The effects of Chiropractic spinal manipulation on the H reflex and muscle strength in children with spastic diplegic cerebral palsy: a feasibility study

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Abstract

Background: Cerebral Palsy (CP) is a term used to describe a group of motor disorders resulting from an injury to the developing brain either during pregnancy, birth or in infants up to 2 years. Children with CP have deficits in various aspects of motor control, including motor neuron excitability, that can affect their muscle strength, gait and ability to perform activities of daily living. The Hoffman (H) reflex is an electrical variant of the spinal stretch reflex and used in neurophysiology to assess motor neuron excitability. Previous research on chiropractic spinal manipulation in healthy adults, athletes and a brain-injured population indicate improvements in motor neuron excitability, muscle strength and various aspects of motor control.

Objectives: To assess feasibility aspects of conducting a large scale randomized, controlled study measuring the effects of chiropractic spinal manipulation on motor neuron excitability and muscle strength in children with CP.

Methods: Children with spastic diplegic CP, aged 8-13 years, were recruited through the New Zealand Cerebral Palsy Registry for a randomized, controlled feasibility study. Feasibility was assessed in the areas of recruitment strategy and rate, data collection procedures, equipment, intervention and compliance. Three children completed data collection comprised of pre and post measurements of the H reflex, V-wave and muscle strength. Participants were randomized into a chiropractic spinal manipulation intervention group or a passive control intervention group.

Results: The recruitment strategy and rate proved to not be feasible in recruiting enough participants to appropriately power a larger scale study of the same design. All data collection procedures were appropriate and complied with except for the V-wave measurement. H reflex threshold decreased and s50 and slope increased in the participants who received chiropractic spinal manipulation. H reflex threshold increased and s50 and slope decreased in the participant who received the passive control intervention. Changes in MVC force were inconsistent between subjects.

Statistical efficacy was not evaluated as the study was designed to measure feasibility only. Recommendations for further research, including changes in recruitment strategy, are provided.

Conclusions: This study answered some important feasibility questions about conducting a large scale randomized controlled study measuring the effect of chiropractic spinal manipulation on motor neuron excitability and muscle strength in children with CP. Some aspects proved feasible, such as H reflex recordings, and some aspects need to be altered for any future research in this area.

Key words: Chiropractic, Cerebral Palsy, spinal manipulation, muscle strength, motor neuron excitability, H reflex

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed:

Jenna Salmons

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Ethics:

This study was granted ethics approval from Auckland University of Technology Ethics Committee (AUTEC), Auckland District Health Board Ethics Committee and the New Zealand Health and Disability Ethics Committee (HDEC 16/NTA/158). An amendment was made to the original ethics application outlining changes in the equipment to be used to measure the muscle strength. This was approved by HDEC (16/NTA/158/AM01).

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Chapter 1- Introduction

1.1 The problem

Cerebral palsy (CP) is an umbrella term used to describe a group of non-progressive motor disorders resulting from an injury to the developing brain either during pregnancy, birth or in infants up to the age of 2 years (Cerebral Palsy Society of NZ, 2018). Its prevalence ranges from 2-2.5 per 1000 live births and is the most common cause of physical disability in children, causing great impact on the function and health related quality of life of those affected (Koman, Smith, & Shilt, 2004).

The injury to the brain that occurs in those with CP causes problems with motor control and the child may develop deficits in movement, posture, balance, co-ordination and muscle strength, all of which will hinder their ability to conduct activities of daily living (Koman et al., 2004; Papavasiliou, 2009). Whilst the causative brain lesion itself is non-progressive secondary problems in muscular and bony abnormalities can occur as the child grows and develops (Heathcock & Nichols-Larsen, 2016). Alongside this comes considerable social, emotional and economical cost to the individual and their families as they manage the lifelong consequences of the disorder.

Muscle weakness is one of the most widely recognized clinical manifestations of CP and a significant contributor to the deficits seen in gait and function. In previous studies it has been noted that children with CP have significantly less muscle strength comparatively to typically developing children of a similar age (Poon & Hui-Chan, 2009; Rose & McGill, 2008). In a review of 51 articles concerning CP and muscle strength, all articles concluded that children with CP are weaker than their typically developed peers (Mockford & Caulton, 2008). The hip extensors, ankle dorsiflexors and ankle plantar flexors have been found to be the weakest with some studies reporting strength values of 24%, 46% and 36% respectively of the typically developed children, while others reporting values as low as 18% in dorsiflexors and 23% in plantar flexors (Poon & Hui-Chan, 2009). Reduced muscle

strength is correlated with reduced walking ability and lower Gross Motor Function classification scores (GMFCS) (Thompson, Stebbins, Seniorou, & Newham, 2010). Ross & Engsberg (2007) report results of a high correlation between strength and GMFCS (r=.83) and stride length (r=.71) and a moderate correlation with gait speed (r=.61).

Historically it was thought that muscle spasticity was the primary issue in the impairments seen with CP and it was considered that strength training would exacerbate muscle spasticity and cause further issues so was rarely used in the management of CP (Ross & Engsberg, 2007). However in the last 20 years new research has shown that muscle weakness and spasticity are largely independent of each other and that muscle strength is more highly correlated with gait and function than spasticity is (Ross & Engsberg, 2007). Given this knowledge there has been a shift in the focus from reducing spasticity to improving muscle strength and the use of strength training regimes in the management of CP has increased. There have been numerous studies conducted assessing the effectiveness of strength or resistance training on increasing muscle strength in children with CP. Systematic reviews on this subject reveal that the evidence is strong for the efficacy of strength training, with the majority of studies reporting significant increases in strength (Mockford & Coulton, 2008; Dodd, Taylor, & Damiano, 2002). However the effect that this has on functional outcomes and gait is not so clear. Not all studies reviewed assessed the impact on function and/or gait but those that did reported small effect sizes on activity and function levels and variable results on mobility, with some studies reporting significant improvement and others reporting no improvement (Mockford & Coulton, 2008; Dodd et al., 2002, respectively). This may be in part due to the variability in the strength training regimes, the samples assessed and the methods used of assessing gait and function. Nevertheless the indications are there that improving muscle strength could help alleviate or reduce some of the impairments seen with CP. Further research needs to be done to assess the impact of improving muscle strength on functional outcomes.

Current treatment of CP is now based around the neuroplasticity of motor learning and maximizing the uninjured parts of the brain (Diaz Heijtz & Forssberg, 2015). Neurorehabilitation treatments are aimed at using the principles of

neuroplasticity in that repetitive movements enhance neuronal connections in the brain. Such treatments include the use of specially designed exercise programme's, robotic assisted therapies, treadmill exercises, constraint induced therapy, functional electrical muscle stimulation, spinal cord electrical stimulation and loading suits to enhance proprioceptive feedback (Papavasiliou, 2009; Solopova et al., 2015). These therapies have shown benefits in reducing spasticity, increasing muscle strength and improving postural stability, however there is limited evidence for the improvement in functional outcomes and gait after the use of these therapies (Solopova et al., 2015). One of the therapies, utilizing the use of a Lokomat, which combines the use of a treadmill, lower limb unloading, orthoses and a feedback module, is one of the few that show improvements in gait and gross motor functional measures (Solopova et al., 2015). The evidence suggests that it is likely a combination of therapies that has the best results for the child (Solopova et al., 2015; Ppavasiliou, 2009).

Other therapies are based on the management of the disorder and are aimed at improving active range of motion, increasing muscle strength and decreasing muscle spasticity (Papavasiliou, 2009). These range from more invasive surgical treatments such as selective dorsal rhizotomy and botulinum toxin therapy, aimed at denervating problematic nerve roots causing severe spasticity, to more conservative therapies such as physiotherapy and occupational therapy treatments (Papavasiliou, 2009). Regardless of the large array of treatments available, reduced muscle strength, and the functional deficits that it contributes to, remains a significant issue for individuals with CP, new therapies and treatments are consistently being sought, including alternative therapies such as chiropractic.

Chiropractic is a health care modality that focuses on the function and the correct motion of the spine with the aim of improving central neural function (Haavik & Murphy 2012). A Chiropractor assesses the spine for areas of dysfunction and then uses their hands in a variety of different techniques to adjust these areas and restore movement to improve CNS function.

Over the past 10 years a growing body of research has been published looking at the effects of chiropractic adjustments or spinal manipulation on the

nervous system.(Haavik Taylor & Murphy 2007, Haavik Taylor & Murphy 2008, Haavik Taylor & Murphy 2010, Haavik Taylor & Murphy 2010, Haavik & Murphy 2011, Haavik & Murphy 2012, Niazi, Türker et al. 2015, Holt, Haavik et al. 2016, Lelic, Niazi et al. 2016, Haavik, Niazi et al. 2017, Haavik, Niazi et al. 2017). It is hypothesized that the articular dysfunctions in the spine cause altered afferent input to the brain, which affects how the CNS processes and integrates all subsequent sensory input (Haavik Taylor & Murphy, 2007). Some studies have shown neural plastic changes such as altered sensorimotor integration and motor control after chiropractic SM (Haavik Taylor & Murphy, 2007; Haavik Taylor & Murphy 2008; Haavik Taylor & Murphy, 2010). Other studies have shown improvements in muscle strength and motor neuron excitability in normal healthy adults and elite athletes, as well as in an adult brain injured population (a chronic stroke population) (Christiansen et al., 2018; Holt et al., 2017; Niazi et al., 2015).

As muscle weakness is correlated with gait problems and poor gross motor function in children with CP, improving muscle strength in this population group could potentially be beneficial over time in changing their gait and increasing functionality, particularly at a time when their nervous system and muscles are still developing (Dodd et al., 2002; Eek & Beckung, 2008; Geertsen et al., 2015; Mockford & Caulton, 2008). This is a hypothesis that needs to be tested in further studies looking at how improving muscle strength affects functional outcomes.

However, these findings of changes in motor control, muscle strength and motor neuron excitability in both healthy and brain injured adult populations following chiropractic SM and the previously outlined issues with muscle weakness that children with CP have, give grounds for investigating the effects of chiropractic SM on muscle strength and motor neuron excitability in children with CP.

1.2 The study

There is limited evidence available in the literature on the effects of chiropractic SM in children with CP and a study of this nature, which investigates

the use of chiropractic SM to improve muscle strength in children with CP, has never been done before. Conducting a large scale, randomized, controlled trial testing the hypothesis that chiropractic SM will result in improvements in motor neuron excitability and muscle strength in children with CP is planned.

However before undertaking the full study it is necessary to do a feasibility study to ascertain the following:

- The recruitment rate, in order to determine if enough participants for the full scale RCT could be recruited in a timely manner.
- The feasibility of the recruitment strategy, will it be sufficient for recruiting enough participants for a large scale RCT based on the recruitment rate.
- Can we measure changes in the H reflex and MVC peak force following chiropractic SM in children with CP.
- Can children with CP tolerate and be compliant with the data collection protocol and length
- Is the chiropractic SM intervention tolerated and appropriate for children with CP.
- Is the equipment used for data collection tolerated by children with CP and does it provide accurate measurements

This study will be discussed in detail in Chapter 3.

Chapter 2- Literature review

2.1 Introduction

This chapter will outline the available literature and information known about CP and chiropractic SM that formed the basis for conducting this study.
First is an outline of the pathophysiological processes involved in CP, this serves to better understand how the deficits occur in the central nervous system (CNS).
Then the physiology of motor control will be outlined and how this changes in those with CP. Muscle strength and the factors associated with force generation in skeletal muscle will be discussed and then how this is affected in those with CP. Then the H reflex and its purpose as a neurophysiological measure will be discussed, including what it known in the literature on how the H reflex changes in children with CP. Finally, chiropractic and its potential role in influencing change in those with CP will be outlined.

The literature on CP was searched using a systematic approach. Databases searched were Access Physiotherapy, AMED Allied and Complementary Medicine, EBSCO Health Databases, CINAHL, OVID, Wiley, PEDro, and Scopus. The literature was searched for information on CP, how it affects neuromuscular control, muscle strength and the current treatment available for improving muscle strength. For all search strategies a limit on linked full text only was applied. Search terms used were 'Cerebral Palsy' and- muscle strength, strength training, 'H* reflex', V-wave, spasticity, motor control, muscle weakness, pathology, neuromuscular control, stretch reflex, neuroplasticity, Chiropractic spinal manipulation, motor neuron excitability, cerebellum, sensorimotor integration, proprioception; 'cerebellum and motor control'; 'prefrontal cortex and motor control'; 'inner body schema'; 'Chiropractic and –cerebellum, motor control, sensorimotor integration, prefrontal cortex, H reflex, muscle strength,

2.2 Pathophysiological processes in Cerebral Palsy

2.2.1 Introduction

This section will cover what is known about the pathophysiological processes that occur with CP. Firstly, factors that are related to the development of CP will be presented, followed by a discussion on the pathophysiological processes that occur, primarily hypoxia, periventricular leukomalacia and infection. Finally the neurological consequences of these events will be outlined.

2.2.2 Factors related to the development of CP

Cerebral Palsy is a complex syndrome with a multitude of variations and severity levels and it can be difficult to define causation, in fact in approximately 30% of cases the cause is unknown, however there are some clearly defined correlations (Jones, Morgan, Shelton, & Thorogood, 2007). One of the most distinct factors that is related to the development of CP is preterm or low birth weight infants. Approximately 70-80% of CP cases can be attributed to prenatal causes, 10-20% to asphyxia during labour & birth and about 10% to postnatal causes such as meningoencephalitis and head injuries (Colver, Fairhurst, & Pharoah, 2014).

There is an inverse association with gestational age and birth weight, in infants weighing less than 1000g the prevalence is approximately 90 per 1000 live births and for infants born at less than 28 weeks gestation the prevalence is 82 per 1000 live births (Colver et al., 2014; Koman et al., 2004; MacLennan, Thompson, & Gecz, 2015).

Despite the scientific advancements in maternal and neonatal medicine the prevalence of CP has remained relatively static over the last 50 years, although there has been a slight decline in the rate amongst preterm infants (Colver et al., 2014). Other factors such as multiple pregnancies, fetal growth restriction, congenital defects, placental hemorrhage, maternal or fetal infections and genetic abnormalities can all contribute to the development of CP (Koman et al., 2004; Maclennan et al., 2015; Colver et al., 2014). It is the underlying pathology that occurs

in these conditions that causes the damage to the vulnerable fetal CNS through hypoxic-ischaemic and infection-inflammation pathways, these will be discussed further below.

2.2.3- Hypoxia-Ischaemia

Hypoxia, a condition in which the body or part of the body is deprived of oxygen, is a major contributor in the pathogenesis of CP. Hypoxic Ischaemic Encephalopathy (HIE) or Neonatal Encephalopathy are terms used to describe the condition in which the neonatal or fetal brain is damaged due to a disruption of the oxygenated blood supply to the brain during labour or prenatally (Rei, Ayres-De-Campos, & Bernardes, 2016). Hypoxia can occur as an acute event or as a chronic condition (hypoxemia) and leads to ischaemic injury to the vulnerable and developing fetal, neonatal or infant CNS and may have life long consequences in the form of CP. Hypoxia can occur due to a number of reasons prenatally, conditions or events affecting the umbilical cord, such as prolapse, compression or tightness; the placenta, such as abruption, infarction, poor placentation or placenta previa and maternal or fetal haemorrhage can all be causes (MacLennan et al., 2015). HIE is suspected in infants whom at birth display signs of poor health with low Apgar scores and who have clinically evident metabolic acidosis as indicated by cord blood pH levels of less than 7.0 and a base excess above 12 at birth (Rei et al., 2016). Birth asphyxia used to be thought of as a major cause of HIE and a contributor to the development of CP, but advances in neuroimaging and diagnostic criteria revealed that actual acute asphyxia at the time of delivery only accounts for approximately 10-20% of CP cases (MacLennan et al., 2015; Colver et al., 2014; Rei et al., 2016). Hypoxia and metabolic acidosis at birth can often be attributable to more long standing factors causing chronic hypoxia that have occurred during the pregnancy (Maclennan et al., 2015; Rei et al., 2016). Differentiating between an acute and chronic condition can be difficult without a known sentinel event such as cord prolapse or uterine rupture, but can be suspected by certain fetal cardiotocography (CTG) patterns, such as reduced fetal heart rate variability, prior to or at the onset of labour (Rei et al., 2016).

The fetal brain is particularly vulnerable to hypoxic insults at various stages of gestation due to the development of the cerebral vasculature, neurons and glial

cells (Takashima, Itoh, & Oka, 2009). The most common brain injury to occur in premature infants is periventricular leukomalcia (PVL), often precipitated by hypoxic-ischaemic insults that occur between 26 and 34 weeks gestation, a time when the deep white matter demonstrates selective vulnerability to injury (Coq, Delcour, Massicotte, Baud, & Barbe, 2016; Koman et al., 2004; Takashima et al., 2009). There are a number of important factors that make the deep white matter vulnerable in this gestational period. Firstly, the blood supply to the deep white matter in the second trimester consists of short perforating branches from the leptomeningial arteries with the end zone in the periventricular white matter, coupled with a transient decrease in vessel density from 28-36 weeks, this creates a system vulnerable to hypoxic and ischaemic insults (Hoon, Vasconcellos Faria, & Faria, 2010; Takashima et al., 2009). Secondly, during the second trimester there is an increased density in oligodendrocyte progenitors, the precursor cells to the oligodendrocytes responsible for the myelin sheath formation of neurons, and these cells display selective vulnerability to free radical oxidative damage created by hypoxic-ischaemic environments (Hoon et al., 2010; Rees, Harding, & Walker, 2011; Volpe, 2009). The destruction of the pre-oligodendrocytes leads to an eventual lack of myelination of neurons. As myelin is responsible for the rapid conduction of an action potential through an axon, this leads to problems with sensorimotor integration, precision of motor outputs, and co-ordination and timing issues and thus is responsible for many of the motor impairments seen in CP (Coq et al., 2016).

Furthermore, subplate neurons reach their maximum density and developmental impact from 24-32 weeks gestation and are thus also vulnerable to destruction in white matter injury (Hoon & Faria, 2010; Volpe, 2009). Subplate neurons are believed to have a crucial function in cortical development and plasticity as they provide connections between the thalamus and cortex and intra-cortically and enhance connections between these systems before these axonal projections have developed (Hoon et al., 2010; Kanold, 2009; Volpe, 2009). They undergo natural apoptosis postnatally in the infant but early destruction of these, as can occur in hypoxic-ischaemic insults in the developing fetal brain, can have profound and devastating affects on cortical development (Kanold, 2009; Volpe, 2009).

Finally, cerebral white matter axons are also undergoing a period of rapid growth and development in the late second/early third trimester of pregnancy and consequently axonal injury is another major component of PVL (Takashima et al., 2009; Volpe, 2009). PVL has two types, cystic PVL, which consists of focal areas of necrosis that evolve over time into multiple large cystic lesions, and the more common type of diffuse or non-cystic, which consists of focal areas of necrosis which evolve into glial scars (Volpe, 2009; Coq et al., 2015).

With the advances in neuroimaging, in the form of cranial ultrasounds, MRI and diffusion weighted imaging, neonates suspected of neonatal encephalopathy can be imaged early on to detect hypoxic-ischaemic injury to the brain and allow for neuroprotective treatments to be established. However detectable white matter injury is highly predictive for the development of CP with white matter injury seen on MRI scans in 75 to 86% of children with CP (Coq et al., 2015).

2.2.4 Infection- Inflammation

While the hypoxia-ischemia pathway is a well-established and known factor in the pathogenesis of CP, there are other processes that can occur in the developing fetus that can cause damage to the (CNS) and lead to CP. Inflammation and its associated inflammatory mediators are emerging as an important factor in the pathogenesis of CP, both as a prenatal and postnatal factor (Girard et al., 2009). In the prenatal period, maternal infections pose the greatest risk to the developing fetus, chorioamnionitis in particular has a high association with the development of CP in preterm infants (Girard et al., 2009; Rees Harding & Walker, 2011). Maternal and consequential fetal infections induce the production of inflammatory cytokines in the fetus, these are able to cross the immature blood brain barrier into the CNS of the fetus. There they exert a deleterious effect through the induction of apoptotic death of oligodendrocytes and astrogliosis with high levels of cytokines found in the brains of neonates with PVL (Girard et al., 2009; Rees et al., 2011). Inflammatory processes may occur on their own but also in conjunction with hypoxic-ischaemic events, with one precipitating the other, and it has been hypothesized that the combination of the two in particular may overwhelm the innate defense systems of the CNS and create an increased vulnerability to white matter injury (Reese et al.,

2011). The exact pathological processes involved in this are likely to include numerous complex interactions and are still under investigation.

2.3 Motor Control

2.3.1 Introduction

Motor control refers to the mechanisms involved in regulating or directing movement. The human body is a highly organized and complex system and motor control is no exception, involving an array of sophisticated, organized processes and interactions between perceptual, movement and cognitive systems (Shumway-Cook & Wollacott, 2001). The purpose of this chapter is to understand how human motor control occurs and how these processes may be affected in an individual with Cerebral Palsy.

2.3.2 Sensory/perceptual systems

While motor control may primarily appear to be about movement and action, sensory and perceptual processes play major roles in the control of movement as they provide vital proprioceptive and sensory information that allows for precision, modulation and control of movement. Human beings undertake a vast array of movements, many of which need to be precisely controlled. Even a seemingly simple task such as getting out of bed in the morning requires a complex set of movements and postural control. In order for this to occur the CNS needs to have a highly accurate picture of where the body is in space and its position relative to the environment, an inner body schema, which is provided by the various sensory receptors of the peripheral nervous system (Curtis et al., 2015; Di Vita, Boccia, Palermo, & Guariglia, 2016; Graziano & Botvinick, 2002; Maravita, Spence, & Driver, 2003; Palermo, Di Vita, Piccardi, Traballesi, & Guariglia, 2014; Scott, 2004). Afferent information provided by these receptors allows for the reception, integration and interpretation of sensory signals involved in motor control.

Muscle spindles are one of the major peripheral sensory receptors. Muscle spindles are found in skeletal muscle and provide proprioceptive information about

the stretch of skeletal muscles (Shumway-Cook & Wollacott, 2001). They are made up of small, specialized muscle fibers called intrafusal fibers, which provide sensory information about muscle stretch and length via group Ia and group II afferent fibers (Boyd-Clark, Briggs, & Galea, 2002). Group Ia afferents code for both the rate of stretch and the length of the muscle, group II afferents code for muscle length only (Fix, 2008). When the muscle is stretched this stretches the intrafusal fibres and excites the Ia afferents, these connect with α motor neurons in the spinal cord that then trigger the relevant skeletal muscle to contract, a process known as the spinal stretch reflex (Trompetto, Merinelli, Mori, Pelosin, Currà, Molfetta & Abbruzzese, 2014). Muscle spindles also have collaterals that ascend to the primary sensory cortex to aid in the formation of the inner body schemas (Fix, 2008). At the same time as the agonist muscle is stimulated, inhibitory interneurons are activated which synapse with the motor neurons of the antagonist muscle and inhibit its activation, a process called disynaptic reciprocal inhibition (Takahashi et al., 2017). This allows for the appropriate motor action to be performed.

The muscle spindles are also innervated by γ motor neurons that are co-activated with α motor neurons, this causes the intrafusal fibers to also contract, keeping the muscle spindle active during a contraction. This allows for ongoing afferent input in response to further changes to muscle length and rate of stretch (Shumway-Cook & Wollacott, 2001). This is an important feature of muscle spindles as the brain first creates a prediction of a movement based on past experiences and proprioceptive information of where the body is in space, however as a movement is being performed the brain may receive afferent information that is different to the prediction (Graziano & Botvinick, 2002; Krigolson & Holroyd, 2007; Scott, 2004). Consequently it is necessary for the CNS to be able to alter and correct a movement and this ongoing afferent input from muscle spindles contributes to this modulation.

Previous studies have found there to be a high density of muscle spindles in the paraspinal muscles and in particular the small sub-occipital muscles of the cervical spine (Boyd-Clark et al., 2002; Cooper & Daniel, 1963; Kulkarni, Chandy, & Babu, 2001). Based on these findings it suggests that these muscle spindles play an important part in postural control by providing sensory feedback on the position

and movement of the body, particularly the head and neck. The importance of these paraspinal muscle spindles will be discussed in more detail in section 2.6.

Golgi tendon organs (GTO) are another type of sensory receptor, found in muscle-tendon junctions, they provide afferent information on muscle tension via Ib afferent fibers (Shumway-Cook & Wollacott, 2001; Fix, 2008). The GTO reflex works by inhibiting the α motor neurons of the muscle that it is attached to via Ib inhibitory interneurons and exciting the antagonist muscle. For example during human standing the GTO will excite the extensor muscles of the leg and inhibit the flexor muscles of the leg (Shumway-Cook & Wollacott, 2001). Whilst muscle spindles are given a lot more credit to human motor control than the GTO it is suggested in the literature that a combination of muscle spindle and GTO afferent feedback is important, particularly for control of posture and fine movements (Kistemaker, Knoek van Soest, Wong, Kurtzer & Gribble, 2013).

Joint capsules contain joint receptors, including Ruffini type endings, paciniform endings, ligament receptors and free nerve endings. Joint receptors provide afferent information on joint position and motion and are important for providing proprioceptive information to the CNS (Shumway-Cook & Wollacott, 2001). Finally cutaneous receptors provide various types of sensory information such as temperature changes, mechanical changes and pain, also providing feedback to the CNS on body position (Fix, 2008).

All of these peripheral sensory receptors send afferent information to the spinal cord. Some of this afferent input is modulated at the spinal cord level, such as the spinal stretch reflex involving the muscle spindles, but all the sensory information is also sent to higher order centers in the brain for processing, via the spinal tracts (Fix, 2008). The primary sensory spinal tracts are the dorsal column medial lemniscus (DCML) and the anterolateral system, which project to the cortex; and the spinocerebellar tracts, which project to the cerebellum (Fix, 2008). The DCML relays sensory information from muscle spindles, GTO's, joint receptors and cutaneous touch and pressure receptors, while the anterolateral system provides sensory information on crude touch, pressure, temperature and pain (Fix, 2008). The information sent from these tracts is ultimately received by the somatosensory

cortex, which combines the information received from the different sensory receptors and processes this to gather a picture of the body and it's environment. This is essential to the production of movement.

One of the key higher order centers that receives and processes this proprioceptive information is the cerebellum. The cerebellum is a central integrator of all sensory information (Doyon, Penhune et al. 2003; Manzoni 2005; Manzoni 2007). It's important for the formation of internal brain models or maps of what is going on in and around your body (Doyon, Penhune et al. 2003; Manzoni 2005; Manzoni 2007) and will be discussed in greater detail below in relation to its role in movement. The Prefrontal cortex is another key higher order center involved with multimodal integration and the formation of inner body schemas, sensorimotor integration and accurate movement performance (Faw, 2003), and will also be discussed in greater detail below. As both these parts of the brain have been shown to be altered with chiropractic interventions (Daligadu, Haavik, Yielder, Baarbe, & Murphy, 2013; Lelic et al., 2016) they may both possibly play a role in the mechanisms of any potential change in motor control function in the CP children that take part in this study.

Other than the somatosensory system, the visual and vestibular systems also provide valuable information that is used to plan, modulate and execute movement. The visual system, made up of the eye, the optic nerves, optic tracts, lateral geniculate nucleus of the thalamus, the superior colliculus and the visual cortices, and provides sensory information on proprioception, object identification and motion sense (Fix, 2008; Shumway-Cook & Wollacott, 2001). This information is then used in complex interactions with various other systems to facilitate motor control, in particular balance control, eye-head control and accuracy in movement for example when reaching for and grasping an object (Peterka, 2002; Wolpert, Ghahramani, & Jordan, 1995).

The vestibular system is made up of the semicircular canals, utricle and saccule in the labyrinth of the inner ear, the auditory nerve and the vestibular nuclei (Fix, 2008). It provides sensory information on the position of the head in space and

movement of the head and is important in aspects of motor control related to balance, posture and eye-head control (Peterka, 2002; Fix, 2008).

The CNS, in particular the cerebellum and the pre-frontal cortex, combines and integrates all the sensory information provided by these various sensory systems in a process called multisensory integration to form the inner brain maps of what is going on in and around the body (Maravita et al., 2003; Peterka, 2002; Stein & Stanford, 2008; Wolpert et al., 1995). It then uses this multisensory information to accurately plan and execute precise movements required by the human body. This is a process called sensorimotor integration (Abbruzzese & Berardelli, 2003; Peterka, 2002).

It is the integration of all the sensory information, the formation of the inner body maps and subsequent sensorimotor integration to perform meaningful movements and postural control, that are proposed to be affected by chiropractic spinal manipulation (Haavik & Murphy 2012). This will be covered in greater detail in subsequent sections.

2.3.3 Movement

With the aid of the sensory systems discussed above, a person is able to form a map of where their body is in space and the environment around them, ie inner body schemas. From this, movement needs to be generated that involves even more complex systems. This part of motor control involves efferent motor information sent via descending outputs.

The highest order processing center for motor output is the motor cortex, made up of the primary motor cortex (M1), the supplementary motor area (SMA) and the premotor cortex. These areas receive sensory input from the basal ganglia, the cerebellum, the thalamus, sensory association cortices and the somatosensory cortex (Fix, 2008; Shumway-Cook & Wollacott, 2001). M1 has its own topographic map of the body, the motor homunculus, in which different areas of the body are represented by specific locations on the map. Body areas are not represented equally but are distorted so that areas that require more finite and detailed control,

such as the hand or mouth, are more greatly represented (Fix, 2008; Shumway-Cook & Wollacott, 2001). M1 is particularly involved in the control of force and direction of movement, the discharge frequency of neurons, or the cortical drive, can be increased or decreased depending on the force required to move an object (Georgopoulos, 2000).

Motor control is further enhanced by the supplementary motor area (SMA) and premotor cortex. While not fully understood, it is believed that the SMA and pre motor cortex are additional areas to the primary motor cortex that are involved in the planning and execution of movement (Shumway-Cook & Wollacott, 2001; Nachev, Kennard, & Husain, 2008). Electrophysiological recordings of the SMA demonstrate that neurons in this area fire before movement occurs and imaging studies show that the SMA is activated even during imagined movements (Carlsen, Eagles, & MacKinnon, 2015; Nachev et al., 2008). These findings indicate that the SMA is involved in the planning, preparation and initiation of complex voluntary movements (Nachev, et al., 2008). Furthermore, research suggests that the SMA is particularly activated in situations that involve movements which are internally referenced or occurring from motor memory, whereas the premotor cortex appears to be more involved in externally or visually initiated or controlled movements and spatial orientation (Solopchuk, Alamia, & Zénon, 2016).

The motor cortex does not only control movement through an act of activating muscles but also through cognitive processes of motor learning, planning and memory and afferent-efferent feedback loop (Faw, 2003; Georgopoulos, 2000; Krigolson & Holroyd, 2007; Scott, 2004). In order to perform a motor task, afferent information contributes to the formation of a motor plan and initial execution of a movement, but also for ongoing feedback on the movement to allow for adaptive responses, movement corrections and fine tuning as discussed above (Graziano & Botvinick, 2002; Krigolson & Holroyd, 2007; Manzoni, 2005; Scott, 2004).

Not only does our CNS control and co-ordinate voluntary movements, such as picking up a spoon, it also must control and co-ordinate posture. This is something that is constantly going on in the background and that we do not have to consciously control, in every action or movement that occurs the CNS is constantly

adapting and correcting our posture in order to keep us balanced (Peterka, 2002). The CNS adopts both feed forward and feedback activation mechanisms (Hodges, Cresswell, & Thorstensson, 1999; Hodges & Richardson, 1997; Manzoni, 2005; Santos, Kanekar, & Aruin, 2010). Feed forward activation occurs when you, for example, lift your arm to reach for something. In this instance your brain would adopt anticipatory postural adjustments and first send messages to the postural control and core stabilizing muscles (including the paraspinal muscles) to first stabilize your body so you maintain your balance while lifting your arm (Hodges et al., 1999; Hodges & Richardson, 1997; Santos et al., 2010). The CNS also utilizes compensatory postural adjustments in response to unanticipated perturbations in posture and movement, such as if someone were to bump into you while you were walking (Santos et al., 2010).

The cerebellum receives afferent input from all of the sensory systems but also outputs to almost all the areas involved in motor control such as the motor cortices, thalamus, reticular formation and vestibular nuclei and is crucial in sensorimotor integration (Shumway-Cook & Wollacott, 2001; Manzoni, 2007). In comparison to the cerebral cortex, the cerebellum is smaller in size but has a higher number of neurons (Herculano-Houzel, 2009). Motor execution is a rapid process and it is thought that the cerebellums primary role in motor control is to act as a comparator, sensing the internal and external environment, constantly detecting and matching the afferent feedback from the sensory receptors to the predicted motor plan to use for error correction in motor control (Manto, Bower, Conforto, Delgado-Garcia, Faria da Guarda, Gerwig, habas, Hagura, Ivry, Mariën, Molinari, Naito, Nowak, Taib, Palisson, Tesche, Tilikete & Timmann, 2012; Manzoni, 2005). The cerebellum plays a vital part in motor learning and has a strong predictive component, for example if there is a fixed sequence of events the cerebellum learns and later predicts the order of events (Manto et al., 2012). Consequently removal or damage to the cerebellum does not cause paralysis or loss of sensation but does have a great effect on the ability to accurately perform any movement (Manto et al., 2012; Manzoni, 2005)

Another area of the brain that is involved with error processing is the pre-frontal cortex. The pre-frontal cortex, as mentioned above, is a high level processing

center of the CNS and is described as the executive controller of the CNS (Lelic et al., 2016, Faw, 2003). It is considered a multimodal association cortex and has functions in motor control and sensorimotor integration through directing and sensing perception of self, attention, memory sequence processing, and motivation (Faw, 2003; Krigolson & Holroyd, 2007; Siddiqui, Chatterjee, Kumar, Siddiqui, & Goyal, 2008). It has neuronal connections with all the major motor control areas of the brain- the motor cortices, basal ganglia, thalamus, cerebellum and spine, and processes and integrates information from these areas and sends back output commands (Faw, 2003; Siddiqui et al., 2008). The pre-frontal cortex plays a role in error processing at a high order level, namely around adjusting motor commands based on system goals drawing from motivation, attention and memory (Krigolsen & Holroyd, 2007).

2.3.4 Motor control changes in Cerebral Palsy

2.3.4.1 Movement deficits

White matter injury causes reduced neurological input to the cortico-spinal tract (CST) and vastly effects motor control (Koman et al., 2004). Damage to the CST and to cortico-cerebellar circuits as occurs in CP, leads to deficits in the force, speed, timing and pattern of voluntary movement (Eileen et al., 2009; Kitai, Hirai, Ohmura, Ogura, & Arai, 2015). Reductions in the volume of the cortex and cerebellum have been found on magnetic resonance imaging (MRI) studies of the brains of children with cerebral palsy (Kulak, Maciorkowska & Gościk, 2016; Mu, Wang, Nie, Duan, Ma, Dai, Wu, Dong, Shan & Ma, 2017). Kitai, Hirai, Ohmura, Ogura, & Arai (2015) report higher incidences of cerebellar injury in preterm infants that was originally thought and that it is a predictor for higher incidences of motor and verbal deficits and epilepsy. Given the importance of the cerebellum in sensorimotor integration, motor planning, motor learning and error correcting, this could explain some of the significant deficits in motor control seen with children with CP.

The term ‘selective voluntary motor control’ (SVMC), describes the ability to isolate selected muscles in a specific pattern during a voluntary movement and

involves many different sensory and motor systems (Eileen et al., 2009; Koman et al., 2004). This ability is often impaired in people with CP and is seen as abnormal motor recruitment patterns and impaired timing of muscle activation (Eileen et al., 2009). In particular there is abnormal co-activation and mass contraction of synergistic muscles (coupled flexor and extensor muscles) during a motor task, normally seen during typical infant kicking and stepping, which has significant impact on gait patterns and overall functioning of the person (Eileen et al., 2009; Rose, 2009). In a study by Tedroff, Knutson, & Soderberg (2006) the motor activation patterns of children with CP were compared with children of normal development during maximal voluntary contraction's (MVC) of the lower extremities, they found that children with CP showed significantly abnormal muscle recruitment order and an inability to activate the prime mover first compared to the children without CP.

2.3.4.2 Co-contraction

Co-activation and co-contraction of muscles is defined as the simultaneous contraction of the agonist and antagonist muscle of the same joint in the same plane of movement (Pierce, Barbe, Barr, Shewokis, & Lauer, 2007). This is a physiological process that occurs normally as a way of slowing down and stabilizing a joint towards the end of a movement, however in children with CP co-contraction can occur in excessive amounts and becomes pathological, increasing joint stiffness, limiting joint movement and is associated with muscle weakness (Damiano, Martellotta, Sullivan, Granata, & Abel, 2000; Pierce et al., 2007; Poon & Hui-Chan, 2009; Sarcher et al., 2017). Excessive co-contraction is a commonly found impairment in children with CP and is thought to occur as a result of motor control strategies employed to help stabilize the joint (Sarcher et al., 2017; Damiano et al., 2000, Pierce et al., 2007). However as descending motor pathways are damaged in CP the muscle activation lacks the fine control and regulations necessary for effective movements, in particular there is a lack of reciprocal inhibition of antagonist muscles through Ia interneurons during a voluntary movement (Trompetto et al., 2014, Damiano et al., 2000). This lack of reciprocal inhibition means that the antagonist muscle, which would normally be inhibited, instead contracts at the same time as the agonist muscle and prevents normal movement of the associated limb (Pierce et al., 2007). The cerebellum, with its

role in fine tuning and timing, is also involved with co-activation and spasticity as seen in CP (Schulman, Davis et al. 1987, Sokal, Rudaś et al. 2015).

2.3.4.3 Muscle spasticity

Muscle spasticity has been defined as a 'velocity dependent increase in tonic stretch reflexes as a result of hyper-excitability of the stretch reflex' (Lance, 1980 as cited by Trompetto et al., 2014). Clinically it manifests as a hypertonic muscle that appears stiff and limits proper movement of the associated limb, this increased tone is more pronounced with faster movements (Nielsen, Crone, & Hultborn, 2007; Trompetto et al., 2014).

The development of muscle spasticity occurs from a combination of supraspinal and stretch reflex changes that occurs with upper motor neuron lesions, such as in CP. In conjunction with corticospinal tract lesions, reduced input or damage to the lateral reticulospinal tract can also occur and exerts supraspinal influence on the stretch reflex and spasticity (Trompetto et al., 2014). The reticulospinal tract is made up of the lateral (LRST) and medial reticulospinal tracts (MRST), the LRST arises from the medullary reticular formation and runs through the lateral funiculus, whilst the MRST originates in the pontine reticular formation and descends through the anterior funiculus (Fix, 2008). These tracts contribute to voluntary motor control through their facilitory effect on alpha and gamma motor neurons, which are involved in the spinal stretch reflex (see section 2.3.2). The MRST has an excitatory effect on the gamma and alpha motor neurons and increases the extensor response, whilst the LRST activates inhibitory circuits in the spinal cord and reduces excitability of the stretch reflex and the extensor response (Trompetto et al., 2014). Damage to the LRST, and/or a lesion in the brain that disrupts the corticobulbar fibres that project to the medullary reticular formation (from which the LRST arises), leads to a lack of inhibitory input to post synaptic and pre synaptic reflex circuits in the spinal cord (Trompetto et al., 2014). Disynaptic reciprocal Ia inhibition, the pathway responsible for inhibiting antagonist muscles, in particular has been found to be decreased in those with spasticity, including in those with CP, and is thought to play a major role in hyper excitable stretch reflexes (Nielsen et al., 2007; Trompetto et al., 2014).

Muscle spasticity is a problematic manifestation of cerebral palsy and is thought to contribute to gait impairments, muscle weakness, joint contractures and pain and many treatments and management for cerebral palsy are aimed at reducing spasticity (Koman et al., 2004; Poon & Hui-Chan, 2009). However there is some debate amongst the literature as to the effect of spasticity on muscle strength, function and gait in those with CP. It was traditionally thought to have a large impact on these areas and muscle strengthening exercises were avoided as they were thought to increase spasticity, but more recent studies have called this in to question. A study conducted by Ross and Engsberg (2007) assessed the relationship between spasticity, strength, gait and function in 97 children with spastic, diplegic CP. Their results showed that muscle strength is positively correlated with the level of gross motor function, gait speed and gait kinematics, whilst spasticity had only a minor positive correlation with gross motor function, gait speed and gait kinematics. Prior to this these authors had assessed the relationship between spasticity and strength and found no correlation between the two (Ross & Engsberg, 2002). Furthermore a study assessing levels of spasticity and muscle strength following selective dorsal rhizotomy showed a decrease in spasticity but this was not correlated with an increase in muscle strength (McLaughlin et al., 2002). In contrast to this, a study conducted by Poon and Hui-Chan (2009) found that there was a positive relationship between spasticity with a hyperactive stretch reflex and muscle weakness. The differences in these results may be due to methodological variability but nonetheless the evidence is unclear on the impact that spasticity has on muscle strength, gait and function. It is likely that problems in these areas have multifaceted causes, of which spasticity is just one.

2.4.3.4 Impaired sensory processing

Impaired proprioception, sensation, sensory processing and sensory integration in children with CP is well documented in the literature (Goble, Hurvitz, & Brown, 2009; Gordon, Charles, & Steenbergen, 2006; Papadelis et al., 2014; Pavão & Rocha, 2017). Gordon et al., (2006), discuss that during object manipulation, anticipation and planning of grip forces is done prior to the

initiation of movement and is an important part of motor control. In children with CP it has been found that they have deficits in controlling grip strength and force when manipulating objects of different weights, this was initially thought to be due to impaired sensation of the involved hand and/or impaired motor output (Gordon et al., 2006). However, in further studies it has been found that information gathered during lifts with the involved hand is transferred to the uninvolved hand, suggesting that it is not disturbed sensation but rather a deficit in the ability to integrate the sensory information with the motor output that is the issue in CP, this is supported by other studies (Gordon et al., 2006; Papadelis et al., 2014).

2.4.3.5 Motor unit recruitment

Finally, cortical lesions that occur in CP affect motor unit recruitment and firing rates. A motor unit consists of a single motor neuron, the neuromuscular junction and the various muscle fibers supplied by the motor neuron (Rose & McGill, 1998). Motor unit firing is both controlled through spinal reflexes as well as descending supraspinal influences, and the force of muscle contraction is controlled via the strength of descending drive, motor unit recruitment and motor unit firing rates (Rose & McGill, 1998). That is a weaker descending cortical input will activate lower threshold motor units, as descending drive increases more motor units are recruited at higher thresholds and firing rates will increase. In CP it is suggested that motor control and force production is disturbed through the inability of motor units to discharge at optimal firing rates and the inability to activate all available motor units (Rose & McGill, 2005, 2008; Xu, Mai, He, Yan, & Chen, 2015). Rose and McGill (2005) conducted a study assessing neuromuscular activation and motor unit firing characteristics in people with CP compared to controls that were typically developed. Their findings suggest that the muscle weakness that occurs in CP can at least be partially explained by the lack of excitatory descending drive that reduces the ability to activate all available motor units and increase motor unit recruitment and firing rates at higher contraction levels (Rose & McGill, 2005). Marciniak, Li, & Zhou (2015) also found a reduction in the actual motor unit numbers and size in adults with CP, although this may be related to changes in muscle characteristics and a reduction in the amount of muscle use that occurs over time in those with CP.

2.4 Muscle strength

2.4.1 Introduction

Muscle strength, as measured by peak torque during a maximal voluntary contraction, is one of the primary outcome measures for this research study. This chapter will first give an outline of the mechanics of skeletal muscle contraction and the influence of skeletal muscle properties on force production. Following this a discussion will be given on what changes occur in children with CP in relationship to muscle strength. Finally, current evidence on the management of muscle weakness in children with CP will be outlined.

2.4.2 Mechanics and properties of skeletal muscle contraction

Muscle strength can be defined as the ability to generate sufficient force and tension in a muscle to produce a desired movement or for postural control (Shumway-Cook & Wollacott, 2001). Muscular contraction involves both elements of the muscle itself as well as neural elements, such as the motor neurons, motor units, spinal tracts and the higher processing motor and sensory cortices.

Muscular contraction cannot occur without there first being neurological input, upon activation of a motor neuron, an action potential is generated which travels along the length of the axon to the synaptic cleft at the neuromuscular junction. Here neurotransmitters, largely acetylcholine, act as chemical messengers to relay the action potential to the end plate of the skeletal muscle fibers, this is then propagated along the skeletal muscle membrane through a transverse tubular system (Lieber, 2002). In order for a muscular contraction to occur there needs to be enough excitation to trigger depolarization and an action potential. Repeated stimulations from increased descending cortical drive of a motor neuron have a facilitative effect, producing larger end plate potentials. Furthermore, stretching of a muscle activates the muscle spindles and Ia fibers, these then cause excitation and activation of the α motor neurons through depolarization's called excitatory post synaptic potentials (EPSP's) (Lieber, 2002). Motor neurons can also receive

inhibitory inputs both from descending cortical tracts and from the effect of group 1a fibers on interneurons that synapse with motor neurons innervating antagonistic muscles, producing inhibitory post synaptic potentials (IPSP's) (Lieber, 2002). Muscular contraction will only occur when the excitatory input from EPSP's and descending drive outweighs the inhibitory input to the same motor neurons.

2.4.3 Changes in Cerebral Palsy

Muscle morphology and structure is well known to play an important role in the generation of muscle force. In particular muscle fiber length contributes significantly to force generation in a muscle through the effects of fiber excursion and the amount of filament overlap and cross bridge linking that occurs (Barber, Barrett, & Lichtwark, 2012; Lieber & Friden, 2000). The physiological cross sectional area (PCSA) is the ratio of muscle belly volume to fascicle length and is directly related to muscle force generating capacity, PCSA is highly correlated with muscle thickness (Lieber & Friden, 2000).

A number of studies have been conducted assessing changes in muscle morphology and muscle architecture and its relationship to muscle weakness in children with CP. In a systematic review by Barrett & Lichtwark (2010) 15 articles were reviewed that assessed muscle morphology and structure changes in individuals with spastic CP. This review demonstrated consistent evidence that children and young adults with CP show a significant decrease in muscle volume, muscle cross sectional areas and muscle belly length in the paretic leg in children with spastic CP, in most cases this was measured in the gastrocnemius muscle (Barrett & Lichtwark, 2010). The evidence for changes in fascicle length is inconsistent, some studies report no differences in fascicle length in the medial gastrocnemius muscle, others report significantly shorter fascicle lengths in the same muscle (Barber et al., 2012; Barrett & Lichtwark, 2010). The discrepancies in these results may be due to methodological differences or sampling issues.

These changes in muscle morphology and architecture are thought to impact on the reduction in muscle strength typically found in those with CP. The extent of this impact is yet to be established, muscle weakness is likely a multifaceted issue with both muscle structure and neurological changes contributing.

2.4.4 Current management of muscle weakness in CP

Reduced muscle strength in children with CP has been established in the literature to contribute significantly to deficits in gait and gross motor function (Ross & Engsberg, 2007). Increasing muscle strength with the goal of improving gait and walking ability is often the primary goal in treating children with CP.

The current literature provides evidence that strength-training exercises are a common method used in the treatment of children with CP. Strength training programme's utilized are variable with the use of isotonic and isokinetic exercises (Dodd et al., 2002; Mockford & Caulton, 2010). Two systematic reviews assessed the efficacy of strength training in children with CP, both of these reported favorable results for significant improvements in muscle strength, in particular for those studies that used isotonic exercises (Dodd et al., 2002; Mockford & Coulton, 2008). Some studies reviewed also showed improvements in gait and gross motor function, although with small to moderate effect sizes.

There is also emerging research being conducted using neurorehabilitation techniques to influence neuroplasticity and improve muscle strength in those with CP. Techniques that have been used in CP rehabilitation include neurodevelopment technique, constraint induced movement therapy and motor relearning therapies (Solopova et al., 2015). These techniques utilize repetitive exercises of various muscle groups that incorporate sensory feedback mechanisms in order to produce neuroplastic changes. This is based on the knowledge that nerve tissue displays plasticity; neural pathways are strengthened based on repetition of activities coupled with sensory feedback, a key component of motor learning. However these techniques generally measure activity and usage of the affected limb as a gauge of the efficacy of the technique, rather than muscle strength as a force or torque measurement.

2.5 Hoffman (H) reflex, M wave and V wave

2.5.1 H Reflex

The H or Hoffman reflex is a neurophysiological marker that has been used in research studies to assess CNS function and is an excellent tool in measuring motor neuron excitability (Misiaszek, 2003). It is the electrical variant of the spinal stretch reflex (reviewed in section 2.3) involving stimulation of a mixed nerve containing 1a afferent fibers and efferent fibers to the test muscle (Misiaszek, 2003; Tucker et al., 2005). The electrical stimulation activates the Ia afferent nerve fibers and an action potential is propagated to the spinal cord where it synapses with the α motor neurons (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). Motor neurons are recruited in an orderly fashion from smallest to largest, therefore the smaller motor neurons are activated first which innervate the slow motor units in the test muscle and activate the muscle fibers (Pierrot-Deseilligny & Mazevet, 2000). This elicits the H reflex that is seen in the corresponding EMG signal. It is commonly assessed in the human soleus muscle through stimulation of the posterior tibial nerve located in the popliteal fossa due to ease of access and the large number of slow twitch fibers in the soleus muscle (Tucker et al., 2005). The H reflex has been shown to have high test re-test reliability, particularly in the position of ankle plantar flexion, with an interclass correlation coefficient (ICC) of 0.96, and at 10% of MVC, with an ICC of 0.93 (Chen et al., 2010).

However the recording conditions and analysis of the H reflex can alter the results and affect their interpretation. Keeping test conditions the same, including the environment and posture, using Mmax for normalization of the H reflex values during data analysis and using curve fit analysis aid in ensuring that any changes in the H reflex can be interpreted as being due to the intervention applied (Brinkworth, Tuncer, Tucker, Jaberzadeh, & Türker, 2007; Misiaszek, 2003; Tucker, Tuncer, & Türker, 2005).

2.5.2 M wave

The M wave or the direct motor response is also measured along with the H reflex. The maximal M wave or Mmax represents the recruitment of all available motor units and is consequently an important component of measuring the H reflex as it is used as a normalization factor in interpreting results (Tucker et al.,

2005). The M wave is seen in the corresponding EMG signal and occurs due to the stimulation of the efferent portion of the mixed nerve. The M wave is elicited at a higher threshold than the H reflex due to the smaller diameter of the motor nerve fibers in comparison to the Ia afferents (Misiaszek, 2003; Pierrot-Deseilliggny & Mazevet, 2000). Electrical stimulation causes both an orthodromic (normal direction) and antidromic (opposite direction) action potential in both the Ia afferents and the motor nerves (Tucker et al., 2005; Pierrot-Deseilliggny & Mazevet, 2000). During progressive increases in electrical stimulation, the antidromic action potential volley along the efferent fibers towards the spinal cord will collide with the orthodromic volley from the Ia afferents heading towards the test muscle, this will result in a progressive decrease in the H reflex (Tucker et al., 2005; Aagaard et al., 2002). Mmax is determined when the H reflex is no longer visible on the EMG and the M wave has reached its highest magnitude and is no longer increasing with increasing stimulus (Tucker et al., 2005).

2.5.3 V wave

The V-wave or volitional wave is a variation of the H reflex measurement and represents the supraspinal input to the muscle during maximal voluntary contraction of the participant (Aagaard et al., 2002). The V-wave is induced at supramaximal electrical stimulation during an MVC and occurs as a result of collision between the antidromic action potentials in the efferent motor axons and the orthodromic impulses arising from descending drive from the motor cortex as the participant voluntarily activates their muscle (Aagaard et al., 2002; Pensini & Martin, 2004). This collision cancels out the antidromic volley from the efferent nerves and allows the evoked reflex response from the afferent neurons to reach the muscle, the higher the level of muscle contraction the greater the antidromic collisions and an increasing V-wave will be seen on the EMG signal (Aagaard et al., 2002; Pensini & Martin, 2004). Measuring the V wave relative to Mmax is a useful tool in detecting changes in the descending cortical drive during test condition variations.

2.5.4 Changes in CP

As discussed by Rose & McGill (2005), children with CP are thought to have difficulty in recruiting higher threshold motor units and/or to drive lower threshold motor units to higher frequency firing rates. They also have muscle spasticity, which is characterized by an exaggerated spinal stretch reflex and enhanced excitability of the α -motoneurons (Frascarelli, Di, Bisozzi, & Castelli, 2010). The H reflex is thought to be an electrical variant of the spinal stretch reflex and, given that CP children have exaggerated stretch reflexes, it is a useful tool to evaluate observed changes in motor neuron excitability with various treatment modalities. The literature suggests that H reflex measurements are a relevant and acceptable tool to use in neurophysiological studies in children with CP. The H reflex has been studied in children with CP previously and it has been observed that they have elevated amplitudes of the H reflex and higher H:M ratios compared to age matched typically developed children (Achache et al., 2010; Frascarelli et al., 2010; Hodapp, Vry, Mall, & Faist, 2009; Soriano, Logigian, Madsen, Scott, & Prahl, 1995). It is proposed that this is due to a lack of supraspinal control of the spinal stretch reflex, probably due to altered modulation of the muscle spindle afferent input (Frascarelli et al., 2010; Soriano et al., 1995). Hodapp, Vry, Mall, & Faist (2009) assessed the modulation of the H reflex during gait in children with CP and assessed whether treadmill training would affect the modulation of the H reflex in children with CP. They discovered that the children with CP showed decreased depression of the H reflex during the swing phase of gait and that the treadmill training over 10 days caused increased depression of the H reflex of the soleus muscle during the swing phase of gait (Hodapp et al., 2009). This finding is thought to be significant clinically for CP children as large soleus H reflex amplitudes during gait indicate an exaggerated stretch reflex and reflect muscle spasticity and/or co-contraction, this may impair dorsiflexion of the foot and reduce foot clearance, problems often seen during gait in children with spastic CP (Hodapp et al., 2009). Further to this, significant reductions in the H:M ratios has been observed in children with CP following treatment with botulium toxin injections which corresponded in a clinically evident reduction in measured plantar flexor spasticity (Frascarelli et al, 2011).

It must be noted that these studies (Achache et al., 2010; Frascarelli et al., 2010; Hodapp et al., 2009; Soriano et al., 1995) have all used slightly different

methodologies, postures and data analysis procedures and have expressed their results using H:M ratios. While this is a commonly used measure it does not use the curve fitting and normalization procedures which are the best analysis methods to use to reduce the affect of other variables, such as changes in electrode positions, on the H reflex results (Brinkworth et al., 2007; Niazi et al., 2015; Tucker et al., 2005). Consequently these results should be viewed with these limitations in mind.

2.6 Chiropractic

2.6.1 Introduction

Chiropractic is a primary health care profession that concerns itself with the function of the spine and its impact on the nervous system and how this affects the overall health of an individual. Chiropractic adjustments, a chiropractic term that is known more commonly as 'spinal manipulation', are made to joints of the spine displaying altered alignment, mobility and/or nerve system interference (New Zealand Chiropractic Board, 2004).

2.62 Scientific basis

There is a growing body of evidence that suggests that Chiropractic adjustments lead to neural changes in multimodal integration, sensorimotor integration, cortical drive, motor control and muscle strength (Haavik Taylor, Holt & Murphy, 2010; Haavik & Murphy, 2012; Marshall & Murphy, 2006; Niazi et al., 2014; Holt, Haavik et al. 2016,;Lelic, Niazi et al. 2016). It is proposed that the areas of joint dysfunction, better known as vertebral subluxations to chiropractors, alter the afferent input that is sent to the brain and are responsible for maladaptive neuroplastic changes in the CNS (Haavik Taylor et al., 2010; (Haavik & Murphy 2012). It is thought that if not corrected over time these maladaptive changes can lead to symptoms of dysfunction and pain (Haavik Taylor et al., 2010; Haavik & Murphy, 2012). Scientists have discovered that people with neck pain have altered proprioceptive input and joint position sense (Knox et al., 2006; Sá & Silva, 2017). Even those who have a history of neck pain but no pain at the time of the study, a population group referred to as subclinical neck pain, also demonstrate altered joint

position sense, proprioception and sensorimotor integration (Haavik & Murphy, 2011; Andrew, Yielder, Haavik & Murphy, 2017; Paulus & Brumagne, 2008; Baarbe, Holmes, Murphy, Haavik & Murphy, 2016). One study investigated changes in multisensory integration, looking at how a group of individuals with subclinical neck pain were able to integrate sound and visual information compared to a group of normal healthy adults with no history of pain. These scientists found that the subclinical neck pain group processed the visual and multisensory information slower than the healthy controls (Farid, Yielder, Holmes, Haavik & Murphy, 2017). They were retested again at 4 weeks and these differences persisted, demonstrating that these multisensory integration issues in people with subclinical neck pain do not improve on their own (Farid et al., 2017). These findings suggest that areas of joint dysfunction, even if they are not causing pain symptoms at the time, may create altered afferent input to the CNS, affecting the internal body schema and motor control through altered sensorimotor integration.

As discussed above in section 2.3, sensorimotor processing and integration is an important part of motor planning and control and in fact an accurate inner body schema and accurate afferent input is essential for perfect and precise movements. Reducing spinal joint dysfunction with chiropractic SM has been shown to alter and improve multimodal integration (Holt, Haavik et al. 2016), sensorimotor integration (Haavik Taylor & Murphy 2008, Haavik & Murphy 2011, Haavik & Murphy 2012) and motor control (Haavik & Murphy, 2012, Niazi et al., 2014; Haavik-Taylor, Holt & Murphy, 2010; Christiansen et al., 2017; Holt et al., 2017). A number of studies have been conducted utilizing neurophysiological measures for sensorimotor processing and assessing the effects of chiropractic SM. Some studies have used somatosensory evoked potentials (SEP's) and shown that SM of dysfunctional joints of the cervical spine alters the N20 and N30 peaks which represent the processing of proprioceptive information at the primary somatosensory cortex and early sensorimotor integration of this information respectively (Haavik Taylor & Murphy, 2010a; Haavik- Taylor, Holt & Murphy, 2010; Haavik-Taylor & Murphy, 2010b; Haavik, Niazi, Holt & Murphy, 2017).

One of the proposed mechanisms for the changes that occur in sensorimotor and multimodal processing and integration is the effect that chiropractic SM has on

joint receptors, mostly muscle spindles. Muscle spindles, and other joint receptors, play a crucial role in providing afferent proprioceptive and feedback information to the CNS (for a full review see section 2.3). It is proposed that a high velocity, low amplitude thrust to a dysfunctional spinal segment, a common form of SM used in chiropractic practice, stretches the muscle, alters the muscle spindle discharge firing rate and the afferent feedback to the brain (Haavik, Murphy & Holt, 2010; Cao, Reed, Long, Kawchuk, & Pickar, 2013). As sensory processing and integration is an essential component of motor planning and control this is an area that could provide some important rehabilitative treatment strategies, and since chiropractic has been shown to alter multimodal sensory integration (Holt, Haavik et al. 2016), sensorimotor integration (Haavik & Murphy 2012; Lelic, Niazi et al. 2016) as well as strength and motor control (Niazi, Türker et al. 2015; Christiansen, Niazi et al. 2017), these findings may be significant for predicting changes in motor control in children with CP following a chiropractic intervention.

Previous research on the effects of chiropractic SM on muscle strength has been conducted in a number of population groups- healthy adults, elite athletes and chronic stroke patients (Niazi et al., 2014; Christiansen et al., 2018; Holt et al., 2017). In each of these studies there was a significant increase in the force produced during maximal voluntary contraction of the soleus muscle during ankle plantar flexion, 15% increase in healthy adults (Niazi et al., 2015), 6% increase in elite Taekwondo athletes (Christiansen et al., 2018) and 65% in chronic stroke patients (Holt et al., 2017). Conversely, in the control groups for each of these studies the participants actually demonstrated a decrease in MCV force (Niazi et al., 2015; Christiansen et al., 2018; Holt et al., 2017). Again, as discussed in section 2.3.2, reduced muscle strength is a problematic manifestation in children with CP and is thought to contribute to deficits seen in gait and gross motor functional outcomes (Eek & Beckung, 2008; Ross & Engsberg, 2007). Thus if similar changes could be induced in a CP population with chiropractic SM, this would likely positively influence the quality of life for CP children.

Within these same studies they also investigated the H or Hoffman reflex and the voluntary drive or V wave (Niazi et al., 2015; Christiansen et al., 2018; Holt

et al., 2017). Similar changes the V wave have been noted pre and post a single session of chiropractic SM in healthy adults, elite athletes and in chronic stroke patients. In the healthy adult group there was a significant increase of 45% in the V wave amplitude following the chiropractic SM, compared to a 23% decrease in the V wave in the control group (Niazi et al., 2015). In the chronic stroke population study, there was a 54% increase in the V wave amplitude following the chiropractic SM and a 12% decrease in the control group (Holt et al., 2017). And in the elite athlete study there was a 33-46% increase in the V wave amplitude recorded over 60 minutes post the chiropractic intervention, with an 11-22% decreases in V wave amplitude for 60 minutes after the control intervention (Christiansen et al., 2018). The threshold to elicit the H reflex significantly decreased by 8.5% following the chiropractic intervention in healthy adult population, with no change noted in the control group (Niazi et al., 2015). These results indicate that the H-reflex pathway may be involved in the neural plastic changes that occur following chiropractic Sm, as the chiropractic intervention altered the net excitability for the low-threshold motor units in this healthy population (Niazi et al., 2015). No significant differences in the H reflex were noted in the chronic stroke study (Holt et al., 2017) or the elite athlete study (Christiansen et al., 2018). However, the authors of these studies both noted their experiments may have been under-powered to pick up on any small H reflex changes. It is therefore possible that some spinal cord excitability changes may have occurred in both of these studies as well, and a type II error occurred. Regardless, considering the large changes in strength and corresponding large changes in V waves, with only minimal H reflex findings (if any at all), it is most likely that the changes in strength seen in these studies in the lower limb post chiropractic SM are due to changes in cortical drive.

It is interesting to note that Vila-Cha, Falla, Correia, & Farina, (2012) performed a similar study that looked at the same measures; ie. MVC force, H reflex and V wave, in a group of healthy adults with a 3 week strength training programme or endurance training programme as interventions. They found similar results in all measures as was found after a single session of chiropractic SM (Niazi et al., 2015). This demonstrates that a single chiropractic intervention has a profound impact on central neural function. However, it is not yet know how

long any central neural effects post chiropractic SM last, with only up to an hour follow ups to date having been performed (Christiansen et al., 2017).

Chiropractic SM has also been known to impact on the cerebellum and its communication with the motor cortex (Baarbé, Debison, Larabie, Haavik, Yielder & Murphy, 2013). Studies have been conducted using a technique called cerebellar inhibition (CBI), where transcranial magnetic stimulation (TMS) pulses are applied first over the cerebellum and then 5-8 milliseconds later over the contralateral primary motor cortex. This process allows for assessing the communication within the cerebellar-thalamo-cortical circuits (Baarbé et al., 2013; Daligadu, Haavik, Yielder, Baarbé & Murphy, 2013). CBI was assessed in three groups, a healthy adult population, a control group with subclinical neck pain and an experimental group with subclinical neck pain who received chiropractic SM. Each group were assessed pre and post a simple typing task to measure motor learning with motor output recorded from a hand muscle (Baarbé et al., 2013). What these scientists found was that firstly the groups with subclinical neck pain show altered communication between the cerebellum and the motor cortex as evidenced by no modulation of CBI with increasing stimulus intensities compared to what was seen in the normal healthy population group (Daligadu et al., 2013). Secondly, the subclinical neck pain group who received chiropractic SM had increased modulation of CBI at even greater numbers than the healthy control group and showed enhanced CBI modulation during motor learning (Baarbé et al., 2013; Daligadu et al., 2013). This was not seen in the subclinical neck pain control group (Baarbé et al., 2013). What these results suggest is that chiropractic SM may normalize the afferent input from the cervical spine allowing for a more correct internal body schema, which allows for enhanced processing of this sensory information in the cerebellum and its communication with the primary motor cortex (Daligadu et al., 2013). In previous discussions above it is noted that the cerebellum is vital in its role in motor control as it processes sensory information from all systems and allows for accurate inner body maps, error correcting during movement, motor learning and appropriate postural control. It has also been shown to have reduced function in children with CP and is likely to play a role in the motor control deficits seen around postural control, timing errors and sequence of muscle activation in CP (Kitai et al., 2014;

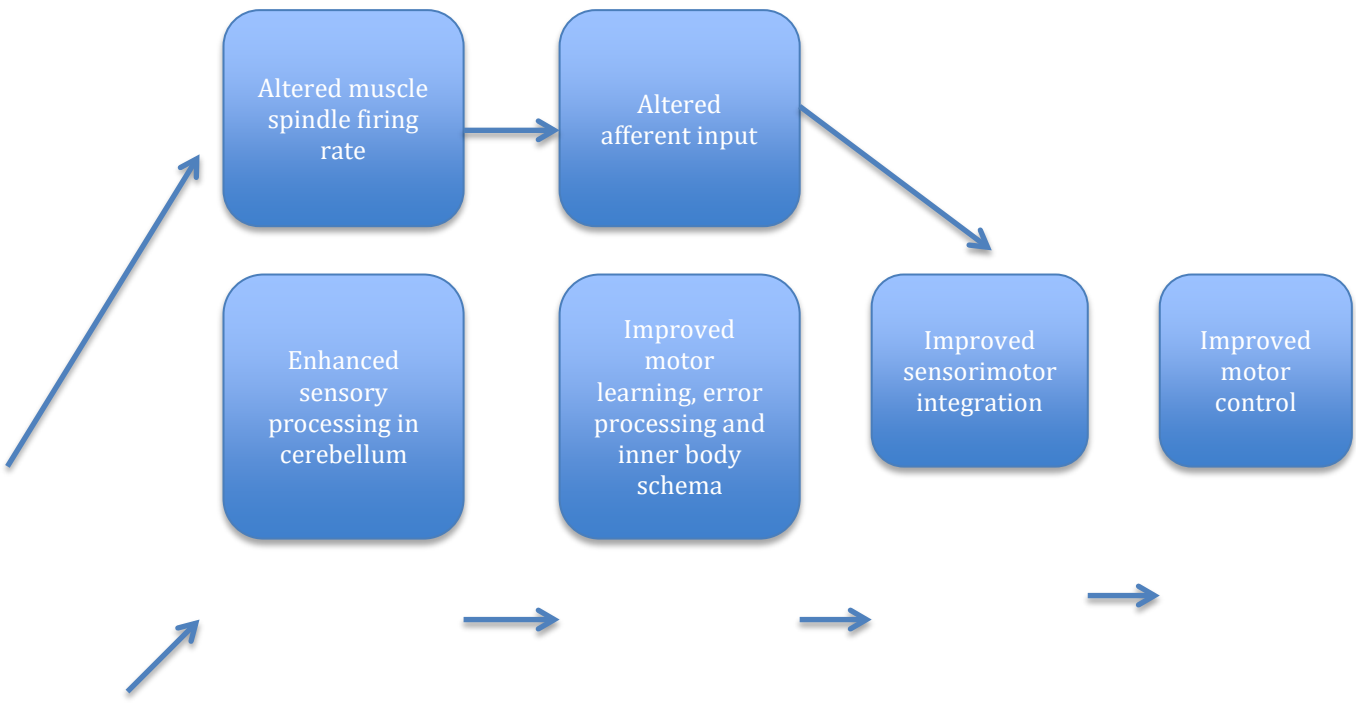
Eileen et al., 2009). Therefore any interventions, such as chiropractic, that can impact on the sensorimotor integration in the cerebellum are worthwhile assessing in children with CP.

The pre-frontal cortex is an area of the brain that is known to play an important role in sensorimotor integration, which was discussed in detail previously in section 2.3. Scientists have identified that chiropractic SM has a significant effect on the pre-frontal cortex (Lelic et al., 2016). Using brain electrical source localization analysis they were able to identify which areas of the brain were impacted by chiropractic SM in regards to somatosensory processing. Their findings demonstrated that the pre-frontal cortex, in particular, showed a significant reduction in cortical activity (Lelic et al., 2016). As the pre-frontal cortex is known to have high level executive functions in co-ordinating sensory and motor information from multiple neural structures, this is an important finding and may explain how chiropractic SM has such a vast array of neurological improvements (Lelic et al., 2016; Faw, 2003). Furthermore if chiropractic SM can affect an area that has significant functions in sensorimotor integration through perceptual, attentive and memory based error processing, then this may alter motor control in those with CP.

2.6.3 Evidence in Cerebral Palsy

To date there is limited published research on the use of chiropractic SM in the management of people with cerebral palsy. The current literature available is in the form of case reports and case series. Of these there are numerous reports of improvements in children with CP following chiropractic SM, most commonly seen in the areas of quality of life and mobility (Goodsell & Schneider, 2010; Kent, McCoy, Malakhova, Safronov, & Scire, 2006; Moss & McKay, n.d.; Valente, 2009). One case series reported substantial decreases in muscle spasticity of the wrist in 29 children and adolescents with cerebral palsy following spinal manipulation and a rehabilitation programme (Kachmar, Voloshyn, & Hordiyevych, 2016). As these are all case reports and case series the results must be viewed with caution as there are inherent limitations in the design of a case study with limitations on the ability to draw conclusions, reduce bias and reproducibility. However there is some evidence

in the literature and in the clinical experience of chiropractors that there are potential benefits to children and adults with cerebral palsy undergoing chiropractic SM. These benefits need to investigated further and with more rigorous research designs. The following research study that is described and the basis for this Masters thesis, is an attempt to further the evidence for the use of chiropractic SM in children with CP.



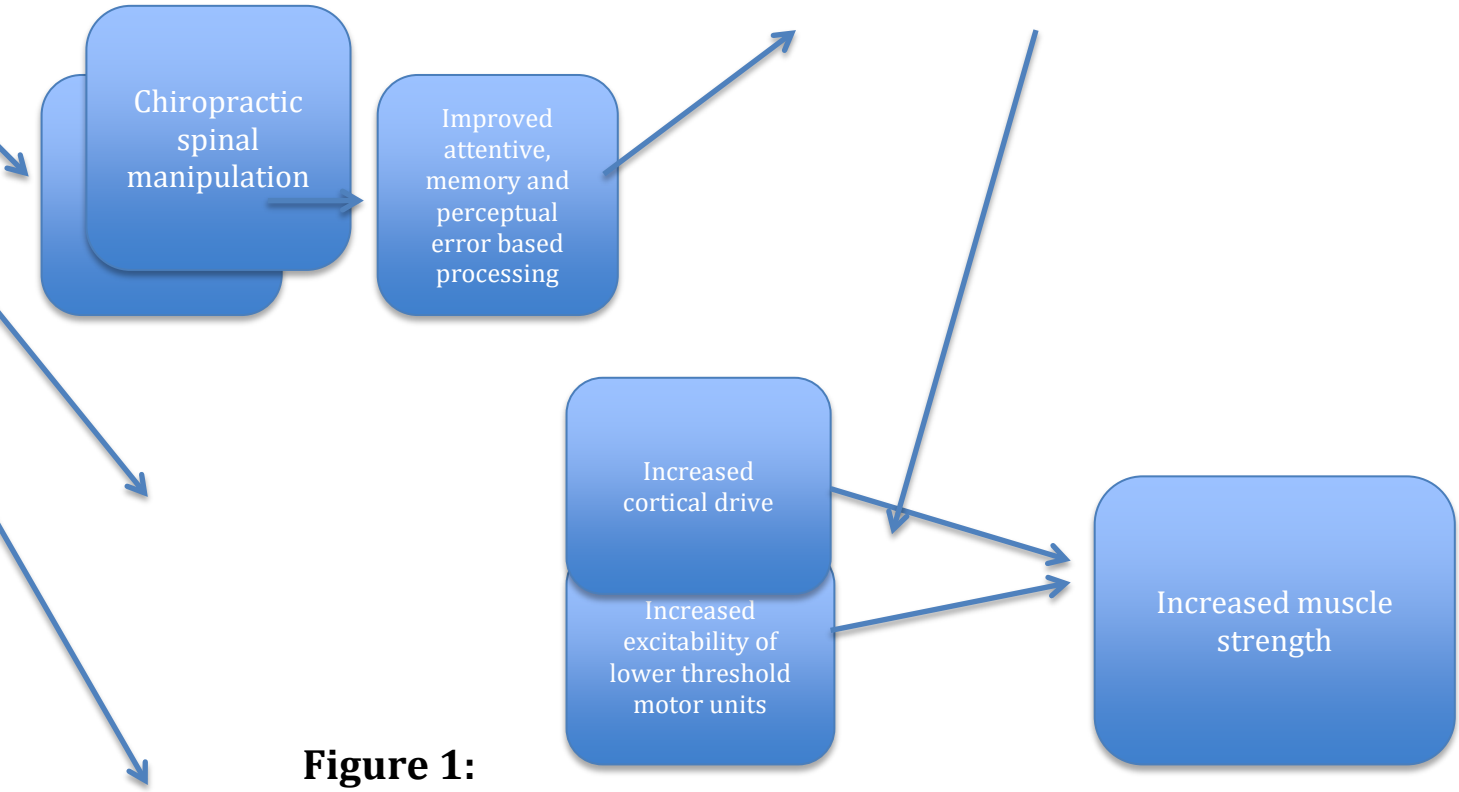


Figure 1:

Conceptual framework- effects of Chiropractic spinal manipulation

Chapter 3- The effects of Chiropractic spinal manipulation on the H reflex and muscle strength in children with spastic diplegic cerebral palsy: a feasibility study.

3.1 Introduction

In previous sections above it has been discussed and outlined that children with CP demonstrate an array of deficits in motor control and that chiropractic SM has been shown to affect various aspects of motor control (Haavik Taylor, Holt & Murphy, 2010; Haavik & Murphy, 2012; Marshall & Murphy, 2006; Niazi et al., 2015; Holt, Haavik et al. 2016; Lelic, Niazi et al. 2016). Consequently, it is possible that SM will result in changes in motor control in children with CP and that one

potential method of measuring this is with H reflex, V wave and force testing. The H reflex has been studied in children with CP previously and is a useful tool in measuring motor neuron excitability (see section 2.5).

A randomized, controlled clinical trial is planned to investigate the effects of chiropractic SM on motor neuron excitability and muscle strength in children with CP. However there are a number of feasibility issues needing to be addressed prior to conducting the full scale RCT. Therefore the aim of this study was to assess the feasibility of conducting a larger scale RCT. The feasibility questions that we sought to be answered were:

- The recruitment rate, in order to determine if enough participants for the full scale RCT could be recruited in a timely manner.
- The feasibility of the recruitment strategy, will it be sufficient for recruiting enough participants for a large scale RCT based on the recruitment rate.
- Can we measure changes in the H reflex and MVC peak force following chiropractic SM in children with CP.
- Can children with CP tolerate and be compliant with the data collection protocol and length
- Is the chiropractic SM intervention tolerated and appropriate for children with CP.
- Is the equipment used for data collection tolerated by children with CP and does it provide accurate measurements

3.2 Methods

3.2.1 Research design

This study was conducted as a feasibility study utilising a single blinded, parallel group, randomized, controlled design, mimicking the full RCT as closely as possible. Sample size for this feasibility study was based on estimated recruitment rate for the larger scale RCT, this is anticipated to be 1 participant per week, based on the relatively small numbers of children that meet the criteria living in Auckland. Data collection for this feasibility study will take place over a 6-week period, therefore a sample size of 6 participants will be used.

Participants were recruited through the New Zealand Cerebral Palsy Registry (NZCPR). Participants were identified on the NZCPR database that had consented to being contacted about research studies. Those identified were then further assessed for eligibility for this study. Potential participants were then posted a letter of invitation to participate and a flyer with information about the study (see Appendix D). The parents were asked to contact the lead researcher with any questions and/or if they wished to participate in the study. Prior to participation in the study informed consent was taken from the parents of the participants and the participants provided informed assent.

3.2.2 Randomization and Blinding

While pre intervention recordings of the H reflex, V-wave and MVC force were taken the chiropractor, who was not involved in data collection or analysis, randomized the participant in to one of two groups, SM intervention or passive movement control intervention, through a coin toss in a separate room. The use of a more rigorous randomization procedure, such as computer generated randomization through a programme like QMinim, was not used due to the small sample size but would be used in a larger scale study to reduce group differences and potential bias.

Following pre intervention recordings the chiropractor then took the participant and caregiver to the separate room to do the spinal examination and provide the SM or control intervention. The participant or caregiver was not informed of which group they were in. Following the intervention the chiropractor brought the participant and caregiver back to the data collection room for post recordings and the chiropractor then left. Documentation regarding the intervention given was kept by the chiropractor until the time that data analysis was complete. At no time before this were the researchers involved with data collection and analysis made aware of the group allocation.

3.2.3 Participants

Inclusion criteria for this study consisted of children with diagnosed spastic diplegic CP, aged 8 -13 years and classified as Level I-II on the Gross Motor Function Classification System (GMFCS), as per the New Zealand Cerebral Palsy registry and confirmed with parents at the experimental session. Participants must be proficient in English and have been able and willing to sign informed consent. Exclusion criteria consisted of any known contraindications to chiropractic SM (previous reaction to spinal manipulation, fracture, cancer, recent trauma, ligamentous instability and known inflammatory or infectious arthritis). This was checked as part of the study consent and health history taking by the researcher at the experimental session. Participants who had any surgery, inhibiting casts or botulium toxin in the last 6 months, as reported by parents, were also excluded from this study.

3.2.4 Data management

All data collected, including health information, was assigned a confidential participant number to safeguard confidentiality. This participant number was not included on consent and assent forms and these forms were kept separately. All electronic files were stored on the New Zealand College for Chiropractic research department server, which is password protected. All hard copies of documents related to the study, including consent and assent forms, were stored in a secure, locked cupboard at the New Zealand College for Chiropractic research department.

The study was discussed at regular meetings with the researchers involved and the two supervisors and this served as the data safety monitoring committee. Participants and families were asked to report any adverse events at any point during the study. In order to preserve blinding of the researchers involved with data collection and analysis, the participants were given the contact details of the chiropractor to report any adverse event related to the interventions.

3.2.5 Outcome Measure procedures

Participants and their caregivers attended one data collection session at the Health and Rehabilitation Research Institute at Auckland University of Technology

(AUT). Prior to the recording of outcome measures, the primary researcher discussed the procedures for the study, answered any questions and gained informed consent and assent from the participant and caregiver. Following this a structured interview was conducted to gather information on the patients age, sex, ethnicity and health history. Muscle strength, H reflex and V wave recordings were then conducted by the primary researcher and a bio-medical engineer. To assess compliance and tolerance to the data collection protocol notes were taken on any observations or comments the participant made about tolerance to the procedures, such as discomfort, boredom, wanting to stop. The participants and their families were also asked at the end of the data collection session if it was ok and how they felt about it.

3.2.4.1 Muscle strength

Muscle strength was recorded by measuring isometric force of the plantar flexors using a custom-made force transducer. The foot of the affected leg was placed into the force transducer and strapped in using Velcro fasteners. The distal thigh was also fixed in place using Velcro fasteners in order to reduce movement of the leg during plantar flexion. Once the leg was fixed the angle of the knee was measured, this was done again post intervention/control to maintain the same conditions. The participant was instructed to push down with their foot as hard as possible for 5 seconds, this was repeated for a total of 3 times. Participants were verbally encouraged during each MVC to aid in the highest possible contraction. Force was recorded with a CED Power 1401 MK 2 Data Acquisition Board at a sample rate of 1 kHz and an isometric strain gauge (Model MLP100 transducer Techniques Tennecula, California, USA). The corresponding computation was done by Spike software. The strongest MVC of the three taken was used to compute the 10% amount required as a background plantar flexion contraction during the H and V wave recordings.

3.2.4.2 Surface electromyography

Surface electromyography (sEMG) measures the electrical activity of a muscle through the placement of electrodes onto the skin over the belly of a muscle (Criswell & Cram, 2011). sEMG was used to record the motor response of the soleus muscle for the H, M and V wave recordings during this experiment. The soleus

muscle was identified by asking the patient to stand on the tip of their toes to produce plantar flexion and then was palpated for location just lateral to the gastrocnemius muscle. In order to produce a clear signal and reduce skin impedance the skin was prepared first by shaving the area, gently abrading the skin with sandpaper, wiping the skin with Nuprep gel and then cleaning the area with alcohol wipes. Following this two bipolar surface electrodes were placed two cm apart along the belly of the soleus muscle, perpendicular to the muscle fibres, to record the innervation zone (Tucker et al., 2005). A ground electrode was placed onto the bony prominence of the medial malleoli. The electrodes were then connected via cables to a custom-built amplifier with built-in stimulus artifact suppressor and high pass filter (20 Hz) and the signals were recorded via SIGNAL software.

3.2.4.3 Electrical stimulation

The H reflex, Mmax and V waves of the soleus muscle were elicited via electrical stimulation of the tibial nerve. After an explanation of the procedure to the participant and carer, a stimulating electrode (cathode) was placed in the popliteal fossa and the anode electrode placed just proximal to the patella. This positioning ensures that the H reflex can be elicited at the lowest possible threshold as the current passes transversely through the tibial nerve. The knee was then bandaged to place pressure on the cathode for ease of stimulation. Electrical stimulation was delivered through a Digitimer isolated stimulator. The position of the electrodes was altered accordingly to provide the lowest stimulation intensity whilst ensuring activation of the entire soleus muscle.

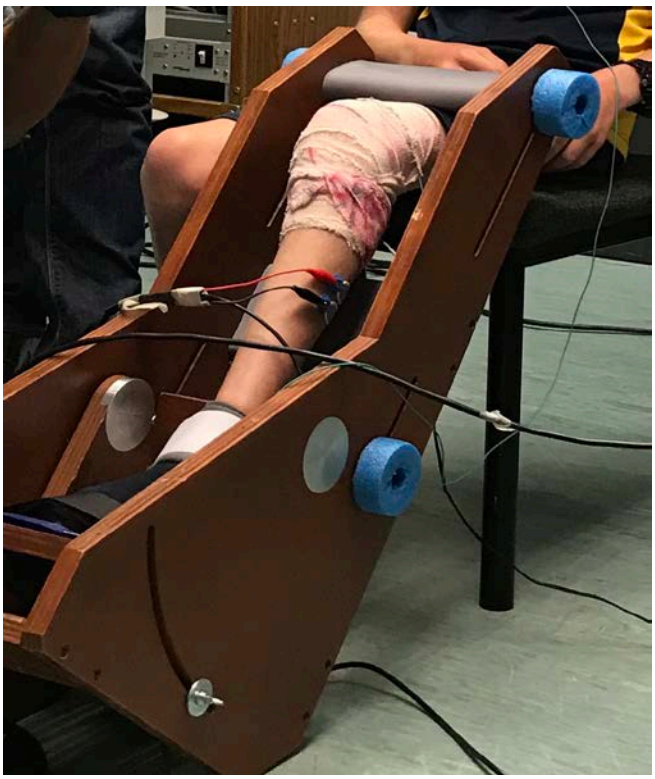


Figure 1- Set up for MVC force, H reflex and V wave recording

3.2.5 Data recording

3.2.5.1 M-Max

The M wave recording was elicited by electrical stimulation of the tibial nerve starting at 5mA and was progressively increased in 5mA increments until the M wave appears in the sEMG. M-max, which represents the recruitment of all motor axons, is reached at the point when the motor response does not increase with further increases in electrical stimulation and the H reflex response has disappeared. This figure was then recorded as M-max, 10% of this is calculated and used in the H reflex recording.

3.2.5.2 H reflex

For the H reflex recording the participant was asked to push down their foot gently to maintain a contraction at 10% of M-max (as determined above in section 3.2.4.1). This was displayed on a computer screen directly in front of the patient as a line for visual feedback. The purpose of this low level constant contraction is to allow for some stable background electrical activity throughout the stimulation protocol so that any changes in the H reflex can be determined to be due to other test conditions (Tucker, Tuncer & Türker, 2005). The H reflex was then elicited via

electrical stimulations of the tibial nerve. The participant received 48 stimulations in total at different intensities, each stimulation was given at 0.5ms intervals. Equally dividing the M-max into 16 determined the intensity levels and then 3 stimulations per level were given. The levels were stimulated at random to reduce predictability of the participant's response.

3.2.5.3 V wave

The V wave was then recorded via sEMG and force. Participants were asked to perform three separate MVC's by pushing down their foot as hard as they can whilst being verbally encouraged by the researcher. During each of these MVC's they were given three electrical stimulations at supra-maximal intensity (110%) of M-max.

3.2.6 Intervention

After the pre-recording session was completed, as outlined above, participants and caregivers were then collected by the chiropractor and taken into a separate room. If placed in the intervention group participants received chiropractic SM by a registered chiropractor. A full spine check was be conducted and SM was performed on specific segments exhibiting evidence of joint dysfunction such as restricted inter-segmental range of motion, tenderness on palpation and intervertebral muscle tension. These are all indicators commonly used in Chiropractic practice and have been shown to be reliable indicators of spinal dysfunction (Cooperstein & Young, 2016; Fryer, Morris, & Gibbons, 2004; Humphreys, Delahaye, & Peterson, 2004). Chiropractors have specific training in paediatric care and participants were thoroughly assessed and technique adapted to lower force applications when necessary. All SM performed, and on which vertebral segments, was recorded by the chiropractor.

If placed in the control group the participants received a control intervention that involved non-specific movements of their head, spine and body but did not include the thrust that is given with SM. This was done in order to control for the proprioceptive input that could have neurological consequences which occurs during the procedure of checking for spinal dysfunction and placing a person into positions for SM. Following the intervention the participants were taken back into the data collection room and post recordings were conducted in the same manner

as the pre recordings.

3.3 Data analysis

3.3.1 Curve fitting and normalization

Variations can be seen in the H reflex due to changes in subject position during recording, alterations in electrode positioning or contact and/or alterations in the muscle itself, which can affect study results if adequate H reflex curve analysis is not performed (Brinkworth et al., 2007; Tucker et al., 2005). Furthermore, thresholds to elicit the H reflex and M wave can be different not only between subjects but also within subjects even if tested on the same day (Brinkworth et al., 2007). In order to account for these changes, to obtain results that reflect genuine H reflex changes from the intervention and to determine the H reflex and V wave at different intensities along the recruitment curve, it is necessary to perform curve fitting and normalization on the raw H reflex data (Brinkworth et al., 2007). This was performed using the procedure described by Brinkworth et al., (2007) and used in previous H reflex studies with chiropractic SM as an intervention (Niazi et al., 2007; Christensen et al., 2017).

Firstly, the peak to peak amplitude of the H reflex, M wave and V waves were obtained from the EMG signal. Normalization was then performed in order to compare the results between subjects. As discussed in section 2.5, M-Max is used as a normalization factor. For each participant in both the pre and post sessions, M-max was used for the corresponding H-reflex, M wave and V waves to give H/Mmax and V/Mmax ratios for each participant. Having this normalized to the specific H reflex or V wave stimuli, for each subject and each session allows for a more accurate assessment of what the changes in the H-reflex and V wave represent (Brinkworth et al., 2007; Niazi et al., 2014; Christensen et al., 2017). Once normalization was performed these values were then modeled for curve fit analysis with a hyperbolic function for the M wave and a Guassian equation for the H reflex and V wave (Brinkworth et al., 2007).

3.3.2 H reflex analysis

After curve fitting and normalization was performed the H reflex were

analysed for threshold levels by identifying the intensity when the H reflex curve starts to rise. A Matlab code was used as an automatized procedure for this, however the time windows for each data set were also manually inspected to ensure accuracy of this level. The results of each session were then superimposed and post intervention/control results were compared with pre intervention/control results. Parameters that were extracted from the curve fitted H reflex data were H reflex threshold, s50 and slope.

3.3.3 V wave analysis

After curve fitting and normalization was performed the V wave was analysed using peak to peak amplitudes, these were then superimposed and averaged to produce a mean value difference between the pre and post sessions.

3.3.4 Force analysis

Maximal voluntary contractions were recorded for force analysis as described in section 3.2. To determine difference in force measurements the EMG signal was manually inspected and analysed using peak to peak amplitude calculations. This was done by placing one cursor at the baseline immediately before contraction starts (as evidenced by a shift in the baseline), and placing a second cursor at the end of the contraction immediately before the return to baseline, then the difference calculated. These values were then compared pre and post intervention/control.

3.3.5 Recruitment rate

The recruitment rate was analysed simply by dividing the number of participants successfully recruited into the study by the number of people who were contacted that met the inclusion criteria for possible participation through the NZCPR . This was then averaged across the 6 week period to get the rate per week.

Chapter 4- Results

This section will present the feasibility results of the recruitment rate and method, data collection procedure, intervention and equipment. The results of the H reflex, V wave, and force analysis will also be presented.

4.1 Feasibility

4.1.1 Recruitment

Participants for this study were recruited through the NZCPR. At the time of this study the NZCPR were newly set up and this was the first study to use them for recruitment. Consequently it took considerable time to set up the process to be able to recruit through them, from the first contact in May 2016 until the first flyers were sent out in July 2017. Also because they were a new organization they were still in the process of approving the registrations that they have on their system, this meant that only the approved registrations could be contacted for this study.

In total, 50 families that were registered in the Auckland region with a GMFCS of I-II and aged between 8-13 years old were sent the study information over a six week recruitment period. From this 50, five parents (10%) made contact via email enquiring about participating in the study. Of these five, three met the inclusion criteria and were included in the study. The two participants that were not included were excluded as one had Athetoid dyskinetic CP and the other was only going to turn eight years old in December, after the study period had finished. This gives a recruitment rate of 6%.

There was a 100% retention rate with every participant completing the session. Sample characteristics are provided in Table 1. Due to the small and unequal sample size the intervention and control groups were inevitably not equally distributed. Interestingly, although this was not an inclusion criteria, all participants had previous experience with chiropractic SM.

Table 1- Sample Characteristics

	Total N=3	Intervention N=2	Control N=1
Mean Age	12	12	12
Gender n,% Female	1 (33)	1 (50)	0 (0)
Gender n,% Male	2 (67)	1 (50)	2 (100)
GMFCS I n,%	3 (100)	3 (100)	3 (100)
GMFCS II n, %	0	0	0
Prev Chiropractic Care- % Yes	3 (100)	3 (100)	3 (100)

The recruitment period was set at 6 weeks, both for timely purposes of completing the study and also to have a set limit in place in order to be able to assess recruitment rate. With three people successfully recruited into the study over a 6 week period, this gives an average of 1 participant every 2 weeks.

For a large scale RCT, an estimated sample size of 128 participants is predicted based on a calculation with a given effect size (d) of 0.5, type 1 error probability (α) of 0.05 and a power of 0.8 (minimally acceptable). Based on this recruitment strategy and a rate of 1 participant every 2 weeks it would take 256 weeks or almost 5 years to recruit enough people. With a 6% recruitment rate, more than 2000 families/potential participants would need to be contacted.

4.1.2 Data collection procedure

All data collection took place at the Health Research and Rehabilitation Institute at AUT. This was well received by all participants and had ease of access with disability carparks, families were also familiar with the location due to the gait analysis clinic for CP children being located in the same area. All consent and child assent forms were well received and reported to the researcher to be understood by the parent and child. Participants were advised that sessions would take approximately two hours for the pre and post combined. This was fairly accurate with sessions taking between 90 minutes and two hours.

In general the data collection procedure was tolerated well. Due to the nature of the measurement protocol using electrical stimulation, participants were advised at the beginning of the session that if they did not want to continue they could ask us to stop at any time. One participant reported feeling bored, had difficulty concentrating and sitting in the chair for the required amount of time, and the parent had to give her a smartphone to play a game to distract her. This participant did not want to do the final part of the pre session recording, which was the V wave recording, so this was also omitted from the post session data collection. This was the only indication of poor tolerance and compliance of the recording protocol. The other two participants had no issues, accepted the protocol fully and without complaints.

4.1.3 Equipment

There were some issues with the custom-made force transducer. The one that was initially planned to be used was in use in another study at the time of the first data collection session and could not be moved. So an older version that used the same measurement was used for the first participant instead. The participant reported this being uncomfortable, this was the same participant that had difficulty accepting the full H, M and V wave protocol. There is a possibility that this was partly due to the discomfort from the force transducer. The second and third participants used the new version, the one originally planned for use in this study. There were no reports of discomfort or problems associated with this.
All other equipment worked well and had no issues.

4.1.4 Intervention

The chiropractic SM intervention and the passive control intervention were tolerated well by all participants. No issues were reported by the chiropractor or the participants and all movements were tolerated well. There were no adverse events reported, serious or minor, due to the intervention or passive control. All participants had previously received Chiropractic care, all more than one year prior to this study, so this may have alleviated any potential for concerns.

4.2 H reflex, V wave and force

Due to the small sample size of 3 participants and the group variation, statistical analysis was not performed on the data obtained for the H reflex, V wave and force. Therefore no conclusions will be made on the efficacy of the intervention versus the passive control. However the following section will present the results as is and trends identified, with the aim of determining if changes can be detected using this protocol and intervention in children with CP in future research studies.

4.2.1 H reflex

Results from the H reflex recording show that both participants in the intervention group had a shift in the H reflex threshold towards the left, or a lowered threshold, post intervention. This is in contrast to the control participant, which had a shift in the H reflex threshold towards the right, or a higher threshold, post passive control intervention. Results of the s50 parameter show that participants in the intervention group both had an increase in s50 suggesting a trend towards a greater number of motor neurons being recruited post chiropractic SM intervention at 50% stimulus compared to pre intervention. The control participant had a decrease in s50. Changes in slope show similar trends with a slope gradient increase post chiropractic SM intervention, suggesting an ability to recruit motor neurons faster. This is in contrast to the passive control intervention, which had a decreased slope gradient. The numerical data of these results is presented in Table 2.

Table 2- H reflex results- threshold, s50 and slope

Subject No.	Control/ Intervention	H reflex threshold Pre	H reflex threshold Post	% change	S50 Pre	S50 post	Slope pre	Slope Post
1	Intervention	7	6.574	-6%	12.87	13.29	0.43	0.63
2	Control	5	5.342	6.8%	10.04	9.701	0.81	0.62
3	Intervention	4	2.017	-49.6%	6.97	7.95	0.44	0.57

4.2.2 V-Wave

As mentioned above the first participant did not wish to continue with the protocol at that time so V wave was only recorded in 2 participants, one control and

one intervention. The participant that received passive control intervention showed a mean reduction in the V-wave amplitude post intervention of 0.39%, so no real change. The participant that received the chiropractic SM intervention showed a mean reduction in the V-wave amplitude post intervention of 62.6%. These results are presented in Table 3.

Table 3- V wave results

Subject number	**Control/ Intervention**	**V/M wave Pre Mean (SD)**	**V/M wave Post (Mean) (SD)**	**% change**
2	Control	0.363 (0.057)	0.361 (0.121)	-0.39
3	Intervention	0.555 (0.066)	0.207 (0.375)	- 62.7%

4.2.3 Force

Changes in MVC force were variable both between participants.

The passive control participant had a 19.5% reduction in MVC force post intervention. In the chiropractic SM intervention group, one participant had a 14.3% increase in MVC force, the other participant had a 48.9% decrease in MVC force. These results are presented in Table 4.

Table 4- MVC Force results

Subject no.	**Control/ Intervention**	**Force (Fraction change from baseline) Pre**	**Force (Fraction change from baseline) Post**	**% Change (pre-post)**
1	Intervention	0.656	0.750	14.3
2	Control	0.690	0.555	-19.5
3	Intervention	0.727	0.371	- 48.9

Chapter 5- Discussion

5.1 Key findings

The aim of this study was to answer specific feasibility questions in order to determine whether a full scale RCT using the same design would be appropriate. Feasibility was assessed in the following areas- recruitment rate and method, equipment, tolerance and compliance of the intervention and data collection protocol and to see whether it's possible to obtain changes in outcome measures. This feasibility study suggests that a full scale RCT assessing the effects of chiropractic SM on motor neuron excitability and muscle strength in children with CP using the same recruitment methods would not be feasible due to a low recruitment rate that would make recruiting in a timely manner for a larger scale RCT difficult. However results of other aspects of the study indicate positive feasibility and thus with alterations to the recruitment methodology a full scale RCT could be conducted. The recommended amendments will be discussed further below.

5.2 Is the recruitment strategy sufficient for recruiting enough participants in a timely manner for a large scale RCT based on the recruitment rate?

All recruitment for this study was conducted through the NZCPR. The NZCPR is a new organization that was still in its setting up stage of operation when this study was conducted, this was not known by the researcher until well into the recruitment set up. Consequently all recruitment procedures were new and the registry had limited numbers of families that were registered and approved. Contact was done by mailing out study flyer and information sheets to all eligible and registered families and then parents/caregivers were required to contact the researcher to be involved. This is an example of convenience or availability sampling and has potential issues (Acharya, Prakash, Saxena, & Nigam, 2013). Firstly any results only represent the small sample population and secondly it possible that there are a large number of children with CP in the Auckland region that were not

yet on the registry and so were not made aware of the study, both of these factors introduce sampling bias (Acharya et al., 2013). To alleviate this potential bias, and to increase recruitment numbers, other sources of potential participants could be used such as recruiting through CP associations or schools that have specialty programme's for CP or high numbers of students with CP. These are potential methods for future studies.

The response rate of only 10% for this study is low. A response rate of 70% and above is suggested to be necessary to represent the target sample population adequately (Patel, Doku, & Tennakoon, 2003). The low response rate may be an indicator of a poor contact method and the use of a multi-tiered contact strategy, with follow up contact via email or phone, may have been beneficial in this circumstance and is thought to be effective in increasing the response rate (Patel et al., 2003). In fact one of the parents of a participant specifically said that they had received the letter but got busy and then forgot about it until they found the letter again by chance a few weeks later. This highlights that mail letters are easily misplaced or ignored and may not be the best contact strategy in this highly digital age. Unfortunately the policies in place with the NZCPR at the time meant that email or phone contact for research purposes was not allowed. These issues should be reviewed for recruitment efforts of future CP research studies.

The low response and recruitment rate and eventual sample size may also be due to having chiropractic SM as the intervention. Although rare, chiropractic SM has a possibility of adverse effects and there has been recent negative media attention, in Australia in particular, about chiropractic SM for children (Todd, Carroll, Robinson, & Mitchell, 2015). This poses a possible deterrent for people, particularly if they have little prior experience or knowledge of chiropractic. This is further supported by the observation that all study participants had been under chiropractic SM before and had positive experiences of it, indicating that perhaps this encouraged them to participate. If this is indeed the case then this would reduce the number of potential participants.

There is also a potential that the age range was too small and could have affected the recruitment rate. All participants were aged 12, the higher limit of the

range was 13, perhaps having a higher limit may improve recruitment. One parent contacted the researcher about participating but their child was only turning 8 in December, 2 months after completion, so perhaps also having a lower limit may have been beneficial. Previous studies assessing H reflex in children with CP have used age ranges of 5-15 years, 5-12 years and 4-6 years (respectively Hodapp et al., 2009; Frascerelli et al., 2011; Soriano et al., 1995). However as only children aged 12 were assessed for tolerance and compliance of the data collection protocol and intervention, decreasing the age limit is not recommended, as it is not tested in the younger age group. A possible amended age range could be 8-14 years.

A GMFCS of I-II was set as an inclusion criterion and participants were only contacted for participation that met this criterion on the NZCPR. This was chosen because GMFCS levels III-V have significantly more mobility impairments and it was thought, as others have suggested, that this would introduce too much variability into the sample set (Palisano, Rosenbaum, Bartlett, & Livingston, 2007). However it was noted by the NZCPR that there was a low number of children meeting this criteria in the lower socioeconomic regions of Auckland, these children had predominately GMFCS levels of III-IV, and consequently this may affect adequate population representation and recruitment rate.

Based on calculations (see section 4.1) a sample size of 128 participants (64 in each group) is estimated for the large scale study. Based on the recruitment rate found in this feasibility study, this would mean needing to contact more than 2000 families. Exact epidemiological data for the number of children with CP living in Auckland is not available, however estimates can be made based on population statistics and CP birth rates. In the greater Auckland region (including Counties Manukau and Waitemata) there is an estimated 440,000 people living under the age of 19 years with diagnosed CP (Ministry of Health NZ, 2016). Based on the birth rates for CP being 2.5 in 1000 live births, this gives an estimated 1100 people living with CP in the greater Auckland region under the age of 19 years. As this does not take into account the age range, GMFCS and other inclusion/exclusion criteria for this study, it may not be possible to contact enough families based on this recruitment strategy.

5.3Can we measure changes in the H reflex and MVC peak force following chiropractic spinal manipulation in children with CP?

As mentioned previously, the results of this study are not intended to be used to make any claims on intervention effects. It is noted, however, that both participants in the intervention group demonstrated changes in the H reflex recordings consistent with that observed in previous studies assessing the effects of chiropractic SM on motor neuron excitability (Niazi et al., 2015; Holt et al., 2017; Christiansen et al., 2017). Interestingly, the results of the V wave are not consistent with previous literature that have found an increase in V wave and force post chiropractic SM (Niazi et al., 2015; Holt et al., 2017; Christiansen et al., 2017). The V-wave represents the volitional drive that is the amount of voluntary drive during a muscle contraction (Aagaard et al., 2002). The V-wave amplitude depends upon the density of action potentials sent down from the supraspinal centers that block of the antidromic action potentials caused by the supramaximal stimulation of the tibial nerve. Thus if maximal effort is not made during the data collection of V-waves their amplitude will be smaller and the maximum force will be smaller. Therefore, in light of the changes in the H-reflex that are consistent with increased corticospinal excitability after the chiropractic SM intervention, and considering that the H-reflex recording protocol did not require any voluntary effort on the child's behalf, the V wave and strength results of the one child post chiropractic SM showing the 62% decrease in the V-wave and 48.9% decrease in MVC force, is likely due to the child simply not trying to maximally contract their muscle after the chiropractic SM intervention. The V wave measure and the maximum force output obviously relies on the child actually trying to contract their muscle as much as they can, and with an almost 50% decrease in force produced after the chiropractic SM intervention it's unlikely this child made a maximum effort, especially considering their H-reflex results indicates an increased corticospinal excitability with a lower H-reflex threshold, increased s50 and increased H-reflex slope. That this particular child most likely did not make an effort during V wave and strength data collection post chiropractic SM is also further supported by the fact that one of the other participants would not even do the V wave part of the protocol. This suggests that if further studies were to be conducted on this

population group the V-wave part of the protocol may need to be omitted, or performed earlier in the post-intervention data recording session.

A lower H-reflex threshold, as has been seen previously post chiropractic SM (Niazi et al., 2015) would suggest that spinal manipulation has lowered the recruitment threshold of motoneurons to Ia afferent input. In other words that the low-threshold motoneurons have become more excitable, or the synapses of the Ia primary afferents became more efficient, since a lower stimulus intensity can now recruit the same motoneuron compared to baseline recordings. The increase in the s50 parameter would suggest a greater number of motor neurons being recruited post chiropractic SM intervention at 50% stimulus compared to pre intervention (Tucker et al., 2005). A steeper H-reflex slope post chiropractic SM suggests that motor neurons could be recruited at a faster rate (Tucker et al., 2005). Thus these three measures that did not require the children's voluntary participation, or maximum effort, would all suggest that the chiropractic SM intervention has resulted in increased corticospinal excitability. These findings could have important implications as it is thought that those with CP have problems with activating available motor units and increasing motor unit firing rates (Rose & McGill, 2005). Again it is important to note that this study was not designed to test efficacy, nor did we have enough subjects to make any such claims. Larger scale studies would need to be conducted to investigate this further.

5.4 Can children with CP tolerate and be compliant with the data collection protocol and length?

The feasibility of the data collection protocol is questionable. Acceptability of the protocol was not measured formally, for example with a post-study questionnaire, but instead tolerance and compliance was assessed as an informal discussion with the participants and parents/caregivers and through observations of the researchers. Consequently, tolerance and compliance of the protocol needs to be viewed with potential for bias from the researchers in mind and results interpreted with caution. Of note, there was one participant that was unable to complete the full protocol and did not want to do the V-wave part, which is at the end of each data recording session. This child claimed to be tired and told us she did

not want to stay sitting and strapped into the force transducer any longer. This participant had apparent attention deficits and needed to play games on the phone to keep her distracted. There was no exclusion criteria set for co-morbid conditions such as attention-deficit-hyperactivity disorder or autism spectrum disorders, this could potentially be added in future studies although this would further reduce the potential sample population. Environmental distractors and changes during H reflex recordings are thought to have an impact on H reflex results so these need to be minimized in future studies (Brinkworth et al., 2007).

5.5 Is the chiropractic spinal manipulation intervention tolerated and appropriate for children with CP?

There were no adverse events as a result of the intervention reported by the participants or families. The chiropractor informed the researcher that all intervention procedures were tolerated well. Again this was not formally assessed and poses a potential for bias from the chiropractor.

This study was conducted using a single-blind approach, where the researchers were blinded to group allocation during data collection and data analysis. The chiropractor could not be blinded, as they had to provide the intervention. Participants were also not told which group they were in and the control involved the same physical examination, interaction, movement, time and set up as the SM intervention (but no thrust). This helps to reduce some of the bias that can occur from doctor-patient interaction, proprioceptive input from cutaneous receptors, vestibular input and mechanoreceptors and time between pre and post data collection sessions, which are arguable issues with manual therapy studies (Vernon et al., 2012; Niazi et al., 2015). However it must be noted that in this study, all three participants had chiropractic SM before and so participants may have been able to guess which group they were in. This was not a variable that was assessed in this study.

No study has assessed changes in muscle strength and motor neuron excitability in children with CP following chiropractic SM so the role of prior chiropractic care in this is poorly understood. It is possible that previous

chiropractic care could have altered the baseline recordings but as none of the participants were new to chiropractic care this is difficult to assess. However for all the participants it had been a minimum of one year since they last had chiropractic SM so it is unlikely any effects significantly altered baseline measurements.

5.6 Is the equipment used for data collection tolerated by children with CP and does it provide accurate measurements?

Issues with the force transducer changes and the reported discomfort with the older model, highlight the need for the explicit use of the new force transducer for use in further studies. As this study was not measuring efficacy of the intervention and no claims are being made based on this, changing the force transducer between subjects is not an issue in this study. However this must be avoided if any future large scale RCT's are to be conducted, as this would affect results interpretation.

5.7 Study limitations and recommendations for future research

This study was designed to answer specific feasibility questions, which it has done so adequately. The small sample size (n=3), change of equipment between participants, sampling bias and uneven sample characteristics are factors that limit any further interpretation of results, efficacy of intervention and generalizability.

There was also no formal assessment of tolerance of the data collection protocol or the intervention, such as a post-study questionnaire assessing acceptability. This is a limitation in this feasibility study as it introduces bias from the researchers in their observations and questioning of the participants and from the chiropractor in assessing tolerance of the intervention. The researcher was also the one that took consent and asked if the participant and caregiver understood the consent and assent forms. This could have influenced the responses and introduced bias.

Another limitation in this study is that all participants had received chiropractic SM before, this means that there is a chance that they were able to guess which intervention they received and conclusions can not be made about

the tolerance of the chiropractic SM intervention in those that have not had SM before.

This study has given some valuable insight and knowledge of issues pertaining to conducting research in a population group of children with CP and a chiropractic intervention. Learning's from this study can help to guide future research, not only using these specific outcome measures, but on recruitment ability for any study involving CP children. What is evident is that there is a strong basis for further assessing what affects chiropractic SM may have on children with CP. Future trials may consider including more 'low-effort' functional outcomes, such as gait, quality of life and ability to perform activities of daily living.

Recommendations for any future research are as follows:

- Recruit from more sources, such as CP associations or schools
- Use a multi-tiered recruitment strategy with follow up phone calls and emails
- Change inclusion criteria by extending the age range to 8-14 years
- Use only the new model force transducer for data collection
- Omit V wave recordings or conduct them earlier in the protocol
- Conduct a formal assessment of tolerance and appropriateness of the chiropractic spinal manipulation as perceived by the children and their caregiver.

5.8 Conclusions

In conclusion, results of this study provide valuable knowledge on the feasibility of a protocol to measure changes in the H reflex, V wave and MVC force in children with CP following a chiropractic SM intervention. It is the first study of it's kind and thus addresses gaps in the current literature of the feasibility of assessing changes in muscle strength and motor neuron excitability in children with CP following chiropractic SM. Much has been learnt about adequate recruitment methods, changes that need to be made to the protocol and the tolerance of chiropractic SM as an intervention. The idea to undertake research in this population group was firstly to investigate further a treatment modality,

chiropractic, which was noninvasive and has a growing body of evidence to suggest improvements in neurological function, and whether this would allow children with CP to have improved quality of life and function.

This feasibility study has shown that modifications to the recruitment method would have to be done in order to run a full scale RCT in this population in the future. Such a full scale RCT does appear to be feasible should the recommendations of this thesis be adhered to, such as modifications in recruitment methods, widening the age range, using only the best equipment and recording the V waves earlier in the collection protocol.

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Appendices

Appendix A- HDEC full application approval

Health and Disability Ethics Committees

Health and Disability Ethics Committees
Ministry of Health
133 Molesworth Street
PO Box 5013
Wellington
6011

0800 4 ETHICS
hdecs@moh.govt.nz

16 November 2016

Mrs Jenna Salmons
659 Mt Wellington highway
Mt Wellington 1062

Dear Mrs Salmons

Re:	**Ethics ref:**	**16/NTA/158**
	Study title:	A feasibility assessment of a study protocol measuring the H reflex and muscle strength in children with spastic diplegic cerebral palsy following Chiropractic spinal manipulation.

I am pleased to advise that this application has been *approved* by the Northern A Health and Disability Ethics Committee. This decision was made through the HDEC-Full Review pathway.

Conditions of HDEC approval

HDEC approval for this study is subject to the following conditions being met prior to the commencement of the study in New Zealand. It is your responsibility, and that of the study's sponsor, to ensure that these conditions are met. No further review by the Northern A Health and Disability Ethics Committee is required.

Standard conditions:

1. Before the study commences at *any* locality in New Zealand, all relevant regulatory approvals must be obtained.

2. Before the study commences at *any* locality in New Zealand, it must be registered in a clinical trials registry. This should be a WHO-approved (such as the Australia New Zealand Clinical Trials Registry, www.anzctr.org.au). However https://clinicaltrials.gov/ is acceptable provided registration occurs prior to the study commencing at *any* locality in New Zealand.

3. Before the study commences at *a given* locality in New Zealand, it must be authorised by that locality in Online Forms. Locality authorisation confirms that the locality is suitable for the safe and effective conduct of the study, and that local research governance issues have been addressed.

Appendix B- Parent Participant and information sheet and consent form

Parent Participation Information Sheet

The feasibility of assessing changes in muscle strength in children with Cerebral Palsy following Chiropractic care.

INVITATION

We are a team of researchers from the Health and Rehabilitation Institute at AUT University and the Centre for Chiropractic Research at the New Zealand College of Chiropractic.

We would like to invite you and your child to take part in a study on the effects of Chiropractic care on muscle strength in children with Cerebral Palsy. This research study is being conducted as part of a Masters in Health Science degree at AUT University.

Whether or not your child takes part is your choice and also theirs, this participant information sheet will help you decide. If you don't want them to take part, you don't have to give a reason, and it won't affect the care they receive. If you do want to take part now, but change your mind later, you can stop your child's participation at any time.

We will go through the information in this sheet with you and answer any questions you, or your child, may have.

If you agree for your child to take part in this study, you will be asked to sign the Consent Form on the last page of this document. You will be given a copy of both the Participant Information Sheet and the Consent Form to keep.

WHAT IS THE PURPOSE OF THE STUDY?

People with Cerebral Palsy often have decreased muscle strength and difficulty controlling their muscles, which leads to changes in how they are able to move their body. This study will investigate the effects of chiropractic care on the way

the brain and nervous system control the muscles in the lower leg and if there is a change in the strength of these muscles in children who have Cerebral Palsy.

WHAT WILL MY CHILDS PARTICIPATION IN THE STUDY INVOLVE?

Children aged 8-13 years who have been diagnosed with Cerebral palsy in the Auckland Region of New Zealand are being invited to participate in this study. If your child participates in this study they will be assessed in the Health Research and Rehabilitation Institute's lab at the North Shore campus of AUT. Only one session is required which will take approximately two hours. During these sessions we will test a reflex in your child's leg as well as the strength in your child's leg.

Your child will be asked to sit down on a special machine that is used to measure how strong different muscles are.

- Muscle strength testing

We will then ask them to lie down on their front on a table. Then we will put an electrode and some tape on their leg and connect some wires to them, we will then give some electrical impulses to their leg so we can measure how your brain is controlling the muscles in their leg. This may feel a bit strange because it makes some of the leg muscles twitch and may be a bit uncomfortable but should not hurt.

Children will be randomly placed into either a treatment or movement control group when they see the research assistant, there is a 50:50 chance of being in either group. Your child will then either receive Chiropractic care by a registered Chiropractor (treatment group), or your child will be set up as if they were going to receive care but the chiropractor won't give care to their spine (movement

control group). Chiropractic care involves the use of adjustments which are gentle, fast pushes on parts of the spine that are not moving properly to help the spine move better.

We will record health information from your child and conduct an assessment to make sure it's safe to adjust your child's spine and we will record what chiropractic care your child received during the study.

Should your child become distressed during any tests, and asks not to continue, the research assistant will immediately stop the test. You, as the child's parent or caregiver, are welcome to remain with your child throughout the entirety of the research session.

WHAT ARE THE POSSIBLE BENEFITS AND RISKS OF THIS STUDY?

Possible Benefits: This project will help us to understand what, if any, effects there are on brain function in children with cerebral palsy as a result of a chiropractic adjustment session. This may have future implication for further research and improvements in the level of functionality for children with Cerebral Palsy.

Possible Risks: Chiropractic care may involve a variety of manual therapy procedures including manipulation or mobilization that have a small risk of causing physical harm. Although side effects of any kind associated with chiropractic care are rare, when they do happen they usually involve short lasting mild muscle soreness that does not require any additional treatment and which goes away by itself. The risks of having a side effect after a chiropractic treatment are deemed to be very low-to-low according to the research literature. A review of the research on side effects in children associated with Chiropractic treatment reported only 4 serious side effects, which were in children with a pre-existing condition (not cerebral palsy), across a 59-year period and billions of treatments.

WHO PAYS FOR THE STUDY?

This study is funded by the Auckland University of Technology's Health and Environmental Sciences faculty and by grants and donations to the Centre for Chiropractic Research and the New Zealand College of Chiropractic (NZCC).

There is no cost to the participant to be involved in this study. Travel costs will be reimbursed with a $20 petrol voucher.

WHAT IF SOMETHING GOES WRONG?

If your child were injured in this study, which is unlikely, you may be eligible for compensation from ACC just as you would be if you were injured in an accident at work, school or at home. You will have to lodge a claim with ACC, which may take some time to assess. If your claim is accepted, you will receive funding to assist in your child's recovery.

If you have private health or life insurance, you may wish to check with your insurer that taking part in this study won't affect your cover.

WHAT ARE MY RIGHTS?

Participation is Voluntary: Being in this study is voluntary and you and your child are under no obligation to agree to take part. If you let us know that you do not wish to take part in the study, we will make sure that the study team does not contact you again.

What if I change my mind: If you decide that your child may participate and later change your mind, you are free to withdraw your child from the project at any stage.

Results of the Project: Group findings of this project will be communicated to the research teams at AUT University and the New Zealand College of Chiropractic. Presentations of the group findings may also be done to interested parties. Neither you nor your child will be identified and no personal information will be revealed in any presentation or publication of the findings.

Privacy, Confidentiality and Disclosure of Information: If you choose to participate in this study, information may be shared with other researchers

involved in the study research program, to better understand the impact of the chiropractic adjustments and brain function.

All health information and consent forms will be stored in a locked filing cabinet and electronic data will be in a password protected file, accessible only by the researchers, for a period of ten years after the child has turned 16 years of age. Test results and consent forms will be shredded prior to their disposal. Data may be used for future research purposes; however all data will be anonymous.

WHO DO I CONTACT FOR MORE INFORMATION OR IF I HAVE CONCERNS?

If you have any questions, concerns or complaints about the study at any stage, you can contact:

Name: Jenna Salmons
Position: (Chief Investigator)
Telephone number: 0274853662
Email: jenna.salmons@nzchiro.co.nz

Name: Dr. Denise Taylor
Position: Co-Investigator
Telephone number: 09 921 9680
Email: denise.taylor@aut.ac.nz

Name: Dr. Heidi Haavik
Position: Co-Investigator
Telephone number: 09 5266789
Email: Heidi.haavik@nzchiro.co.nz

If you want to talk to someone who isn't involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050
Fax: 0800 2 SUPPORT (0800 2787 7678)
Email: advocacy@hdc.org.nz

You can also contact the health and disability ethics committee (HDEC) that approved this study on:

Phone: 0800 4 ETHICS
Email: hdecs@moh.govt.nz

If you require Māori cultural support talk to your whānau in the first instance. Alternatively, you may contact the administrator for He Kamaka Waiora (Māori Health Team) by telephoning 09 486 8324 ext 2324.

If you have any questions or complaints about the study you may contact the Auckland and Waitematā District Health Boards Maori Research Committee or Maori Research Advisor by phoning 09 4868920 ext 3204.

Adult Participant Consent Form

Please tick to indicate you consent to the following *(Add or delete as appropriate)*

I have read, or have had read to me in my first language, and I understand the Participant Information Sheet.	☐
I have been given sufficient time to consider whether or not to participate in this study.	☐
I have had the opportunity to use a legal representative, whanau/ family support or a friend to help me ask questions and understand the study.	☐
I am satisfied with the answers I have been given regarding the study and I have a copy of this consent form and information sheet.	☐
I understand that taking part in this study is voluntary (my choice) and that I may withdraw my child from the study at any time without this affecting their care.	☐
I confirm that to the best of my knowledge, my child does not have any physical reason why they should not be receiving chiropractic care.	☐
If I decide to withdraw my child from the study, I agree that the information collected about my child up to the point when they withdraw may continue to be processed.	☐
I understand that my child's participation in this study is confidential and that no material, which could identify me or my child personally, will be used in any reports on this study.	☐
I understand the ACC compensation provisions in case of injury during the study.	☐
I know whom to contact if I have any questions about the study in general.	☐
I understand my responsibilities as parent or carer, of a study participant.	☐
I wish to receive a summary of the results from the study.	☐

Declaration by participant's parent or adult who takes care of them:
I hereby consent for my child to take part in this study.

Parent or adult who cares for participant name:

Signature: Date:

Childs name:

Declaration by member of research team:

I have given a verbal explanation of the research project to the participant, and have answered the participant's questions about it.

I believe that the participant understands the study and has given informed consent to participate.

Researcher's name:

Researcher's Signature: Date:

Appendix C- Child participant information sheet and assent form

Participant Information Sheet

Chiropractic care and changes in muscle strength in children with muscle weakness

INVITATION

We are researchers from AUT University and the New Zealand College of Chiropractic. We would like you and other children your age to be part of a study where we measure a reflex in your leg and the strength of one of your legs before and after Chiropractic care.

We are asking you to be part of this study because you are aged between 8-13 years and you have a weakness in some of your muscles.
Your mum or dad, or whoever takes care of you, has said that it is ok for you to do the test to measure the strength of your leg. However, we also want to make sure that you are happy to do the test.

This information sheet was written for you to tell you about why we are here. Please read this information sheet carefully. You can ask any questions you like about the research to the researcher who has given you this sheet.

WHAT IS THE PURPOSE OF THE STUDY?

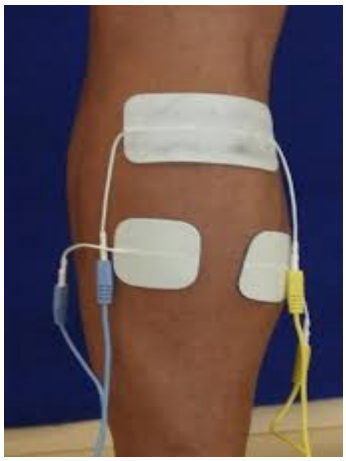
The reason we are doing this study is so we can measure if chiropractic care can change the strength of the muscles in your leg and how your brain controls your leg.

WHAT WILL MY PARTICIPATION IN THE STUDY INVOLVE?

You will be asked to sit down on a special machine that is used to measure how strong different muscles are. We will get you to push down with your foot as hard as you can, we will get you to do this three times.

- Muscle strength testing

We will then get you to lie down on your tummy on a table. Then we will put an electrode and some tape on your leg and connect some wires to them, we will then give some electrical impulses to your leg so we can measure how your brain is controlling the muscles in your leg. This may feel a bit strange because it makes some of your leg muscles twitch and may be a bit uncomfortable but should not hurt.

Reflex testing in the leg - 

After we have done these tests you will either get put into the treatment group or the movement control group. A computer chooses which group you go into, there is a 50:50 chance of getting put into either group.

If you are in the treatment group a Chiropractor will check your neck, back and hips for any areas that are not moving well or feel sore or have tight muscles around them. The Chiropractor will then use his or her hands to gently push on the part of your back, neck and hips that need it to help it work better. If feels like they squash you a bit but this will not hurt.

If you are in the movement control group the Chiropractor will gently move your neck, back and hips into different positions but they will not push or squash you as much.

After this you will have the muscle strength and reflex tests one more time to see if they change.

All together this will take about 2 hours. You will be in the same room as a researcher and your mum or dad or an adult who looks after you. Your mum or dad or adult who looks after you will be here the whole time.

WHAT ARE MY RIGHTS?

We will not tell anyone apart from other researchers involved in the study about your results to the test.

No information about you, like your name or the name of your school, will be reported to anyone.

WHAT HAPPENS AFTER THE STUDY OR IF I CHANGE MY MIND?

It is up to you if you want to do the test or not. We will not get upset and you will not be in trouble if you do not want to do any of the tests, or if you change your mind and do not want to finish the test, even if you're part way through it.

Child Assent Form

If you need some help understanding this form and what it means, please ask the research assistant to help you. This form explains about the game and asks for your permission to take part.

Please tick to indicate you consent to the following *(Add or delete as appropriate)*

I have read, or have had read to me what the research is about, and I understand it.	Yes ☐	No ☐

Declaration by child participant:
I give my permission to take part in this study.

Child Participant's name: _____

Signature or name here: _____ Date: _____

Declaration by member of research team:

I have given a verbal explanation of the research project to the participant, and have answered the participant's questions about it.

I believe that the participant understands the study and has given informed consent to participate.

Research Assistants name: _____

Signature: _____ Date: _____

Appendix D- Study flyer

AUT UNIVERSITY

TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

NEW ZEALAND COLLEGE OF CHIROPRACTIC

graduating hands, hearts & minds

Child volunteers needed for a Chiropractic research study

Does Chiropractic care improve muscle strength in children with Cerebral Palsy?

We are a team of researchers from AUT University and the New Zealand College of Chiropractic. We are conducting a study investigating the effects of Chiropractic care on muscle strength in children with Cerebral Palsy. It involves a one off session only.

To be eligible your child must:

- Have Cerebral Palsy with a Gross Motor Functional Classification Level 1 or 2
- Be 8-13 years old
- Have had no surgery, inhibiting casts or Botox treatment in the last 6 months

For more information or to participate
Email or phone Jenna:
jenna.salmons@nzchiro.co.nz
0274853662

Appendix E- Study protocol

The study will be conducted at the Auckland University of Technology's (AUT) Health and Rehabilitation Research Institute (HRRI) on the Akoranga Campus, North Shore, Auckland.

- Participants and caregiver arrive at HRRI and meet with CI in study room
- Any further questions answered
- Informed consent and assent obtained
- Procedures explained in full

Equipment

Two computers

Two CED boards

BNC cables

Electrical stimulator

Force transducer

Amplifier

Razors

Alcohol wipes

Nuprep

Sandpaper

T splitter

Straps

Electrodes

E-Stim pads

Equipment set up

Turn on computers

Turn on CED boards (always do first before connecting patient)

Amplifier set to 1000 gain

Open Spike & Signal programmes

Plug in BNC cable using a T-splitter into Port 1 on first CED board (EMG)

Plug in BNC cable from E-Stim to DAC output 0

USB connected from CED (back) to computer

Rainbow cord from black box to back of CED board

E-Stim plugged into black box
Set force transducer amplifier (orange box) gain to 200

Turn on E-Stim
Reset by flicking the top right switch to off until red light turns off
Set mA to x10 and start at 0.05

Plug in BNC cable from port 1 on first CED board to Port 1 on second CED board
Plug in BNC cable from force transducer to Port 0 on second CED board

Patient set up

- With the patient standing ask them to go on their tiptoes to locate the belly of the soleus, mark this area.
- Prepare the skin over the belly of the soleus about 5 cm below the gastrocnemii–Achilles tendon junction by shaving the area to remove the hair, gently abrading the area with soft sandpaper, apply Nu prep, wipe off with gauze swab and clean with an alcohol wipe.
- Prepare skin 1cm above the patella as above
- Place a bipolar surface electromyography (SEMG) recording electrode (Duo-Trode® silver/silver chloride, with a 12.5mm active surface and 19mm inter electrode distance) on the prepared area on the soleus.
- Prepare a small area of skin over the medial malleoli of the ankle as above and place EMG electrode as a ground.
- Seat patient
- Attach electrode cables- black to popliteal fossa, red to patella, ground
- Connect cable from CED board to force transducer
- Secure popliteal fossa electrodes with ball and bandage
- Place affected leg into the force transducer.
- Secure with Velcro straps over foot and lower leg
- Turn on E-stim (double check output light is off)

Muscle strength

At baseline both groups will have the muscle strength of the plantar flexor muscle group (Gastrocnemius/Soleus) assessed using a custom made force transducer designed to measure ankle strength.

Recording

- Open Spike Guru programme and start
- Tell participant- Im going to count down from 3, when I say Go I want you to push down with your foot as hard as you can
- Count down 3,2,1- Go gogogogogogogo- relax
- Wait 2 mins
- Null offset
- Repeat above x2
- Save values in excel spread sheet
- Stop programme
- Click x-range, show all
- Click cursor, new horizontal
- Move horizontal to lowest force point of max
- Click ctrl 1 then 2
- Place cursors at beginning and end of force wave
- Click Cursor-cursor regions- peak to peak
- Get MVC average from Force box
- Click save
- Calculate 10% of that value, note this down
- Click new data document
- Click show/hide, remove EMG channel
- Add new horizontal
- Click set position, put in !0% value from above

M Max

Recording

- Open Signal
- Load configuartion- H reflex- CP kids
- Click on cycle
- Click 'more' to test

- Click Start
- Increase amps by 5
- Click more
- Keep increasing by 5 until threshold (plateau)
- Decrease until it drops, note level + 5= Mmax

H Reflex

- During the H- and M- recruitment curve recordings, the participant will be asked to plantar flex his or her right leg at around 10 % of their own MVC. They will be provided with visual feedback of the contraction level on a computer face.
- While the subject performs this low-level tonic contraction, the direct motor response (*M*-wave) and the H-reflex of the SOL muscle will be elicited via electrical stimulation of the tibial nerve. The stimulus intensity required to obtain the maximal M- wave will be determined by increasing the stimulus intensity in 5mA increments, and assessing with online feedback when the M-wave reaches its maximum size.
- To construct the M- and H-recruitment curves, the maximum intensity will then be divided into 12 segments that are equally separated. For each randomly chosen current intensity, a total of three stimuli will be delivered at varying time intervals between 2 and 3 s. The participant will be instructed to inform the outcome assessors if they are experiencing fatigue and the experiment will be paused.

Recording

- Open Signal
- Load configuration H reflex
- Run now
- Click cycle
- Get pt to look at screen and contract 10% MVC (look at line)
- Start
- 48 stims
- Finish
- Save

V wave

- Open Signal
- Load configuration V wave
- Run now
- Reset Spike
- Click show/hide- show EMG
- Add to% to mA
- Instruct pt to push with maximum effort
- Count down 3,2,1 then go,go,go,go,go,go,go,go
- Watch Spike- when 90% MVC press start (Wait until see 3 dots)
- Wait 2 mins
- Click Null offset
- Repeat 2 more times

Intervention/Control

- In a separate room the chiropractor tosses a coin for random group allocation. Heads- Intervention, Tails- Control
- Researchers unstrap participant from the force transducer
- Take them and their caregiver to another room to see the Chiropractor
- If in the intervention group the participant will then receive a full spinal analysis for areas of joint dysfunction and spinal manipulation will be carried out on the appropriate segments. All findings and adjustments will be recorded.
- If in the control group participant will receive a passive control that involves movements of their head, spine and body.. This will involve the subjects being moved into the adjustment setup positions where the chiropractor would normally apply a thrust to the spine to achieve the adjustments.

Notes on intervention session:

During each adjustment session full spine adjustments will be carried out as required. The entire spine and sacroiliac joints will be assessed for vertebral subluxations, and adjusted where deemed necessary, by a registered chiropractor. The vertebral subluxation indicators that will be used prior to and after each spinal adjustment intervention include assessing for tenderness to palpation of the

relevant joints, manually palpating for restricted intersegmental range of motion, assessing for palpable asymmetric intervertebral muscle tension, and any abnormal or blocked joint play and end-feel of the joints. All of these biomechanical characteristics are known clinical indicators of spinal dysfunction (Fryer, Morris, & Gibbons, 2004; Hestboek & Leboeuf-Yde, 2000). These findings will be documented prior to and after each spinal adjustment intervention. The improvements in segmental function following spinal adjustments will also be recorded for each subject.

Subluxation indicators

The most reliable cervical spine subluxation-indicator is tenderness with palpation of the dysfunctional joint (Hubka & Phelan, 1994; Jull, Bogduk, & Marsland, 1988). Cervical joint restriction has also been shown to have good interexaminer reliability (R. Cooperstein, Young, & Haneline, 2013). Therefore, for the purpose of this study cervical vertebral subluxations will be defined as the presence of both restricted intersegmental range of motion and tenderness to palpation of the joint in at least one cervical spine segment. For the thoracic spine good interexaminer reliability has also been shown for motion palpation (Cooperstein, Haneline, & Young, 2010). For the lumbar spine, intersegmental range of motion has also been shown to have acceptable reliability, particularly for the lower lumbar segments (Strender, Sjoblom, Sundell, Ludwig, & Taube, 1997). Although it is recognized that clinical tests of sacroiliac joint function have questionable reliability (Herzog, Read, Conway, Shaw, & McEwen, 1989; Potter & Rothstein, 1985), these tests are still widely used clinically, and Flynn et al (Flynn et al., 2002) have adopted them as one of the criteria for a clinical prediction rule of whether a patient is likely to benefit from sacroiliac manipulation. For the purpose of this study lumbopelvic dysfunction has been defined as the presence of both restricted intersegmental range of motion and tenderness to palpation of at least one lumbopelvic spinal joint segment.

Spinal assessment

For the cervical spine functional assessment the chiropractor will gently move the subjects head passively from the neutral position to the maximal range of lateral flexion in the coronal plane, while palpating over each segment and applying

gentle pressure to both the left and the right sides. If this movement appears restricted, the examiner will apply additional gentle pressure to the joint, while watching for signs of discomfort from the subject. The examiner will also ask the subject if the pressure to the joint elicited discomfort or pain.

To assess the function of the lumbar segments, the examining chiropractor will palpate the movement of individual lumbar segments while the participant's spine is laterally flexed to the right and left. Where the movement feels restricted, the examiner will apply gentle pressure to the joint and surrounding soft tissues, while watching for signs of discomfort from the subject. The examiner will also ask the subject if the pressure to the joint elicited pain and/or tenderness.

To assess the function of the sacroiliac joints, subjects will be asked to walk up and down on the spot with their knees flexed to assess the movement of each ilium relative to the sacrum while the assessor holds their thumbs on the inferior margin of either the right or the left posterior iliac spines and the adjacent aspect of the sacrum. When the posterior superior iliac spine (PSIS) and the sacrum moves together, the joint will be considered to be restricted in this plane. Subjects will also be asked to bend sideways while the examiner's thumbs contact the right and left PSIS's. Subjects where the sacrum does not shift toward the contralateral side will be considered to be restricted in the lateral flexion plane. When apparent movement dysfunction is identified on one side, the clinician will then palpate over the sacroiliac joints and ask the participant if the palpation elicited tenderness over the joint. The clinician will also palpate the musculature adjacent to the sacroiliac joint on each side, assessing for palpable differences in muscle tension. All information will be recorded in an experimental log book.

Spinal Adjustments

All of the spinal adjustments to be carried out in this study will be high-velocity, low- amplitude thrusts to the spine. This is a standard adjustment technique used by manipulative physicians, physiotherapists, and chiropractors. The mechanical properties of this type of CNS perturbation have been investigated; and although the actual force applied to the subject's spine depends on the therapist, the patient, and the spinal location of the adjustment, the general shape of the force-time history of spinal adjustments is very consistent (Hessell, Herzog, Conway, &

McEwen, 1990) and the duration of the thrust is always less than 200 milliseconds (for review see Herzog, 1996).The high-velocity type of adjustment was chosen specifically because previous research (Herzog, Conway, Zhang, Gail, & Guimaraes, 1995) has shown that reflex EMG activation observed after adjustments only occurred after high-velocity, low-amplitude adjustments (as compared with lower-velocity mobilizations). This adjustment technique has also been previously used in studies that have investigated neurophysiological effects of spinal adjustments (for review see Haavik & Murphy, 2012).

For cervical segments the thrust will be applied to the spine held in lateral flexion, with slight rotation and slight extension. Thoracic spine adjustments will be carried out either in the supine or prone position. For supine thoracic adjustments the flexed hand of the chiropractor will contact the relevant thoracic segments over the spinous processes, so that the spinous processes lie in the groove between the chiropractors flexed fingers and the thenar area of their thumb. The subjects arms will be flexed and folded over their chest. The thrust will be applied over the subjects arms which will be positioned over the chiropractors contact hand held under the subject (see Figure 7 below for this setup). For prone thoracic segment adjustments the chiropractor will contact either side of the subjects spinous process with both thenar areas of their thumbs. The thrust will be applied in a posterior to anterior and inferior to superior direction.

Figure 3: Supine thoracic adjustment setup

Lumbar or sacroiliac joint adjustments will be carried out with the subject positioned in the lateral decubitus position (see figure 8 below). The free superior leg will be flexed at the knee and the pelvis so as to flex the lumbar spine (Herzog, 1996). The pisiform bone of the clinician's inferior (in relation to the subjects head) hand will contact the relevant lumbar spinal segment over the spinous process, or the PSIS of the sacroiliac joint and an adjustive thrust will be applied in a posterior to anterior, and lateral to medial direction for the lumbar spine, or along the plane of the ilium with an inferior and lateral line of drive for the sacroiliac joint.

Figure 4: Lumbopelvic adjustment setup

Notes on Control session:

Participants in the control group will receive a passive control that involves movements of their head, spine and body that will be carried out by the same chiropractor who performs the adjustments in the experimental intervention session. This control intervention will involve the subjects being moved into the adjustment setup positions where the chiropractor would normally apply a thrust to the spine to achieve the adjustments. However, the Chiropractor will be particularly careful not to put pressure on any individual spinal segments. Loading a joint, as is done prior to spinal adjustments has been shown to alter paraspinal proprioceptive firing in anesthetised cats and will therefore be carefully avoided by ending the movement prior to end-range- of-motion when passively moving the subjects (Pickar & Wheeler, 2001). No spinal adjustments will be performed during any control intervention. This control intervention is not intended to act as a sham adjustment but to act as a physiological control for possible changes occurring due to the cutaneous, muscular or vestibular input that will occur with

the type of passive and active movements involved in preparing a subject/patient for an adjustment. It also acts as a control for the effects of the stimulation necessary to collect the dependent measures of the study, and acts as a control for the time required to carry out the adjustment intervention.

Participants will then return to the HRRI room and have the same MVC force and H reflex measures repeated.