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The Effects of Neuromuscular Stimulation and Exercise Intervention on the Upper Limb of Children with Spastic Hemiplegia

By

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A research dissertation submitted to the Faculty of Health Science, School of Therapeutic Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of MSc Med by dissertation in the field of Biokinetics

Johannesburg, 2021

Supervisor: Prof Demitri Constantinou

Dr Janine van der Linde

DECLARATION

I, **Bibi Fatima Hoorzook** , declare that this research dissertation is my own work. It is being submitted for the degree of Masters of Science in Biokinetics in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university/institution.

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PLAGIARISM DECLARATION

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ABSTRACT

Introduction: Children with hemiplegic cerebral palsy (CP) have a topographic distribution of spasticity unilaterally with the upper limb being more involved than the lower limb. They often have complete disregard of the affected upper limb relying solely on the unaffected arm to conduct activities of daily living (ADL). **Purpose:** This dissertation explored the combined effects of neuromuscular electrical stimulation (NMES) in addition to isometric and isotonic bicep curls on the upper limb of children with spastic hemiplegic CP, specifically addressing; flexibility, spasticity, and hand functionality.

Method: A multiple case study design was used in which nine participants aged between six and eighteen years consented to the intervention twice a week over an eight-week period. Prior to children receiving the NMES intervention, flexibility, spasticity and hand functionality were measured. Thereafter children received NMES which was applied to the biceps brachii muscle and consisted of four stages; 1) electromyography (EMG), 2) concentric stimulation, 3) electrically triggered stimulation (ETS) combined with isometric bicep curls and 4) stimulation modulation combined with isotonic bicep curls. Following the intervention, flexibility, spasticity and hand functionality were assessed and compared against outcomes obtained at baseline. Data was analysed using test pivot on Excel to extract means and Wilcoxon sign in which $p<0.050$ indicated a high significant relevance

Results: Significant improvements were noted in flexibility measurements during; shoulder flexion ($p=0.008$), shoulder abduction ($p=0.012$), shoulder internal rotation ($p=0.008$), elbow flexion ($p=0.012$), elbow extension ($p=0.008$), and wrist extension ($p=0.008$). Decreases in Ashworth spasticity scores of the shoulder, elbow, and wrist joint were noted. No improvements were noted in Tardieu spasticity scores, however; there were improvements in the joint angle range of motion at which spasticity occurred. The quality of the upper extremity skills test (QUEST) showed improvements in dissociated movements of the shoulder, elbow, and wrist ($p=0.007$), grasps ($p=0.011$), and a summary score ($p=0.008$).

Conclusion: The evidence suggests that the combined effects of NMES and bicep curl exercise improves flexibility, reduces spasticity, improves dissociation of the upper extremity, and the ability to grasp.

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OPERATIONAL DEFINITIONS

Spasticity: "Spasticity is manifested by increased stretch reflex which is intensified with movement velocity." (Lance J, 1980)

Hemiplegia cerebral palsy: "Involvement of ipsilateral upper and lower limbs, with the upper limb more severely affected than the lower limb, hand function being most affected. " (Bialik GM and Givon U, 2009, p 2)

Neuromuscular electrical stimulation: "the application of an electrical current of sufficient intensity to elicit muscle contraction." (Merrill DR, 2009, p 1)

Electromyography: is a "biofeedback therapy is an active, conscious rehabilitation training, by collecting the active motor muscle contraction intensity of the child to guide the repeated active training and closed-loop stimulation training through various forms of feedback ." (He et al., 2019, p 2)

Electrically triggered stimulation: "Electrical stimulation is voluntarily triggered by EMG in the affected limb." (Takeda et al., 2017, para 12)

Quality of life: "Quality of life is a measure of an individual's ability to function physically, emotionally and socially within their environment at a level consistent with his/her own expectations." (Church MC, 2005, p 80)

Activities of daily living: "Activities of daily living (ADL) are tasks that are fundamental to supporting participation across school, home and community environments." (James et al., 2014, p 233)

The Goal Attainment Scale (GAS): "A patient-centred outcome measure of clinically meaningful change." (Finlayson H, 2017)

Dissociation movements: "Physical movement that characterized by the ability to differentiate amongst different parts of the body." (Farlex, 2012)

Grasp: "A grasp is every static hand posture with which an object can be held securely with one hand." (Feix et al., 2009)

LIST OF ABBREVIATIONS

CP	Cerebral Palsy
QoL	Quality of Life
ADL	Activities of Daily Living
NMES	Neuromuscular Electrical Stimulation
CNS	Central Nervous System
ROM	Range of Movement
GMFCS	Gross Motor Functional Classification System
MAS	Modified Ashworth Scale
HABIT	Hand-Arm Bimanual Intensive Therapy
EMG	Electromyography
LSEN	Learner with Special Educational Needs
NCPPD	National Council for Persons with Physical Disability
SA	South Africa
AP	Action potential
Hz	Hertz

CHAPTER 1: INTRODUCTION

1.1 Introduction to the study

The use of neuromuscular electrical stimulation (NMES) has been widely studied and documented as a successful intervention modality for various conditions. However, there is a lack of recent evidence of its use in the affected upper limb of children with cerebral (CP) with the most recent study dating back to 2010 (Postans et al., 2010).

Cerebral palsy is defined as a motor disorder that is a result of prenatal, perinatal, or, postnatal factors with most causes of CP in South Africa (SA) being as a result of perinatal and postnatal complications (Mathye & Eksteen, 2016; Malherbe et al., 2018; Katangwe et al., 2020). Cerebral palsy is the most common type of motor disability worldwide, which affects both the upper and lower extremities in children and is divided into various types based on the topographical pattern. Hemiplegic CP presents with unilateral spasticity, mainly flexor patterned, resulting in children having developmental disregard of the affected upper limb (Gilmore et al., 2010). The degree of spasticity, agonist-antagonist response, range of motion, and weakness of muscle has a direct impact on activity limitations of both gross and fine motor skills in individuals with CP resulting in avoidance of upper limb usage and the reliance on the unaffected arm to conduct activities of daily life (ADL) (Beckung & Hagberg, 2002; Carnahan et al., 2007).

South Africa has noted an increase in the prevalence of physical disability from 5% in 2010 to 6% in 2016 and a current total prevalence of CP to be 10 / 1000 live births (Adnams, 2010; Mathye & Eksteen, 2016, Katangwe et al., 2020). Dyskinetic CP accounts for 7%, ataxic CP accounts for 4% and spastic CP accounts for 85% of cases, with hemiplegia making up 40% - 60 % of this population (Coombe, 2017; te Velde et al., 2019).

Early intervention modalities are important in managing and improving the quality of life in individuals with CP, with the focus on maintaining and building on functions to assist the independence of individuals. Previous research using NMES in children diagnosed with CP yielded positive outcomes as a treatment modality. In this research, the effects of NMES and exercise on the bicep muscle were explored to determine changes in spasticity and flexibility of the shoulder, elbow, and wrist joint as well as on possible improvements in hand functionality.

1.2 Statement of the problem

Recent studies (Adnams, 2010; Mathye & Eksteen, 2016; du Toit, 2019; Katangwe et al., 2020) have shown increases in the prevalence of cerebral palsy (CP) due to improvements in the healthcare system producing an increase in survival rates with a direct impact of morbidity in children.

A recent focus on CP in SA reported having a prevalence of 10 per 1000 live births (Donald et al., 2014; Katangwe et al., 2020). Recent studies completed in different parts of SA have concluded the prevalence of CP in children aged between 4 and 15 years to be 10/1000 live births in rural Umkhanyakude District, KwaZulu-Natal (KZN) in children under the age of 10 while children between the ages of 2 and nine years old in rural Mpumalanga having a prevalence of 0.5% in motor disabilities (Couper, 2002; Coombe, 2017; Kakooza-Mwesige et al., 2017; Duke et al., 2020). A study conducted in KZN by Couper J in 2002 and a recent study conducted by Katangwe et al in 2020 found that the prevalence of CP in SA to be higher than that in developed countries (Australia, England, Sweden, and India).

Numerous studies (Beckung & Hagberg, 2002; Carnahan et al., 2007; Gilmore et al., 2010; Lee, 2017,) have presented limitations in upper limb functionality in individuals diagnosed with hemiplegic CP. Cerebral Palsy in children with hemiplegia has hindered the functional capacity of the upper limb, preventing individuals from adequate participation in activities of daily living (ADL). The upper limb impairments range from limiting hemiplegics' ability to execute fine motor and manual ability tasks as opposed to gross motor tasks, with increased difficulty in executing bimanual tasks and in other cases choosing not to use the affected arm at all (Beckung & Hagberg, 2002; Carnahan et al., 2007; Lee, 2017). The affected upper limb impairments include difficulty in executing tasks such as "grasping, reaching, releasing and manipulating objects" (Gilmore et al., 2010). This increases the need for external assistance and results in individuals being unable to conduct ADL, effectively decreasing their ability to be independent.

These functional difficulties have increased the need for various therapies to manage individual complications arising from CP. Previous interventions used to manage upper limb discrepancies, particularly in children with hemiplegic CP include constraint-induced movement therapy, hand-arm bimanual intensive therapy, and mirror therapies (Eliassin et al., 2005; Gordan et al., 2007; Park et al., 2016). The interventions listed were conducted internationally with no research having been done in South Africa (SA).

The biokineticist plays a vital role as part of the multi-professional team in the treatment of CP and uses intervention modalities made available to them such as the application of neuromuscular electrical stimulation (NMES). Research (Carmick, 1993; Carmick, 1997; Schekar et al, 1999; Wright & Granat, 2000; Kamper et al, 2006; Ozer et al, 2006; Postans et al, 2010) has suggested the use of NMES as a treatment modality for children with hemiplegic CP and yielded positive outcomes with upper limb improvements in spasticity, range of motion (ROM), grasping, grip, and hand functionality.

Neuromuscular electrical stimulation (NMES) is commonly used to stimulate either the nerve or motor point of the nerve, and the response assists in the generation of a muscle contraction or to increase the synaptic efficacy of a muscle producing better movement and better outcomes of muscle function (Maffieulleti NA, 2010). This results in the improvement of the rehabilitation process and often yields positive results for a variety of conditions through the selection or creation of appropriate NMES programmes (Maffieulleti NA, 2010; Bergquist et al., 2011).

There is, however, a gap in the evidence on the use of NMES on the commonly affected upper limb of CP, especially on the influence of NMES when it is applied to the bicep brachii muscle and if it will improve hand functionality. This then posed the question whether the use of NMES on the upper extremity of the upper limb will be useful in eliciting change in spasticity and flexibility of the shoulder, elbow, and wrist joint, and hand functionality.

The researcher sets out to explain the findings of the study and the usefulness of the intervention in a clinical setting.

1.3 Research question

What are the combined effects of neuromuscular electrical stimulation and with an associated single type exercise intervention on the upper limb (bicep brachii muscle) in CP children with flexor patterned hemiplegia?

1.4 Purpose of the study

The purpose of the study was to determine clinical outcome measures on spasticity and flexibility of the shoulder, elbow and wrist joint, and quality of upper extremity skills following implementation of NMES with an associated single type exercise intervention

(isometric and isotonic bicep curl during the NMES intervention) among CP children with hemiplegia.

1.5 Aim of the study

This study aimed to determine the effects of NMES with an associated single type exercise intervention on the agonist muscle of the upper limb (bicep brachii muscle) to determine any improvement in range of motion, spasticity, dissociated hand movements, and grasps, in individuals with spastic hemiplegic cerebral palsy.

1.6 Objectives of the study

To determine the effects of determine the effects of NMES with an associated single type exercise intervention applied to the bicep brachii muscle on:

- range of motion of the shoulder, elbow, and wrist joint
- the spasticity of the shoulder, elbow, and wrist joint
- functional hand placement, grasps, and dissociated movement
- the change in functional expected outcomes

1.7 Hypothesis

The combined effects of neuromuscular stimulation and associated single type exercise applied to the bicep brachii muscle will decrease spasticity and improve flexibility, spasticity and hand functionality among children with flexor patterned hemiplegic CP.

1.8 Justification

The most recent evidence of NMES usage dates back to 2010 in which NMES was used on the wrist and elbow extensors in children with fixed joint contractures which yielded slight improvements in wrist contractures and passive elbow extension (Postans, 2010). Prior to 2010, there were a few intervention studies which focused on the usage on NMES on the wrist and forearm, either alone or in combination with splinting and dynamic bracing. This intervention was chosen relative to gap expressed in literature by Merill

(2009) which guided future research to be conducted on the other muscle groups of the upper limb. Furthermore, the bicep brachii muscle was chosen as hemiplegics often present with a contracted bicep brachii muscle resulting in elbow flexion. There is a lack of evidence based interventions having been completed on this population group within a South African context. The positive outcomes of this study could further be implemented into clinical settings and serve as a basis for future research.

1.9 Organisation of the dissertation

This chapter presents the intervention whereby NMES will be applied to the bicep brachii muscle in children, with isometric and isotonic bicep brachii contractions being completed in stages three and four, respectively. The research problems, its purpose, questions guiding the research together with the aims, objectives, and hypothesis have all been presented.

Chapter two is a review of the relevant literature on cerebral palsy in terms of its definition, epidemiology, aetiology, classifications, activity limitation, and treatment interventions particularly focusing on spastic hemiplegia.

Chapter three is an outline of the methodology used in conducting the research.

Chapter four presents the findings of the research and the outcomes are discussed in chapter five.

Chapter six summarises the research findings, provides clinical implications, and recommendations of the study.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Introduction to the review of literature

This chapter includes a definition of CP and combines literature on the classifying of CP, the prevalence and aetiology as well as the deficits and activity limitations due to the upper limb of hemiplegic CP, functional assessment and intervention by the multidisciplinary team including NMES. The relevant literature was obtained from but not limited to Google scholar, Wiley, Pub Med, and Research Gate.

2.2 Definition of Cerebral Palsy

Researchers (Stanley et al., 2000; Dan & Cheron, 2004, p. 58; Bax et al., 2005 p. 572; Rosenbaum et al., 2006; Baxter et al., 2007; Kurt EE, 2016) have had difficulty defining cerebral palsy (CP) due to the diverse nature of this condition. Continuous efforts have been made to build onto the existing definition with a more concise understanding of neuro-physiological aspects (Bax et al, 2005). Cerebral palsy can be broken down into sub parts in which cerebral refers to the brain and palsy to a lack of muscular control. Cerebral palsy can therefore be defined as a neuromuscular disorder or a motor disorder stemming from a non-progressive brain insult, such as lesions or anomalies in the immature brain during its development in the womb or before the full development of the brain (Badawi et al., 1998). The severity of the lesion or area of the brain which is; “injured, diseased, or defective” determines the extent of motor and sensory impairment and is prevalent throughout the individuals’ lifespan (Rana et al., 2017).

2.3 Epidemiology / Prevalence of Cerebral Palsy

Gladstone (2010) mentioned that the World Health Organisation (WHO) estimated that 200 Million individuals’ are suffering from some sort of disability. The global incidences of disability account for 5.1 % of the total population aged between 0 - 14 years old with physical disabilities ranging between moderate to severe ranging from a combination of physical, mental, and intellectual impairments to Down’s syndrome, spina bifida, and CP which in turn hinder their ability to participate in day to day activities (Mathye & Eksteen, 2016).

In 2010, SA had a population of 49 million people, classified as an upper middle-income country with a disability prevalence of 5% (Adnams, 2010). There has recently been an increase in the prevalence of disability equating to 6% of the population within SA. The 6% sum is attributed to a 2.1% and 3% prevalence of physical disability in children aged between 0 – 9 years and 10 – 17 years respectively (Mathye & Eksteen, 2016). According to the National Council for Persons with Physical Disability in South Africa (NCPPD), South Africa has a 2:1 ratio of children with disabilities in comparison to those without disabilities. The population size is expected to double by 2050 and this would result in a higher prevalence of disabilities and co-morbidities (Katangwe et al., 2020).

The global prevalence of CP is 2/1000 live births and ranges between 1.5 - 4 per 1000 births globally in both developed and developing countries (Donald et al., 2014; Kurt, 2016; Rana et al., 2017). The prevalence of CP has decreased in developed countries but continues to increase in developing countries such as in Africa. Lower-income countries and upper-middle income countries have an increased burden of CP (Tseng et al., 2018). Africa is deemed as a lower-income country and increases seen in prevalence rates of CP can be attributed to; lack of access to medical services resulting in perinatal complications, postnatal complications such as malaria, traumatic brain injuries, etc, and delayed disability presentations (Rana et al., 2017) A recent focus on CP in South Africa (SA) reported having a prevalence of 10 per 1000 live births (Donald et al., 2014; Katangwe et al., 2020)

The prevalence of CP in children aged between four and fifteen years old residing in rural Umkhanyakude District, KwaZulu-Natal (KZN) is 10/1000 live births (Couper J, 2002) while in rural Mpumalanga a 0.5% prevalence in motor disabilities were noted in children aged between two and nine years old (Coombe, 2017; Kakooza-Mwesige et al., 2016; Duke et al., 2020).

A study conducted in KZN by Couper (2002) and a recent study conducted by Katangwe et al. (2020) found that the prevalence of CP in SA to be higher than those in developed countries. South Africa being a developing country has a higher CP prevalence which is associated with a decrease in mortality rates due to mothers having access to healthcare facilities (Donald et al., 2015; du Toit, 2019). However, certain healthcare institutes in rural SA still lack expertise in successfully assisting in birthing and places the baby at risk of perinatal factors while in other instances, postnatal factors contribute to CP (Mathye & Eksteen, 2016; Malherbe et al., 2018; Katangwe et al., 2020).

Decrease in infant mortality rate and associated improvements in healthcare results in a much rarer occurrence of CP. Furthermore, accessibility to an array of therapies for

individuals diagnosed with CP in SA means a longer life expectancy. Specialist treatment for CP will therefore be required in various stages of the individuals' lifespan (du Toit, 2019).

2.4 Aetiology of Cerebral Palsy

Understanding the definition of CP is crucial in identifying the presence of CP as they always present as a non-progressive motor disorder. Badawi et al. (1998) identified the following as possible risk factors; vascular accidents, hypoxia, infections, and congenital anomalies of the central nervous system (CNS), and postnatal diagnosis of CP occurred up until the age of five. A follow-up study by Smitthers-Sheedy et al. (2014) included certain diseases, syndromes, and postnatal acquired brain injuries up to the age of four years to be constituents of CP.

There is no comparison in aetiology of CP in low-income and middle-income countires to developed or higher-income countries as low-income countries do not have access to proper medical services while middle-income countries have varying accessibility (Donald et al., 2014; Burton, 2015; Abdel Malek et al., 2020). The most common causes of CP in developed countries are a result of prenatal factors with most postnatal causes being documented within the first two years. In developing countries, perinatal and postnatal factors are constituents of CP with risk factors being either singular or multi-factorial and are often documented until the age of five (Stanley et al., 1998, te Velde et al., 2017). According to Patel et al. (2020), brain injuries that are acquired after the neonatal period up until 5 years have been accepted under the umbrella for CP.

Earlier studies have looked at aetiology in the various parts of the African continent and found the leading causes of CP to be due to perinatal and postnatal factors. These factors included asphyxia, meningitis, cerebral malaria, severe or untreated jaundice, septicaemia, meningoencephalitis, measles, pertussis, and human immunodeficiency syndrome.

A more recent study conducted after 2010, reinforced that the constituents of CP in resource-poor settings are due to perinatal and postnatal complications. The African Child Neurology Association included birth asphyxia, central nervous system (CNS) infections, kernicterus, and traumatic brain injuries that occur before a child turns two years old as contributors to CP in Africa (Donald et al., 2014). Kakooza-Mwesige et al. (2016) similarly concluded that 25% of CP in Uganda prevailed due to CNS infections and cerebral

malaria while Katangwe et al. (2020) proposed premature births, intrauterine hypoxia, congenital and postnatal infections to be leading causes of CP in SA.

Perinatal factors and postnatal infections continue to be the leading cause of CP in Africa with perinatal factors resulting in more severe impairments including spastic diplegia or quadriplegia while cerebral infarcts being responsible for most cases of hemiplegic CP which may occur either prenatal or perinatal (Donald et al., 2015; Kakooza-Mwesige et al., 2016; Coombe, 2017).

2.5 Classification of Cerebral Palsy

Cerebral palsy is classified according to the type, topography, and severity of the motor impairments (Mienar, 1956; Bax et al., 2005; te Velde et al., 2019).

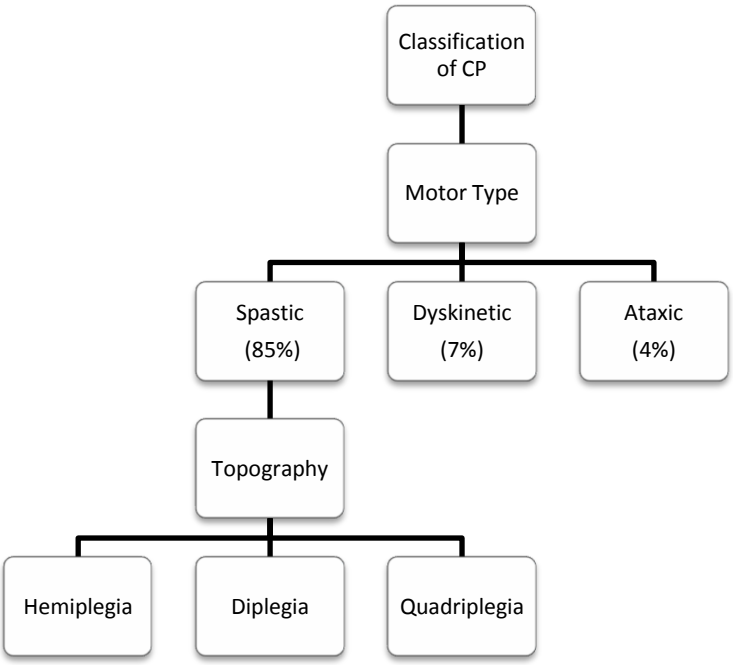


Figure 2.1: The hierarchy classifies CP into its various motor types and further subgroups the spastic motor types based on the topographical pattern (Coombe, 2017; te Velde et al., 2019).

Spastic CP is currently the most prevalent motor type accounting for 85% of cases and presents as quadriplegia, diplegia, monoplegia, or hemiplegia. In low- income and middle-income countries more severe types of spastic CP are prevalent (Sankar & Mundkur, 2005), whereas higher income countries have a higher prevalence of hemiplegic CP accounting for 40% - 60% than any other type of CP (Coombe, 2017).

Hospital-based studies in Africa presented higher rates of spastic diplegia than any other type of spastic CP with the least common type being hemiplegic CP (Gladstone, 2010). According to the National Council for Persons with Physical Disability in South Africa, spastic CP accounts for 77.4% of this population group. However, there is a lack of topographical sub-grouping of spastic CP in SA making accurate determinations of a sample size for research purposes challenging.

Typical clinical features of a spastic CP include inhibition of the stretch reflex directly affecting the velocity-dependent stretch producing resistance to stretch (Barrett & Lichtwart, 2010). Clinical features typically associated with spasticity include an increase in muscle tone and tendon reflexes, muscle tremors, muscle weakness and altered gait patterns (Krigger, 2006). Topographical distribution of motor impairments is used to further classify individuals by evaluating the number of limbs involved i.e. quadriplegic CP in which the entire body is involved or diplegic which affects only the lower limbs (Howard et al., 2005). According to Sankar and Mundkur (2005) quadriplegia involves the trunk as well as motor impairments of all four limbs with the upper limbs more affected than the lower limbs, while more severe forms of diplegia affect only the lower limbs resulting in “scissoring” appearance and milder forms of diplegia exhibiting toe walking (Sankar & Mundkur, 2005).

Hemiplegia appears as unilateral spasticity with the upper limb being more involved than the lower limb (Sankar & Mundkur, 2005).

2.6 Hemiplegic Cerebral Palsy

Hemiplegic CP arises as a result of either brain malformation or abnormalities of the periventricular white matter or lesions found in the cortical or subcortical tract or a postnatal brain injury which is non-progressive (Cioni et al., 1999). Brain malformations and cortical or subcortical lesions produce moderate forms of hemiplegia while abnormalities of the periventricular white matter and postnatal brain injuries produce milder forms. Bilateral lesions present in the periventricular white matter results in more lower limb involvement while the other causes have more upper limb involvement (Cioni et al., 1999). Damage to cerebral white matter and utero infections were also identified as leading causes of hemiplegia (Bax et al., 2005). The common clinical cause of hemiplegia result from the presence of; ventricular lesions, cerebrospinal fluid space abnormalities, or combined grey and white matter damage (Korzeniewski et al., 2011), whereas Patel et al. (2020) refer to the hemiplegic insult being as a result of utero or

perinatal stroke. Upadhyay et al. (2020), explained the neural basis of hemiplegic CP to be due to the presence of a cerebral infarct in the middle cerebral artery.

The site of the lesions plays a vital role in the presentation of individuals with hemiplegic cerebral palsy. Upper limb hemiplegic impairments are due to brain malformations, cortical or subcortical lesions, and postnatal brain injuries (Cioni et al., 1999).

Hemiplegia presents as flexor patterns where spastic impairments of the upper limb include: increased flexor tone; shoulder flexion, elbow flexion, forearm pronation, wrist flexion, finger and thumb flexion, and ulnar deviation, whilst dorsiflexion and foot eversion are present on the lower limb of the affected side (Sanker & Munker, 2005; Rana et al., 2017).

The above pattern makes grasping and releasing of objects difficult (Kamper et al., 2006). Due to the lack of elbow extension and forearm supination during activities, there is compensation using the trunk when trying to reach (Jaspers et al., 2009). Upper limb impairments in children with hemiplegic CP can be attributed to agonist-antagonist muscle imbalances, abnormality in muscle tone, and motor control impairment problems with alignment, spasticity, and strength deficits which directly impact activity limitations (Kamper et al., 2006).

2.7 Activity limitations

Motor projection pathways play an important role in determining activity limitations in CP. Hemiplegic hands may receive motor projections either; 1) contralaterally, from one hemisphere of the brain which is associated with good function and the ability to improve or 2) ipsilaterally, from both sides of the brain resulting in poor function (Holmstrom et al., 2009).

The degree of spasticity, agonist-antagonist response, range of motion, and weakness of muscle depend on the severity of the neurological insult which in turn has a direct impact on activity limitations of both gross and fine motor skills in individuals with CP (Beckung & Hagberg, 2002; Carnahan et al., 2007).

Hemiplegic children that present with lesions in the motor cortex and corticospinal tract often suffer from more severe upper limbs impairments (Steenbergen et al., 2007) while others may have damage to the left cerebral hemisphere resulting in the inability to accurately plan motor plan which in turn affects activities of daily life (ADL) (Steenbergen

& Gordan, 2006). Characteristics of the hemiplegic hand include slow weak uncoordinated movements, incomplete finger fractionation, spasticity, and impaired tactile sensibility (Eliassin et al., 2005).

Insults to the corticospinal tract and other motor pathways are associated with impaired finger movement and fingertip coordination whilst middle cerebral artery infarct affects fine motor sensory skills (Upadhay et al., 2020). The impairments of the motor and sensory pathways result in children diagnosed with hemiplegic CP learning and performing tasks with their unaffected arm resulting in reduction in use or complete disregard of the affected upper limb (Gilmore et al., 2010).

The presenting upper limb impairments limit hemiplegics' ability to execute fine motor and manual ability tasks as opposed to gross motor tasks, with increased difficulty in executing bimanual tasks and in some cases avoidance of using the affected arm altogether (Beckung & Hagberg, 2002; Carnahan et al., 2007; Lee, 2017). Hemiplegic activity limitation disorder does not only exist in the execution of the movement but also the planning of the movement (Steenbergen et al., 2007).

According to Steenbergen et al. (2007), movement planning is an essential component in executing skilled tasks and requires coordination of the trunk, shoulder, elbow and wrist together with appropriate grip, and loading forces. Skill tasks such as grasping and grips are skills acquired in early development which is reproduced throughout an individual's life and play an important role in ADL. During a grasp the object's weight and centre of mass assist appropriate motor planning for future interactions of the same object while the grip associates postural changes based on the outcome movement of the object (Elliason and Gordan, 2000).

Due to hemiplegics' disregard and lack of interaction with objects on the affected upper limb, they are unable to appropriately plan their fingertip forces accordingly, resulting in an inability to grasp (Upadhyay et al., 2020). Hemiplegics' motor planning impairment affects precision grasping, object manipulation, and bimanual coordination (Upadhyay et al., 2020).

Children diagnosed with hemiplegic CP have the intellectual ability to attend mainstream school, however, the individual limitations of the upper extremity results in a decreased ability to fully participate in educational, social, and leisure activities and they often struggle with their overall social image (Chiu & Ada, 2016; Lee, 2017). Furthermore, their cognitive ability and voluntary control play an important role in determining hand function

in children with hemiplegia on the basis of the child's ability and what the child actually does (Carnahan et al., 2007).

Various scales have been researched to determine the severity of the motor impairments and ability to use the upper extremity for participation in activities in individuals with hemiplegia. Such scales include; Gross Motor Function Classification Scale (GMFCS), Ashworth scale, Tardieu scale, Quality of Upper Limb Skill Test (QUEST) (Russell et al., 1998; Rosenbaum et al., 2002; Klingels et al., 2008; Singh & Singh, 2019; te Velde et al., 2020).

2.8 Functional assessment for hemiplegic cerebral palsy

The commonly used assessment scales and tests available to monitor developmental milestones and assess the quality of life (QoL) of individuals with hemiplegic cerebral palsy are detailed below:

The Gross Motor Functional Classification System (GMFCS) was developed by Palisano et al. (1997) which is a five-point scale and classifies children with cerebral palsy according to the level of their motor ability. The more functional the child, the lower the score on the GMFCS scale. The scale has high reliability scoring with an ICC > 0.90 and serves as an effective scale for beginner and expert therapists (Ko et al., 2011). This scale has been used in studies to develop research for clinical application (Morris & Bartlett, 2004), compare functional profiles of different types of CP (Wood et al., 2000; Damiano et al., 2006; Carnahan et al., 2007; Rosenbaum et al., 2008; Gorter et al., 2009), measurement of gait and energy efficacy, activity and participation restriction and health-related QoL (Ko et al., 2011).

The Manual Ability Classification Scale (MACS) was developed by Eliasson et al. (2006) to assist in classifying how well a child with CP handles objects in daily activities. It consists of a five-point scale whereby level 1 indicates the ability to handle objects at ease and level 5 indicates the inability to handle an object and has severe limitation in executing simple actions (Eliasson et al., 2006). The scale showed good interrater reliability which concluded an ICC 0.97 between therapist and 0.96 between parents and therapist. This scale is widely used in children with CP (Kuijper et al., 2010; Jeevanantham et al., 2015) and children with disability (Öhrvall et al., 2013).

The Modified Ashworth Scale (MAS) was created by Bohannon and Smith (1987) which is used to measure the spasticity of a joint. It consists of a six-point scale ranging from zero

to four whereby zero indicates no presence of spasticity and four indicates the limb being rigid in flexion or extension (Bohannon & Smith, 1987). The scale showed good reliability of 0.847 using Kendall's tau correlation (Bohannon & Smith, 1987). The reliability of the MAS was studied by Mutlu et al. (2007) which concluded an ICC 0.61 – 0.87 which proves it to have good reliability. This scale has been used to measure spasticity in; children diagnosed with CP (Mutlu et al., 2008, Yam & Leung, 2006; Numanoglu & Gunel, 2012), spinal cord injuries (Haas et al., 2006; Charalambous, 2014), stroke survivors (Gregson et al., 1999; Pandyan et al., 2003) and brain injuries (Mehrholz et al., 2005)

The Tardieu Scale was developed by Tardieu G, (1966) which evaluated a muscle spasticity response by applying a passive stretch to a joint at various pre-defined velocities (Gracies et al., 2010). The Tardieu scale has excellent intrarater and interrater reliability with scores of $p<0.001$ (Gracies et al., 2010). This scale has been used in brain injuries (Mehrholz et al., 2005; Ansari et al, 2006), disability and rehabilitation (Haugh et al., 2006), strokes (Alhusaini et al., 2010; Paulis et al., 2011), and cerebral palsy (Gracies et al., 2010).

Goniometry or range of motion (ROM) was initially described by Silver (1973). It is the process of measuring active flexibility movements in various joint by means of a hand-held goniometer (Norkins & White, 2016). The goniometer consists of a fulcrum, moving arm, and stationary am and uses a neutral-zero-method to measure limitations that may be present (Norkins & White, 2016). It provides information on tissue stiffness, abnormal fixed joint positions and pain (Norkins & White, 2016). No studies were found on the reliability or validity and uses of this method.

The Quality of Upper Extremity Skills Test (QUEST) was developed by Dematteo et al. (1992) and is used to measure the quality of hand and upper extremity function. The components included in the QUEST is dissociation movement of the shoulder, elbow, forearm, wrist joint, and fingers, type of grasp and release (one inch cube), postural deviations of the shoulder, type of grasp used whilst handling various objects (one inch cube, piece of cereal and a crayon). The reliability scores ranged between ICC 0.75 – 0.95 which shows excellent reliability (Dematteo et al., 1992). Various studies have used the QUEST in cerebral palsy (Hoare et al., 2007; Gilmore et al., 2010; Thorley et al., 2012)

The goal attainment scale (GAS) is a standardised measure used to quantify goal attainment and is a versatile tool used to set goals following an initial outcome assessment and engages participants in goal selection (Wasserman D, 2009). Scoring is completed using a five-point scale in which a score of +2 indicates the participant having

reached the much greater than expected outcome and -2 indicating their baseline level. The scale has an acceptable level of rater reliability ICC =0.832 (Wasserman D, 2009). The scale has been used for purposes of neuropsychological rehabilitation (Malec, 1999), nursing (Gordan et al., 1999), teaching (Roach & Elliott, 2005).

These scales provide valuable information on the child's ability to use the affected side and the intervention needed to promote movement and functional use of the limb. Intensive practice on the affected side may assist with effective motor planning of activities while sensory and motor input on the unaffected side could be used to facilitate movement on the affected extremity and bimanual therapy being considered as an effective therapy for the treatment of hemiplegia (Steenbergen & Gordan, 2006; Steenbergen et al., 2007).

2.9 Treatment of Hemiplegic Cerebral Palsy

2.9.1 The Importance of a Multidisciplinary Team

A multidisciplinary approach serves as an integral part of managing individuals with CP. The approach used is determined by the severity of the neurological insult and presenting motor disorder.

A comprehensive approach in a multidisciplinary setting provides modalities of intervention and assists in developing numerous levels of function which relies on different approaches at different time periods in relation to the arising needs of the individual (Rosenbaum et al., 2006; Novak et al., 2017). According to Patel et al. (2020), a multidisciplinary approach is the best model of care in managing both primary and secondary conditions in children with CP. Communication between disciplines is an integral part of ensuring the needs of the child and family are met (Gunel, 2009).

Neurodevelopment physiotherapy (NDT), occupational therapy, speech therapy, assistive devices, orthotics, corrective surgeries, medical treatment are required in the rehabilitative management of hemiplegic CP (Gunel, 2009). NDT therapy includes decreasing spasticity to reduce pain and improve positioning and function while reducing the risk of secondary complications and surgery. Furthermore, NDT plays an important role in the improvement of gross motor function, active movements, mobility, and transfers to ensure the optimal potential of the child is reached (Gunel, 2009)

Occupational therapy (OT) aids in gross and fine motor development as well as, visual and sensory development to appropriately conduct ADL (Gunel, 2009). An important role of the OT is their ability to improving upper limb usage (Rana et al., 2017). Improvements in fine motor function of the upper limb are directly related to improvement in independence as well as ADL (Patel et al., 2020).

Speech therapy also plays a significant role in the management of CP. Most children with CP including hemiplegic CP require speech therapy as spastic CP is associated with drooling and in some cases speech impairments (Thoya, 2018).

Biokineticist play a role in the management of CP through the identification of individual needs and limitations (van Wyk, 2017). It focuses on maintaining and improving the quality of life (QoL) for individuals and in turn reducing musculoskeletal and sensory impairments and improving activity and participation (van Wyk, 2017). Biokineticist condition individuals according to their needs and use various modalities to assist in pain management to ensure the easier continuation of ADL (Malan, 2014). They further assist in improving physical and health status, and QoL of life through individualized program design according to pathology (Ellapen & Swanepoel, 2017). Some modalities which can be used by Biokineticist in the treatment of CP include aquatic-based therapy which focuses in the improvement of strength, reduction of spasticity as well as, improvement in gross motor function, and neuromuscular electrical stimulation which aids in resistant training of muscles to produce ADL in a functionally correct manner. These therapies play an important role for family members in the management of the child in their ADL (Thoya, 2018).

Improvements in the SA healthcare system in the treatment and management of CP have seen more individuals living with CP surpassing the age of 30 (du Toit, 2019). He proposed the possibility of reinventing and implementing a multidisciplinary approach that will follow through an individual's life from birth into adulthood and possibly old age. This approach would be advantageous to the health of the individual (du Toit, 2019).

2.9.2 Intervention strategies in hemiplegic cerebral palsy

The aim of rehabilitation in CP is to minimise physical impairments, improving independence and overall quality QoL (Gunel, 2009, Novak et al., 2013). Improvements in developmental capabilities are important in reducing secondary impairments (Patel et al., 2020).

Different forms of therapy involved in the treatment of children with hemiplegic CP include:

Constraint-induced movement therapy is the process in which the unaffected upper limb is constrained and usage of the affected upper limb is encouraged through intensive practice using various techniques in the training of the hand (Eliassin et al., 2005). A study conducted by Eliassin et al. (2005) used constraint-induced movement therapy in children aged between 18 months and four years old over a two month period. The study yielded positive outcomes and concluded that it produced effective movement patterns and dexterity to the affected upper limb (Charles et al., 2006) leading to more independent usage of the affected limb (Eliassin et al., 2005). This type of therapy is often combined alongside NDT or OT intervention (Gordon et al., 2005).

Hand-arm bimanual intensive therapy (HABIT) uses principles of motor learning and neuroplasticity to coordinate movements of both hands as a more functional approach to play and ADL (Gordan et al., 2007). A study conducted by Gordan et al. (2007) evaluated the efficacy of HABIT applied 6 hours a day over a 10 day period in children aged between three years 6 months old and 15 years 6 months old. The study concluded HABIT to be an effective approach in engaging the unaffected limb in assisting with upper limb bimanual tasks (Gordan et al., 2007).

Mirror therapy relies on the activation of the mirror neuron system whereby mirror neurons are activated by observing ones upper limb movement reflected in a mirror and improves bimanual coordination, muscle strength, motor speed, and the ability to carry out ADL using both hands (Park et al., 2016).

Other strategies include exercise and electrical stimulation as a treatment modality (Upadhyay et al., 2020). In some cases, there are difficulties in resistant strength training which is due to spasticity resulting in decreases in motor strength. For this reason, electrical stimulation is seen as a useful modality in improving strength and motor outcomes (Gunel, 2009). The application of NMES on the bicep brachii muscle has not been previously researched and was chosen for this study to determine if its application would produce any changes to the overall upper limb placement and functionality often presented in children with spastic hemiplegic CP.

2.9.2.1 Exercise

Exercise is another component used in the management of CP, including hemiplegic CP. It consists of planned, structured, and repetitive movements which is used to condition muscle, improve health and fitness, or for rehabilitative purposes (Clementina et al., 2016). The rehabilitative use of exercise involves repetitive motor tasks done either actively or passively to improve strength, ROM, motor learning, and motor function (Miyaguchi et al., 2016).

Children diagnosed with CP have strength deficits which affect their functional capacity and inhibition of the stretch reflex which later results in joint restrictions (contractions) (Shortland, 2009; Barett & Lichtwark, 2010). Furthermore, their inability to produce maximal muscle contractions forces them to rely on antagonist muscles for movements (Barett & Lichtwark, 2010).

There are various structural deficits present within spastic muscles. Spastic muscles have altered fiber size, distribution, and proliferation (Lieber & Friden, 2002), altered stiffness in the spastic muscle and extracellular matrix (Foran et al., 2005), decreases in muscle volume and thickness (Shortland, 2009), and decrease in the muscle cross-sectional area and belly length (Barett & Lichtwark, 2010)

Individuals with CP have a greater muscle fiber size and tend to have a predominance of one fiber type over another which in turn affects muscle energy expenditure and activity (Rose et al., 2005). A study conducted by Mathewson and Lieber, (2013) concluded there to be an increase prevalence of Type II muscle fibers present in the bicep brachii muscle in individuals with CP. Furthermore, there is an increase in strength of the proximal musculature in comparison to the distal musculature (Fowler et al., 2007). The muscle stiffness observed is attributed to the abnormal organization of the extracellular matrix and increase in collagen which directly increases tissue stiffness (Mathewson & Lieber, 2015). Some of the stiffness observed is further produced by the shortened length of the muscle fibers (Mathewson & Lieber, 2015). The upper limb tends to have more stiffer individual muscle fibers with the extracellular matrix occupying a larger area (Mathewson & Lieber, 2015).

Previous studies that have researched the effects of exercise on the upper limb of individuals with CP found there to be improvements in fine motor tasks, and coordination when completing bilateral tasks (Damiano, 2006; Huber et al., 2010; Howcraft et al., 2012; Hutzler et al., 2013). A review conducted by Mathewson & Lieber, (2015) concluded that exercise has positive outcomes on strength, ROM, and spasticity.

2.9.2.2 Neuromuscular Electrical Stimulation

Neuromuscular electrical stimulation (NMES) involves the application of superficial electrodes placed either on the muscle belly or motor point of a nerve and electrical impulses are sent to the nerve which produces muscle contractions (Doucet et al., 2012). NMES can be used on healthy and impaired muscles in which the stimuli are applied intermittently to produce a muscle contraction (Maffieulleti NA, 2010). NMES is used to produce muscle tetany for functional purposes snd is achieved by utilizing frequencies between 20 hertz (Hz) to 50 Hz (Doucet et al., 2012). Insults to the central nervous system (CNS) or nerve tissue damage affect the propagation of an action potential (AP) resulting in the need for retraining of the muscle. Numerous studies (Maffieulleti NA, 2010; Sheffler & Chae, 2007) have focused on the clinical usage of NMES and concluded positive outcomes.

The physiological properties of NMES vary considerably in comparison to voluntary skeletal muscle activation. The AP generated through NMES has the same physiological properties as those generated through voluntary contractions (Sheffler & Chae, 2007). Type I muscle fibres are referred to as slow-twitch fibres that produce lower forces and are associated as being fatigue-resistant .Type II glycolytic fibres or fast twitch fibres have large muscle fibre diameters which are found superficially and can be either fatigue resistant, fatigue intermediate, or fast fatiguing fibres depending on the motor units' metabolic enzyme (Sheffler & Chae, 2007). NMES selects type II muscle fibres due to their superficial placement which results in muscle fatigue; however, if NMES is applied chronically to the muscle, it has the ability to reverse the recruitment pattern of the muscle fibres (Sheffler & Chae, 2007).

NMES produces a reverse recruitment order and recruitment threshold which is due to the presence of larger diameter muscle fibres that are easily excited and recruited first due to their superficial location (Maffieulleti NA, 2010). At relatively low intensities NMES activates both fast fibres and slow fibres and is termed a non-selective recruitment pattern (Maffieulleti NA, 2010). The recruitment pattern has a high metabolic cost which often results in fatigue of the stimulated muscle even at low intensities (Maffieulleti NA, 2010). Motor unit recruitment using NMES occurs in a synchronous manner and application at a constant intensity produces continuous muscle contractions to the same muscle fibres (Maffieulleti NA, 2010). The electrical current produced by NMES has the potential to produce an AP at low intensities and gradual increases in intensity produce a deeper depolarization (Maffieulleti NA, 2010).

NMES has shown to influence the central nervous system structures (CNS) in addition to muscle structures. NMES is considered to increase cortical activity and spinal motor neuron recruitment which overrides the CNS resulting in the production of central torque. The current which develops is referred to the interneurons and produces sustained depolarization of sensory axons (Maffieulleti NA, 2010). However, activation of the supraspinal mechanism arising from NMES causes both peripheral and central fatigue (Maffieulleti NA, 2010). Peripheral effects in rehabilitation settings are produced by motor unit recruitment and are associated with improvements in muscle quality which assist in the production of functional movements, whereas, activation of central pathways assist in the production of a contraction in a natural physiological manner through activation of sensory pathways which in turn synapse onto motor neurons within the spinal cord (Bergquist et al., 2011). NMES can stimulate the CNS by utilizing lower amplitude stimulations in combination with longer pulse duration and a higher frequency (Bergquist et al., 2011). Stimulation of the nerve trunk elicits a greater CNS contribution and results in a more orderly recruitment pattern of muscle fibres which are spatially diffused throughout the muscle and tend to have a lower synchronous behaviour together with a lower rate of fatigue (Bergquist et al., 2011).

NMES is important in both a rehabilitative and clinical setting as impairments are often associated with muscular atrophy and usage of NMES serves as a re-training modality that assists in the preservation of muscle mass and functions, recovery of muscle following periods of disuse and immobilization as well as improves muscle functionality (Maffieulleti NA, 2010).

Neurological impairments are associated with limited or no cooperation of muscle function. However, a greater degree of impairment produces a greater NMES response (Maffieulleti NA, 2010). Children with CP have a lowered motor unit recruitment and discharge of motor units, increased co-activation in the agonist-antagonist response during contractions, and altered muscle morphology which has a direct effect on muscle force production (Stackhouse et al., 2007). NMES together with voluntary isometric strength training increases muscle force production through improvements in strength (Stackhouse et al., 2007).

The effects elicited through the application of NMES that stimulate the motor axons which produce contractions through peripheral pathways at sufficient intensities to produce therapeutic effects i.e. reduction in spasticity of the stimulated muscle, improvements in strength, reduction in co-activation and improvements in range of motion which are due to soft tissue changes (Merrill, 2009). Stimulation of motor nerve has the capability to

stimulate the CNS structures altering brain plasticity of motor learning, however, engagement of the CNS requires the activity to be highly repetitive, task-specific, physiologically relevant, cognitively orientated, performed under supervision at the limit of performance and with feedback of performance (Merrill, 2009). According to Bergquist et al., (2011) both motor and sensory axons are activated by NMES. Stimulation of sensory axons produces contractions by synapsing on motor neurons in the spinal cord. The ability of NMES to evoke a sensory volley alters the maladaptive plasticity of the brain. These changes include the development of the stretch reflex, decrease spasticity by reducing the agonist-antagonist reciprocal inhibition which produces an increase in the strength of the CNS pathways and CNS activity resulting in improved neuromuscular functioning (Bergquist et al., 2011).

The studies that currently exist utilise NMES either alone or in combination with splinting and or dynamic bracing on the wrist and forearm and in some instances the tricep. Each study presented an exploration of a previous study to provide evidence based conclusions or comparative outcomes. Merill, (2009) recommended the need for future studies using NMES to focus its application on the upper extremity of the affected upper limb.

2.9.2.3 Neuromuscular Electrical Stimulation in Hemiplegic CP

Carmick (1993) conducted a case study on two children, one aged 19 months and the other aged six years eight months old. NMES was applied to the tricep bachii muscle on the 19-month-old child and the child was able to immediately bear weight onto the affected arm in a quadruped position. During the second week of the NMES application, the child was able to use the affected arm in creeping which was a result of increased strength and awareness of the affected arm. At the end of the fifth week, the child exhibited full elbow extension. Thereafter, NMES was applied to the wrist extensors and finger flexors and there was immediate usage of both hands together for various types of activities and the child had better hand awareness. NMES was used for a further two months in which various muscle groups were stimulated. At the end of the two-months the child had improved motor function. At 25 months, the child had significant improvements in grasping, gripping, reaching, creeping, and climbing using both hands.

NMES was applied to the wrist extensors and finger flexors of the almost seven-year-old child. After seven sessions, the child had improved hand awareness and began independently using the hand to grasp and release objects with active wrist extension of the affected upper limb. This was the first study conducted that applied NMES on the

upper limb of children with hemiplegia (Carmick, 1993). However, only two participants were used in the study which serves as a limitation to the study.

Carmick (1997) applied NMES to the wrist extensors and finger flexors of a child. Sessions involved activities that required bilateral hand usage in combination with NMES stimulation. Improvements were noted in the child's ability to grasp objects, maintain active wrist ROM and bilateral hand usage. During the research period, the child sustained an injury and a splint was administered. NMES was used with the splint and noticeable improvements were seen. These included; decreased wrist flexion, more effective grasping and releasing, better functional and independent hand usage. The child was able to maintain wrist extension during grasping of lightweight objects, had usage of the index finger, and was more functional in ADL (tying shoelaces, swinging, climbing). The limitation is that this was a case study using only a single participant and it is uncertain as to whether or not the same outcomes would be present in this population group.

In 1999, Schekar et al evaluated the effects of dynamic bracing and NMES application on the tricep, wrist, and finger extensors in children aged between three to 34 months diagnosed with hemiplegic CP. Nineteen participants partook in the study over a three – 43-month period. NMES on the tricep and wrist extensors and dynamic orthotic traction on the wrist and elbow joint were administered during the day and static bracing of the elbow and wrist joint at night. There were improvements in; the quality of movement of the affected upper extremity, wrist and finger extension, hand functionality, and spasticity.

Wright & Granat (2000) evaluated the cyclic usage of functional electrical stimulation on the wrist extensors on eight children over a period of six weeks. Following the intervention period, children were able to grip and release objects of different sizes, stack draughts one on top of the other, and were able to use both hands to play and conduct ADL (tying shoelaces). Children had improved; awareness of the affected upper limb, ROM, strength of wrist extensors producing active wrist extension, and hand functionality. The children were also able to complete tasks using the affected upper limb in a much shorter time frame.

Kamper et al. (2006) applied a biphasic stimulation using NMES on the potential impairment mechanism on the wrist flexors and extensors coupled with isometric wrist flexion at 20 degrees. Eight children aged between five and fifteen were used in the pilot study which produced varying results. Those children that had a greater degree of impairment produced no improvements. Those that had a lesser degree of impairment showed improvements in active wrist extension against gravity beyond neutral as well as

increases in wrist extensor torque. No changes in passive wrist ROM or spasticity were noted.

Ozer et al. (2006) applied dynamic bracing coupled with NMES applied to the tricep, wrist, and finger extensors through a biphasic response. The study had 24 participants aged between three and 18 years old that were treated over 12 weeks. The combined effect of NMES and dynamic bracing is a more effective approach than using either one alone. Improvements in grip forces were noted only during the treatment period and were not present after treatment. Improvements that were made following the intervention included; better wrist and finger function, active and passive ROM, grip strength, and better control of the affected upper extremity. No changes in spasticity were noted. The participants were divided into 3 groups with no control group and had low statistical power.

Postans et al. (2010) combined dynamic splinting with NMES application to the elbow and wrist extensors in individuals with significantly restricted joint movements as well as contractures of the wrist and elbow joints. Six children aged between seven and 16 years old received NMES and dynamic splinting for an hour a day. There were greater improvements in upper limb function of those with wrist contractures as opposed to those with elbow contractures. Furthermore, there were improvements in passive joint ROM of the wrist and elbow which were produced towards the end of the intervention period. Passive changes in elbow ROM did not affect hand functionality changes.

Usage of NMES as an adjunct to different forms of therapy has been shown in several reported cases to improve upper limb functionality, posture, strength, ROM, and reduce spasticity. In our study, the combined effects of NMES on the bicep muscle and isometric and isotonic bicep curl exercise was explored to determine changes in spasticity, range of motion and hand functionality, as this area has not been previously investigated.

2.10 Summary

Cerebral palsy is defined as a motor disorder due to the presence of a non-progressive brain lesion that occurs prenatal, perinatal, or post-natal. The prevalence of CP within SA is 10/1000 live births and is a result of perinatal and post-natal complications resulting in more severe forms of CP (diplegia and quadriplegia), and has the potential to increase with improved healthcare. Hemiplegic CP is caused due to the presence of a lesion either in either the periventricular white matter or cortical or subcortical tract. Hemiplegic CP presents with unilateral spasticity in which the upper limb is more involved than the lower

limb. They also tend to have an increased flexor tone of the shoulder, elbow, and wrist joint of the upper limb and dorsiflexion and foot eversion of the lower limb. The greater upper limb impairment is associated with complete disregard of the affected upper limb. They have difficulty with dissociation movement patterns, grasping, gripping, object manipulation, and ADL on the affected upper limb. Children with hemiplegic CP benefit from a multidisciplinary approach as the combined approach assist in minimizing the impairment, improving independence and QoL. Previous intervention strategies such as constraint-induced movement therapy, HABIT, mirror therapy have yielded positive outcomes on the affected upper limb of children with hemiplegic CP. Neuromuscular electrical stimulation has also been an effective treatment modality on the affected upper limb in children with hemiplegic CP and produced positive outcomes on; ROM, strength, grasp, release, hand functionality, bilateral hand usage, awareness, and ADL. Neuromuscular electrical stimulation (NMES) has been widely used as a treatment modality for a variety of neurological conditions with most research on CP focusing primarily on the affected lower limbs and very little research available on the affected upper limb. This research drew on studies conducted on NMES as a treatment modality on the upper limb of children with CP and compares the outcomes on the uses of NMES as a treatment modality which has been outlined in this study.

CHAPTER 3: METHODOLOGY

3.1 Research Design

A multiple case study design was used to quantitatively describe the combined effects of neuromuscular electrical stimulation NMES and exercise intervention in the upper limb of children with cerebral palsy. This case study assessed the effects that the intervention had on range of motion (ROM) of the shoulder, elbow, and wrist joint, spasticity of the shoulder, elbow, and wrist joint, dissociation movements of the upper limb, grasps, and goal attainment. Replication methodology was applied on and amongst each participant over eight-weeks (two sessions per week, each session 30 minutes in duration). The replication logic used in this study allow for relevant comparison in findings to be made between this case study and other studies (Zainal, 2007). Cases had been chosen based on children having met the inclusion criterion that was set in this study design.

A case multiple case-study design had been chosen due to the limitations imposed by the corona virus, whereby accessing children became difficult, and the data that had been collected was not sufficient to fulfill an experimental study. The findings of this study could further be substantiated relative to previous experimental studies by supporting previous studies and enhancing knowledge if new findings emerge, aiding to the robustness of a multiple case study design. A case study approach is therefore practically relevant as multiple cases will be investigated within the same context (Zainal, 2007; Teegavarapu et al., 2008).

This intervention design within the context of this research has not been previously studied. For this reason, a multiple case study design utilising a quantitative approach will allow the researcher to evaluate the impact that the research may have. The approach is used when an intervention has not been extensively researched within a specified sample. A quantitative approach allows for data collection and analysis at a macro level allowing for generalised conclusions (Zainal, 2007).

A systematic approach had been used in the data collection process, based on the theoretical propositions of range of motion, spasticity and hand functionality, which underlies the usage of NMES to ensure fulfillment of rigour for the purpose of scientific research (Zainal, 2007; Teegavarapu et al., 2008).

Nine children aged between six years and 18 years old with hemiplegic CP within Learners with Special Educational Needs (LSEN) schools were recruited in the study

once consent was received from the Department of Education (Appendix B), schools (Appendix C), parents (Appendix D, E, F) and children (Appendix G). The children participation in the study was based on them having met the inclusion criteria. Thereafter, an initial assessment was completed which consisted of the following components; 1) range of motion (ROM) of the shoulder, elbow, and wrist joint, spasticity of the shoulder, elbow, and wrist joint, 3) dissociation movement patterns of the shoulder, elbow, and wrist joint, and grasps were assessed. The researcher used these outcomes to set individual goals which were communicated to the participant. The combined NMES and exercise intervention was administered twice a week for 30 minutes, over eight-weeks. A photograph of the affected limb was taken at the start and end of each session. After eight-weeks a final assessment on ROM, spasticity, dissociation movement patterns, grasps, and goal attainment had been assessed and the data was analysed.

3.2 Site of Study

The study was conducted at LSEN schools and in some cases the child was accessed at their homes. Children with hemiplegic CP have special needs and are placed either in a home school, mainstream school or LSEN schools depending on the nature of impairment. Children attend LSEN schools from the age of six years old and they access therapy at school during school hours and due to children being available at schools, these sites had been chosen for purposes of the research.

3.3 Study Population and sample

Children with hemiplegic CP were sampled using replication logic relative to previous studies that proposed the sample to be receptive to NMES. The study population comprised of both male and female children diagnosed with right or left-handed spastic hemiplegic cerebral palsy between the ages of six and eighteen years. The sample was limited to children that displayed flexor-patterned spasticity. The children that had met the inclusion criteria listed below (Table 3.1), formed part of the participants in the case study and underwent the NMES programme.

Table 3.1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Consent and assent forms from parent/guardians and participant Right and left-handed spastic hemiplegic Children aged between six and eighteen years old Both male and female participants Individuals who are able to cognitively understand the protocol procedure and able to give subjective feedback If seizures are a clinical feature they must be controlled Individuals who are currently receiving other forms of treatment, as long as the treatment received remains constant throughout the testing (maintenance)	Hemiplegic with other secondary complications such as; Hydrocephalus chromosomal abnormalities Syndromes Having had Botox or surgical muscle release within the previous one year. Cognitive impairments

3.4 Sample Size

The multiple case-study design consisted of nine participants that underwent the intervention during the data collection period and met the criteria for NMES application in terms of absence of seizures or controlled seizures, and maintenance of other therapies being received.

3.5 Data collection instruments

3.5.1 Demographic information sheet

The demographic information sheet and medical checklist (Appendix E), was used to capture the participants age, gender, affected side, puberty, presence of seizures, medication used to control seizure, secondary medical complications and medications used to control the medical complications.

Sexual maturation and puberty in individuals with moderate to severe motor impairments tend begin earlier, nine years, and end later in life for both male and female (Worley et al., 2002). Understanding that CP is non progressive in nature, the effect of puberty does not disrupt or progress the impairment.

The medical checklist was used to aid the researcher of possible complications of the participant and ensure measures were taken to overcome any complications that had occurred during the study period. This is specifically important as the study had been implemented on minors within schools.

Once consent had been received, the researcher began with the initial assessment. The assessment was conducted in the following order; range of motion (ROM), Modified Ashworth scale (MAS), Tardieu scale, Quality of upper Limb Extremity Skills Test (QUEST) and goals were set thereafter using the goal attaintment scale (GAS)

3.5.2 Range of motion

Children were asked to perform various active ranges of motion movements of the shoulder, elbow, and wrist (Table 3.2). A handheld goniometer was used to measure the angle of the various movements produced of the aforementioned body segments.

Table 3.2: Active ROM showing position of the goniometer and movements of body segments that were measured (Shultz et al., 2010).

Body Region	Movement	Position	Fulcrum	Stationary Arm	Moving Arm	Instruction

Shoulder	Flexion	Supine	Central humeral head	Midline lateral trunk	Long axis of the humerus	Humerus moves overhead in anterior upward direction
	Abduction	Supine	Anterior gleno-humeral head	Parallel to sternum	Long axis of the humerus	Humerus moves in lateral and upward direction
	Internal Rotation	Supine	Olecranon process	Perpendicular to floor	Long axis of the ulna	Arm abducted at 90 degrees, move the palm of the hand inferiorly towards table
	External Rotation	Supine	Olecranon process	Perpendicular to floor	Long axis of the ulna	Arm abducted at 90 degrees, move the back of the hand superiorly towards the head of table
Elbow	Flexion	Supine	Lateral epicondyle of the humerus	Long axis of the humerus	Long axis of the 5^{th} radius	Palm is moved toward shoulder
	Extension	Supine	Lateral epicondyle of the humerus	Long axis of the humerus	Long axis of the 5^{th} radius	Elbow straightened as far as possible
Wrist	Flexion	Supine	Ulnar styloid process	Long axis of the ulna	Long axis of the 5^{th} meta-carpal	Move palm towards the volar aspect of wrist
	Extension	Supine	Ulnar styloid process	Long axis of the ulna	Long axis of the 5^{th} meta-carpal	Move the dorsum of the hand to the dorsal aspect of wrist

3.5.3 Spasticity Scale

3.5.3.1 Modified Ashworth Scale

The modified Ashworth scale is a six-point rating scale with scores ranging between 0-4 (Appendix H), used to detect the amount of resistant experienced by the joint when it is taken through a passive movement (Alhusaini et al., 2010). A score of (0) indicates no increase in muscle tone, (1) indicates slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion , (1+) indicates slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder of the ROM, (2) indicates a more marked increase in muscle tone through most of the ROM, but affected part(s) easily moved, (3) indicates considerable increase in muscle tone, passive movement difficult, and (4) indicates the affected part(s) rigid in flexion or extension.

The modified Ashworth scale was used to determine the amount of spasticity that was present during; shoulder flexion, shoulder abduction, shoulder internal rotation and external rotation, elbow flexion and extension, and wrist flexion and extension. These movements were graded in a supine position, whereby a passive stretch at a quick velocity was applied to determine the presence of spasticity and grade the resistance. These were measured in a supine position.

3.5.3.2 Tardieu scale

The Tardieu scale is a six-point scale which uses a velocity-dependent approach to assess the quality of muscle reaction through a passive stretch application to different muscles using various speeds (Alhusaini et al, 2010). A score of (0) indicates no resistance throughout passive movement, (1) indicates slight resistance throughout, (2) indicates a clear catch at a precise angle, (3) indicates a fatigable clonus (<10secs) and (4) indicates an unfatigable clonus (>10secs) (Appendix I).

The Tardieu scale was used to determine the amount of spasticity that was present during; shoulder flexion, shoulder abduction, shoulder internal rotation and external rotation, elbow flexion and extension, and wrist flexion and extension.

In this study, only a fast-velocity stretch had been applied to the muscles tested (the limb was passively moved as quickly as possible through the range of motion and the

presence of a “catch” or clonus were documented followed by the joint angle being measured using a hand-held goniometer. These were measured in a supine position.

3.5.4 Quality of upper limb skills test

Children with hemiplegic CP often choose not to use the affected arm as they experience difficulty in using the arm. They tend to have a total disregard for the affected upper limb. The challenges associated with the affected upper limb include the inability to dissociate movements, grasp of use the extremity in a functional manner. For these reasons, the quality of upper limb extremity skills test (QUEST) was used to determine functional hand placements, grasps and dissociated movements The QUEST was used to evaluate both functionality as well as quality of movement produced by the upper extremity during dissociation movement of each joint, grasping and hand placement.

It comprises of 34 items which are subdivided into four sub-sections requiring different level of responses. Items are scored in relation to whether or not the participant is able to execute the task (Yes – 2 points, No – 1 point and Not Tested – 1 point) (Dematteo et al, 1993) (Appendix K).

The items tested followed the guidelines as set out in each section of the QUEST during the evaluation. The quality of dissociated movements of the shoulder, elbow, wrist and fingers together with posture evaluation and grasps of a 1’’ cube, cereal and pencil were evaluated and scored (Dematteo et al, 1993). The items were measured in a seated position.

3.5.5 Goal attainment scale

The goal attainment scale (GAS) GAS is a five point scale which was chosen as it is a standardized way of measuring the goals and it involves the participant having been aware of the goal set for them which in turn assists as form of motivation to the participants in reaching their expected outcomes.

The goal attainment scale score ranges between +2 to -2, in which (-2) indicates a lot less, (-1) indicates a little less, (0) indicates the expected outcome achieved, (+1) indicates a little more, and (+2) indicates a lot more (Steenbeek et al, 2010) (Appendix J).

The goal set in this study was done by the researcher and based on the child's initial outcomes. Each child's goal was individualized in relation to their ability.

The goal attainment T-score is determine by a formula where Wi is the weight assigned to the i-th goal (if equal weights, Wi¼1), Xi is the numerical value achieved (between _2 and þ2), _ is the expected correlation of the goal scales. T score is worked out with a mean of 50 and standard deviation of 10, with ρ is set at 0.3.

Formula:

$$\text{Overall GAS} = 50 + \frac{10\,\Sigma(w_i x_i)}{[(1-\rho)\,\Sigma w_i^2 + \rho(\,\Sigma(w_i)^2]^{½}}$$

If all scores are achieved as expected the GAS T score will be 50 but if the scores is lower than 50 the child did less well than expected

3.6 Intervention modality

An initial assessment was conducted prior to participants receiving the NMES intervention. In the initial assessment ROM and spasticity scores were documented, the QUEST was used to evaluate hand functionality and the GAS was used to set a goal amongst the participants.

Thereafter participants underwent the NMES programme, using the Neurotrac Myoplus 2 (NeuroTrac®, Verity Medical Ltd, United Kingdom). The intervention was scheduled twice a week over eight-weeks and the duration of sessions was 20 minutes in length or patient dependent. Before the start of the intervention session, the researcher had taken front view and side view photograph of the affected upper limb and postural changes seen on the affected upper limb were documented.

One surface electrode (50mmx50mm) with a negative lead was placed near the insertion, over the muscle belly of the bicep, while the other electrode (50mmx50mm) with a positive lead was placed on the muscle belly of the bicep where the motor nerve enters. A third electrode (50mmx50mm) with a reference lead had been placed on the glenohumeral joint as a reference point for accurate results to be obtained from the electromyography and electrical triggered stimulation phases.

The passive-active function (P+A) program had been exclusively customised for the stipulated population group. The intensity applied during each phase was according to individual tolerance levels.

Tolerance levels were monitored throughout the intervention and had been indicated through usage of a robot (Appendix L). The four stages used in the passive-active function were:

- Stage 1

Electromyography (EMG) was used to determine the initial muscle performance which consisted of five work phases followed by a rest phase in between. During the work phases, the participant was asked to maximally contract their bicep. An automatic feature was used to calculate 80% of the maximum contraction.

- Stage 2

Concentric Stimulation at a frequency of 10 hertz and pulse width of 200us was used to warm up the muscles for 4 minutes.

- Stage 3

Electrical Triggered Stimulation (ETS) was used to re-evaluate the muscle performance and contraction for this phase had been measured at 80% max effort. The frequency used was 10 hertz with a 200us pulse width. The stimulation was removed during the rest phases and re-established during the work phases. This phase consisted of 10 work phases whereby the participant was asked to isometrically hold a bicep curl for 20 seconds during each work phase with a 5 second rest between each of the work phases.

- Stage 4

Stimulation modulation was used in the final phase in which the muscle underwent a high frequency (15 hertz) intensity with a pulse width of 250uS for 5 seconds and a low frequency (2 Hertz) intensity with a pulse width of 250uS for 10 seconds. During the low frequency phase, participants were asked to complete as many bicep curls as possible.

The children were seated with the upper limb supported on the arm rest of a chair. Following the intervention, a front view and side view picture of the affected upper limb was taken and postural changes seen on the affected upper limb were documented.

A final assessment on ROM, spasticity, hand functionality, and goal attainment were measured at the end of the eight-week and the data had been analysed.

3.7 Data Analysis

Data was captured on an excel spreadsheet for easy analysis. The mean values were calculated on Microsoft Excel using a test pivot which was used to sort, reorganize and group data so that calculations could be done in terms of sum, mean, minimums and maximums which was then represented in the form of tables of pictorial graphs

Statistica was used to do the Wilcoxon signed test. A Wilcoxon signes test is a nonparametric test that was used as the distribution of the data was not normal and was used to compare two sets of scores derived from the same participant. The statistically significant values of the Wilcoxon signed test is the **z score** which indicates a 95% confidence interval and is significant when z equal to or greater than 1.96, and the **p value** which indicates strong evidence against the null hypothesis and is statistically significant when $p < 0.05$.

The Wilcoxon signed test was preferred for this study due to the small sample size as well as to conclude overall statistical evidence wherever possible. The Wilcoxon signed test was used to obtain summary post intervention results of ROM, QUEST and GAS scales. The reason for this is that the components set out for each of these scales were performed by each participant and the components were scored accordingly. In terms of the MAS and Tardieu scales, the presence of spasticity within muscle groups varied amongst participants which made it difficult to determine summary scores using a statistical program. For this reason the post intervention spasticity scores were measured against the individual pre intervention scores and reported for each individual.

3.8 Ethical consideration

To ensure assessment practices are fair and ethical during the research study, the following standards had been implemented;

Clearance (M181023) was obtained from the Human Research Ethics Committee (Medical) HREC-Medical of the University of Witwatersrand before commencement of the study (Appendix A). Thereafter, permission was obtained from; (1) the Department of Education (Appendix B), (2) LSEN schools (Appendix C), (3) parental/guardians of the participant (Appendix D, E, F), and (4) the participant (Appendix G).

Privacy, anonymity and confidentiality were maintained an each participant had been treated in a courteous, respectful and impartial manner. Participants were made aware of their rights and responsibilities in terms of; human dignity, justice, equality, freedom of

choice, expression and participation. The participant was notified that they could freely withdraw at any given time from the study without prejudice.

Each test had been explained in an understandable manner to the participants and associated risks and discomforts were explained. All necessary steps were taken to ensure the safety and comfort of each participant during the intervention. Results were stored safely and securely using an encoded briefcase to prevent threats to the integrity during the data collection phase. Only the researcher had access to the data at all times.

Due to the study focusing on children, enormous care and consideration had been given during the intervention. A brief and concise explanation of the method, benefits, risks and discomforts had been written up in the informed consent given to each entity. Parents were given the necessary contact numbers in the event they had any uncertainties or concerns. Voluntary participation had been reinforced throughout the intervention.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter consists of the demographical results and outcomes in flexibility, spasticity, hand functionality and goal attainment of the nine participants following an eight-week NMES and exercise intervention programme.

4.2 Demographic Information

The population consisted of nine participants aged between six and eighteen years old, with five males and four females. Four participant displayed unilateral spasticity on the left side while five had unilateral spasticity present on the right side. Due to SA having more severe cases of CP, the sample included children aged between six and eighteen years old as we can deduct from the previous statement that hemiplegia makes up a smaller percentage of cerebral palsy in SA. One participant presented with seizures that was being managed by medication and was included as an inclusion criterion to reduce risks within the study. Of nine participants, seven attended other forms of therapy at schools which continued during the intervention period as not to skew the results obtained.

Table 4.1: Summary of demographic information findings

Participant Number	Diagnosis	Age	Gender	Affected side	Dominant side	Seizures	Controlled Seizures	Other Therapies
1	Hemiplegia	10	M	Right	Left	No	N/A	Yes
2	Hemiplegia	8	M	Left	Right	No	N/A	Yes
3	Hemiplegia	11	F	Right	Left	No	N/A	Yes
4	Hemiplegia	11	F	Left	Right	No	N/A	Yes
5	Hemiplegia	17	M	Left	Right	No	N/A	Yes
6	Hemiplegia	10	M	Left	Right	No	N/A	Yes
7	Hemiplegia	18	M	Right	Left	Yes	Yes	No
8	Hemiplegia	13	F	Right	Left	No	N/A	Yes

9	Hemiplegia	13	F	Left	Right	No	N/A	No

4.3 Range of motion of the shoulder, elbow and wrist joint

4.3.1 Introduction

Range of motion in the shoulder, elbow and wrist joint were measured to determine the presence of limitations within joint structures. Due to hemiplegic CP displaying flexor patterned spasticity, the following movements were measured; shoulder flexion, abduction, internal and external rotation was measured, elbow flexion and extension was measured, and wrist flexion and extension was measured. Range of motion was measured using a handheld goniometer and instructions were followed as described by Shultz et al. (2010).

4.3.2 Flexibility measurement of the shoulder, elbow and wrist joint

A Wilcoxon signed test, a nonparametric test that was used since the distribution of the data is not normal to compare pre and post-test scores amongst the nine participants. The mean for each movement was calculated on excel using a test pivot which was used to sort, reorganize and group data so that calculation can be done in terms of; sum, mean, minimums and maximums which was then represented in a form of a figure.

4.3.2.1 Shoulder Flexibility

Significant changes were noted in various shoulder flexibility movements. These included an mean change of; 39.33 in shoulder flexion (Z=2.668 & p=0.008), 26.78 in shoulder abduction (Z=2.521 & p=0.012), 24.11 shoulder internal rotation (Z=2.668 & p=0.008) (Figure 4.1)

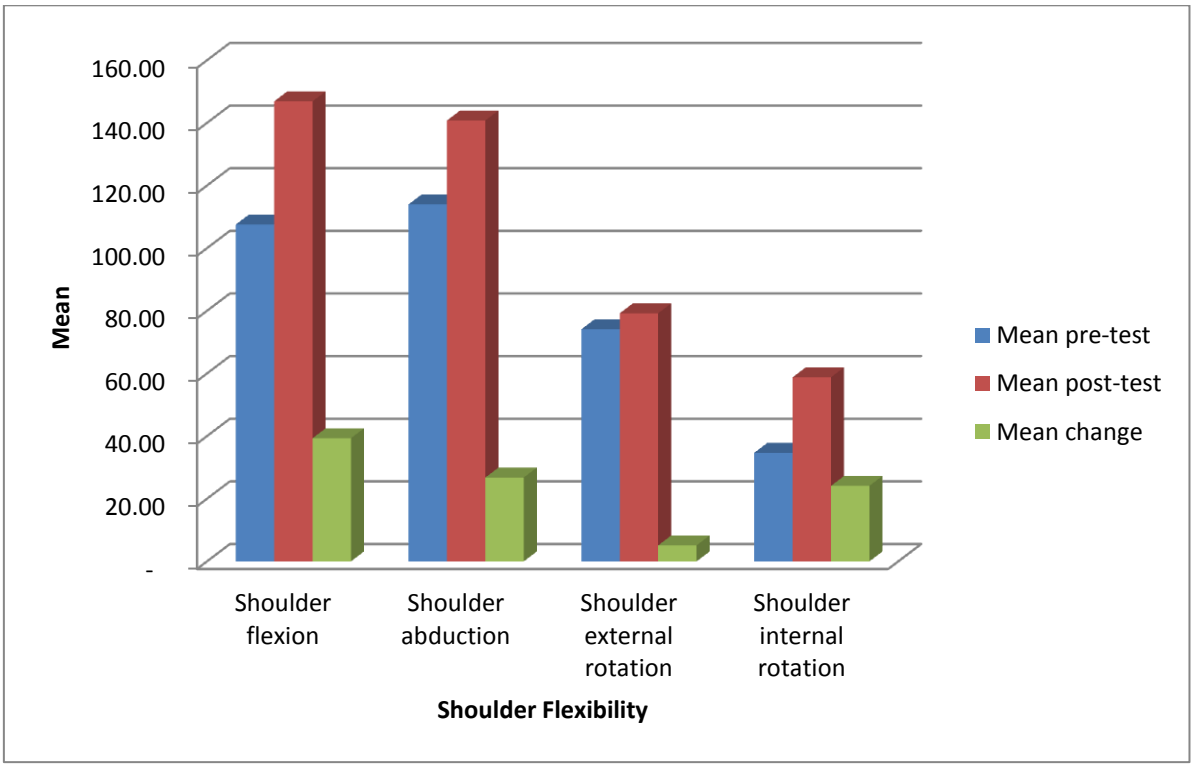


Figure 4.1: Consolidated view of the 9 participants' mean pre-test, mean post-test and mean score change for various shoulder flexibility movements

4.3.2.2 Elbow Flexibility

There were further significant improvements in elbow flexion with a mean change of 11.78 (Z=2.527 & p=0.012), elbow extension had an average change of 20.22 (Z=2.666 & p=0.008) (Figure 4.2).

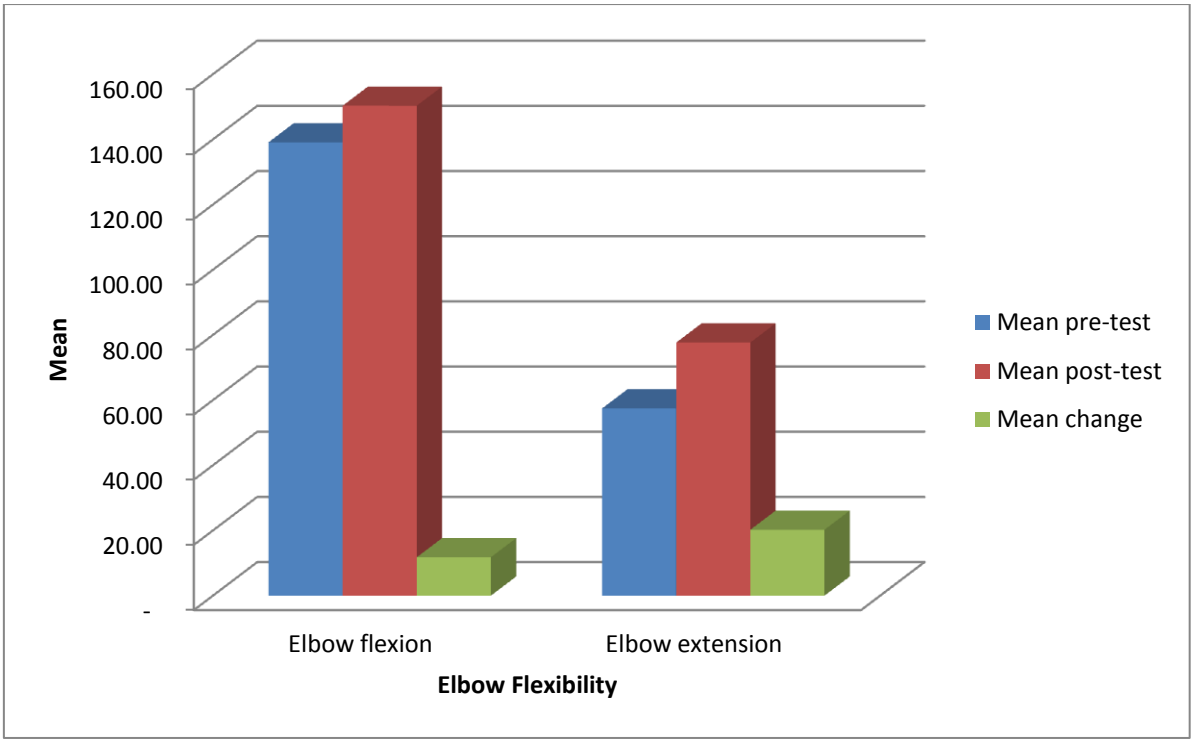


Figure 4.2: Consolidated view of the 9 participants' mean pre-test, mean post-test and mean score change for various elbow flexibility movements.

4.3.2.3 Wrist Flexibility

Children diagnosed with hemiplegic CP have poor wrist neutrality and extension as seen in figure 4.3. Following the intervention period, children were able to extend the wrist at a greater angle; however, the angle did not exceed the neutral position. The Wilcoxon signed test showed significant improvements were noted in active wrist extension with a mean change of 18.44 (Z=2.226 & p=0.026) (figure 4.3).

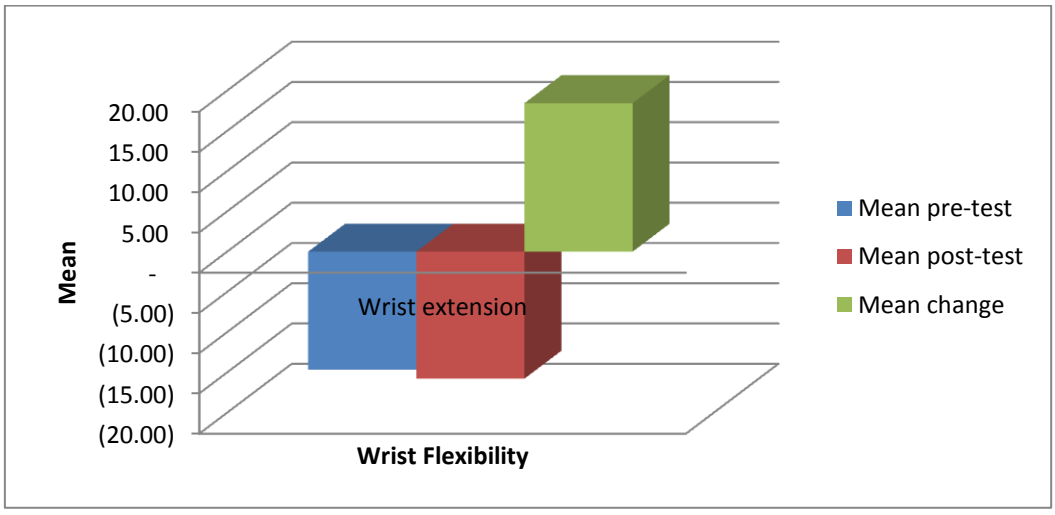


Figure 4.3: Consolidated view of the 9 participants' mean pre-test, mean post-test and mean score change for various wrist flexibility movements

4.3.3 Overview of flexibility measurements

Improvements in flexibility were present in the shoulder, elbow and wrist joint of all participants. Improvements in ROM were also noted in the participant that presented with a contracture.

4.4 Spasticity of the shoulder, elbow and wrist joint

4.4.1 Introduction

Spasticity scales were used to determine the presence of increased muscle tone in various movements of the shoulder, elbow and wrist joints. Spasticity was measured in shoulder flexion, abduction, internal and external rotation, elbow flexion and extension and wrist flexion and extension. Two scales were used in measuring spasticity namely; modified Ashworth scale and Tardieu scale.

4.4.2 Spasticity Scales

4.4.2.1 Modified Ashworth Scale

Modified Ashworth Scale (MAS) in which a quick passive stretch was applied to the various joints structures and the outcome was based on a five-point scale.

The greater the impairment the higher the scoring on the Modified Ashworth scale while the lesser the degree of impairment, the lower the scoring. Improvements were noted by changes in Modified Ashworth scores from a higher score to a lower score.

Participant 1 presented with a slight increase in muscle tone followed by a catch and release during shoulder internal rotation, elbow extension and wrist extension (1). Following NMES intervention, the participant had spasticity changes to zero. This indicates that there were improvements in spasticity as zero is defined as no increase in muscle tone. This outcome was present in all structures (Figure 4.4) (Table 4.2).

Participant 2 improvements were noted in elbow flexion with a change from a moderate increase in tone (2) to a slight increase in muscle tone followed by a catch and release (1). There had also been noticeable changes in elbow extension from slight increase in muscle tone followed by a catch and release (1) to there being no presence of spasticity (0). Further improvements were noted in wrist extension from there being a considerable increase in tone which made passive movement difficult (3) to there being a presence of a more marked increase in muscle tone, but the limb was easily flexed (2). No spasticity (0) in the elbow extensors were noted prior to the intervention (Figure 4.4) (Table 4.2).

Participant 3 more marked increases in tone however; the limb was easily flexed (2) during shoulder flexion, shoulder internal and external rotation and elbow flexion. There was considerable increase in muscle tone which made passive movement of wrist extension difficult (3). Following NMES intervention, there was a marked improvement in spasticity scores with slight increases in muscle tone (1) present during shoulder flexion and no presence of spasticity (0) during elbow flexion. There was improvement in wrist extension whereby there was an increase in muscle tone however; the wrist was easily extended (2). No improvements in shoulder internal and external rotation were noted. There were no changes in elbow extension scores for this participant (Figure 4.4) (Table 4.2).

Participant 4 initially presented with a more marked increase in muscle tone through most of the ROM but the limb was easily flexed (2) during shoulder flexion, shoulder abduction, shoulder internal rotation, elbow extension and wrist extension. Following NMES intervention, the participant displayed improvements in spasticity scores in which there was a slight increase in muscle tone manifested by a catch and release (1) during shoulder flexion, shoulder abduction, elbow extension. It was further noted that there were improvements in spasticity scores during wrist extension; with no presence of spasticity noted (0) in the wrist following NMES. No improvements were noted during shoulder internal rotation (Figure 4.4) (Table 4.2).

Participant 5 initially presented with the limb being rigid (4) during shoulder flexion and shoulder abduction. There was a more marked increase in muscle tone through most of the ROM, but the limb was easily flexed (2) during shoulder internal and external rotation and elbow extension. The wrist presented with considerable increase in muscle tone which made passive wrist extension difficult (3). Following NMES intervention, there were no improvements noted in spasticity scores. The elbow and wrist joint presented with considerable increases in muscle tone resulting in difficulty while passively extending the joint (3). (Figure 4.4) (Table 4.2).

Participant 6 presented with considerable increase in muscle tone, however the limb was easily flexed (2) during shoulder internal and external rotation and elbow extension. During wrist extension a considerable increase in muscle tone was experienced which made it difficult to move the wrist into extension (3). Following NMES intervention, improvements in spasticity was only noted in the elbow joint in which there was no spasticity present (0) during elbow extension (Figure 4.4) (Table 4.2).

Participant 7 presented with the shoulder joint being rigid in flexion (4) during shoulder flexion and more marked increase in muscle tone (2) were noted during shoulder internal rotation, elbow extension and wrist extension. However, the joint was able to move easily through shoulder internal rotation, elbow and wrist extension movements. Following NMES intervention, changes, improvements were noted in shoulder flexion whereby the limb was no longer rigid in flexion but instead it displayed considerable increase in muscle and there was difficulty in moving the limb passively through its range (3). During shoulder internal rotation and elbow extension, there was a slight increase in muscle tone followed by catch and release (1). This participant showed improvements in spasticity scores of shoulder flexion, shoulder internal rotation and elbow extension. No improvement in spasticity scores of the wrist were noted (Figure 4.4) (Table 4.2).

Participant 8 had considerable increase in muscle tone that made passive movement difficult (3) during shoulder flexion, shoulder abduction, shoulder internal rotation, shoulder external rotation, elbow flexion, elbow extension and wrist extension. Following NMES intervention, there were improvements noted in spasticity scores for all shoulder movements except shoulder external rotation. Improvements were also noted in elbow flexion and extension and wrist extension. These improvements indicated a more marked increase in muscle tone, but the limb was easily flexed (2) (Figure 4.4) (Table 4.2).

Participant 9 presented with a more marked increase in muscle tone with the limb being easily moved (2) during elbow flexion and extension as well as wrist extension. Following NMES intervention, there were improvements in spasticity scores, with slight increases in muscle tone (1) being noted during elbow flexion and extension. No improvements were noted in wrist extension spasticity (Figure 4.4) (Table 4.2).

Table 4.2: Individual changes in spasticity scores using the Modified Ashworth scale

	Pre test score	**Post test score**
1		

Shoulder internal rotation	1	0
Elbow extension	1	0
Wrist extension	1	0
2		
Elbow flexion	2	1
Elbow extension	0	1
Wrist extension	3	2
3		
Shoulder flexion	2	1
Shoulder external rotation	2	2
Shoulder internal rotation	2	2
Elbow flexion	2	0
Elbow extension	2	2
Wrist extension	3	2
4		
Shoulder flexion	2	1
Shoulder abduction	2	1
Shoulder internal rotation	2	2
Elbow extension	2	1
Wrist extension		

	2	0
5		
Shoulder flexion	4	4
Shoulder abduction	4	4
Shoulder external rotation	2	2
Shoulder internal rotation	2	2
Elbow extension	2	3
Wrist extension	3	3
6		
Shoulder external rotation	2	2
Shoulder internal rotation	2	2
Elbow extension	2	0
Wrist extension	3	3
7		
Shoulder flexion	4	3
Shoulder internal rotation	2	1
Elbow extension	2	1
Wrist extension	2	2
8		
Shoulder flexion	3	2
Shoulder abduction		

	3	2
Shoulder external rotation	3	0
Shoulder internal rotation	3	2
Elbow flexion	3	2
Elbow extension	3	2
Wrist extension	2	2
9		
Elbow flexion	2	1
Elbow extension	2	0
Wrist extension	2	2

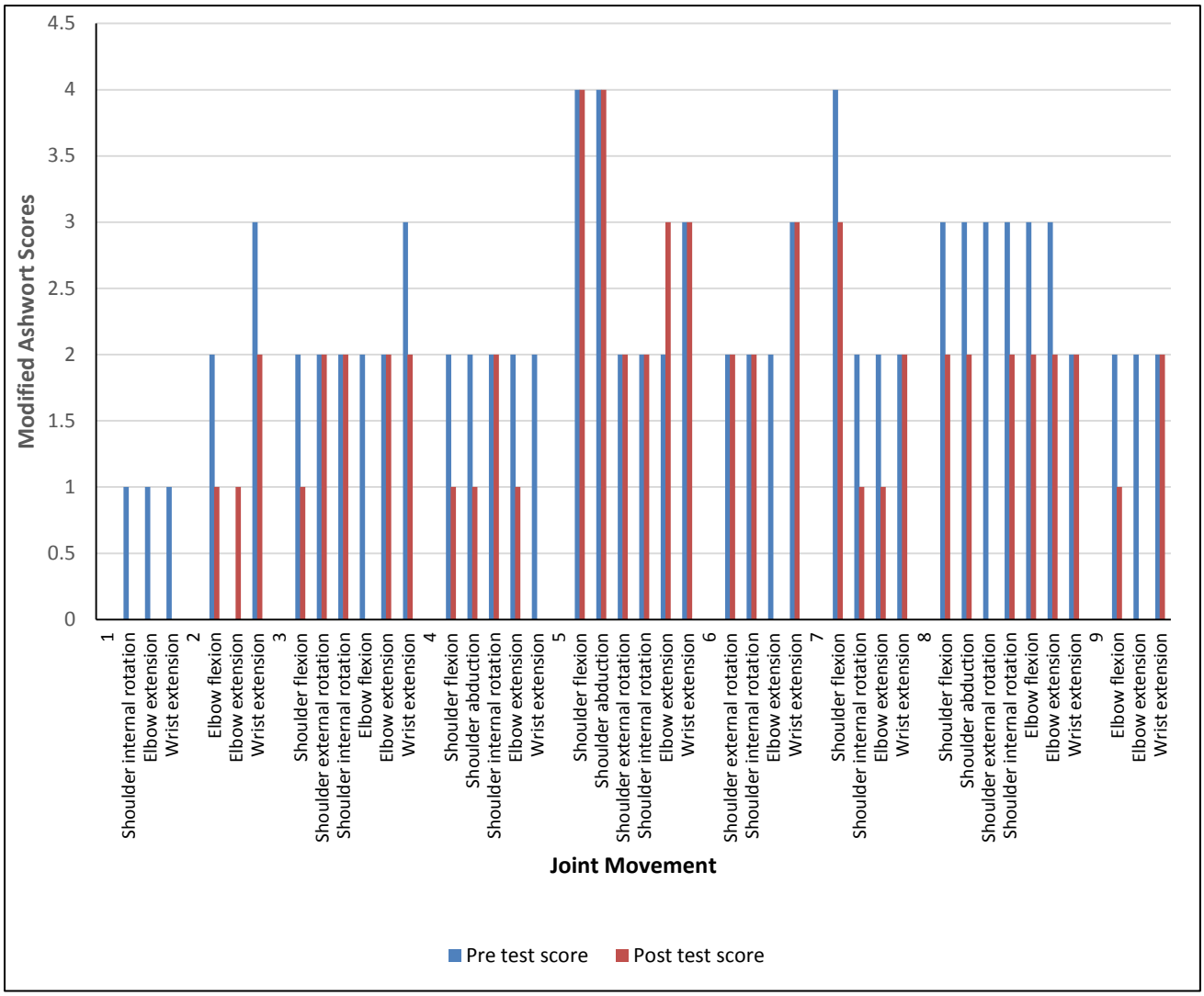


Figure 4.4: Pre-test and post-test Modified Ashworth score changes for each participant

4.4.2.2 Tardieu Scale

The Tardieu Scale was used to measure of spasticity of the various movements as mentioned earlier through by applying a passive stretch to the joint at a predetermined velocity. In this study a fast velocity stretch was applied and the point at which a discrepancy appeared was measured by a handheld goniometer. The goniometric measurements were conducted as set out by Shults et al. (2010) and spasticity was scored in relation to the impairment.

The greater the impairment the higher the scoring on the Tardieu scale while the lesser the degree of impairment, t he lower the scoring. Improvements are noted by changes in

Tardieu scores from a higher score to a lower score and improvements in joint ROM (increasing value) in which the spasticity is present.

4.4.2.3 Spasticity and change range of motion reporting using the Tardieu scale for each participant

Table 4.3: Participant 1: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**		**ROM: Angle of catch at V2/V3 (high velocity)**		
Participant: 1	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	0	0	0	0	0
Shoulder abduction	0	0	0	0	0
Shoulder internal rotation	1	1	15	40	25
Shoulder external rotation	0	0	0	0	0
Elbow flexion	1	0	33	0	33
Elbow extension	2	1	85	140	55
Wrist flexion	0	0	0	0	0
Wrist extension	2	0	12	60	48

Participant 1 presented with slight resistant throughout the movement (1) during shoulder internal rotation and elbow flexion. A clear catch (2) was noted during elbow extension at an 85-degree angle. A clear catch was noted during wrist extension at a 12-degree angle. Following NMES intervention, n no changes were noted in spasticity of the shoulder internal rotation, however; there were marked improvements in elbow flexion, elbow extension and wrist extension in which these movements displayed no resistance (0) (Table 4.3).

Table 4.4: Participant 2: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**		**ROM: Angle of catch at V2/V3 (high velocity)**		
Participant: 2	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	0	0	0	0	0

Shoulder abduction	0	0	0	0	0
Shoulder internal rotation	1	0	25	0	25
Shoulder external rotation	0	0	0	0	0
Elbow flexion	2	2	80	75	5
Elbow extension	1	1	0	0	17
Wrist flexion	0	0	0	0	0
Wrist extension	4	2	11	10	1

Participant 2 presented with a clear catch (2) at 25-degrees of shoulder internal rotation and 80-degrees of elbow flexion. A slight resistance (1) was noted through elbow extension and an unfatigable clonus (4) was present at 10-degrees of wrist extension. Following NMES intervention, improvements were noted in which there was no resistance (0) during shoulder internal rotation. Further improvements were noted during wrist extension which produced a clear catch (2) at 11-degrees of wrist extension and the wrist was able to move further through the range. No changes were noted during elbow flexion and extension post-intervention (Table 4.4).

Table 4.5: Participant 3: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**		**ROM: Angle of catch at V2/V3 (high velocity)**		
Participant: 3	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	2	1	89	130	41
Shoulder abduction	0	0	0	0	0
Shoulder internal rotation	2	2	39	55	19
Shoulder external rotation	0	2	0	74	74
Elbow flexion	2	0	69	0	69
Elbow extension	2	2	85	110	25
Wrist flexion	0	0	0	0	0
Wrist extension	2	2	10	12	2

Participant 3 presented with a clear catch (2) at 89-degrees of shoulder flexion, 39-degrees of shoulder internal rotation, 69-degrees of elbow flexion, 85-degrees of elbow extension and10-degrees of wrist extension. Following NMES intervention, improvements were noted during shoulder flexion which presented with a slight resistance (1) throughout

the course of movement and during elbow flexion in which no resistance (0) was noted. No improvements were noted in the quality of muscle reactions during shoulder internal rotation, elbow flexion and extension, and wrist flexion. However, improvements were noted in the joint angles at which a catch appeared. A catch appeared at 130-degrees of shoulder flexion, 55-degrees of shoulder internal rotation, 110-degrees of elbow extension and 12-degrees of wrist extension (Table 4.5).

Table 4.6: Participant 4: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**		**ROM: Angle of catch at V2/V3 (high velocity)**		
Participant: 4	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	2	1	144	162	18
Shoulder abduction	2	1	136	152	16
Shoulder internal rotation	2	2	31	48	17
Shoulder external rotation	0	0	0	0	0
Elbow flexion	0	0	0	0	0
Elbow extension	2	2	115	132	17
Wrist flexion	0	0	0	0	0
Wrist extension	2	2	25	34	9

Participant 4 presented with a clear catch (2) at 144-degrees of shoulder flexion, 136-degrees of shoulder abduction, and 31-degrees of shoulder internal rotation, 115-degrees of elbow extension and 25- degrees of wrist extension. Following NMES intervention, improvements were noted in shoulder flexion and shoulder abduction which displayed a slight resistance (1) throughout the course of movement and improvements in the angle of catch at 162-degrees for shoulder flexion and 152-degrees for elbow abduction. No improvements were noted in terms of spasticity scoring for shoulder internal rotation, elbow extension and wrist extension. However, there were improvements in the joint angles at which a catch was noted. A catch was noted at 48-degrees of shoulder internal rotation, 132-degrees of elbow extension and 34-degrees of wrist extension (Table 4.6).

Table 4.7: Participant 5: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle**	**ROM: Angle of catch at V2/V3 (high**

	reaction (X)		velocity)		
Participant: 5	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	4	4	98	132	34
Shoulder abduction	4	4	90	116	26
Shoulder internal rotation	2	2	14	50	36
Shoulder external rotation	2	2	60	81	21
Elbow flexion	0	0	0	0	0
Elbow extension	4	4	84	132	48
Wrist flexion	0	0	0	0	0
Wrist extension	3	3	-84	2	82

Participant 5 presented with unfatigable clonus (4) at 98-degrees of shoulder flexion, 90-degrees of shoulder abduction, and 84-degrees of elbow extension. A fatigable clonus (3) was measured at 84-degrees of wrist extension and a clear catch (2) was present at 14 degrees of internal rotation and 60-degrees of external rotation. Following NMES intervention, no improvements were noted in spasticity for shoulder flexion, shoulder abduction, shoulder internal rotation, shoulder external rotation, elbows extension and wrist extension. However, improvements were noted at the angles at which resistance was encountered. Unfatigable clonus was present at 132-degrees of shoulder flexion, 116-degrees of shoulder abduction, and 132-degrees of elbow extension. Improvements were also noted during wrist extension in which the fatigable clonus appeared at a two-degree angle of wrist extension. Further improvements were noted during shoulder internal and external rotation which presented a catch at 50-degrees and 81-degrees, respectively (Table 4.7).

Table 4.8: Participant 6: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**		**ROM: Angle of catch at V2/V3 (high velocity)**		
Participant: 6	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	0	0	0	0	0
Shoulder abduction	0	0	0	0	0

Shoulder internal rotation	2	2	35	62	27
Shoulder external rotation	2	2	55	75	20
Elbow flexion	0	0	0	0	0
Elbow extension	2	0	140	0	-140
Wrist flexion	0	0	0	0	0
Wrist extension	3	3	-10	0	10

Participant 6 presented with a clear catch (2) at 35-degrees of shoulder internal rotation, 55-degrees of shoulder external rotation, and 140-degrees of elbow extension. A fatigable clonus (3) was present at -10-degrees of wrist extension. Following NMES intervention, improvement was noted during elbow extension with no resistance being present (0). No changes were noted in spasticity during shoulder internal rotation, shoulder external rotation and wrist extension. Changes were however noted at the joint angle. A clear catch was present at 62-degrees of internal rotation and 75-degrees of external rotation. (Table 4.8).

Table 4.9: Participant 7: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**		**ROM: Angle of catch at V2/V3 (high velocity)**		
Participant: 7	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	4	3	120	135	15
Shoulder abduction	0	0	0	0	0
Shoulder internal rotation	3	1	21	31	10
Shoulder external rotation	0	0	0	0	0
Elbow flexion	0	0	0	0	0
Elbow extension	2	1	89	114	25
Wrist flexion	0	0	0	0	0
Wrist extension	2	1	9	22	13

Participant 7 presented with fatiguable clonus (3) at 120-degrees of shoulder flexion and 21-degrees of shoulder internal rotation. A clear catch (2) was present at 89-degrees of elbow extension and 9-degrees of wrist extension. Following NMES intervention, improvements were noted in spasticity scores as well as the joint angles at which

spasticity was present. A slight resistance in movement (1) was noted during shoulder internal rotation, elbow flexion and wrist extension, while a clear catch (2) was noted at 135-degrees of shoulder flexion (Table 4.9).

Table 4.10: Participant 8: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**		**ROM: Angle of catch at V2/V3 (high velocity)**		
Participant: 8	**Pre-test score**	**Post test score**	**Pre-test score**	**Post test score**	**Change ROM**
Shoulder flexion	4	2	25	47	22
Shoulder abduction	3	3	60	75	15
Shoulder internal rotation	3	2	30	55	25
Shoulder external rotation	3	0	32	0	-32
Elbow flexion	3	2	88	75	-13
Elbow extension	3	2	110	120	10
Wrist flexion	0	0	0	0	0
Wrist extension	2	2	22	45	23

Participant 8 presented with unfatigable clonus (4) at 25-degrees of shoulder flexion. There was a presence of fatigable clonus (3) at 60-degrees of shoulder abduction, 30-degrees of shoulder internal rotation, 32-degrees of shoulder external rotation, 88-degrees of elbow flexion, and 110 degrees of elbow extension. A clear catch (2) was noted a 22-degrees of wrist extension. Following NMES intervention, improvements were noted in spasticity scores and the joint angle at which spasticity occurred. A clear catch (2) was present at 47-degrees of shoulder flexion, 55-degrees of shoulder internal rotation, 75-degrees of elbow flexion, 120-degrees of elbow extension, and 45-degrees of wrist extension. A fatigable clonus (3) was present at 75-degrees of shoulder abduction and no resistance was present during shoulder external rotation (Table 4.10).

Table 4.11: Participant 9: Individual changes in scores using the Tardieu scale

Tardieu:	**Quality of muscle reaction (X)**	**ROM: Angle of catch at V2/V3 (high velocity)**

Participant: 9	Pre-test score	Post test score	Pre-test score	Post test score	Change ROM
Shoulder flexion	0	0	0	0	0
Shoulder abduction	0	0	0	0	0
Shoulder internal rotation	0	0	0	0	0
Shoulder external rotation	0	0	0	0	0
Elbow flexion	2	2	89	95	6
Elbow extension	2	0	130	0	-130
Wrist flexion	0	0	0	0	0
Wrist extension	2	1	90	16	-74

Participant 9 presented with a clear catch (2) at 89-degrees of elbow flexion, 130-degrees of elbow extension, and 90-degrees of wrist extension. Following NMES intervention, significant changes were noted in spasticity scales and joint angles during elbow extension and wrist extension. A clear catch (2) was noted at 95-degrees of elbow flexion and no resistance (0) was noted in elbow extension. During wrist extension, there was slight resistance (1) present during the course of movement (Table 4.11).

4.4.2.4 Mean outcomes of the Tardieu scale range of motion

The Wilcoxon signed test was used to analyze the mean change in the mean scores for the nine participants' scores for the Tardieu scale range of motion.

4.4.2.4.1 Shoulder joint

Significant improvement were noted in shoulder internal rotation (Z=2.207, p=0.027) which had a mean change of 20.44 degrees but none of the other movements in the shoulder joint. Other shoulder flexibility improvements included mean changes of 14.44 degrees in shoulder flexion, 6.33 degrees in shoulder abduction, and 9.22 degrees for shoulder external rotation (Figure 4.5)

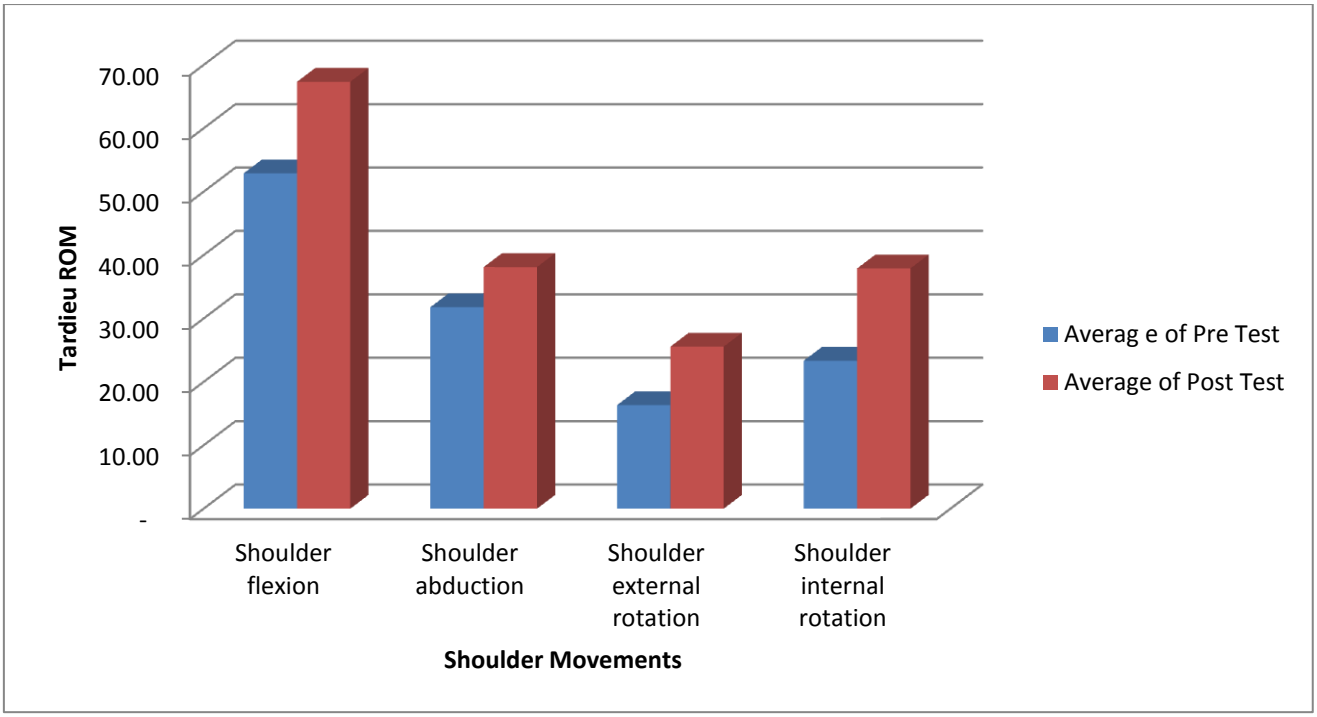


Figure 4.5: Mean pre-intervention and post-intervention changes in Tardieu shoulder ROM scores

4.4.2.4.2 Elbow joint

There were further improvements in; elbow flexion with an average change of 11.11 degrees (Figure 4.6) with a significant change in elbow extension (z= 2.371, p=0.018) post test.

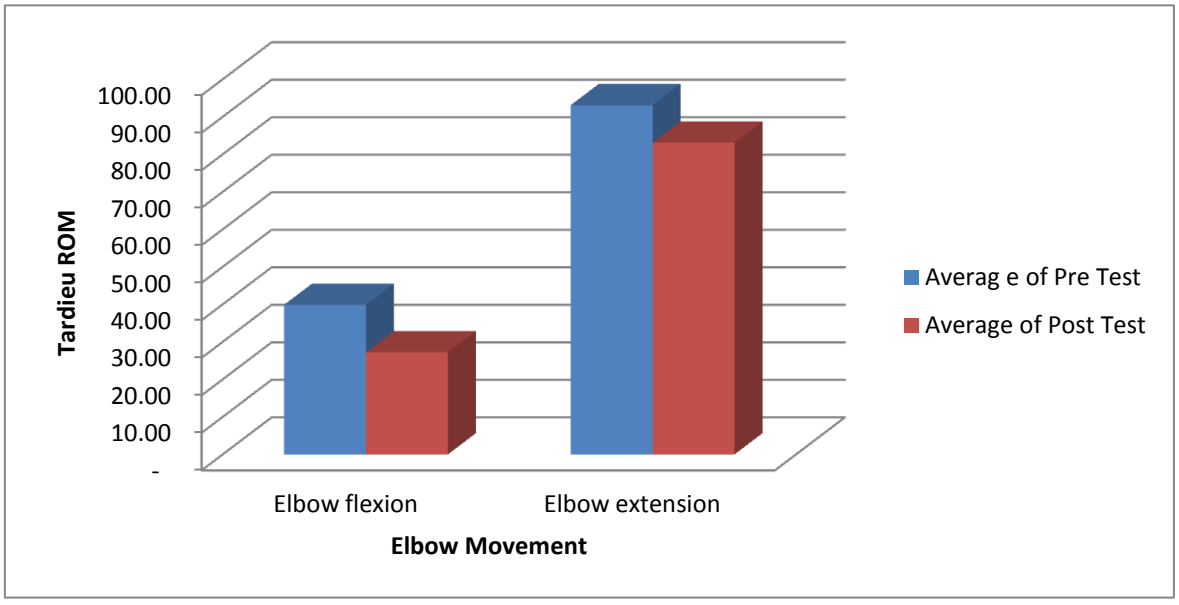


Figure 4.6: Mean pre-intervention and post-intervention changes in Tardieu elbow ROM scores

4.4.2.4.3 Wrist joint

In the wrist joint there was no change that reached significant with a mean change in wrist extension of 4.89 degrees (Figure 4.7)

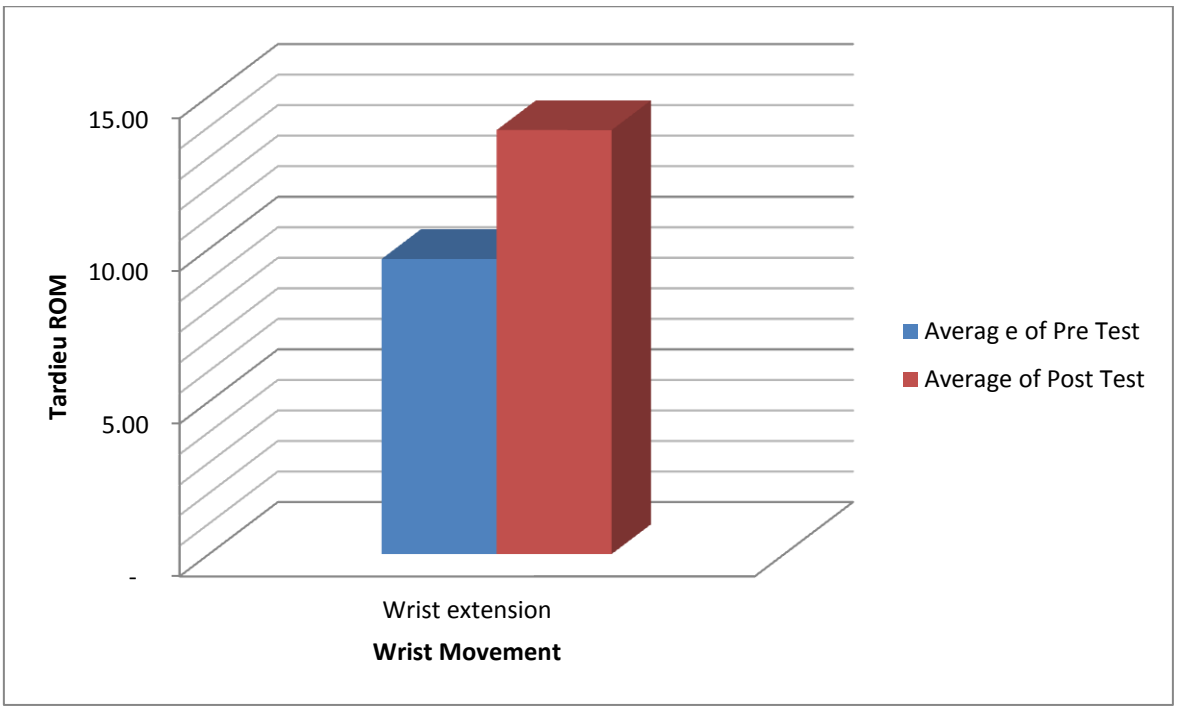


Figure 4.7: Mean pre-intervention and post-intervention changes in Tardieu wrist ROM scores

4.5 Functional hand placement, dissociated movement, and grasps

4.5.1 Introduction

In this study, we evaluated outcomes observed on dissociation, grasp and hand placement following NMES application.

4.5.2 Quality of upper skills test outcomes on dissociation movements and grasps

A Wlicoxon signed test is a nonparametric test was used to analyze the results of the QUEST in terms of dissociated movements and grasp.

4.5.2.1 Dissociation movements

The QUEST outcome measure was used to determine changes in dissociated movement patterns and grasps. The dissociative movement pattern included; keeping fingers together and apart with the elbow extended and wrist neutral during shoulder flexion and abduction, supinating and pronating of the forearm during elbow flexion and extension, wrist extension with elbow flexion and extension, wrist extension with forearm pronation and supination and finger dissociation, grasp and release of a 1” cube.

Initial dissociation scores ranged between 50% - 70% for most participants as they struggled with extending the elbow and placing the wrist in neutral as well as forearm supination. Furthermore, they were unable to produce movements more than 90 degrees (halfway) without flexing the elbow or wrist and they were unable to independently dissociate each finger from the next and use the fingers to grip and release the 1” cube. Participants were able to initially grasp and release the 1” cube through assistance from the other hand.

Following NMES intervention, significant improvements were noted in dissociated movement patterns with scores above 70%. The shoulder was able to produce flexion and abduction above 90 degrees (more than halfway) with the elbow extended and wrist neutral. There were noticeable improvements in forearm supination whereby some participants were able to produce supination halfway while others were able to fully supinate during elbow flexion and extension. There were further improvements in active wrist extension while extending and flexing the elbow and whilst supinating and pronating the forearm. There were improvements in finger dissociation movements. Some children were able to dissociate each finger from the next while others were only able to dissociate a few fingers from the others. Participants that independent finger dissociation were able to use the fingers to grasp and release the cube while those that could only dissociate a few fingers used those fingers to grasp and participants that still had difficulty with finger dissociation grasped and released the cube using the thumb.

The participants presented with a mean score of 69.79 for dissociated movements pre test. Following NMES application, an overall improvement in the mean score was noted with a mean valuescore of 87.50 which was significant (Z=2.677 & p=0.007) (Figure 4.8). Improvements in dissociated movements were noted in all nine participants

4.5.2.2 Grasping

Grasping activities of the QUEST included the type of grasp to pick up; a 1" cube, piece of a cereal and crayon or pencil. Initial grasp scores ranged between 60% and 70%. Most of the grasps observed were a palmar or radial palmar grasp of a 1" cube, inferior scissor grasping of a piece of cereal and digital pronate grasp of pencil. The unaffected hand was used to place the object into the affected hand.

Following NMES intervention improvement in grasps were observed with mean scores ranging above 75%. Participants were able to grasp the 1" cube on the affected side independently and displayed a radial palmar grasp to radial digital grasp. Participants that had significant improvements in finger dissociation were able to pincer grasp a piece of cereal while others that still had challenges with finger dissociation were unable to grasp a piece of cereal and required assistance from the unaffected side. The pencil grasps which were noted post intervention included a digital pronate grasp and in some participants a static tripod grasp.

The participants presented with a mean score of 71.60 for grasps pre test. Following NMES application, an overall improvement in the mean was noted with a mean value of 85.19. The Wilconox test for grasps showed statistical significance with scores of (Z=2.533 & p=0.011) (Figure 4.8). Improvements in grasps were noted in all nine participants.

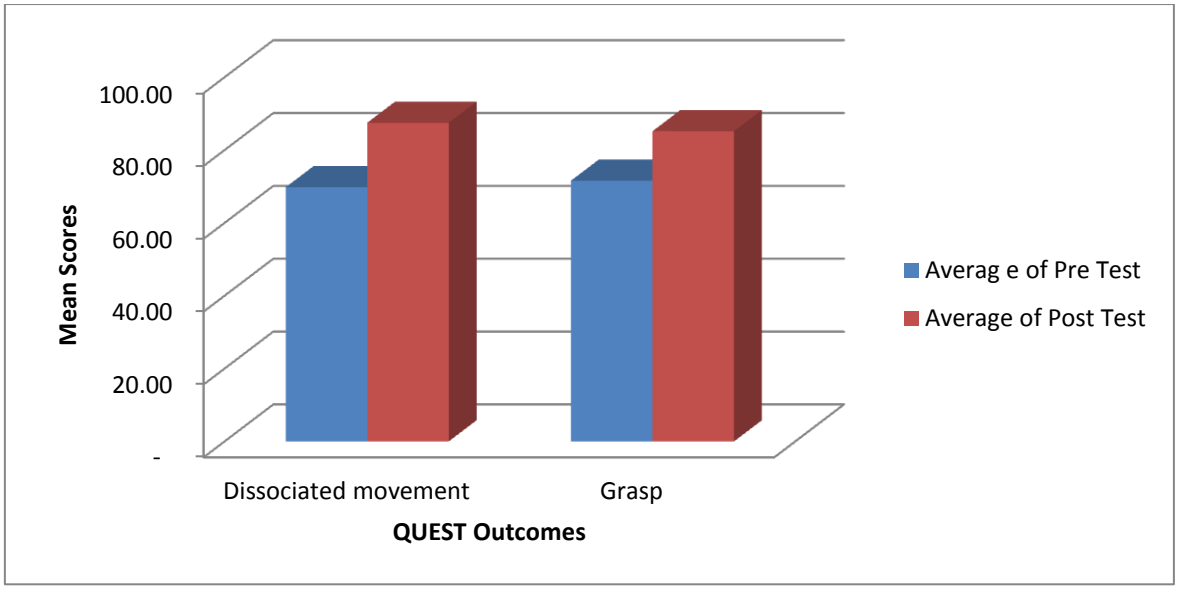


Figure 4.8: Mean pre-intervention and post-intervention changes in dissociated movement and grasp using the QUEST

4.5.2.3 Summary Scores

This is sum of dissociated movements and grasping that was expressed in a percentage form out of 100. The participants presented with a mean summary score of 70.7 pre-test, which showed statistical significance (Z=2.666 & p=0.008) (Figure 4.9).

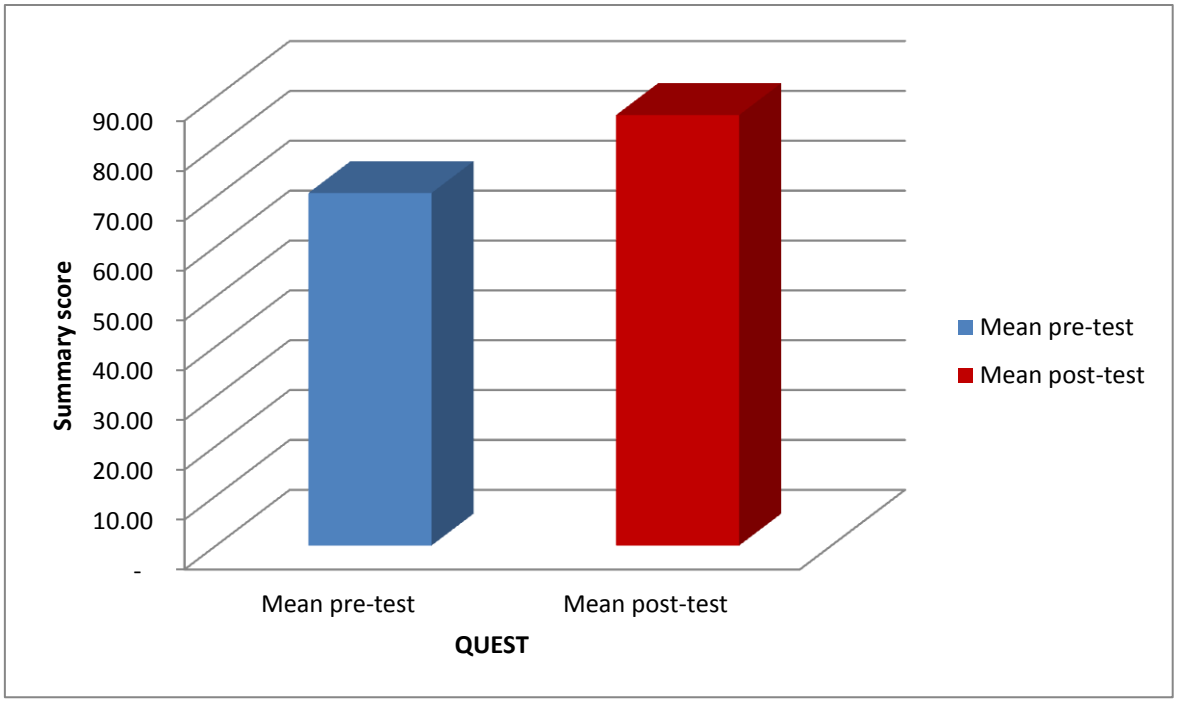


Figure 4.9: Mean pre-intervention and post-intervention changes in summary scores using the QUEST

4.5. 3 Overview of the QUEST outcomes

Improvements in dissociated movements were noted in all nine participants. Initial scores obtained were quite low which ranged between 50% and 70% for 7 of the participants and between 80% - 90% for two of the participants. Following NMES application, dissociation mean scores were above 70% for all nine participants.

Improvements in grasps were noted in all nine participants. Initial scores obtained were quite low which ranged between 60% and 70% for eight of the participants and between above 90% for one participant. Following NMES application, grasp mean scores were above 75% for all nine participants.

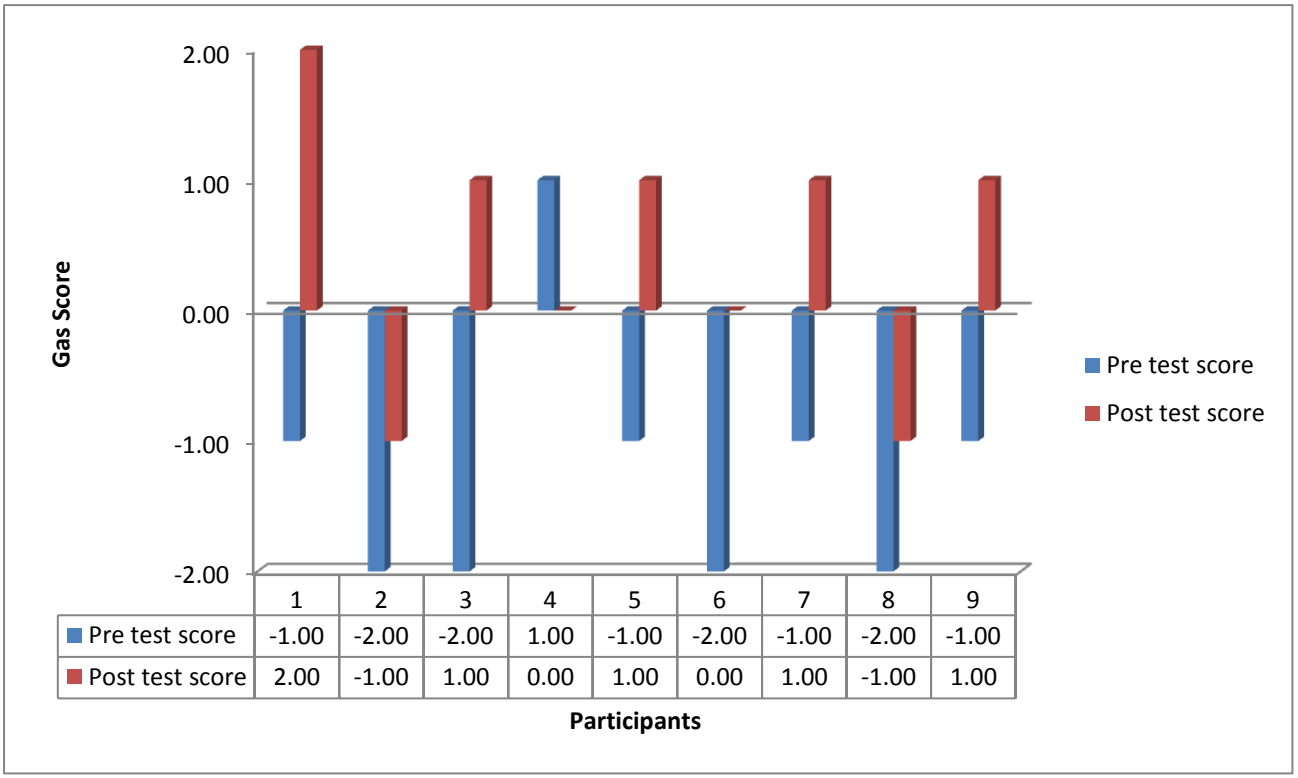
Furthermore, improvements in the summary scores pre-test ranged between 50% and 70% for 7 of the participants and between 80% - 90% for two of the participants. Following NMES application, dissociation mean scores were above 75% for all nine participants.

4.6 Change in functional expected outcomes

4.6.1 Introduction

At the end of the pre-test measures, goals were established for each of the participants. The goals that were set were determined by the researcher based on the extent of the impairment. The two goals set for the participants included grasping and reaching.

4.6.2 Goal Attainment Scale



	1	2	3	4	5	6	7	8	9
Pre test score	-1.00	-2.00	-2.00	1.00	-1.00	-2.00	-1.00	-2.00	-1.00
Post test score	2.00	-1.00	1.00	0.00	1.00	0.00	1.00	-1.00	1.00

Figure 4.10: Pre-intervention and post-intervention GAS scores for the nine participants

Participant 1 had functional restriction of the hand. The participant was able to grasp the cube correctly with a digital grasp and complete elbow extension 2/10 times which was a lot less than expected and reach for the cube using complete elbow extension, neutral wrist and dissociated fingers 4/10 times which was a little less than expected. Following NMES intervention, significant improvements were noted in this participant in achieving the goal of being be able to grasp the cube correctly with a digital grasp and complete elbow extension 10/10 times and reaching for the cube with complete elbow extension, neutral wrist and dissociated fingers 10/10 times during the post-intervention session (Figure 4.10) (Appendix J).

Participant 2 presented with quite severe impairments of the wrist joint. The participant was not able to grasp the cube correctly using a palmar grasp and complete elbow extension 2/10 times and reaching for the cube with complete elbow extension 2/10 times were not met initially as performance was a lot less than expected. Following NMES intervention, the participant was able to grasp the cube using a palmar grasp and complete elbow extension 2/10 times however; performance was still a lot less than expected. Improvements were as expected during reach wherein the participant was able to reach for the cube with an extended elbow and neutral wrist 6/10 times during the post-intervention session (Figure 4.10) (Appendix J).

Participant 3 presented with moderate impairments of the elbow and wrist joint. The pre-intervention outcomes of the participant included grasping the cube correctly using a radial palmar grasp 2/10 times and reaching with an extended elbow and neutral wrist 2/10 times, which was a lot less than expected. Following NMES intervention, the improvements noted in this were a little less than expected whereby the participant grasped the cube using a radial palmar hold 4/10 times. The participant was however able to reach for the cube using an extended elbow and neutral wrist 10/10 resulting in a much better than expected outcome (Figure 4.10) (Appendix J).

Participant 4 presented with no impairments of the elbow and wrist joint and were able to use the hand and fingers. The pre-intervention goals included a digital grasp of the cube using an extended elbow 6/10 times and reaching for the cube using an extended elbow and neutral wrist 6/10. The pre-intervention goals were much better than expected as the participant correctly executed both tasks 10/10 times. Following NMES intervention, the outcomes noted in this participant remained consistent (Figure 4.10) (Appendix J).

Participant 5 presented with an elbow contraction and sever limitations of the wrist. The participant was able to grasp using a radial palmar grasp with a neutral wrist 4/10 which is a little less than expected and was able to reach for the cube correctly using a neutral wrist and dissociated fingers 2/10 times which is a lot less than expected. Following NMES intervention, the improvements noted in this participant was a little more than expected with the participant being able to radial palmar grasp a cube using a neutral wrist 8/10 times and reaching using neutral wrist and dissociated fingers 8/10. These post-intervention outcomes were somewhat better than expected (Figure 4.10) (Appendix J).

Participant 6 presented with limitations in functionality of the wrist and hand. The participant was able to correctly palmar grasp a cube with complete elbow extension 2/10 times and reach for the cube using and extended elbow and neutral wrist 2/10 times. These pre-intervention outcomes were a lot less than expected. Following NMES intervention, the participant was able to correctly palmar grasp the cube with complete elbow extension 6/10 times, which was as expected. The participant was further able to reach for the cube using an extended elbow and neutral wrist 8/10, which is somewhat better than expected (Figure 4.10) (Appendix J).

Participant 7 presented with minimal limitations in functionality of the wrist and hand. The participant was able to radial grasp the cube with complete elbow extension 10/10 times which was much better than expected. The participant was initially able to reach for the cube using complete elbow extension, neutral wrist and finger dissociation 4/10 times

which was a little less than expected. Following NMES intervention, the participant was still able to radial grasp the cube 10/10 times and was also able to reach for the cube with complete elbow extension, neutral wrist and finger dissociation 10/10 times which is much better than expected (Figure 4.10) (Appendix J).

Participant 8 presented with severe limitations in functionality of the wrist and hand. The participant was able to palmar grasp the cube using an extended elbow 2/10 times which was a lot less than expected. Furthermore the participant was able to reach for the cube using an extended elbow and neutral wrist 2/10 times which was a lot less than expected. Following NMES intervention, no changes were noted in the participants' ability to grasp, however; their ability to reach for the cube using an extended elbow and neutral wrist was as expected with a score of 6/10 times (Figure 4.10) (Appendix J).

Participant 9 presented with minimal limitations in functionality of the wrist and hand. The participant was able to digital grasp the cube with complete elbow extension 10/10 times which was much better than expected. The participant was initially able to reach for the cube using complete elbow extension, neutral wrist 2/10 times which was a lot less than expected. Following NMES intervention, no changes were noted in the participants' ability to grasp, however; their ability to reach for the cube using an extended elbow and neutral wrist was somewhat better than expected with a score of 8/10 times (Figure 4.10) (Appendix J).

Table 4.12: GAS T scores for participants to indicate if goals were achieved as expected

	GAS T Baseline	GAS T Achieved	GAS T Change
Participant 1	31.4	62.4	31
Participant 2	25.2	37.6	12.4
Participant 3	25.2	56.2	31
Participant 4	70	70	0
Participant 5	31.4	62.4	31
Participant 6	25.2	64.2	37.2
Participant 7	50	74.8	24.8
Participant 8	25.2	37.6	12.4
Participant 9	50	68.6	18.6

Achieved score: If T > 50 = goal achieved. If T < 50 = goal not achieved.

In summary, 2 out of the 9 participants had not reached the outcome expected, while the remainder of the participants reached the expected outcomes.

4.7 Summary

In conclusion, it was found that following NMES application twice a week over an eight-week period had statically significant outcomes on flexibility of the shoulder, elbow and wrist joint. Changes in post-test intervention modified Ashworth scores presented show that there were also improvements in spasticity in various movements' patterns of the shoulder, elbow and wrist joint. The use of the Tardieu scale showed varying outcomes whereby 7 of the participants had no improvements in overall spasticity scores but improvements for all nine participants were noted in the ROM angles at which spasticity occurred. Two participants showed significant improvements in Tardieu scores. Statistical analysis could not provide sufficient evidence for significance for both spasticity scales and Tardieu ROM due to the lack of participants. Significant statistical evidence was observed for dissociated movements and grasps of all nine participants using the QUEST.

CHAPTER 5: DISCUSSION

5.1 Introduction

The outcomes of the results on; flexibility of the upper limb, spasticity of the upper limb, dissociation, grasps, hand placement, and goal attainment will be discussed in this chapter.

5.2 Demographics

South Africa is considered as an upper-middle income country with a disability prevalence of 6% (Mathye & Eksteen, 2016). According to the National Council for Persons with Physical Disability, spastic CP accounts 77.4% of the disability prevalence. Diplegic CP is the most common type of CP found in Africa while hemiplegic CP being the least common form of CP (Gladstone, 2010). South Africa lacks epidemiological studies as well as CP registers which in turn negatively influences further discussions. This study was made up of children aged between eight years and 18 years old and included both males and females diagnosed with hemiplegic CP. Children diagnosed with CP have an earlier onset of puberty, however, this does not result in further impairments due to the lesion being non-progressive in nature (Whorley et al., 2002). Furthermore, the presence of contractures was noted in children over the age of 15 years old that attended various therapies at school, however; they had better hand functionality than their younger counterparts which could be a result of them having a milder form of hemiplegic CP. Younger participants responded positively to the intervention in earlier weeks in comparison to the older adolescence which could be a result of plasticity changes being elicited earlier (Merill DR, 2010).

5.3 Range of motion of the shoulder, elbow, and wrist joints

The application of NMES on the bicep brachii in addition to single-type exercise produced improvements in both active and passive flexibility of the shoulder, elbow, and wrist joint movement, including the participant that presented with an elbow contracture. The greatest improvements were noted during shoulder flexion, shoulder abduction and shoulder internal rotation. Each of these muscle groups insert along certain areas of the humerus below the bicep brachii muscle. Children diagnosed with cerebral palsy often

have low muscle mass (Day et al., 2007) and it is possible that for this reason the stimulation penetrated deeper structures resulting in ROM changes of the shoulder joint. The greatest changes in flexibility of the elbow joint were noted during elbow extension and of the wrist joint during wrist extension. The muscles used to initiate wrist extension originate on various parts of the distal humerus. Taking into account the low muscle mass present in the bicep muscle, the stimulation could have also initiated changes to distal musculature of the lower part of the upper limb.

The changes in ROM produced by NMES may possibly be attributed to the activation of both central and peripheral pathways as opposed to initiation of only a single pathway. The application of NMES to the motor point of a nerve activates the peripheral pathways and has the potential to improve ROM by decreasing co-contractions and producing positive soft tissue changes that surround the joint (Merill, 2009). Furthermore, NMES activation of central pathways would produce plasticity changes in the brain (Merill, 2010). The engagement of central pathways evokes a sensory volley which produces changes in plasticity and reverses maladaptive changes (Berquist et al., 2011). Changes in plasticity reduce reciprocal inhibition of the agonist-antagonist muscle and allow for the development of a stretch reflex which improves ROM (Berquist et al., 2011).

The ROM improvements noted in the elbow and wrist joint relate to changes in noted in previous studies. These include improvements in elbow extension (Carmick J, 1993), wrist extension (Carmick J, 1997, Schekar et al., 1999; Wright & Granat, 2000; Kamper et al., 2006; Ozer et al., 2006).

Surprisingly, the effects produced were not localized to the muscle being stimulated but instead to all the joints of the upper limb. This study brings to light the possibility that NMES may stimulate a variety of structures and produce a “carry-over” effect as changes in ROM were noticed in all joint structures. There is definite CNS input through NMES usage and possible development of a sensory volley which heightens signaling into and out of Golgi tendon organs and muscle spindles. No studies have been done to postulate these outcomes.

5.4 Spasticity of the shoulder, elbow, and wrist joints

Both the Ashworth and Tardieu spasticity scales were used to measure spasticity, which was measured on different movement patterns. These included shoulder flexion,

abduction, internal rotation, and external rotation, elbow flexion, and extension and wrist flexion, and extension.

5.4.1 Modified Ashworth Scale

The application of NMES on the bicep brachii in addition to single-type exercise produced improvements in spasticity score. The location of spasticity for each individual varied; however, improvements in spasticity using the Ashworth Scale were seen in all of the various muscle groups for all nine participants. This opposes the idea that changes in spasticity are only produced in the muscle being stimulated through NMES application (Merill, 2009).

There is a possibility that changes in spasticity on various joint structures following NMES stimulation to the bicep can be produced by a “carry-over effect” through changes in individual muscle fibre spasticity, muscle morphology, and biomechanics, and altered muscle signalling in addition to CNS stimulation. As mentioned by Foran et al., (2005) the area which is spastic is associated with an increase in individual muscle fibre stiffness, decrease the stiffness of the muscle bundle (fascicle), and a significant amount of extracellular matrix which consists of poor amounts of collagen, proteoglycans, and water. The extracellular matrix plays an important role in supporting muscle structures and recent evidence has mentioned that the extracellular matrix may also play a role in signalling by converting extracellular signals to intracellular response (Grzelkowska-Kowalczyk, 2016). Neuromuscular electrical stimulation and exercise intervention used in this study could have produced an overload effect on the muscle and may have resulted in hypertrophy of the muscle. The overload effects produced by NMES coupled with exercise may further have produced a reduction in spasticity to individual muscle fibres and promoted remodelling of the extracellular matrix components (Grzelkowska-Kowalczyk, 2016).

The possibility of the combined effects of NMES and exercise intervention choice affecting the spasticity of individual muscle fibres and overall signalling, and changes in the material of the extracellular matrix are still unknown. This study confirms previous studies in which NMES alters brain plasticity as seen by the reduction in spasticity and the ability of NMES to evoke the sensory volley producing a reduction in reciprocal inhibition agonist-antagonist response and the development of a stretch reflex (Merrill, 2009; Bergquist et al., 2011). A study previously conducted mentioned that spasticity is only

decreased in the muscle being stimulated (Merill, 2009), however, in this study spasticity changes were noted in all joint structures.

The post-intervention improvements that showed reductions in Ashworth spasticity scores relate to the study completed by Schekar et al. (1999) that evaluated the outcomes in spasticity on the tricep muscle and wrist and finger extensors following NMES application and dynamic bracing. The study found a significant reduction in spasticity scores in the tricep and wrist extensors.

5.4.2 Tardieu Scale

The application of NMES on the bicep brachii in addition to single-type exercise produced post-intervention improvements in the joint angle ROM at which spasticity occurred without changes in the scoring of spasticity. This is possibly due to the sensitivity of the scale as well as the lack of movement through a full range.

This brings to light the question of whether or not spasticity produces positive changes to the stretch reflex and decreases inhibition of the motor neurons of the agonist muscle which results in improved ROM. Furthermore, one could question the possibility of NMES eliciting independent effects on spasticity and ROM without either one producing a corresponding effect on the other. In mentioning this, noticeable improvements in spasticity were observed in all nine participants when using the Ashworth Scale.

The outcomes observed using the Tardieu spasticity scales in this study align with a study conducted by Alhussaini et al. (2010) which mentioned that the Tardieu Scale failed to identify a measure of spasticity in children with cerebral palsy. The Tardieu scale is an appropriate measure to be used in individuals with contractures as it differentiates spasticity from the presence of a contracture (Alhussaini et al., 2010).

The presence of a joint contracture restricts movement and limits activity. Following NMES on a participant with an elbow contracture, no noticeable improvements in spasticity were measured using the Tardieu Scale. The inability to produce changes in spasticity could be a result of decreased period if NMES usage, shortened tissues surrounding the joint combined with disuse of the arm and possibly age. An increased period of NMES may reduce stiffness in individual muscle fibers which would directly reduce spasticity, since the individual muscle fibers of the upper limb in children with CP tend to be stiffer, while the muscle bundle is more compliant (Mathewson & Lieber, 2015). Contractures are often associated with contractile tissue, intramuscular connective tissue,

and connective tissue shortness which occurs parallel to a joint (Postans et al., 2010). The shortened connective tissue is often a result of increased collagen or abnormal organization of the extracellular matrix Mathewson & Lieber, 2015). Furthermore, the lack of muscle usage caused by age and, or disease have a direct effect on the number and length of sarcomeres (Mathewson & Lieber, 2015). The number and length of sarcomeres rapidly reduce as children get older and continue to have disuse of the arm with the arm often kept in a flexed position (Mathewson & Lieber, 2015).

5.5 Quality of upper limb extremity skills tests

The application of NMES on the bicep brachii in addition to single-type exercise produced post-intervention improvements in hand function. It is evident that reductions in spasticity, improvements' in flexibility directly improve dissociation of the shoulder, elbow, and wrist joints. Furthermore, the combined improvements in spasticity, ROM, and dissociation in the affected upper limb have a direct effect on motor planning, grasping, upper limb awareness, assistive hand usage, and independent hand usage.

Combined effects of upper limb awareness and the ability to motor plan resulted in some children being able to use the affected limb independently while others were able to use it to assist the unaffected limb in bilateral tasks, and ADL (dressing, bathing, and playing). The improvements are particularly important as the increased independence of the child improves their quality of life and ability to meet their goals, expectations and be more socially interactive. These assist parents and caregivers in managing the child, but also reduce the need for external assistance from parents, teachers, and caregivers. The activity of daily living outcomes was not included as part of the study, however, it had been mentioned to the researcher by parents, caretakers, and nurses of children that resided in hostels.

Children had better functionality of the affected upper limb which can be attributed to NMES stimulation of motor neurons in both central pathways and peripheral pathways. Stimulation of motor neurons in the peripheral pathways improves functional movements and muscle quality for rehabilitation purposes (Bergquist et al., 2011), while changes in spasticity as a result of central pathway stimulation result in motor learning (Merill, 2009). Furthermore, coordination of the trunk, shoulder, elbow, and wrist combined with appropriate grip forces allows for the execution of movements (Steenbergen & Andrew, 2006).

The outcomes of this study in terms of grasping objects are consistent with findings of previous studies conducted by Carmick J, (1993) and (1997). Children were able to grasp and release a one inch cube which is consistent with findings by Wright & Granat, (2000) in which children were able to grip and release objects of various sizes.

5.6 Goal Attainment Scale

The goals were individualized according to each participant's capability and served as an encouragement to the participants. This aspect comprised of two components, namely; handling of a 1" cube and reaching for a 1" cube. During the initial handling evaluation, seven of the nine participants struggled with grasping the 1" cube while almost all participants had difficulty with correctly reaching for the 1" cube.

Varying results were achieved using the GAS scale with some participants reaching or surpassing the desired outcome, while others reached an outcome that was a little less than expected and some a lot more then the desired outcome. The varying outcomes can be due motivation and behaviour patterns.

The combined effects of determination and motivation played an important role in childs' ability to reach their goal. Those individuals that were determined and motivated had better activity outcomes and fewer behavioural issues in relation to those individuals that lacked determination and motivation. The outcomes mentioned above align with a study conducted by Majnemer et al., (2010) that concluded the importance of motivation on participation engagement. The greater the degree of motivation, the higher the engagement in more challenging types of activities. The goal attainment directly impacted the quality of life of these participants. No quality of life assessment was made during this study, however, changes in the QoL were observed and it is important to report these. Participants' that had reached their goal showed; enthusiasm, happiness, confidence, and reduced self consciousness.

5.7 Summary

The combined effects of NMES paired with isometric bicep curl and isotonic bicep curl exercise improved flexibility of the shoulder, elbow, and wrist joint, and reduced spasticity in the shoulder, elbow, and wrist joint. The Ashworth Scale was an effective measure in spasticity in children with cerebral palsy; however, no changes in spasticity were noted in the Tardieu Scale. There were improvements in the Tardieu ROM at which spasticity occurred. The reduction in spasticity and improvement in flexibility had a direct effect on

upper limb function. Participants had improved dissociation of the shoulder, elbow, and wrist joint which had a positive outcome on grasping. The goals attained varied amongst participants and these outcomes were directly associated with motivational and behavioural factors.

CHAPTER 6: CONCLUSION

6.1 Main findings

The findings from this case study design support the hypothesis that NMES in combination with isometric bicep curl and isotonic bicep curl exercise have significant effects on the upper limb of children with hemiplegic CP. There was statistically significant evidence suggesting that the effect of NMES in combination with exercise intervention resulted in improved ROM of the shoulder, elbow, and wrist joint. The changes noted can be attributed to both central and peripheral pathway activation through NMES application. The neuromuscular application that stimulated peripheral pathways resulted in reduced co-contraction of the agonist-antagonist muscle and creates soft tissue changes that improve ROM (Merill DR, 2009). Furthermore, the application of NMES that stimulates central pathways produces a stretch reflex and decreases reciprocal inhibition of the agonist-antagonist muscle which improves ROM (Bergquist et al., 2011). The outcome in ROM relate to previous studies conducted by Carmick (1993), Cramick (1997), Wright and Granat (2000), Ozer et al. (2006) and Postans et al. (2010)

Improvements were noted in spasticity scores using the Ashworth scale. Participants had a decrease in Ashworth scores post-intervention. These improvements are a result of central and peripheral pathway activation through NMES application which decreases brain plasticity which reverses maladaptive changes (Merill, 2009; Bergquist et al., 2011). The outcomes in the Ashworth spasticity scores relate to the study conducted by Schekar et al. (1999). No improvements were noted in spasticity scores using the Tardieu specifically in children with cerebral palsy which aligns with the outcomes in the study conducted by Alhussaini et al. (2016). The most common outcome observed was the improvement in the joint angle at which spasticity occurred.

Reduction in spasticity and improvements in ROM of the shoulder, elbow, and wrist joint resulted in improved dissociation movement patterns of the shoulder, elbow, wrist, and fingers, which align with numerous other studies. These improvements had a direct effect on the participants' ability to grasp, however, it was noted that post-intervention, participants were able to better grasp bigger objects as opposed to smaller objects, and participants with higher levels of determination, motivation and good behaviour reached the expected outcome and in some instances more than the expected outcomes.

6.2 Implication for clinical practice

Neuromuscular electrical stimulation is an inexpensive device and can be implored in a variety of settings (public health facilities, private healthcare, and home) as well as on different types of spastic cerebral palsies. Furthermore, the positive changes observed can assist individuals to better perform tasks in ADL and being more functionally independent.

This study provides evidence that NMES application to the bicep brachii muscle coupled with isometric and isotonic bicep curl exercise, done twice a week, for 20 minutes, over eight-weeks, in children with cerebral palsy produced significant improvements in ROM, reduction in spasticity, improvements in dissociation movement patterns and grasps.

The improvements presented during the sixth week of the intervention period and a maintenance effect seems to have presented during the last two weeks of the intervention. The improvements were evidenced with photographic visual aids.

Recent evidence concluded a high prevalence of CP in SA as well as an increase in children with disabilities from 2010 to 2016. Different treatment modalities are therefore required to assist in improving and maintaining function in children with CP. Neuromuscular electrical stimulation should be considered as a treatment modality in treating cerebral palsies as it is effective in reducing spasticity, improving flexibility, producing dissociative movements, and improving hand function (grasps, grip, etc).

6.3 Limitations of the study

Certain schools preferred children to undergo the study after school hours and in the confines of their homes. The distance required to travel to and between children was not feasible and resulted in a small sample size.

In certain instances protest actions or in which the area in which the child resided made its unsafe for the researcher to access children in instances where it was allowed. Furthermore, children that utilized school transport often reached home late and were required to complete chores at home, which resulted in a lack of time availability for them to partake in the study.

Other limitations included time constraints allocated by schools to ensure children were still able to be in the classroom for learning. A small sample size resulted in the absence of a control group and a lack of blinding. Furthermore, case studies conducted over

extended periods with data collection on a continuous basis poses challenges to data analysis and therefore a generalized GAS outcome was used to keep measurements similar.

6.4 Recommendations

The combined effects of NMES to the bicep brachii muscle and bicep curl exercises implemented twice a week over six-weeks improve ROM, reduces spasticity and improves upper extremity function.

Future studies should focus on including quality of life assessment as it seemed that there were improvements to the participants' quality of life. Further studies are required to gage insight into the time period that the effects are present after stopping NMES and how often would NMES need to be applied as maintenance therapy.

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APPENDICES

APPENDIX A: Ethical clearance letter

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

R14/49 Mrs Bibi Fatima Hoorzook

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M181023

NAME: (Principal Investigator)	Mrs Bibi Fatima Hoorzook
DEPARTMENT:	Centre for Exercise Science and Sport Medicine Therapy Worx Cantapaeds the centre for paediatric therapy Childrens Therapy Cleverme Occupational Therapy
PROJECT TITLE:	The effects of Neuromuscular Stimulation and Exercise Intervention on the Upper Limb of Children with Spastic Hemiplegia
DATE CONSIDERED:	26/10/2018
DECISION:	Approved
CONDITIONS:	Permission from Study sites
SUPERVISOR:	Demitri Constantinou and Janine van der Linde
APPROVED BY:	Doctor CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	11/12/2018

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

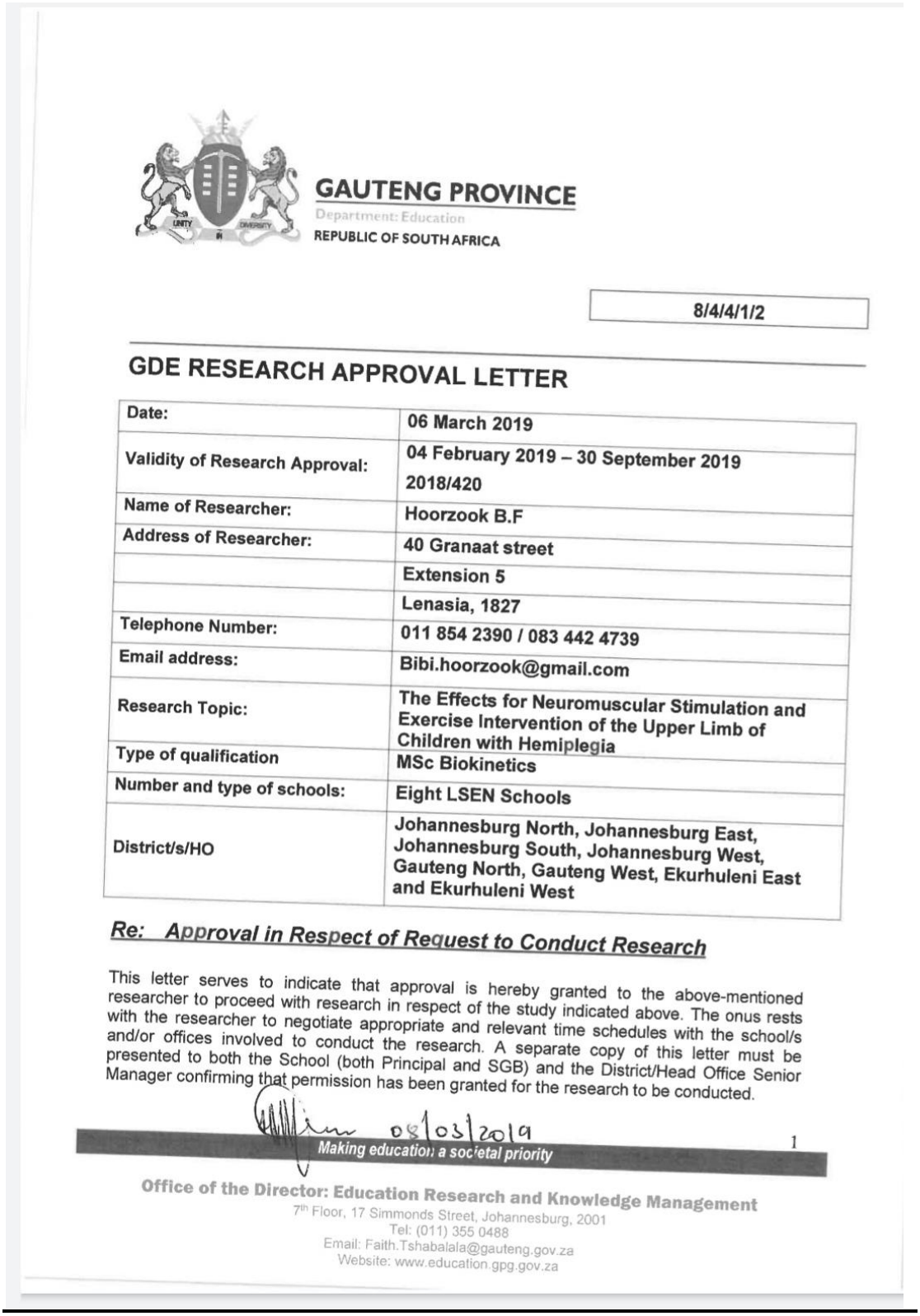
To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in **October** and will therefore be due in the month of **October** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX B: Permission from the Department of Education



GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

8/4/4/1/2

GDE RESEARCH APPROVAL LETTER

Date:	06 March 2019
Validity of Research Approval:	04 February 2019 – 30 September 2019 2018/420
Name of Researcher:	Hoorzook B.F
Address of Researcher:	40 Granaat street
	Extension 5
	Lenasia, 1827
Telephone Number:	011 854 2390 / 083 442 4739
Email address:	Bibi.hoorzook@gmail.com
Research Topic:	The Effects for Neuromuscular Stimulation and Exercise Intervention of the Upper Limb of Children with Hemiplegia
Type of qualification	MSc Biokinetics
Number and type of schools:	Eight LSEN Schools
District/s/HO	Johannesburg North, Johannesburg East, Johannesburg South, Johannesburg West, Gauteng North, Gauteng West, Ekurhuleni East and Ekurhuleni West

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

08/03/2019

1

Making education a societal priority

Office of the Director: Education Research and Knowledge Management
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za

above study subject to the conditions listed below being met. Approval may be withdrawn should any of the conditions listed below be flouted:

1. *The District/Head Office Senior Manager/s concerned must be presented with a copy of this letter that would indicate that the said researcher/s has/have been granted permission from the Gauteng Department of Education to conduct the research study.*
2. *The District/Head Office Senior Manager/s must be approached separately, and in writing, for permission to involve District/Head Office Officials in the project.*
3. *A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB) that would indicate that the researcher/s have been granted permission from the Gauteng Department of Education to conduct the research study.*
4. *A letter / document that outline the purpose of the research and the anticipated outcomes of such research must be made available to the principals, SGBs and District/Head Office Senior Managers of the schools and districts/offices concerned, respectively.*
5. *The Researcher will make every effort obtain the goodwill and co-operation of all the GDE officials, principals, and chairpersons of the SGBs, teachers and learners involved. Persons who offer their co-operation will not receive additional remuneration from the Department while those that opt not to participate will not be penalised in any way.*
6. *Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal (if at a school) and/or Director (if at a district/head office) must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage.*
7. *Research may only commence from the second week of February and must be concluded before the beginning of the last quarter of the academic year. If incomplete, an amended Research Approval letter may be requested to conduct research in the following year.*
8. *Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.*
9. *It is the researcher's responsibility to obtain written parental consent of all learners that are expected to participate in the study.*
10. *The researcher is responsible for supplying and utilising his/her own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institutions and/or the offices visited for supplying such resources.*
11. *The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not appear in the research report without the written consent of each of these individuals and/or organisations.*
12. *On completion of the study the researcher/s must supply the Director: Knowledge Management & Research with one Hard Cover bound and an electronic copy of the research.*
13. *The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned.*
14. *Should the researcher have been involved with research at a school and/or a district/head office level, the Director concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.*

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

.....

Mr Gumani Enos Mukatuni
Acting CES: Education Research and Knowledge Management

DATE: 08/03/2019

Office of the Director: Education Research and Knowledge Management
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za

APPENDIX C: Permission from schools

Upon receiving ethical clearance, schools will be contacted to inform them of the study being undertaken and to obtain permission to conduct research at their premises, which will be followed by an email communication.

Email Draft:

Good Day

I trust this email finds you in good health.
I am currently completing my masters research at the University of Witwatersrand. My research is focused on the effects of neuromuscular stimulation and exercise intervention on the upper limb of children with hemiplegia.

In simpler terms, I will be looking at the effects that fatiguing of the bicep has on the overall hand functionality of these individuals. The age category which i hope to attain research from is between 6-18 years old. I feel that this is quite an important research as it might allow these individuals to have some sort of hand functionality on the affected side, particularly in these individuals whereby the upper limb is usually more affected than the lower limb.

The research will be conducted by me as I am the primary researcher. The intervention should be no longer than 20 minutes per participant. Following the intervention results will be made available to the parents.

At current, I have received ethical clearance, however, initially all research was supposed to have been completed at multi disciplinary therapy centers. Due to the chosen age category, it has come to my knowledge that hemiplegic children begin entering schools from the age of 6 and acquire all therapies onsite. I am in the process of obtaining permission from the Department of Education should schools be willing to accept me onsite.

I would appreciate any help I can receive in order to determine if there is an alternate way that we could assist these individuals.

I look forward to hearing from you.

Kind Regards

Bibi Fatima Hoorzook

APPENDIX D: Informed consent form



Information Sheet

This informed consent form is for the parents of children with hemiplegia between the ages of 6 and 18 years old whom we wish to invite to participate in our research study

Name of Principal Investigator: Bibi Fatima Hoorzook (083 442 4739)

Name of Organization: University of Witwatersrand

The Effects of Neuromuscular Electrical Stimulation and Exercise Intervention on the Upper Limb of Children with Spastic Hemiplegia

PART I: Information Sheet

Introduction

My name is Bibi Fatima and I am a Biokineticist working in a paediatric centre. I will be conducting research on the upper limb of hemiplegic individuals as they seem to have significant difficulty in this area

Purpose

Cerebral Palsy has increased in prevalence over the years, with hemiplegia accounting for between 20-30% of cases. We have noticed that upper limb movement and hand usage is minimal in these individuals. The purpose of this research is to use certain interventions to allow the release of the spastic muscle and evaluate its effects on hand functionality.

Type of Research Intervention

The individuals that have received consent from the parent/guardian as well as assented will have the opportunity to undergo the intervention twice a week for 8 weeks. The intervention involves a stimulation process whereby a device will be attached to the arm and small pulses sent through the arm. At some point during the stimulation, the individual will be asked to complete certain exercises and changes found will be documented.

Participant selection

Hemiplegic individuals have been chosen for this study as we wish to look for ways to improve upper limb functionality and make them more independent in their daily lives. We also would like to understand how this intervention is perceived by the individuals in terms of its effectiveness.

We are inviting your child/children to take part in this research because it is important that we try to assess ways to improve functionality on children who have difficulty in executing basic hand movements and functions and try to allow them to live a better quality of life.

Voluntary Participation

Your decision to have your child participate in this study is entirely voluntary. You may also choose to change your mind later and stop participating, even if you agreed earlier, and the intervention will stop immediately for your child.

Procedures and Protocol

The individual will undergo a 20 – 30 minute session under supervision by the biokineticist. Research will take place at the school which your child currently attends or in their home. There will be no cost involved in terms of them partaking in the research. The initial assessment will include:

a flexibility measurement whereby the angle of the elbow will be measured

hand function test to test the individuals handling of an object

Thereafter the 4 stage intervention will proceed and will remain constant throughout the study period. The processes involved are:

Pads will be attached to the upper arm of the individuals and linked up to a machine.

Stage 1- The machine will evaluate the initial activation present in the muscle

Stage 2 – the machine will send an impulse through the muscle to warm up the muscle

Stage 3 – the individual will be asked to execute a bicep curl and hold for 20 seconds. During this stage, the machine will only send an impulse through when the bicep is being worked.

Stage 4 – this stage involves alternating stimulation of low stimulation and moderate stimulation sequencing. During the low stimulation, the individual will be required to execute 5-10 bicep curls and will continue until the muscle becomes tired.

Thereafter, the individuals hand function will be documented using visuals.

On the last day of the study, the individuals' flexibility and hand function will be re-assessed to determine improvements.

Duration

The research takes place twice a week over 8 weeks.

Side Effects

The individual may experience slight discomfort from the stimulation which may only be present during the time of the intervention. To ensure discomfort is minimal, the intensity will be individually adjusted to ensure the individual is comfortable. Should the discomfort be too much, the test will be stopped. The individual may have muscle pains the following day and may last a day or two.

Risks

Should your child suffer from seizures or has a history of seizure and are not currently on treatment, they will be excluded from the study. In the event of a seizure, medical staff at the schools will be notified in advance and nearby paramedics and hospitals will be on call. Every effort will be taken to ensure the safety of your child.

Confidentiality

The information that we collect from this research project will be kept confidential. Information about your child that will be collected from the research will be put away and no-one but the researchers will be able to see it. Any information about your child will have a number on it instead of his/her name. Only the researchers will know what his/her

number is and we will lock that information up with a lock and key. It will not be shared with or given to anyone except the professor supervising this study.

Sharing of the results

The knowledge that we get from this study will be shared with you before it is made widely available to the public. Confidential information will not be shared. Afterwards, we will publish the results in order that other interested people may learn from our research. This will be in a group and no individual will be identifiable.

Right to Refuse or Withdraw

You do not have to agree to your child taking part in this research if you do not wish to do so and refusing to allow your child to participate will not affect your treatment or your child's treatment at this centr in any way. You and your child will still have all the benefits that you would otherwise have at this centre. You may stop your child from participating in the research at any time that you wish without either you or your child losing any of your rights.

Who to Contact

Provide the name and contact information of someone who is involved, informed and accessible (a local person who can actually be contacted.) State also that the proposal has been approved and how.

If you have any questions you may ask them now or later, even after the study has started. If you wish to ask questions later, you may contact the following:

Bibi Fatima Hoorzook

40 Granaat Street, Extension 5, Lenasia

083 442 4739

bibi.hoorzook@gmail.com

This proposal has been reviewed and approved by HREC-Medical of the University of Witwatersrand which is a committee whose task it is to make sure that research participants are protected from harm.

This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg (“Committee”). A principal function of this

Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.

If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za.

Informed Consent Parent/Guardian

PART II: Certificate of Consent

I have been invited to have my child participate in research of a new intervention on muscle release. I have read the foregoing information. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily for my child to participate as a participant in this study.

Print Name of Participant_____

Print Name of Parent or Guardian_____

Signature of Parent or Guardian _____

Date _____

Day/month/year

APPENDIX E: Demographic information sheet and medical check list

AGE: _____ GENDER: _____ AFFECTED SIDE: _____

PUBERTY: Yes / No

Does he/she suffer with seizure? _____

If yes, state medication and dosage _____

_____

Does he/she suffer from any other secondary or chronic medical conditions?

_____

If yes, kindly inform us of the medical conditions _____

_____

List medications and dosage for above _____

_____

Is he/she currently undergoing any other therapies, such as, Physiotherapy,

Occupational therapy etc._____

_____

Kindly provide a list of therapies below

_____ _____

_____ _____

_____ _____

Kindly provide a list of allergies below

_____

APPENDIX F: Consent for photograpy

I would like to take photographs of participants during the research following each intervention. Photographs will not include the participants face and will be taken anteriorly, from the neck down.

Any images taken will be securely stored and backed up by a password for the duration of the research. To comply with the Data Protection Act 1988 the Medical Research Council (MRC) requires your permission to do this.

I agree that my child will appear in photographs to be taken for Medical Research Council publicity, information and exhibition purposes including those promoted via the internet. I understand that they may be used in articles and display material seen by the general public. I also understand that these images will not be used by other organisations other than in relation to the promotion of MRC activities and that I will not benefit financially from the future use of these images.

Print Name of Participant_____

Print Name of Parent or Guardian_____

Signature of Parent or Guardian _____

Date _____

Day/month/year

APPENDIX G: Assent consent form

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



TITLE OF THE RESEARCH PROJECT: The Effects of Neuromuscular Electrical Stimulation and Exercise Intervention on the Upper Limb in Spastic Hemiplegia.

RESEARCHERS NAME: Bibi Fatima Hoorzook

ADDRESS: 40 Granaat Street, Extension 5, Lenasia

CONTACT NUMBER: 083 442 4739

Information Sheet

My name is Bibi and my job is a researcher. I do hope that you will be able to help me in receiving information that may help you and many other children that may have the same challenges as you.

I am going to give you information and invite you to be part of a research study. You can choose whether or not you want to participate. We have discussed this research with your parent(s)/guardian and they know that we are also asking you for your agreement. If you are going to participate in the research, your parent(s)/guardian also have to agree. But if you do not wish to take part in the research, you do not have to, even if your parents have agreed.

There may be some words you don't understand or things that you want me to explain more about because you are interested or concerned. Please ask me at anytime and I will take time to explain.

What is RESEARCH?

Research helps us to find out more about the way things work. It also helps us to understand about diseases and illness and finding ways of helping children who are unable to do certain tasks

What is this research project all about?

In this research, we will be trying to relax the muscle in the upper arm by using stickers on the top of the arm which attaches to a machine. The machine will send a sensation through the muscle, almost like ants crawling in the muscle. Whilst the sensation is felt, you will be required to move the arm up and down.

Why have I been invited to take part in this research project?

We are testing children between the ages of 6-18 years old and that is having a difficult time trying to use the arm. We want to try and help the arm move better.

Who is doing the research?

I am Bibi and I will be doing the research. I am a biokineticist and I use exercises to help people feel better. I work with a lot of kids to try and help them move better. I would like you to help me do this research so that I may help you move your arm better and to understand how you feel about the machine and the exercise so that I may use your input to help other children.

What will happen to me in this study?

I will be using a machine and some exercises to help improve your flexibility of the elbow. I will be seeing you twice a week for the next 8 weeks. We will use the same machine and

exercises every time I see you to try and get the muscles to relax and the hand to function better.

Can anything bad happen to me?

You may feel a little uncomfortable when the machine is being used. I will try to keep the discomfort as little as possible. The muscle may also feel tired after the exercise. If you do feel too much pain or feel ill after the exercise, you should inform your parent so that they may inform me.

Can anything good happen to me?

You may feel the arm relaxing and it being able to straighten out a bit more. You may also be able to have more function in the hand.



Will anyone know I am in the study?

The information will be kept private and only I, the teachers and your parents will know that you have taken part in this study.

Who can I talk to about the study?

You may discuss anything in this form with your parents or friends or anyone else you feel comfortable talking to. You can decide whether to participate or not after you have talked it over. You do not have to decide immediately.

What if I do not want to do this?

You may refuse to take part even if you parent/guardian has agreed for you to participate. If you choose to partake in the study and are not happy to continue for the 8 weeks, you may leave the study at any point.

Do you understand this research study and are you willing to take part in it?

YES	NO

Has the researcher answered all your questions?

YES	NO

Do you understand that you can pull out of the study at any time?

YES	NO

_____ _____

Signature of Child Date

Declaration by participant

By signing below, I ……..……. agree to take part in a research study entitled The Effects of Neuromuscular Electrical Stimulation and Exercise Intervention on the Upper Limb in Spastic Hemiplegia.

I declare that:

I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.

I have had a chance to ask questions and all my questions have been adequately answered.

I understand that taking part in this study is voluntary and I have not been pressurised to take part.

I may choose to leave the study at any time and will not be penalised or prejudiced in any way.

I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) .....…..…….. on (*date*) ……...…….. 2018.

_____ _____

Signature of participant Signature of witness

Declaration by investigator

I Bibi Fatima Hoorzook declare that:

I explained the information in this document to the participants.

I encouraged him/her to ask questions and took adequate time to answer them.

I am satisfied that he/she adequately understands all aspects of the research, as discussed above

I did/did not use an interpreter. (If a interpreter is used then the interpreter must sign the declaration below.

Signed at (*place*) .....…….. on (*date*) ……...…….. 2018.

_____ _____

Signature of investigator Signature of witness

APPENDIX H: Modified Ashworth Scale (MAS)

Score	Description
0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end o the range of motion when the affected part(s) is moved in flexion or extension
1+	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance throughout the remainder (less than half) of the range of motion
2	More marked increase in muscle tone through most of the range of motion, but affected part(s) easily flexed
3	Considerable increase in tone, passive movement difficult
4	Affected part(s) rigid in flexion or extension

Adapted from Mutlu A,Livanelioglu A, Gunel MK (2009**)**

APPENDIX I: **Tardieu Scale**

Table I. Modifid Tardieu Scale.*

Grade	Description
0	No resistance throughout the course of the passive movement
1	Slight resistance throughout the course of the passive movement, with no clear catch at precise angle
2	Clear catch at precise angle, interrupting the passive movement, followed by release
3	Fatigable clonus (<10 seconds when maintaining pressure) occurring at precise angle
4	Infatigable clonus (>10 seconds when maintaining pressure) occurring at precise angle

Adapted from Yam WK & Leung MS (2006)

APPENDIX J: Goal Attainment Scale

GAS 5-Point Rating Scale	
Score	**Predicted Attainment**
-2	Much less than expected outcome
-1	Less than expected outcome
0	Expected outcome after intervention
+1	Greater than expected outcome
+2	Much greater than expected outcome

Adapted from Steenbeek et al. (2010)

GAS Outcomes set for each child

	-2 *(much worse)*	-1 **Current level of function** **(*somewhat worse)***	0 **Expected outcome**	1 *(somewhat better)*	2 *(much better)*
Participant 1 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 10/10 times during an intervention session.
Participant 1: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 8/10 times during an intervention session..	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 10/10 times during an intervention session.
Participant 2 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 10/10 times during an intervention session.

Yellow – Pre-intervention outcomes
Blue – Post-intervention outcomes

Participant 2: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 8/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 10/10 times during an intervention session.
Participant 3 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a radial palmar grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and complete elbow extension 10/10 times during an intervention session.
Participant 3: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 8/10 times during an intervention session..	The child will be able to reach for the cube correctly with complete elbow extension and neutral wrist 10/10 times during an intervention session.
Participant 4 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 10/10 times during an intervention session.

Yellow – Pre-intervention outcomes
Blue – Post-intervention outcomes

Participant 4: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 8/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 10/10 times during an intervention session.
Participant 5 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a radial palmar grasp and neutral wrist 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and neutral wrist 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and neutral wrist 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and neutral wrist 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a radial palmar grasp and neutral wrist 10/10 times during an intervention session.
Participant 5: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with neutral wrist and finger dissocitaion 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral wrist and finger dissocitaion 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral wrist and finger dissocitaion 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral wrist and finger dissocitaion 8/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral wrist and finger dissocitaion 10/10 times during an intervention session.
Participant 6 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 10/10 times during an intervention session.

Yellow – Pre-intervention outcomes
Blue – Post-intervention outcomes

Participant 6: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with neutral elbow and wrist 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 8/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 10/10 times during an intervention session.
Participant 7 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 10/10 times during an intervention session.
Participant 7: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 8/10 times during an intervention session.	The child will be able to reach for the cube correctly with complete elbow extension, neutral wrist and finger dissocitaion 10/10 times during an intervention session.
Participant 8 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a palmar grasp and complete elbow extension 10/10 times during an intervention session.

Yellow – Pre-intervention outcomes
Blue – Post-intervention outcomes

Participant 8: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with neutral elbow and wrist 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 8/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 10/10 times during an intervention session.
Participant 9 **Goal 1:** **Hand function**	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 2/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 4/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 6/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 8/10 times during an intervention session.	The child will be able to grasp the cube correctly with a digital grasp and complete elbow extension 10/10 times during an intervention session.
Participant 9: **Goal 2:** **Reach**	The child will be able to reach for the cube correctly with neutral elbow and wrist 2/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 4/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 6/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 8/10 times during an intervention session.	The child will be able to reach for the cube correctly with neutral elbow and wrist 10/10 times during an intervention session.

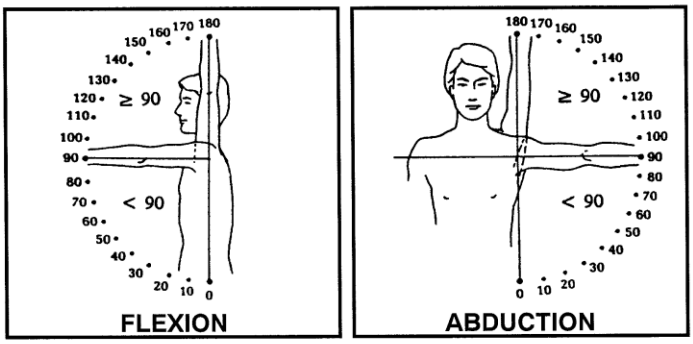
T-score with a mean of 50 and standard deviation of 10, with ρ is set at 0.3. If T > 50 = goal achieved. If T < 50 = goal not achieved.

Yellow – Pre-intervention outcomes
Blue – Post-intervention outcomes

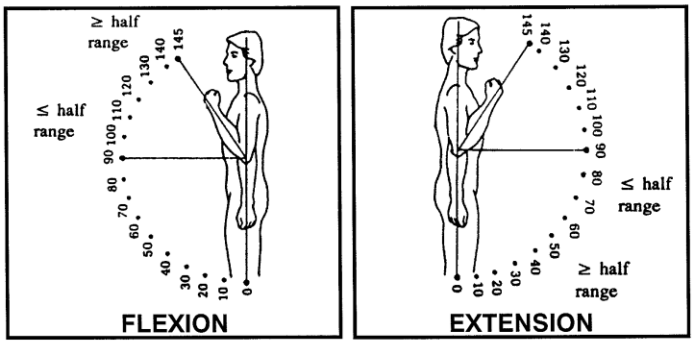
APPENDIX K: Quality of Upper Extremity Skills Test (QUEST)

Guidelines for range calculations are as follows:

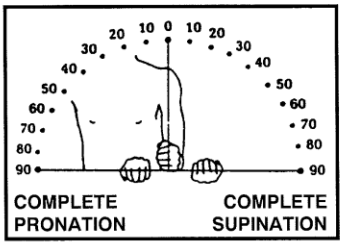
Shoulder Items



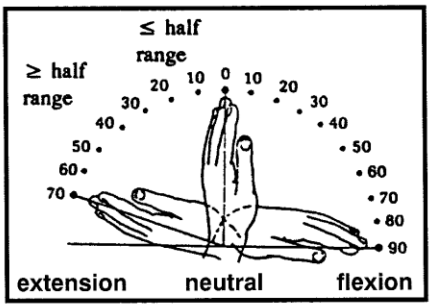
Elbow Items



Forearm Criteria



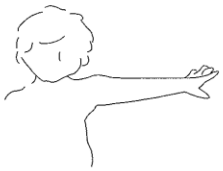
Wrist Criteria



Figures used with permission of Moss Rehabilitation Hospital, Department of Physical Therapy, Philadelphia PA.

A. DISSOCIATED MOVEMENTS
Shoulder Items

Start Position: sitting in chair no table hands on lap

ITEM "SHOULDER"	SCORE L <90	SCORE L ≥90	SCORE R <90	SCORE R ≥90	CRITERIA
1. Flexion	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension
					
2. Flexion with Fingers Extended	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension
					
3. Abduction	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension
					
4. Abduction with Fingers Extended	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension
					

✔ ☐ ✘ ☐ NT ☐ 2.

A. DISSOCIATED MOVEMENTS continued
Elbow Items

Start Position: sitting in chair no table hands on lap

ITEM "ELBOW"	SCORE L half <range	SCORE L half ≥range	SCORE R half <range	SCORE R half ≥range	CRITERIA
1. Flexion	☐	☐	☐	☐	forearm: complete supination
2. Extension	☐	☐	☐	☐	forearm: complete supination
3. Flexion	☐	☐	☐	☐	forearm: complete pronation
4. Extension	☐	☐	☐	☐	forearm: complete pronation





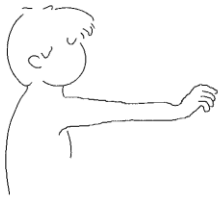




✔ ☐ ✘ ☐ NT ☐ 3.

A. DISSOCIATED MOVEMENTS continued
Wrist Items

Start Position: sitting at table forearms may be on table

ITEM "WRIST"	SCORE L half <range	SCORE L half ≥range	SCORE R half <range	SCORE R half ≥range	CRITERIA
1. Extension 	☐	☐	☐	☐	elbow: complete extension* *see manual for definition of complete extension
2. Extension 	☐	☐	☐	☐	elbow: at least 10° flexion
3. Extension 	☐	☐	☐	☐	forearm: complete pronation
4. Extension 	☐	☐	☐	☐	forearm: complete supination
5. Flexion 	☐	☐	☐	☐	forearm: complete supination

✔ ☐ ✘ ☐ NT ☐ 4.

A. DISSOCIATED MOVEMENTS continued
Finger Items

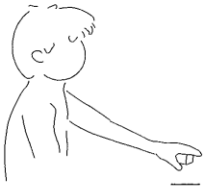
Start Position: sitting at table forearms must rest on table

ITEM	SCORE L	SCORE R	CRITERIA
1. Independent Finger Wiggling 	☐	☐	dissociation of all fingers no associated reactions
2. Independent Thumb Movement 	☐	☐	no associated reactions

Grasp of 1" Cube

Start Position: sitting at table cube at distance requiring elbow extension

Note: If Item 1 is performed, then Item 2 should also be scored YES

ITEM	SCORE L	SCORE R	CRITERIA
1. Grasp Using Thumb 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension
2. Grasp Using Palm 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension

✔ ☐ ✘ ☐ NT ☐ 5.

A. DISSOCIATED MOVEMENTS continued
Release of 1" Cube

Start Position: sitting at table cube in child's hand *

*** Allowable to put cube in child's hand if he/she can't actively grasp**
Note: If Item 1 is performed, then Item 2 should also be scored YES

ITEM	SCORE L	SCORE R	CRITERIA
1. Release from Thumb and Fingers 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension
2. Release from Palm 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension

✔ ☐ ✘ ☐ NT ☐

Scoring for Part A: DISSOCIATED MOVEMENTS *(pages 2-6)*

Total ✔ : ☐ = a

Total ✘ : ☐ = b

Total NT : ☐ = c

TRANSFER TO QUEST SCORING SHEET ON PAGE i

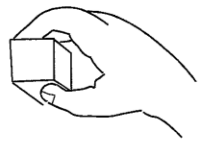
6.

B. GRASPS continued
Grasp of 1" Cube

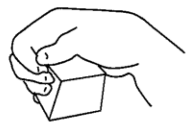
Start Position: sitting at table cube on table within comfortable reach

Note: Once a grasp has been performed, give a YES score for all those below it. If grasp observed is not listed, then score NO in all boxes and describe it under "Other" below.

ITEM	SCORE L	SCORE R	CRITERIA
1. Radial Digital	☐	☐	wrist: neutral to extension
2. Radial Palmar	☐	☐	wrist: neutral to extension
3. Palmar	☐	☐	







Other:

_____

_____

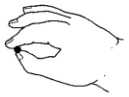
✔ ☐ ✘ ☐ NT ☐ 8.

Dametteo et al., 1992

B. GRASPS continued
Grasp of Cereal

Start Position: sitting at table

Note: Once a grasp has been performed, give a YES score for all those below it. If grasp observed is not listed, then score NO in all boxes and describe it under "Other" below.

ITEM	SCORE L	SCORE R	CRITERIA
1. Fine Pincer 	☐	☐	wrist: neutral to extension
2. Pincer 	☐	☐	wrist: neutral to extension
3. Inferior Pincer 	☐	☐	
4. Scissor 	☐	☐	
5. Inferior Scissor 	☐	☐	

Other:

_____

_____

✔ ☐ ✘ ☐ NT ☐ 9.

B. GRASPS continued
Grasp of Pencil or Crayon

Start Position: **sitting at table** **pencil placed midline vertical with point facing child**

Note: **Child must pick up pencil on his/her own.**
Once a grasp has been performed, give a YES score for all those below it.

Circle one of: **L** Dominance **R** Dominance **L** Preference **R** Preference

Circle one of: grasp of **Pencil** grasp of **Crayon**

ITEM	SCORE L	SCORE R	
1. Dynamic Tripod (pencil, grasped distally - precise opposition of thumb, index & middle finger)	☐	☐	
2. Static Tripod (pencil grasped proximally - crude approximation of thumb, index & middle finger)	☐	☐	
3. Digital Pronate	☐	☐	
4. Palmar Supinate	☐	☐	

Other: _____

✔ ☐ ✘ ☐ NT ☐

Scoring for Part B: GRASPS *(pages 8-10)*

Total ✔ : ☐ = f

Total ✘ : ☐ = g

Total NT : ☐ = h

TRANSFER TO QUEST SCORING SHEET ON PAGE **ii**

10.

Adapted from Dametteo et al. (1992)

APPENDIX L: **Visual Aid – Determine tolerance level during intervention**

