in making a precise motor execution it would be expected that it result in error. Continued effort to accomplish a task in combination with continued error would most likely result in larger than normal amount of variance.

It was also determined that the gain was significantly different when performing the Simple Lift task. It is again possible that the limited statistical power was restricting in finding more meaningful differences, like in the Ramp and Hold. Usually when these variables are different it would indicate that the participants who performed the task utilized a different force modulation technique to determine how much force to apply. If the SD group did use a different grip modulation technique, as the data suggests, it could be related to the difficulty in regulating an appropriate GF/LF ratio or a difficulty in recognizing an inappropriate ratio.

Further analysis should definitely be done to determine whether or not this is the case. Because of the high variability in this data, a study should be performed with as many participants with SD as possible. This may allow more conclusive statistics that will help show group difference that will prove whether the force modulation is really the problem it seems to be at this point. Other studies that should be considered based on the outcome of this investigation should involve the comparison of neuro-imaging during force coordination tasks like the Ramp & Hold and Simple Lift. This will provide a large amount of detail in the task's measurements, like force coordination, but also may bring out any differences in neural corollaries to motor output.

It may also be of interest to compare the spastic hand coordination of someone with SH or spastic quadriplegia (SQ) to that of the non-spastic coordination seen in this study by people with SD. This could also be done in different ways. The use of anesthetics or botox could be used to change the excitatory signal to the muscles. This would change the affect of spasticity on hand coordination. If these results were to be compared to this and other studies much more about force coordination in people with CP would be known and possible explanations for coordination deficits in individuals with CP could be discussed more thoroughly.

Chapter 6

GENERAL CONCLUSIONS

A lot can be taken from this study. The methods used and data obtained not only teach us about cerebral palsy (CP) but can also tell us what we can do in the future to further our understanding of this neurological condition. This is the first time that this type of perspective has been considered with cerebral palsy, giving special attention to the individual characteristics of a specific category of CP known as spastic diplegia (SD). Also, this was the first time individuals with SD were asked to perform certain tasks. Finally, the interpretations of the data may offer scientists and clinicians insight into how these methods can be used to further understanding of defining and treating deficits that individuals with SD and other types of CP may have.

In this study, three different methodological paradigms were used to understand the motor behavior of individuals with SD. A standardized hand function test, the Jebsen Taylor Test, was used to represent the level of proficiency of manual manipulation skills in activities of daily living. A test to isolate and measure anticipatory motor planning ability, End Task Comfort (ETC), was used to determine what role cognitive factors played in the biomechanical output seen in the participants. Proficiency in this test represented an awareness of an individual's body within the context of his or her movement. Poor performance in this paradigm is supposed to represent an inability to properly prepare and plan for the biomechanics needed to efficiently and comfortably perform a task and would represent a deficiency in motor imagery or motor planning. The third paradigm applied utilized the coordination of the forces involved in gripping. Gripping in typically developing individuals exhibit a certain behavior to allow for efficient, flexible grip strategies. Differences in grip strategy can sometimes reveal deficits in the ability to properly execute force coordination in the hands in a functional way.

In each of these paradigms, this was the first time a comparison between participants with SD and typically developing participants was used to determine if there were deficits in the SD group. Previously these types of studies have been performed with experimental groups consisting of either a different type of CP, such as spastic hemiplegia (SH), or have consisted of multiple types of CP, preventing conclusions from being able to be made regarding SD specifically (Hadders-Algra, et al, 1999; Hirschfeld, 2007; Mackenzie, et al, 2009; Steenbergen & Gordon, 2006). This is an important consideration because of the neurological differences between the various types of CP. Also some of the previously studied types of CP have shown deficits in these areas but also have notable spasticity in the hands and upper limbs. This confounding factor makes it difficult to determine if this is the cause of manual deficits in individuals with CP and does not explain why there are similar deficits in people who have SD, a type of CP where spasticity is generally pronounced in the lower limbs and usually minimally affecting the hands and upper limbs (Himmelmann, et al, 2006). This study, by taking the global approach towards CP motor deficits, is the first step towards understanding why these types of deficits exist in the absence of pronounced spasticity in individuals with CP.

When the results from the Jebsen Taylor Test were analyzed, it was found that the participants with SD performed significantly slower than the typically developing control group in each of the six subtests performed. This can be interpreted as a deficit in manual coordination in tasks pertaining to activities of daily living and is the first time it has been shown with adult participants who have the SD subtype of CP. This confirms data in previous studies showing a correlation between gross motor function and bimanual fine motor function (Himmelmann, et al, 2006). It also indicates that there is a functional manual coordination deficit in individuals with SD. However, it is difficult to fully explain the origin of this deficit with there being no significant form of spasticity in the motor areas being tested. This would indicate that there is a global motor deficit in individuals with CP independent of spasticity.

One possible explanation for these results would be that individuals with SD have difficulty appropriately utilizing motor imaging and anticipatory motor planning to adapt their movements with respect to the context of their biomechanics. In previous studies it was found that in SH, individuals with lesions affecting their left hemisphere found it difficult to perform tasks pertaining to ETC (Mutsaarts, et al, 2006). Because the lesion patterns in individuals with SD are bilateral in nature, it was appropriate to consider that this could be an option. The results for this task were not as clear. It was difficult to discern, statistically or otherwise, the difference between the performance of individuals with SD and the performance of the typically developing controls.

One interpretation of this finding could be that the SD group was able to perform just as proficiently as the typically developing control group. However, this would not explain the deficits seen in the Jebsen Taylor Test, nor agree with data seen in other studies examining non-spastic coordination in individuals with SD or other forms of CP. It is most likely that the methods used to test this measure of motor behavior were not effective in determining skill level for either group participating with enough precision as to isolate the differences between the individuals with SD and the typically developing controls. If other techniques are determined capable of presenting those group differences more effectively, they should be utilized in order to properly determine if there is indeed a difference between groups regarding motor imagery and anticipatory motor planning. It is still expected that, under the right methodology, the SD group would perform significantly worse. If this were the case it would indicate a deficit in attention to or awareness of biomechanical context in motor behavior. This idea is confirmed by a study showing a lack of the awareness of position during motor performance. After an intervention was performed and participants were made aware of their error, improvements in motor performance were achieved (Thorpe & Valvano, 2002).

Based off of the differences seen in the ability to effectively control grip force, this could also serve as an explanation for the worse performance on the Jebsen Taylor Test. Also, because of the high amount of error seen in the Ramp & Hold test, there may also be an indication that this study has begun the process of defining what may possibly be a new deficit in SD and CP in the ability to proficiently control output based off of integration of sensory feedback. This might explain the higher than necessary GF during both the Simple Lift and the Ramp & Hold and may also indicate why there was so much variability in the output.

Answers to the origin of these high amounts of error, variability, and GF may be able to be found in some of the other descriptors of grasping behavior. Higher gain, different offset, and lower r values all indicate that the CP group performs motor behavior differently from the TD group. A higher gain indicates that there the motor area responsible for determining appropriate GF in an individual with CP will more likely have a higher than necessary excitatory effect on the output, resulting in the higher than typical GF/LF ratio. Also, the individuals in this study with SD had lower r values indicating that there was less of a correlation between the GF and the LF. This was in both feedback and feed-forward tasks indicating that it is built into the person's ability to perform motor tasks in general. However, the results were more significant in the feedback task. This shows that being present in both tasks, integration of sensory feedback affects the ability to properly execute proficient motor behavior, especially when sensory information is more critical to the task.

It is possible that the lesion in the motor cortex affects sensorimotor integration, especially with regards to its effective output. This is supported by the idea that under changes of tactile conditions individuals with CP take longer to make the appropriate adjustments when compared to TD controls. The adaptions are eventually made however they take much longer (Gordon & Duff, 1999). If this is truly the case, it could be seen in different areas and motor relationships across the body. Difficulty in exhibiting flexible motor stability would explain this difficulty of smooth integration from one set of required motor conditions to another, such as gripping a slippery object with high grip and adjusting to an easier grip for an object with a very high coefficient of friction. The high gain and poor correlation may represent this lack of stability in this particular motor behavior.

Future considerations would be to consider the neurology of individuals with CP, resulting in these global motor deficits. If there is prenatal damage to the oligodendrocyte progenitor cells (Riddle, et al, 2006), it could cause a different wiring of the white matter in the motor cortex. It may be possible that the lesion may exhibit circuitry behavior directly responsible for this type of output. It would be of interest to examine the structural and functional differences between the motor cortex of an individual with CP to that of a TD individual while performing tasks such as the gripping tasks presented in this study. The differences in the function of the motor cortex may be able to be linked to differences in motor output and explain the origins of the motor deficits. This information could allow clinicians to fully understand the disparate motor behavior of someone with CP and allow them to take the most effective route in assisting them to learn new skills and utilize their motor system to the best of their ability.

Bibliography

Ada, L., Vattanasilp, W., O'Dwyer, N. J., & Crosbie, J. (1998). Does spasticity contribute to walking dysfunction after stroke? *Journal of Neurology, Neurosurgery, & Psychiatry*, 64, 628-635.

Beckung, E., & Hagberg, G. (2002). Neuroimpairments, activity limitations, and participation restrictions in children with cerebral palsy. *Developmental Medicine & Child Neurology*, *44*, 309-316.

Bennett, B. C., Abel, M. F., Wolovick, A., et al. (2006). Center of mass movement and energy transfer during walking in children with cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, 86, 2189-2194.

Cohen, R. G., & Rosenbaum, D. A. (2004). Where grasps are made reveals how grasps are planned: generation and recall of motor plans. *Experimental Brain Research*, 157, 486-495.

Dellon, A. L. (1978). Moving two point discrimination test: Clinical evaluation of the quickly-adapting fiber receptor system. *Journal of Hand Surgery*, *3*, 478-481.

Duff, S. V., & Gordon, A. M. (2003). Learning of grasp control in children with hemiplegic cerebral palsy. *Developmental Medicine & Child Neurology*, 45, 746-757.

Eliasson, A. C., Forssberg, H. , Hung, Y. C., & Gordon, A. M. (2006). Development of Hand Function and Precision Grip Control in Individuals With Cerebral Palsy: A 13-Year Follow-up Study. *Pediatrics*, *118*, 1226-1236.

Eliasson, A. C., Gordon, A. M., & Forssberg, H. (1995). Control of isometric fingertip forces during grasping in children with cerebral palsy, *Developmental Medicine & Child Neurology*. *37*, 72-84.

Fonseca, S. T., Holt, K. G., Fetters, L., et al. (2004). Dynamic resources used in ambulation by children with spastic hemiplegic cerebral palsy: Relationship to kinematics, energetics, and asymmetries. *Physical Therapy*, 84, 344-354.

Gordon, A. M., Charles, J., & Duff, S. V. (1999). Fingertip forces during object manipulation in children with hemiplegic cerebral palsy. II: Bilateral coordination. *Developmental Medicine & Child Neurology*, 41, 176-185.

Gordon, A. M., Charles, J., & Steenbergen, B.. (2006). Fingertip force planning during grasp is disrupted by impaired sensorimotor integration in children with hemiplegic cerebral palsy. *Pediatric Research*, 60, 587-591.

Gordon, A. M., & Duff, S. V. (1999). Fingertip forces during object manipulation in children with hemiplegic cerebral palsy. I: Anticipatory scaling. *Developmental Medicine & Child Neurology*, 41, 166-175.

Granata, K. P., Ikeda, A. J., Abel, M. F.. (2000). Electromechanical delay and relfex response in spastic cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, 81, 888-894.

Hadders-Algra, M, van der Fits, I. B. M., Stremmelaar, E. F., & Touwen, B. C. (1999). Development of postural adjustments during reaching in infants with CP. *Developmental Medicine & Child Neurology*, 41, 766-776.

Himmelmann, K., Beckung, E., Hagberg, G., & Uvebrant, P. (2006). Gross and fine motor function and accompanying impairments in cerebral palsy. *Developmental Medicine & Child Neurology*, *48*, 417-423.

Hirschfeld H. (2007). Motor control of every day motor tasks: Guidance for neurological rehabilitation. *Physiology & Behavior*. 92, 161-166

Hirtz, D., Thurman, D. J., et al. (2007). How common are the "common" neurological disorders?. *Neurology*, 68, 326-327.

Jaric, S, Knight, C. A., Collins, J. J., & Marwaha, R. (2005). Evaluation of method for bimanual testing coordination of hand grip and load forces under isometric conditions. *Journal of Electromyography and Kinesiology*, 15, 556-563.

Jebsen, R. H., Taylor, N., Trieschmann, R. B., et al. (1969). An objective an standardized test of hand function. *Archives of Physical Medicine and Rehabilitation*, 50, 311-319.

Johansson, R. S. & Westling, G.. (1991). Afferent signals during manipulative tasks in humans. Somatosensory Mechanisms, 25-48. Macmillan Press. London, United Kingdom

Johnston, T. E., Moore, S. E., Quinn, L. T., & Smith, B. T. (2004). Energy cost of walking in children with cerebral palsy: relation to the gross motor function classification system. *Developmental Medicine & Child Neurology*, 46, 34-38.

Kozeis, N., Anogeianaki, A., Mitova, D. T., Anogianakis, G., Mitov, T., & Klisarova, A. (2007). Visual function and visual perception in cerebral palsied children. *Ophthalmic and Physiological Optics*, *27*, 44-53.

Krageloh-Mann, I., & Horber, V. (2007). The role of magnetic resonance imaging in elucidating the pathogenesis of cerebral palsy: a systematic review. *Developmental Medicine & Child Neurology*, *49*, 144-151.

Krishnan, V., & Jaric, S. (2008). Hand function in multiple sclerosis: Force coordination in manipulation tasks. *Clinical Neurophysiology*, 119, 2274-2281.

Krumlinde-Sundholm, L., Eliasson, A. C. (2002). Comparing tests of tactile sensibility: aspects relevant to testing children with spastic hemiplegia. *Developmental Medicine & Child Neurology*, 44, 604-612.

Kulak, W., Sobaniec, W., Kuzia, J. S., & Bockowski, L. (2006). Neurophysiologic and neuroimaging studies of brain plasticity in children with spastic cerebral palsy. *Experimental Neurology*, *198*, 4-11.

Law, L. S. H., Webb, C. Y.. (2005). Gait adaptation of children with cerebral palsy compare with control children when stepping over an obstacle. *Developmental Medicine & Child Neurology*, 47, 321-328.

Mackenzie, S. J., Getchell, N., Modlesky, C. M., Miller, F., & Jaric, S. (2009). Using grasping tasks to evaluate hand force coordination in children with hemiplegic cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, 90, 1439-1442.

Miller, F. (2005). Cerebral Palsy. New York, New York, United States of America: Springer Science + Business Media, Inc.

Mohagheghi, A. A., Khan, T., Meadows, T. H., et al. (2008). In vivo gastrocnemius muscle fascicle length in children with and without diplegic cerebral palsy. *Developmental Medicine & Child Neurology*, 50, 44-50.

Mutsaarts M, Steenbergen B, Bekkering H. (2006). Anticipatory planning deficits and task context effects in hemiparetic cerebral palsy. *Experimental Brain Research*, 172: 151-162

O'Sullivan, M. C., Miller, S., Ramesh, V., Conway, E., Gilfillan, K., & McDonough, S. (1998). Abnormal development of biceps brachii phasic stretch reflex and persistence of short latency heteronymous reflexes from biceps to triceps brachii in spastic cerebral palsy, *121*, 2381-2395.

Olree, K. S., Engsberg, J. R., Ross, S. A., Park, T. S.. (2000). Changes in synergistic movement patterns after selective dorsal rhizotomy. *Developmental Medicine & Child Neurology*, 42, 297-303.

Palisano, R., Rosenbaum, P., Walter, S., et al. (1997). Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Developmental Medicine & Child Neurology*, 39, 214-223.

Pirila, S., van der Meere, J., & Pentikainen, T. (2007). Language and motor speech skills in children with cerebral palsy. *Journal of Communication Disorders*, *40*, 116-128.

Purves, D., Augustine, G. J., Fitzpatrick, D., et al. (2008). Central visual pathways. Fitzpatrick, D., *Neuroscience* (pp.289-311). Sunderland, Massachusetts, United States of America: Sinauer Associates, Inc. Publishers.

Riddle, A., Ning, L. L., Manese, M. , Beardsley, D. J., Green, L., & Rorvik, D. A. (2006). Spatial heterogeneity in oligodendrocyte lineage maturation and not cerebral blood flow predicts fetal ovine periventricular white matter injury. *Neuroscience*, *26*, 3045-3055.

Rosenbaum, D. A., Halloran, E. S., & Cohen, R. G. (2006). Grasping movement plans. *Psychonomic Bulletin & Review.* 13, 918-922.

Rosenbaum, D. A., Meulenbroek, R. J., Vaughan, J., & Jansen, C. (2001). Posture based motion planning: applications to grasping. *Psychological Review.* 108, 709-734.

Rosenbaum, D. A., van Heugten, C. M., & Caldwell, G. E. (1996). From cognition to biomechanics and back: the end-state comfort effect and the middle-is-faster effect. *Acta Psychologia, 94*, 59-85.

Rost, K., Nowak, D. A., Timmann, D., & Hermsdörfer, J. (2005). Preserved and impaired aspects of predictive grip force control in cerebellar patients. *Clinical Neurophysiology*, 116, 1405–14.

Russell. S. D., Bennett, B. C., Kerrigan, D. C., & Abel, M. F.. (2006). Determinants of gait as applied to children with cerebral palsy. *Gait & Posture*, 26, 295-300.

Schenker, R., Coster, W. J., & Parush, S. (2005). Neuroimpairments, activity performance, and participation in children with cerebral palsy mainstreamed in elementary schools. *Developmental Medicine & Child Neurology*, *47*, 808-814.

Schmidt, R., & Lee, T. D.. (2005). Sensory contributions to motor control. Motor Control and Learning (128-130). Champaign, Illinois, United States of America, Human Kinetics

Serrien, D. J., Burgunder, J. M., Wiesendanger, M. (2002). Control of manipulative forces during unimanual and bimanual tasks in patients with Huntington's disease. *Experimental Brain Research*, 143, 328–34.

Shevell, M.I., Majnemer, A., & Morin, I. (2003). Etiological yield of cerebral palsy: A contemporary case series. *Pediatric Neurology*, 28, 352-359.

Steenbergen, B., & Gordon, A. M. (2006). Activity limitation in hemiplegic cerebral palsy: evidence for disorders in motor planning. *Developmental Medicine & Child Neurology*, 48, 780-783.

Steenbergen, B., Hulstjin, W., & Dortmans, S. (2000). Constraints on grip selection in cerebral palsy: minimizing discomfort. *Experimental Brain Research*, 134, 385-397.

Takanashi, J., Tada, H., Barkovich, A. J., & Kohno, Y. (2005). Magnetic resonance imaging confirms periventricular venous infarction in a term-born child with congenital hemiplegia. *Developmental Medicine & Child Neurology*, 47, 706-708.

Tilton, A. H. (2006). Therapeutic interventions for tone abnormalities in cerebral palsy. *The Journal of the American Society for Experimental NeuroTherapeutics*, 3, 217-224.

Thorpe, D. E., & Valvano, J. (2002). The effects of knowledge of performance and cognitive strategies on motor skill learning in children with cerebral palsy. *Pediatric Physical Therapy*, 14, 2-15.

van Roon, D., Steenbergen, B., & Meulenbroek, R. G. J. (2005). Trunk use and co-contraction in cerebral palsy as regulatory mechanisms for accuracy control. *Neuropsychologia*, 43, 497-508.

Verrel, J., Bekkering, H., & Steenbergen, B. (2007). Eye-hand coordination during manual object transport with the affected and less affected hand in adolescents with hemiparetic cerebral palsy. *Experimental Brain Research*, 187, 107-116.

Viehweger, E., Robitail, S., Rohon, M. A., et al. (2008). Measuring quality of life in cerebral palsy children. *Annales de Readaptation et de Medecine Physique*, 51, 129-137.

Wright, F. V., Rosenbaum, P. L., Goldsmith, C. H., et al. (2008). How do changes in body functions and structures, activity, and participation relate in children with cerebral palsy?. *Developmental Medicine Child Neurology*, 50, 283-289.

Wood, E. (2006). The Child with Cerebral Palsy: Diagnosis and Beyond. *Seminars in Pediatric Neurology*. *13*, 286-296.

Appendix

THESIS INFORMED CONSENT FORM
UNIVERSITY OF DELAWARE

Research Study: Hand Function Deficits in People with Spastic Diplegia

Investigator: David Clizbe, B.S.

SUBJECT NAME: ______________________________________

1. PURPOSE / DESCRIPTION OF THE RESEARCH

You are being asked to participate in a research project at the University of Delaware. The purpose is to improve our understanding of how people with cerebral palsy perform in various tasks involving coordination. More specifically we are focusing on the participant's abilities to coordinate his or her hand(s) while performing tasks similar to what he or she would be doing in activities of daily living.

Previous studies have indicated that people with the hemiplegic form of cerebral palsy have presented deficits in the ability to coordinate gripping forces with lifting forces during use of their hands. Other studies have shown that this group of people also presents difficulties in standardized object manipulation tests. Further study revealed that general coordination regardless of the presence of spasticity was at a deficit in subjects with cerebral palsy when compared with subjects who have had a stroke and with subjects who are typically developing. This study intends to further examine these conditions in people with spastic diplegia. This will allow us to better understand cerebral palsy as a whole as well as the possible existence of non-spastic deficits in cerebral palsy.

You were chosen as a possible participant because you are between the ages of 13 and 25 years old. You were also chosen because you either have cerebral palsy that minimally affects your hands (spastic diplegia) or because you could serve as a typically developing subject to use for comparison.

The first thing you will do is go through some descriptive measurements to allow the investigators to have an objective understanding of your ability to perform general tasks of activities of daily living. For example the range of motion of your arms and hands will be measured as well as sensitivity to touch. You will then move on to the rest of the tasks in a randomized order.

You will be asked to complete a standardized test which assesses fine motor skills. This test will involved timed manipulation of common objects typically found in everyday situations. You will also be asked to complete some nonstandardized tasks. These tasks involved using one or two hands to apply force to a sensor to control the movement of a cursor on a computer monitor. This will allow you to complete a task requiring the controlled increase of force. You will also be asked to one at a time and simultaneously lift the force sensors as if you were lifting a common object like a glass. Another task that you will do involves rotating a large wooden wheel with a handle to allow investigators to measure the motor planning aspects of that particular movement. These tests have been used previous with children and adults of many different ages who are typically developing as well as those who have hemiplegic cerebral palsy. The total amount of time expected to complete all the tests in this study is 1-2 hours.

2. CONDITIONS OF SUBJECT PARTICIPATION

Information about you obtained from this study will be kept strictly confidential. You will not be individually identified, except by a subject number that is known only to the researchers. All data obtained during this study will be stored as paper files or on a computer disk and will be kept in a locked cabinet for at least three years. After three years your data files will be archived within our lab but all personal information such as your name and contact information will be destroyed. Your name or identity will not be revealed in any subsequent publication or presentation of results in any journal and/or conference. In the event you suffer from a physical injury as a direct result of these research procedures, you will receive first aid. If you should require additional medical treatment, you will be responsible for the cost. You are free to withdraw from the study at any time without any penalty.

3. RISKS AND BENEFITS

POSSIBLE RISKS AND DISCOMFORTS: The test involves only seated activities with reaching and manual manipulation components so very little discomfort is expected. We expect the amount of exertion for the participant to be to the same degree that he or she uses to perform typical tasks performed every day.

POTENTIAL BENEFITS: There is no direct benefit to you from this research. We hope that the results of this research will benefit people with cerebral palsy in the future. It is the goal of this study to learn information regarding hand function that may better assist in therapeutic interventions for people with cerebral palsy such as motor strategies and approaches to individual skills.

4. FINANCIAL CONSIDERATIONS

There is no financial compensation for this particular study.

5. CONTACTS

If you have any questions about this research study, its procedures, or risks and benefits, you can contact the principal investigator, David Clizbe at (302) 379-6633. You may also address questions to Dr. Nancy Getchell (302)831-6682. Additionally any of the assistants for this study may be able to help you with any questions as well.

If you have any questions or concerns regarding the rights of individuals who agree to participate in this study you can contact the Chair of the Human Subjects Review Board at the University of Delaware (302) 831-2136.

6. SUBJECT'S ASSURANCES

Your signature below indicates you have read the parental informed consent document. The purpose, procedures, and risks/benefits of this study have been explained to you. You knowingly assume the risks involved and understand that you may withdraw your consent to participate in this study at any time without penalty. Your signature also indicates you have received a copy of this consent document.

7. CONSENT SIGNATURES

Your signature below indicates that you have read and understand the above information, agree to participate in the study, and that a copy of this form has been given to you.

Participant's Name (printed): ___________________________

Participant's Signature: ___________________________ Date: ________

I certify that I have explained the purpose and procedures of this study to the potential participant. I have explained the potential risks and benefits of this study and have answered any questions or concerns which were raised. I have witnessed the above signature and I have provided the parent with a copy of this consent form.

Principal Investigator’s Signature: ___________________________Date: _______

INFORMED CONSENT FORM

Research Study: ASSESSMENT OF HAND FUNCTION THROUGH FORCE COORDINATION IN MANIPULATION TASKS

Investigators: Slobodan Jaric, PhD (Health and Exercise Sciences)

1. PURPOSE/DESCRIPTION OF THE RESEARCH

Slobodan Jaric has requested your participation in this research study. The purpose of this research is to examine how people exert different patterns of forces along a hand-held device. You are one of approximately 30 individuals who are recreationally active adults without a neurological disorder between the ages of 18 and 60 who will participate in this study. You will be asked to attend either one or two testing sessions lasting between 1 and 1.5 hours each.

At each session, you will sit in a chair or stand still and comfortably hold a lightweight device in front of you with tips of your fingers. At the beginning of the session, there will be a handedness test to make sure you are right handed. Then you will grip that the device with as much force as you can exert with each of your hands. Next, you will be given instructions on how to hold the device and what kind of forces to produce with your hands while holding it. The most applied force you will be asked to use during this part of the testing will not be greater than the forces produced while doing such things as eating with fork and knife, or lifting a glass of water.

2. CONDITIONS OF SUBJECT PARTICIPATION

Your participation is totally voluntary. The experimental results will be reported in aggregate form only. You will not be individually identified, except possibly by a subject number known only to the researchers. The results of the research study may be published but your name or identity will not be revealed. All data and records will remain confidential, securely stored as computer files or paper documents in a locked cabinet in the investigator's office indefinitely, and will only be accessed by the investigator. In the unlikely event of physical injury during laboratory testing procedures, you will receive first aid. If you require additional medical treatment, you will be responsible for the cost. Testing will be stopped if you cannot adequately perform the tasks. You may withdraw your consent and discontinue participation in this study at any time without penalty.

3. RISKS AND BENEFITS

There is a small risk of some transient muscle fatigue, however the task is not more strenuous than ordinary tasks of manipulating lightweight objects or using external supports we regularly perform during daily living. You will be given opportunity to rest during the testing session, if necessary.

There are no direct benefits to you for participation. However, this study should provide new information about the neural control of patterns of unimanual and bimanual forces in various manipulative tasks.

5. CONTACTS

If you have questions about the research study, you may call Dr. Slobodan Jaric (302/831-6174), Associate Professor, Department of Health and Exercise Sciences. If you have questions

Subject's initials: ________

regarding the rights of individuals who agree to participate in this research you may call the Chair of the University of Delaware IRB (302/831-2137).

6. SUBJECT'S ASSURANCES
I have read the above informed consent. The nature, demands, risks and benefits of the project have been explained to me. I understand that I may withdraw my consent and discontinue my participation in this study at any time without penalty or loss of benefit to myself. My participation in this research study is not related to any course grade associated with the University of Delaware. A copy of this consent form has been given to me.

7. CONSENT SIGNATURES

Subject's Signature: ______________________________ Date:__________

Subject's Name (printed): ______________________________ Date:__________

I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. I have provided the subject with a copy of this informed consent document.

Signature of the Investigator: ______________________________ Date:_________

Subject's initials: _________