The Effect of Atlanto-Occipital Manipulation on Neck and Shoulder Proprioception and Range of Motion: A Randomized Controlled Trial

by

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A thesis submitted to the
School of Graduate and Postdoctoral Studies in partial
fulfillment of the requirements for the degree of

Master of Health Sciences in Kinesiology

Faculty of Health Sciences
University of Ontario Institute of Technology (Ontario Tech University)
Oshawa, Ontario, Canada

December, 2021

THESIS EXAMINATION INFORMATION

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Masters of Health Sciences in **Kinesiology**

Thesis title:

The Effect of Atlanto-occipital Manipulation on Neck and Shoulder Proprioception and Range of Motion: A Randomized Control Trial

An oral defense of this thesis took place on December 15, 2021 in front of the following examining committee:

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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

Long-term neck pain is associated to maladaptive neuroplastic alterations in the brain, that affect head and neck proprioception. The One to Zero (OTZ) tension technique aims to correct dysfunction between the occiput (C0) and first cervical vertebrae (C1). Due to the physiological location of the adjustment, and deep sensorimotor connections of the cervical spine, the treatment could have positive effect on shoulder range of motion, along with head and neck proprioception. Participants with atlanto-occipital dysfunction were randomly arranged into a control group (n=33) or treatment group (n=32). The rotation and joint position sense of the head and neck were measured using a Cervical Range of Motion (CROM™) device at baseline and following treatment or control period (2 to 3 weeks). Statistical results showed that shoulder range of motion, neck rotation and head joint position sense significantly improved.

Keywords: Proprioception; Atlanto-occipital Dysfunction; Joint Position Sense

AUTHOR'S DECLARATION

I hereby declare that this thesis consists of original work of which I have authored. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Halima Hossinzehi

STATEMENT OF CONTRIBUTIONS

Data collection was done with the assistance of Ushani Ambalanavar, Tracey Patrick, and Brianna Grant. All spinal adjustments were conducted by Dr. Patricia McCord, a certified chiropractor at the Total Body Chiropractic Clinic. I conducted all data synthesis, statistical analyses and primary interpretation of results. Dr. Murphy provided feedback and made minor editorial adjustments to the manuscripts contained within.

I, Halima Hossinzehi, hereby certify that I am the sole author of this thesis. I have used standard referencing practices to acknowledge ideas, research techniques, or other materials that belong to others. Furthermore, I hereby certify that I am the sole source of the creative works and/or inventive knowledge described in this thesis.

ACKNOWLEDGEMENTS

There are many people who have helped contribute to completing this thesis, both directly and indirectly. I would first like to express my sincere gratitude towards my supervisors, Dr, Paul Yeilder, and Dr. Bernadette Murphy for their continuous support and guidance through my master's study and research. Dr. Murphy graciously gave me the opportunity to volunteer in her lab during my undergraduate degree, introducing me to the wonderful world of research. It has been quite the ride, and an absolute pleasure to have you both as mentors through my undergraduate, and master's degree.

To Dr. Patricia McCord, you are a remarkable chiropractor and I am so glad I got to work with you in a research study. You are filled with wisdom, and so much care towards humanity. I will always appreciate the experience I have gained at your clinic and the time I have spent with you.

To Ushani Ambalanavar, you have been especially caring through data collection and always there to advise me through any technicalities I was dealing with. I really appreciate that.

To my fellow research assistants, Tracey Patrick, and Brianna Grant, I could not have completed data collection without you guys. I am so thankful for all your support and assistance.

To my best friend Fahima Wakeely. We planned on going through this master's journey together and I am so glad we did. This has been a rollercoaster but you have been such an amazing person to go through this experience with.

To my sweet and loving husband, Ali Muhammad Farid, you have been my rock through this experience. Thank you for keeping me sane, and being my cheerleader. I love you.

To my lovely parents, Saaed, and Rafieh and my siblings Mahdi, Sarah, Mohammad, and Hanna, along with my brother in law, Mustafa, thank you for the constant support. I love you guys.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of variances
AS	Anterior Scalene
BA	Broadmann areas
CNS	Central Nervous System
CJPS	Cervical Joint Position Sense
JPS	Joint Position Sense
M1	Motor Cortex
OTZ	One to Zero
PNS	Peripheral Nervous System
SCNP	Subclinical Neck Pain
SCM	Sternocleidomastoid
S1	Somatosensory Cortex
SMI	Sensorimotor Integration
ROM	Range of Motion
UMN	Upper Motor Neurons

CHAPTER 1 INTRODUCTION

Neck pain is a global public healthcare concern and is becoming an increasingly common disability (D. Hoy et al., 2014; D. G. Hoy, Protani, De, & Buchbinder, 2010). The global burden of disease considers neck pain to be one of the top five highest rankings of conditions that cause disability (D. Hoy et al., 2014; D. G. Hoy et al., 2010). It is estimated that the number of people experiencing neck pain will significantly increase over the upcoming decades (D. Hoy et al., 2014). The prevalence of neck pain is higher in first-world countries compared to third-world countries, and higher in urban areas than rural areas (D. Hoy et al., 2014; D. G. Hoy et al., 2010). Neck disability is common for individuals that spend several hours in sedentary positions resulting with alterations in the way the brain communicates with the head, neck and shoulders (Deborah Falla, Bilenkij, & Jull, 2004; Helgadottir, Kristjansson, Mottram, Karduna, & Jonsson Jr, 2010; D. Hoy et al., 2014; Revel, Andre-Deshays, & Minguet, 1991; Revel, Minguet, Gergoy, Vaillant, & Manuel, 1994; Zabihhosseinian, Holmes, Howarth, Ferguson, & Murphy, 2017).

Incorrect neck posture for long periods of time causes a higher risk of developing neck fatigue and neck pain (D. Hoy et al., 2014; D. G. Hoy et al., 2010). Poor posture contributes to increased stress on the cervical spine, and muscle overload that can lead to neck pain (Deborah Falla & Farina, 2007; D. Falla, Jull, Russell, Vicenzino, & Hodges, 2007; Mahmoud, Hassan, Abdelmajeed, Moustafa, & Silva, 2019; Yip, Chiu, & Poon, 2008). This is known to cause impairments in joint positioning, posture, balance and direction awareness (proprioception) leading to inaccurate movement throughout daily tasks (Kandel, 2013; Joanna Joy Knox et al., 2006; Lee, Wang, Yao, & Wang, 2008; Paulus & Brumagne, 2008; Reddy, Tedla, Dixit, & Abohashrh, 2019; Treleaven, 2008; Zabihhosseinian et al., 2017). Proprioceptive information is processed through sensorimotor integration (SMI), which is known as the central communication ground of sensory input from the surrounding environment to produce an appropriate musculoskeletal movement (Kandel, 2013). The bulk of proprioceptive input is processed in the cerebellum (Bhanpuri, Okamura, & Bastian, 2013). The cerebellum is essential for processing timing, rhythm and synchronization for movement (Kandel, 2013). Neuroplasticity, also known as brain plasticity, is the brain's ability to adapt and change both neural structures and function in response to growth, and experience (Standring, 2020). Neck pain and fatigue lead to maladaptive neuroplasticity in areas related to sensorimotor integration which is likely the mechanism leading to proprioceptive impairment resulting in disrupted movement (Haavik-Taylor & Murphy, 2007; H. Haavik & Murphy, 2012; Paulus & Brumagne, 2008; Peng, Yang, Li, Liu, & Liu, 2021; Zabihhosseinian, Holmes, & Murphy, 2015).

The head and neck's main source of proprioceptive afferents is derived from sensory receptors known as muscle spindles located in the cervical musculature (Boyd-Clark, Briggs, & Galea, 2002; Goodwin, McCloskey, & Matthews, 1972; Lee et al., 2008; Peng et al., 2021; van der Wal, 2009). The proprioceptive sensory receptors within the muscle spindles and the external environment are used by the central nervous system (CNS) to provide an internal reference model for the musculoskeletal system (Prud'Homme & Kalaska, 1994; Sainburg, Ghez, & Kalakanis, 1999). Neck pain causes alterations in muscle coordination causing an irregularity in muscle activation altering proprioception in the head, and neck (Jull, Falla, Treleaven, Hodges, & Vicenzino, 2007; Kang et al., 2015; Peng et al., 2021; Reddy et al., 2019). Impairments in upper limb motor control are a result of altered sensory input from the neck (Deborah Falla et al., 2004; Peng et al., 2021; Woodhouse & Vasseljen, 2008; Zakharova-Luneva, Jull, Johnston, & O'leary, 2012) . Neck pain and fatigue have an effect on altered proprioception in the upper limb and elbow (Lee et al., 2008; Rix & Bagust, 2001; Zabihhosseinian et al., 2015).

The external branch of the spinal accessory nerve moves through the C0-C1 vertebrae that innervates the neck and shoulder musculature which are important for movement (D. Campos, Rieger, Mohr, Ellwanger, & Borba, 2010; D. d. Campos et al., 2012). Neck pain causes proprioceptive impairments in muscle coordination and communication for the head, neck and upper limb (Jull et al., 2007; Kang et al., 2015; Joanna J Knox & Hodges, 2005; Treleaven, 2008). It is highly likely that the accessory nerve carries proprioceptive afferents from the neck and shoulder muscles through the atlanto-occipital joint (de Campos, Rieger, Mohr, Ellwanger, & de Borba Junior, 2017; Orhan, Saylam, Ikiz, Üçerler, & Zileli, 2009; Schneider, Biörnsen, & Hagenah, 1996; Walker, 1990). Due to the deep neural proprioceptive connections, the atlanto-occipital joint should be observed in patient assessment and treatment (D. Campos et al., 2010; de Campos et al., 2017; Orhan et al., 2009; Walker, 1990).

Spinal manipulative therapy treatment for neck pain minimizes discomfort, increases range of motion, causes changes in neurophysiological activity presenting a positive effect on SMI and proprioception in the head, neck and shoulder (Daligadu, Haavik, Yielder, Baarbe, & Murphy, 2013; Haavik-Taylor & Murphy, 2007; Heidi Haavik & Murphy, 2008; Lelic et al., 2016; Murphy, Hall, D'amico, & Jensen, 2012; Peng et al., 2021; Reddy & Alahmari, 2015; Revel et al., 1994). A novel technique focusing on the adjustment of the atlanto-occipital joint in the cervical spine (also known as the One to Zero (OTZ) technique), is only reported in one series design, which found a significant increase in shoulder mobility post- treatment (Murphy et al., 2012). However, improvements in head and neck proprioception in response to OTZ have not been investigated. A randomized control trial is recommended to determine whether this novel spinal manipulation technique is valid and reliable in minimizing neck pain, increasing mobility, and improving proprioception in the head and neck.

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CHAPTER 2 LITERATURE REVIEW

This literature review will focus on the clinical research surrounding the evidence on the effect of spinal manipulative treatment on head and neck proprioception, along with neck and shoulder mobility. This will consist of the neuroanatomy of sensorimotor integration with a focus on proprioception, kinesthesia and body schema, neck pain and altered sensory feedback, effects of spinal manipulation on altered sensorimotor integration, the atlanto-occipital joint, methodology of the OTZ technique, and experimental technique to measure sensorimotor function. This review will also focus on the equipment that is used to measure proprioception, including the validity and reliability of each apparatus. This segment will conclude with rationalizing the correlation between the physiological location of the adjustment, and deep sensorimotor connections of the cervical spine providing a justified objective to observe the effects of upper neck manipulation on proprioception and mobility.

2.1. Sensorimotor Integration

Sensorimotor integration (SMI) allows for synaptic adaptation and neural communication between afferent stimuli coming from the external environment, which is then sent to cortical motor areas that process the sensory information resulting in accurate efferent output to create movement (Wolpert, Ghahramani, & Jordan, 1995; Wolpert, Goodbody, & Husain, 1998).

2.1.1. Neuroanatomy

2.1.1.1. Somatosensory System

The brain is a structure that recognizes, processes, and integrates external and internal stimuli (Kandel, 2013; Standring, 2020). There is a subsystem in the brain known as the somatosensory system which controls motor development, regulation, and adaption (Standring, 2020).The purpose of this system is to modulate a perception of the sensory information ascending from the muscles, joint capsules, skin and viscera (Cruccu et al., 2008). The somatosensory system is involved with the conscious and unconscious perception of touch, proprioception, temperature, and pain (Lundy-Ekman, 2013). This system is specifically responsible for five modalities which are mechanoreception (tactile recognition of external objects, skin localization, and detection of vibration), proprioception (movement, force, and joint position sense), thermoreception (temperature sense), nociception (pain sense), and visceroception (consciousness of the viscera) (Cruccu et al., 2008). The afferent system is also involved with an abundance of voluntary and involuntary motor pathways and feedback loops that lead into the spinal cord, brainstem, and forebrain (Cruccu et al., 2008). The somatosensory system contains two main parts; the Dorsal column-lemniscal system and the spinothalamic tract system (Cruccu et al., 2008). The dorsal column-leminiscal system conveys mechanoreception and proprioception. The spinothalamic system conveys nociception, thermoreception and visceroception. For this proposed thesis, there will be an emphasis on the dorsal - column lemniscus system pathway since it has been recognized to be the main pathway conveying sensory input from the mechanoreceptors involved in creating the sense of proprioception (Cruccu et al., 2008; Haavik-Taylor & Murphy, 2007).

2.1.1.2. Dorsal - Column Medial Lemniscus Pathway

The dorsal – column medial lemniscus pathway is essential for conveying sensory information from the spine to the primary somatosensory area in the cerebral cortex (Lundy-Ekman, 2013). The primary somatosensory system is in the lateral part of the parietal lobe of the cerebellum specifically known as the postcentral gyrus. The somatosensory cortex receives a bulk of the thalamocortical projections from the ascending sensory pathways (Lundy-Ekman, 2013). The lower body sensory information is received from the medial column also known as the fasciculus gracilis; and the upper body's sensory input ascends through the lateral column which is called the fasciculus cuneatus (Lundy-Ekman, 2013). The dorsal column lemniscus tract can be divided into three sections. The soma of the first order neuron in the posterior root ganglia ascend from either the fasciculus gracilis, or the fasciculus cuneatus, which travel to the medulla (Cruccu et al., 2008). The axons of the first order neuron synapse with the second-order neuron in the dorsal column nuclei which crosses the midline (decussates) and ascend as the medial lemniscus tract to the thalamus. A large mass of grey matter located at the center of the brain is known as the thalamus. It is the powerhouse of the brain, constantly exchanging and transferring a variety of sensory and motor impulses to and from the cerebral cortex which includes the primary somatosensory cortex, and basal ganglia (Lundy-Ekman, 2013). Once the second order neuron synapse with the third-order neuron, the information is carried through the axons to an appropriate area in the primary somatosensory cortex where the data is processed to be executed back to the periphery (Kandel, 2013; Lundy-Ekman, 2013).

2.1.2. Proprioception

The awareness of muscular, joint and position sense that allows an individual to perceive where the body is in 3-dimensional space is essential for movement and is known as proprioception (Kandel, 2013). As the body interacts with the external environment proprioceptive cues are transmitted through the skin, musculature and joints which are used to produce accurate movement (Sherrington, 1906). The body's sensitivity and input of sensory information from the exterior setting is known as exteroception (Sherrington, 1906). Whereas the internal and biological stimuli (i.e stress, heart rate, blood flow) that is observed from inside of the body is known as interoception (Sherrington, 1906).

2.1.2.1. Muscle Spindles and Golgi Tendons

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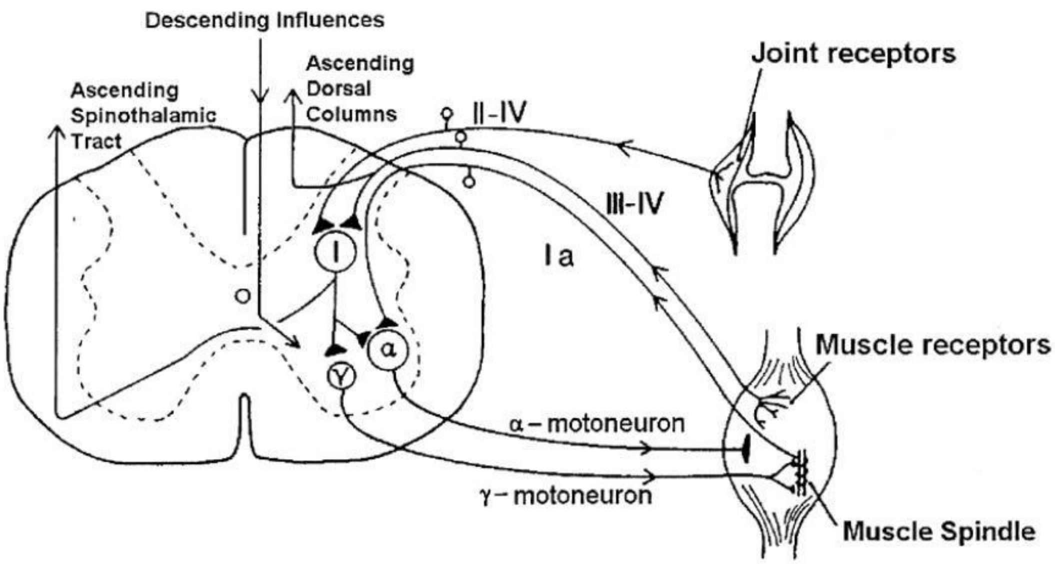

Figure 2.1. Visual diagram demonstrating sensory pathways responding to joint movement (Joel G Pickar, 2002).

The muscle effectors in the neck are the Golgi tendon organs within the tendons of the muscle and muscle spindles located in the belly of the muscle (McLain, 1993). These effectors surround the cervical facet joints (Freeman & Wyke, 1967; McLain, 1993, 1994). Golgi tendon organs provide output to translate the level of load applied on a tendon (Lundy-Ekman, 2013). They are also known to work with muscle spindles for postural control and movement tasks (MacKinnon, 2018). Muscle spindles are embedded in muscle bundles that assist in creating joint position sense and movement sense (Proske & Gandevia, 2012). As a body joint moves and manipulates muscles (i.e. stretching), the change detected by muscle effectors are relayed to the CNS to be processed which is then sent back to the periphery (Ogawa, 2009). Mechanical features of intero/exteroception are primarily provided by muscle effectors (Ogawa, 2009). Information derived from these muscle effectors initiate protective muscular reflexes preventing injury and monitoring joint excursion along with capsular tension (McLain, 1993). Mechanoreceptors have been found in every joint capsule in the body, and are especially populated in cervical facet joints (McLain, 1994; Peng, Yang, Li, Liu, & Liu, 2021; Proske & Gandevia, 2012). Mechanoreceptors are somatosensory receptors mainly involved in detecting mechanical proprioceptive sensations such as touch, pressure, stretching, gravity and positioning (McLain, 1993, 1994). A number of encapsulated mechanoreceptors with large nerve endings are commonly found in the cervical facet joints indicating that the head and neck are under constant observation of the central nervous system (McLain, 1993). The presence of mechanoreceptors in the cervical facet joints indicate that neural input is essential for cervical spinal function (McLain, 1993). In the presence of mechanoreceptive impairment, the proprioceptive and general communication from the neck to the CNS is likely to be affected negatively.

2.1.2.2. Neural Tracts

Neural pathways are used to have efficient and consistent communication within the CNS (Kandel, 2013; Lundy-Ekman, 2013). A neural tract is a group of axons that connect two or more neurons to enable an interaction between them (Lundy-Ekman, 2013). These pathways can be in the brain, communicating between several neural structures, or they can be the link between the brain and the spinal cord (Kandel, 2013). The tracts run bilaterally, one for each cerebral hemisphere, and hemisection of the spinal cord (Lundy-Ekman, 2013).

2.1.2.2.1. Ascending Tracts Integrating the Neck and Upper Limb

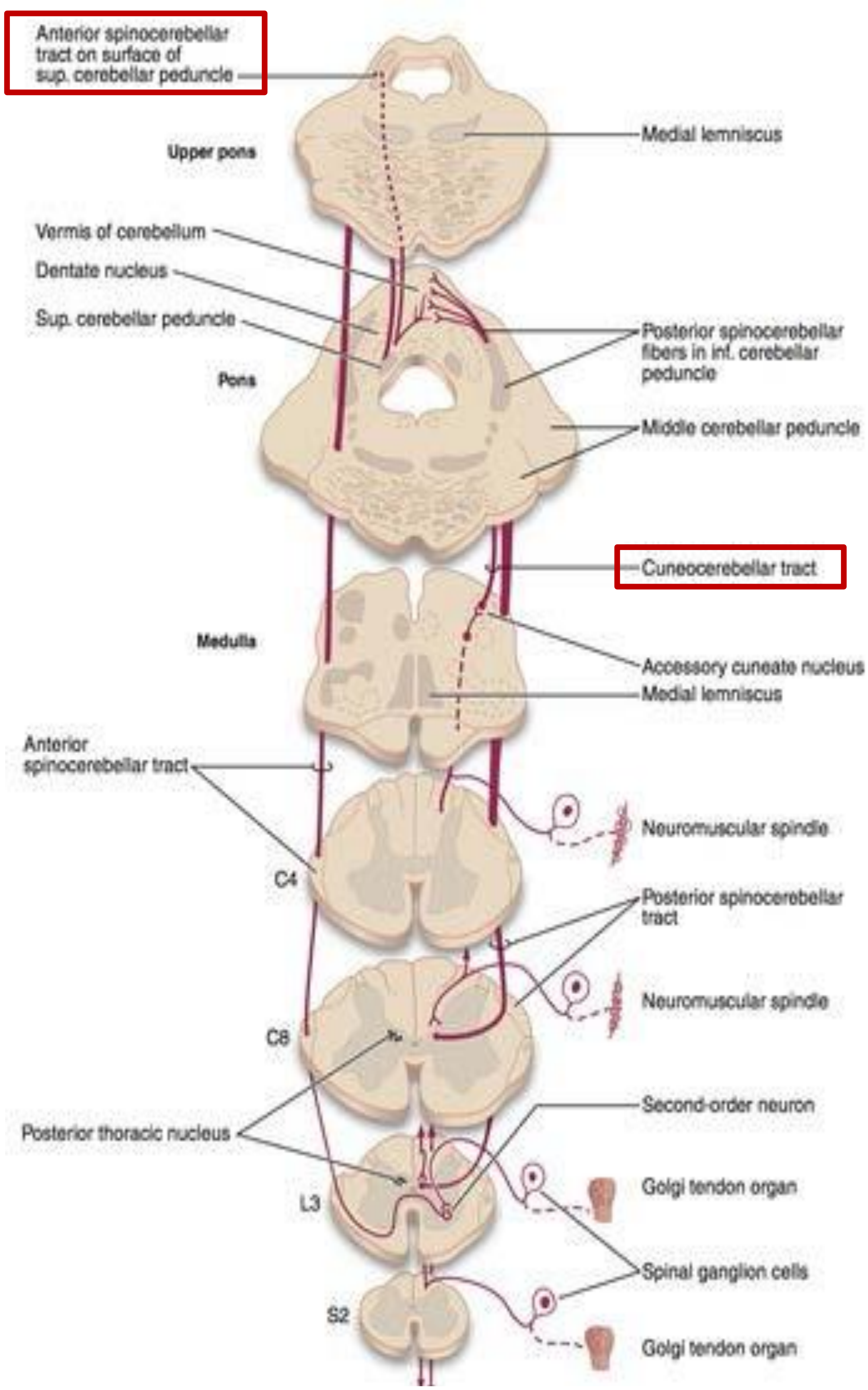

Figure 2.2: Ascending Tracts Integrating the Neck and Upper Limb ("Catalyst…", 2014)

While the dorsal column lemniscus pathway tract is involved with sending sensory information to the somatosensory cortex, there are two other ascending spinocerebellar tracts that integrate and transmit unconscious proprioceptive sensory information from the periphery (neck and upper limb from the lower motor neurons) via spinal cord to the cortex (Lundy-Ekman, 2013). The first one is the cuneocerebellar tract, and the second is the rostral spinocerebellar tract (Lundy-Ekman, 2013). They are known to carry proprioceptive information from the upper limb and neck arising from the muscle receptors (e.g. muscle spindles and golgi tendon organs), transmitted to cell bodies in the dorsal root ganglion and continuing to the ipsilateral cerebellum (Lundy-Ekman, 2013). The cuneocerebellar tract starts after the peripheral processing travels to the CNS. The first-order neuron starts at the posterior central grey horn in the spinal cord and ascends through the accessory cuneate nucleus (Lundy-Ekman, 2013). Then the second-order neurons, also known as external arcuate fibers, move through the inferior cerebellar peduncles, to arrive at the cerebellar cortex (Lundy-Ekman, 2013). The rostral spinocerebellar tract conveys mainly afferent golgi tendon information from the upper extremity, ascending to the dorsal root ganglion (Lundy-Ekman, 2013). Then the first order neuron travels to the lamina 5 (at C5-C8) where it synapses, and travels through the fasciculus cuneatus, and the information goes through the inferior peduncle and the third synapse occurs at the purkinje cells (large inhibitory neurons), and finally the fourth synapse where the proprioceptive information is processed is deep in the cerebellar nuclei (Lundy-Ekman, 2013).

2.1.2.2.2. Descending Tracts Integrating the Neck and Upper Limb

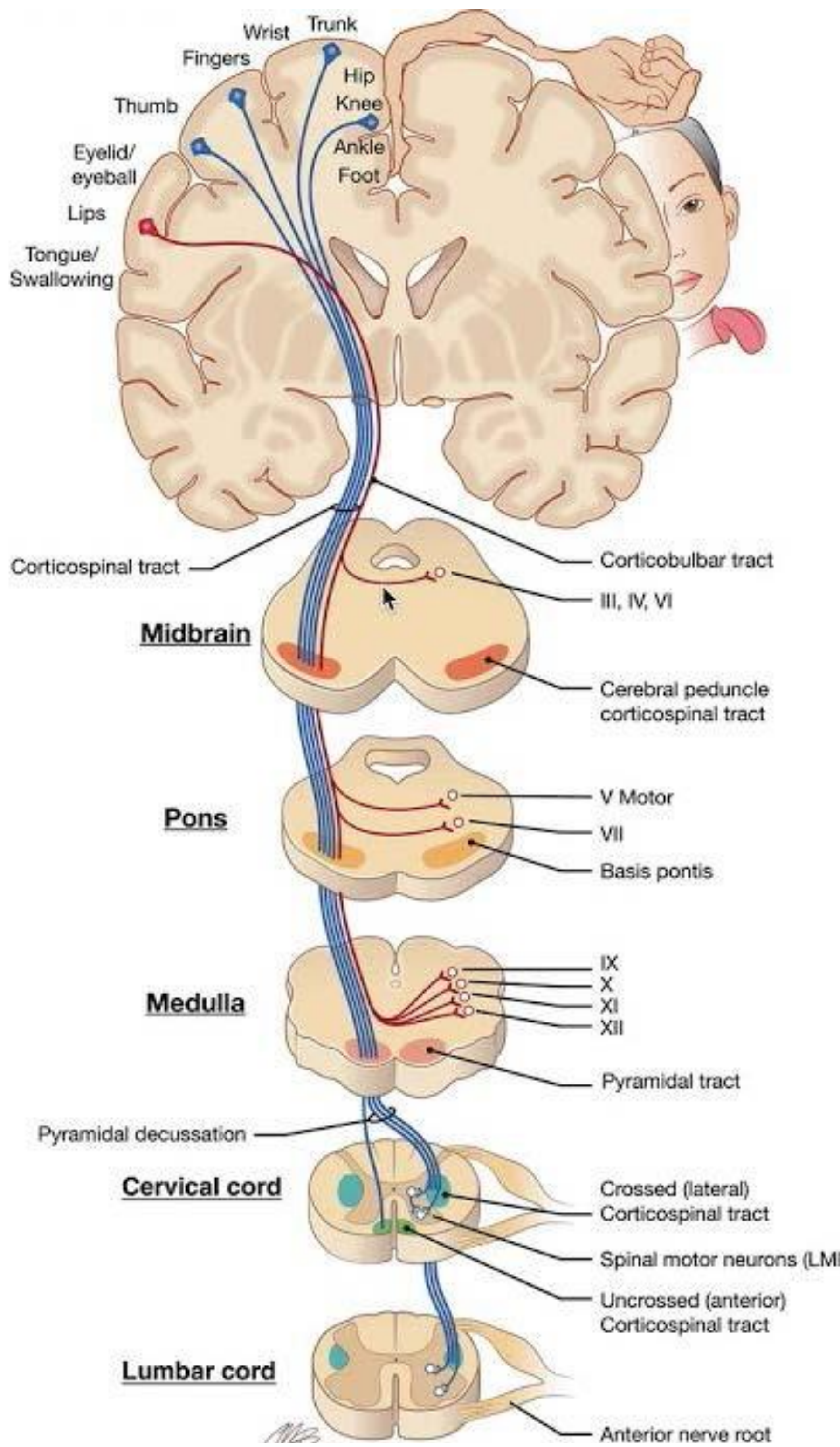

Figure 2.3: Ascending Tracts Integrating the Neck and Upper Limb (Hurling, 2014)

The descending pyramidal (voluntary movement) pathways to integrate upper limb and neck movement are known as the corticospinal tract and corticobulbar tracts (Lundy-Ekman, 2013). These pathways relay processed upper limb and neck proprioceptive motor signals from the CNS to lower motor neurons in the spinal cord to accurately execute voluntary movement (Lundy-Ekman, 2013). The corticospinal tract commences in the motor cortex, moving through the corona radiata (sheet of white matter between the thalamus and basal ganglia), through the midbrain, pons and then into the anterior lower medulla (Lundy-Ekman, 2013). After that the bulk of the corticospinal sensory fibers cross over to become the lateral corticospinal tract while the rest of the fibers become the anterior corticospinal tract (Lundy-Ekman, 2013). Both pathways descend via the spinal cord and synapse with the lower motor neurons in the ventral horn which transmit impulses through the anterior roots of the spinal nerve (from the cervical, brachial regions) to the peripheral nerves leading to skeletal muscle in the neck and upper limb (Lundy-Ekman, 2013). The neural input is transferred to the muscle through neuromuscular junctions resulting in muscle movement (Lundy-Ekman, 2013). The lateral corticospinal tract focuses on the fine movements of the limbs, the anterior corticospinal tract controls the movement integration of the trunk (Lundy-Ekman, 2013).

2.1.3. Cerebellum

Figure 2.4: Cerebellum (Janulla, 2012)

Under the occipital and temporal lobes of the cerebral cortex lies the cerebellum (Lundy-Ekman, 2013). The outer cerebellar layer is grey matter containing three cortical layers. The outer and inner cortex are saturated with interneurons (exclusively located and communicate in the CNS), while the middle cortex contains purkinje fibers. The purkinje fibers act as output cells of the cerebellum which send out sensory information processed from the cerebellum (Lundy-Ekman, 2013). The cerebellum consists of three lobes including an anterior, posterior and flocculonodular lobe (Lundy-Ekman, 2013).

2.1.3.1. The Cerebellum and Motor Control

The coordination between the cerebellum, limb movement, balance, and posture were established in early studies observing patients with hereditary ataxia, cerebellar cortical atrophy and trauma to the cerebellum (Babinski, 1899; Brown, 1892; Fine, Ionita, & Lohr, 2002; Gruol, Gruol, Noriyuki Koibuchi, & Mario Manto, 2016; HOLMES, 1907). These studies verified that functionally movement can be classified into three broad classes which are equilibrium, gross movements, along with fine movements (Gruol et al., 2016; Kalk, 2012). The flocculonodular lobe specifically controls equilibrium, and sensory information that goes and comes from the vestibular cerebellum (Gruol et al., 2016; Kalk, 2012). The vermal region (that connects the two cerebellar hemisphere) in the posterior lobe focuses on gross movements. The vermal section controls activity of medial upper motor neurons from the corticospinal, vestibulospinal and reticulospinal tracts (Gruol et al., 2016; Kalk, 2012). The lateral hemispheres of the cerebellum are associated with dexterity. Fine movement input is received from the middle peduncle and output is transmitted through the thalamus and motor cortex (Kalk, 2012). A large fraction of the human cerebellum coordinates to cerebral association networks in a systematic way with a focus on movement and postural control (Kandel, 2013). The cerebellum is associated with learning the timing, rhythm, and synchronization of stored movement patterns (Kandel, 2013). It obtains information regarding intended and actual movement; Intended movement is recognized via the cerebral cortex and internal feedback tracts through the spinal cord (Kandel, 2013). Whereas actual movement is recognized via proprioceptors through dorsal column lemnisci tracts (Kandel, 2013). The function of the cerebellum is critical for processing proprioception which allows the body to develop and use one’s stereognosis skills to produce accurate motor movement (Bhanpuri, Okamura, & Bastian, 2013; Kandel, 2013).

2.1.4. Sensory Motor Area

The primary Somatosensory Cortex (S1) is found in the parietal lobe, posterior to the central sulcus, in the postcentral gyrus (Kandel, 2013). The S1 receives the bulk of sensory and proprioceptive information from the dorsal – column medial lemniscus pathways, through the third order neuron(Kandel, 2013; Lundy-Ekman, 2013). The information is then processed in the S1 and transmitted to the descending pathway. Broadmann areas (BA) 3a, 3b, 1, 2, respectively, are the make-up of the S1 cortex. BA 3a and 3b receives a bulk of information from the thalamus however 3a is mainly concerned with proprioception. BA 1, and 2 receive a bulk of input from BA 3b, however BA 1 focuses on relaying information on texture whereas BA 2 emphasizes on size and shape. BA 3a and 2 receive the most proprioceptive input from musculature and joints (Kandel, 2013).

2.1.5. The Motor Cortex

The term motor cortex is usually used to describe the frontal lobe however it is more commonly referred to the primary motor cortex (M1) or BA 4, which is situated in the precentral gyrus (K. Brodmann, 1909; K. G. L. Brodmann, 1999; Edwards, 2006; Kandel, 2013). The M1 is densely packed with pyramidal cells also known as betz cells, which are the upper motor neurons (UMNs) in the area (Edwards, 2006). UMNs mediate the planning, initiation, and acquisition of sequenced voluntary movements (Edwards, 2006). The M1 contains the pre-motor and supplemental motor regions of the brain which are involved in movement planning. The supplementary motor region assists in movement initiation and preparation, as well as sensorimotor and synchronous motor coordination. The motor cortex is constantly receiving motor-related input from the somatosensory area, basal ganglia, and cerebellum through relays of information to and from the thalamus (Edwards, 2006). Once the M1 has efficiently connected with all the pre-motor regions, and the information is processed, it finally generates direct projections to the spinal cord to produce and execute an accurate voluntary movement (Zang et al., 2003).

2.1.6. Thalamus

In the brain's central region, above the midbrain, there is a structure that is a mass of mostly grey matter cells known as the thalamus (Lundy-Ekman, 2013). It regulates how motor and sensory information is sent from one portion of the cerebral region to another and controls consciousness (Lundy-Ekman, 2013). The thalamus is made up of a series of nuclei that are formed by excitatory and inhibitory neurons which have built a complex network of nerve fiber connections to and from the cerebral cortex in numerous directions. Although the thalamus is covered in predominantly grey matter, some areas of the lateral surface are covered with white matter (axons) and are known as the external medullary laminae, and the internal medullary laminae divides the grey matter (nuclei) into anterior, medial, and lateral groups (Lundy-Ekman, 2013; Savage, Sweet, Castillo, & Langlais, 1997). The thalamus is a crucial sensory conductor and modulator for processing and integrating upper limb and neck proprioceptive information through important afferent and efferent pathways (Kandel, 2013; Lundy-Ekman, 2013).

2.1.7. Basal Ganglia

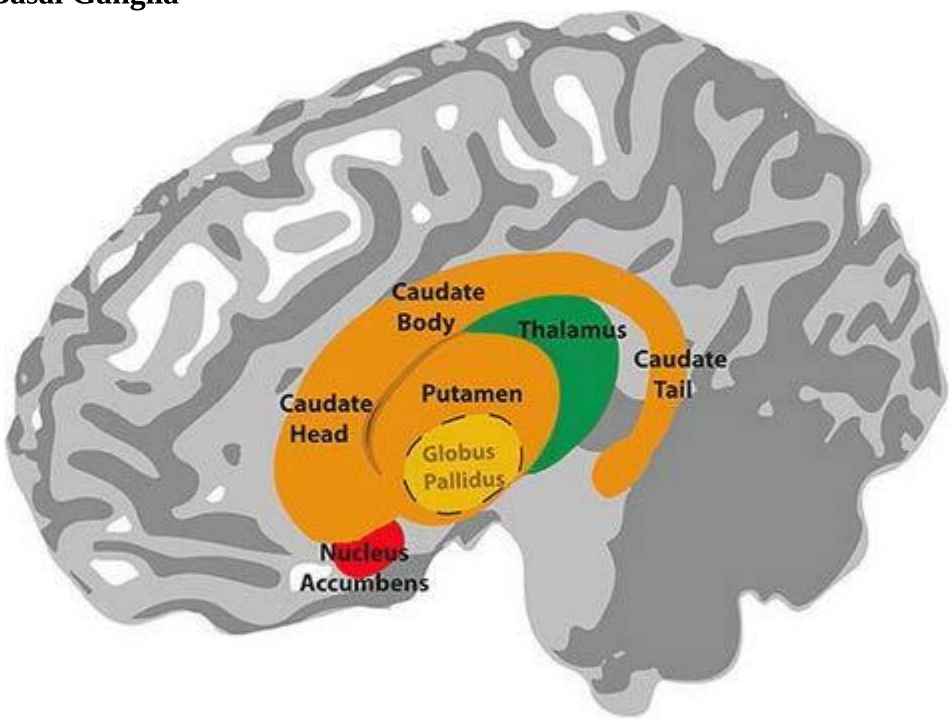

Figure 2.5: Anatomy of basal ganglia with the thalamus located underneath (Lim, Fiez, & Holt 2014)

The thalamus is linked to subcortical cell groups (corpus striatum, caudate-putamen and globus pallidus) which make up the basal ganglia, however there are related structures known as the substantia nigra in the midbrain, and the subthalamic nucleus in the diencephalon that are commonly known to be associated with the basal ganglia (Fix, 2008; Lundy-Ekman, 2013). These structures predominantly play a role in motor control, motor learning, behaviour, and emotion. The basal ganglia is involved with sensorimotor integration because the corpus striatum, ventral pallidum, and substantia nigra are involved with the acquisition and processing of movement, posture and skill (Lundy-Ekman, 2013). The putamen is known to regulate movement, and influence learning, the globus pallidus regulates voluntary movement especially unconscious movement (Lundy-Ekman, 2013). The putamen, and globus pallidus harmonize to assist in producing smooth, controlled movement. The subthalamic nucleus mainly sends signals to the globus pallidus and substantia nigra, it is also anatomically positioned relative to the thalamus, but functions like the basal ganglia. The basal ganglia is highly integrated and intertwined with processing, and relaying sensory and motor information so one could argue that if there is a lesion in the region of the basal ganglia, sensory feedback is impaired therefore effecting sensorimotor integration and indirectly proprioceptive abilities (Lundy-Ekman, 2013; Nowak & Hermsdörfer, 2006).

2.1.8. Central Nervous System Plasticity

2.1.8.1. Unaltered Feedback Loop

The CNS has an underlying goal to control all the muscles, limbs and joints needed to successfully execute a specific action aligned to the body's internal motive and external environment (Kandel, 2013). This is highly dependent on neural plasticity which is constantly adapting and changing as it responds to internal and external demands of the mind and body. Anatomical and functional changes in the CNS are recognized as neural plasticity (Kandel, 2013). The CNS also relies on feedback, which is the transfer of all afferent information from peripheral receptors to the control center (i.e. sensory receptors, proprioceptors, vision, auditory, and equilibrium) (Kandel, 2013). The purpose of feedback is to constantly update the CNS system to provide corrections or identify any errors during movement. A continuous example is a sensory feedback loop that the body requires for constant relay of sensory perceptions in a rapid sequence in order to be kinesthetically aware (Kandel, 2013; MacKinnon, 2018). The sensory feedback is used to establish an internal body map to orient and coordinate itself in relation to the environment (MacKinnon, 2018).The sensory feedback system utilizes multisensory input and projects this information to motor and premotor neurons in the spinal cord (MacKinnon, 2018). This neural feedback circuit is retained and refined to go from a closed feedback loop to an open feedback loop. A closed feedback loop is usually used for a novel motor pattern, that requires high precision hence why it is highly dependent on feedback (Kandel, 2013). Whereas an open loop is independent of feedback because it is used for a motor pattern that is well learned, and requires less precision (Kandel, 2013). The body can retrieve sensory information from feedback loops which permits one to sense how and where the body should be positioned for accurate movements without excessive effort resulting in normal proprioception and SMI (MacKinnon, 2018).

2.2. Kinesthesia and Body Schema

In 1888, Bastian devised the term kinesthesia, meaning the sense of joint position, and movement in the limbs without the use of vision, and hearing. Muscular sense is a specific version of a sensory modality that encapsulates the sensations of joint movement and joint position sense (Bastian 1887; 1888; McCloskey, 1978). This proprioceptive sensation is served by the receptors located within the muscles, specifically the muscle spindles (Goodwin et al., 1972). External changes in the environment and internal forces of the musculoskeletal system in the periphery are coordinated by the nervous system (Sensorimotor integration) (Sainburg, et al. 1999; Kendal, 2013). The proprioceptive sensory receptors within the muscle spindles (Kalaska, 1994) and the external environment are used by the CNS to provide an internal reference model for the musculoskeletal system (body schema) (Sainburg, et al. 1999). The proprioceptive signals are interpreted using two methods, one being with reference to the body, and the second is in reference to the external environment (Lackner & DiZio, 2000; Paulus & Brumagne, 2008). As the body moves, muscle tissue changes, causing afferent signals to flow from the periphery to the central processing system. The sensory information is analyzed to determine the body schema, current motion, and motor output. A sensory feedback loop refers to the quick transmission of sensory perceptions to and from the CNS, so the body schema is constantly updated (Kandel, 2013).

2.2.1. Cervicocephalic Kinesthetic Sensibility

The proprioceptive sensory receptors within the skin, musculature, joints, ligaments, and tendons, all transmit information to the CNS about tissue activity (Kalaska, 1994). The densely packed muscle spindles in the deeper cervical musculature are the primary source of proprioception afferents in the neck that communicate with the CNS to assist in executing motor movement (Kulkarni 2001; Cooper, 1963; Peng et al., 2021). The perceived position of the head and neck play a vital role in re-positioning the upper limb, head, and neck (Knox & Hodges, 2005; Revel et al., 1991). The ability to reproduce a motor movement is highly dependent on cervicocephalic kinesthetic sensibility. Knox & Hodges indicated that elbow repositioning errors increase when the head is positioned in flexion and rotation, compared to decreased elbow repositioning errors when the head was in neutral posture (2005). This study demonstrates that accurate upper limb positioning is dependent on head and neck position sense (Joanna J Knox & Hodges, 2005). Cervicocephalic joint position sense requires further investigation because it is clear that the other joints in the body are highly dependent on head and neck proprioception to create an accurate body schema (H. Haavik & Murphy, 2011; Joanna Joy Knox et al., 2006; Joanna J Knox & Hodges, 2005; M. Zabihhosseinian, M. W. Holmes, & B. Murphy, 2015).

2.2.1.1. Joint Position Sense

Joint position sense (JPE) allows an individual to sense the positioning of a joint without the use of vision and minimal exteroceptive cues (Kandel, 2013). JPE is a crucial part of proprioception and primarily effects the afferent input from the cervical musculature, discs, and joints, to the CNS (de Vries et al., 2015; Peng et al., 2021). Altered afferent input in the cervicocephalic region leads to impaired joint position sense (JPS) in the head and neck (Chen & Treleaven, 2013). There are different methods used to measure cervical spine JPS. For example, Revel et. al. demonstrated a reliable method to quantify cervical JPS through the evaluation of an error after angular displacement of the head (1991). Angular displacement was measured in centimeters and this was converted to angular measurements in reference to the participants center of rotation. A helmet with a fixed light beam attached to the top projected light from the center of the head to the center of a target (Revel, Andre-Deshays, & Minguet, 1991). The participant was seated with their back against a chair, feet flat on the floor, and their vision was occluded using goggles while positioned to face the target. This was deemed to be their neutral positioning. Participants were examined using two testing techniques to measure the participants ability to sense their neutral positioning only through muscle memory (Revel et al., 1991; Revel, Minguet, Gergoy, Vaillant, & Manuel, 1994). One was quantifying their repositioning error for rotating their head to neutral head positioning and the other was for rotating their head from neutral positioning to a target angle.

2.2.1.1.1. Head to Neutral

For measuring head to neutral, participants were instructed to memorize their resting positioning exclusively through muscle memory and then replicate this positioning after active movement of maximal amplitude of the head. Once they had reproduced their neutral position, the displacement between their original self-neutral position, and repositioning, was used to calculate their JPS error (Revel et al., 1991; Revel et al., 1994).

2.2.1.1.2. Head to target

The second test known as head to target was measured similarly, except for this test the participants were passively moved to a certain target angle and then brought back to neutral only to then reproduce the angle using muscle memory (Revel et al., 1991). The displacement between the participant's produced angle and target angle was used to consider their JPS error. After each trial the participant would reposition to their initial self-neutral position and they were not provided with any feedback from the research team. A total of 10 trials were completed to the right, and 10 trials to the left (Revel et al., 1991). Range of motion of the head and neck was also documented through maximal neck flexion and extension (Revel et al., 1991). Cervical proprioceptive signals through multisensory afferents play a dominant role in orienting the head (Revel et al. 1991). Evidence has indicated that dysfunction in neck sensory input, due to neck pain, alters joint position sense and head and neck repositioning (Revel et al., 1991; Revel et al., 1994). Interestingly, through a rehabilitation exercise program, individuals with neck pain improved in head repositioning accuracy (Revel et al., 1994). Jul et al., attained similar outcomes with a chronic neck pain group that was provided proprioceptive training (Jull, Falla, Treleaven, Hodges, & Vicenzino, 2007). This demonstrates that the proprioceptive system in the head and neck which is critical for cervicocephalic kinesthesia, has learning capabilities, and with rehabilitation techniques it can restore head repositioning accuracy and increase kinesthetic awareness (Revel et al., 1994).

2.4. Altered Sensory Feedback, Sensorimotor Integration and Neck Pain

Sensory function and SMI is crucial for performing appropriate coordination and communication between the CNS and sensory feedback as the body interacts with the environment to produce an accurate motor movement (Kandel, 2013). Sensory perceptual alterations surface when there is miscommunication between the CNS and PNS due to distorted sensory input. If the sensory feedback loop is not providing the correct information to update the body schema, then causing impairments within the proprioceptive receptors in the muscle effectors resulting in altered movement (Deborah Falla & Farina, 2007; D. Falla, Jull, Russell, Vicenzino, & Hodges, 2007; Kim, 2015; Peng et al., 2021). The neck's principal source of proprioception afferents are the densely packed muscle spindles located in the deeper cervical musculature (Jull et al., 2007; Peng et al., 2021; van der Wal, 2009). These modifications in muscle coordination causes an irregular decrease in muscle spindle activation of the deep cervical muscles, and an increase of superficial muscle activation, altering afferent input to the CNS resulting in an impairment in proprioception (Deborah Falla & Farina, 2007; Kim, 2015; Peng et al., 2021). Sensorimotor impairments are known to develop after trauma to the head and neck, following neck fatigue, and/or in response to recurrent neck pain (Falla, 2004; Woodhouse & Vasseljen, 2008; Haavik & Murphy, 2007; Haavik & Murphy, 2012; Zabihhosseinian et al., 2017). Research has demonstrated that the presence of neck pain and joint dysfunction in the cervicocephalic region of the spinal may lead to maladaptive changes in the CNS specifically within the somatosensory system and in SMI (Wall & Wang, 2002; Haavik & Murphy, 2007;2012). Neck pain and/or fatigue from the head, neck and shoulders leads to altered sensory feedback from the region, which causes maladaptive changes in SMI, resulting in reduced strength and endurance of cervical flexor and extensor muscles (Falla, 2004; Lee et al., 2008; Helgadottir, et al., 2010; Wegner et al., 2010; Haavik Murphy, 2012; Zabihosseinian et al., 2017).

2.4.1. Effect of Muscle Fatigue on Accuracy of Neck, and Limb Proprioception

Accurate proprioception can be negatively affected if there is miscommunication between the periphery and central nervous system (Knox & Hodges, 2005; Paulus & Brumagne, 2008; Zabihhosseinian, Holmes, & Murphy, 2015). Traumatic, and idiopathic neck pain has been correlated to altering upper limb and neck joint position sense (Falla, 2004; Knox & Hodges, 2006; Woodhouse & Vasseljen, 2008; Rix & Bagust, 2001; Lee et al., 2008; Zabihhosseinian et al. 2015). Individuals that have had a whiplash injury had a significantly larger elbow joint position error compared to individuals without the experience of a whiplash injury (Knox & Hodges, 2006; Woodhouse & Vasseljen, 2008). Neck fatigue and subclinical neck pain have also resulted in altered elbow and upper limb proprioception (Rix & Bagust, 2001; Lee et al., 2008; Zabihhosseinian et al. 2015). The examination of cervical fatigue in the sternocleidomastoid (SCM) and anterior scalene muscles (neck flexor and extensor muscles) was measured in individuals with neck pain using electromyography (D Falla, Jull, Edwards, Koh, & Rainoldi, 2004). The findings indicated significantly greater neck muscular fatigue in the neck pain group when compared to the control group (Falla et al., 2004). They found a greater activation of accessory neck muscles when compared to the asymptomatic group (Falla et al., 2004). Falla et al. purposed that the altered pattern of muscle activity may indicate increased activation of superficial cervical muscles to compensate for decreased activity of painful muscles (Falla et al., 2004; Kulkarni, Chandy, & Babu, 2001). Fatigability of the SCM and anterior scalene muscles was ipsilateral to the side of neck pain (Falla et al., 2004). Therefore, when neck fatigue, pain or whiplash injury is present, the altered sensory feedback results in an inaccurate perception of body schema and altered neck and upper limb movement patterns (Joanna Joy Knox et al., 2006; H.-Y. Lee, Wang, Yao, & Wang, 2008; Rix & Bagust, 2001; Woodhouse & Vasseljen, 2008).

2.5. Effects of spinal manipulation on Altered Sensorimotor Integration

The experimental and clinical literature consistently indicates distorted muscular activity and SMI in populations living with neck pain or fatigue (Chen & Treleaven, 2013; Deborah Falla & Farina, 2007; D Falla et al., 2004; H. Haavik & Murphy, 2012; Zabihhosseinian, Holmes, Howarth, Ferguson, & Murphy, 2017; Zakharova-Luneva, Jull, Johnston, & O'leary, 2012). Spinal manipulation is becoming a common form of treatment used to relieve neck pain (Hogg-Johnson et al., 2008). Spinal manipulative therapy is a non-invasive clinical technique in which the trained clinician would use their hands to produce a controlled thrust with a specific magnitude and direction on a spinal joint (Hogg-Johnson et al., 2008). This is a typical procedure that is commonly carried out by a chiropractor.

2.5.1. Subclinical neck pain

Repetitive overuse of cervical musculature over long periods of time causes neck fatigue that leads to neck pain. Subclinical neck pain (SCNP), is untreated, re-occurring stiffness, and soreness usually in the musculature with the experience of pain-free days. Research indicates that SCNP is associated with neural plastic alterations in central processing and SMI (Haavik & Murphy 2007; 2012). Alterations in neural processing and SMI have led to a decrease of proprioceptive awareness, causing imprecise motor movement (Rix & Bagust, 2001; Falla et al., 2004; Lee et al., 2008; Zabihhosseinian et al. 2015).

2.5.1.1. Increased Mobility After Spinal Manipulation

There is an accumulation of clinical studies that have observed spinal manipulation as a treatment method for individuals with SCNP, and their findings demonstrated a significant decrease in neck pain, increase in neck ROM and restoration of normal functioning SMI (Daligadu, Haavik, Yielder, Baarbe, & Murphy, 2013; Haavik-Taylor & Murphy, 2007; H. Haavik & Murphy, 2010; H. Haavik & Murphy, 2012; J. G. Pickar, 2002; Saavedra-Hernández et al., 2013; Wayne Whittingham & Niels Nilsson, 2001). Somatosensory processing was altered before spinal manipulation for a recurrent neck pain group, and adjustments delivered to areas of neck joint dysfunction, reversed maladaptive cortical neuroplastic changes suggesting alterations, restoring SMI (Haavik-Taylor & Murphy, 2007). These outcomes suggest that spinal manipulation provides restoration of sensorimotor functional ability in individual with neck joint dysfunction (Haavik-Taylor & Murphy, 2007). A research study was done evaluating a SCNP group before and after spinal manipulation. A motor learning task was used to assess stimulation patterns between the cerebellum and motor cortex (Daligadu et al., 2013). The SCNP group presented a significant improvement in task performance post neck adjustment and motor sequence task indicated by a 19% decrease in average response time (Daligadu et al., 2013). A randomized control trial was also done observing the effect of spinal manipulation on neck pain. The results indicated a significant decrease in neck pain severity (Saavedra-Hernández et al., 2013). Whittingham and Nilsson also found spinal manipulation to be significantly beneficial in increasing cervical mobility (W. Whittingham & N. Nilsson, 2001). The literature indicates that spinal manipulation of the cervical spine leads to normalizing afferent input, the restoration of SMI along with a significant decrease in neck disability (Daligadu, Haavik, Yielder, Baarbe, & Murphy, 2013; Haavik, & Murphy, 2007; 2010; 2012; Pikar, 2002; Saavedra-Hernández et al. 2013).

2.5.2. Shoulder Pain

Shoulder pain ascends from the glenohumeral, acromioclavicular, and sternoclavicular joints and the surrounding musculature (R. J. Murphy & Carr, 2010). It is commonly recurrent, and can be present for long periods of time (Van der Windt et al., 1996; Winters et al., 1999). The phenomenon of peripheral pain from the shoulder originating from the cervical vertebrae is well documented in literature (Behrsin & Maguire, 1986; Cloward, 1959; Hawkins, Bilco, & Bonutti, 1990; Kellgren, 1938; Walker, 1990). A more recent cross-sectional study was done inspecting trapezius muscle behaviour in individuals with neck pain and scapular dysfunction (Zakharova-Luneva et al., 2012). An Electromyogram (EMG) measured muscular activity from the upper, middle, and lower trapezius muscle. Participants exerted maximal MVC’s, 50% MVC’s and 20% MVC’s for isometric shoulder abduction, external rotation, and flexion

(Zakharova-Luneva et al., 2012). The findings indicated an alteration in behaviour for the lower trapezius in participants with neck pain and sca1pular dysfunction. Another study observed the effects of a cervical mobilization intervention on individuals with shoulder pain, and their results indicated an immediate change in shoulder ROM and pain (McClatchie et al., 2009). This warrants further investigation on the trapezius, and shoulder movement when observing participants with cervicocephalic impairments.

2.6. The Atlanto-Occipital Joint

The C0-C1 joint, or the atlanto-occipital joint, is a synovial joint between the occipital and the first cervical spine and it is known to control neck flexion (Kandel, 2013; Lundy-Ekman, 2013). Similar to the suboccipital region, this joint is also densely packed with high muscle spindle content, signifying higher complex proprioceptive activity, and fine motor movement (Peng et al., 2021). The cervical spine carries an intricate proprioceptive system involved with the musculature and nerves that integrate information from the head, neck and shoulders (D. Campos, Rieger, Mohr, Ellwanger, & Borba, 2010; Peng et al., 2021; Richmond & Abrahams, 1979; Treleaven, 2008).

2.6.1. The Spinal Accessory Nerve's Relationship to Head Neck, and Shoulder Movement

There are 12 cranial nerves, that regulate the sensory and motor functions of the head, and neck along with the involuntary movement of the body (Kandel, 2013; Standring, 2020). Majority of the cranial nerves originate from the nuclei of the brain (Kandel, 2013; Standring, 2020). However there are two that emerge from the forebrain (olfactory and optic nerve) and another has a nucleus in the spinal cord known as the accessory nerve (Kandel, 2013). The spinal accessory nerve is identified as the eleventh cranial nerve that has associations to the head, neck, and muscles assisting the scapula (D. d. Campos et al., 2012; Walker, 1990). The external branch of the spinal accessory nerve travels between the atlanto-occipital joint and innervates the trapezius and sternocleidomastoid (SCM) muscle which control stability and movement in the head, neck, and shoulder (D. Campos et al., 2010; Walker, 1990). The SCM is a superficial neck muscle at the base of the skull on both sides down the neck; It attaches on the top of the sternum and inserts on the mastoid process (Bordoni, Reed, Tadi, & Varacallo, 2019). The trapezius is a superficial back muscle that has upper, middle and lower muscle fibers. The trapezius originates on the occiput, ligamentum nuchae and the spinous process of C7 to T12. It's insertion points are the clavicle, acromion process and spine of the scapula (de Campos, Rieger, Mohr, Ellwanger, & de Borba Junior, 2017). The SCM and trapezius muscles are crucial for lateral neck flexion, and neck rotation (Bordoni et al., 2019). The trapezius is also used for the abduction of the shoulder (Walker, 1990). Clinical research has identified that the spinal accessory nerve has a connection to the first cervical nerve that carries ascending motor fibers, and assists in motor control of the head, neck, trapezius and SCM (D. Campos et al., 2010; D. d. Campos et al., 2012; Kandel, 2013; Orhan, Saylam, Ikiz, Üçerler, & Zileli, 2009; Ouaknine & Nathan, 1973; Walker, 1990). As the body adapts to the presence of pain in a muscle, it reduces deep muscle activation, which contain the muscle spindles that provide majority of the proprioceptive information, and increases the activation of superficial muscle fibers in the trapezius and SCM (Deborah Falla & Farina, 2007; Kulkarni, Chandy, & Babu, 2001; Peng et al., 2021; van der Wal, 2009). These alterations may cause proprioceptive impairments in muscle coordination and communication for the head, neck and upper limb (Jull et al., 2007; Kang et al., 2015; Joanna J Knox & Hodges, 2005; Treleaven, 2008). Evidence indicates that the accessory nerve arising from the trapezius and SCM, carries proprioceptive afferents connecting the head, neck and shoulders. The atlanto-occipital joint communicates to the spinal nerve C1 (de Campos et al., 2017; Orhan et al., 2009; Schneider, Biörnsen, & Hagenah, 1996; Walker, 1990). Due to the physiological location of the adjustments, and deep sensorimotor connections of the cervical spine, treatments such as spinal manipulation, in the presence of a dysfunctional atlanto-occipital joint (C0-C1) joint may have positive effect on neck and shoulder range of motion (ROM), along with head and neck proprioception (D. Campos et al., 2010; Corcoran & Conner, 2014; Kulkarni et al., 2001; F. X. Murphy, Hall, D'amico, & Jensen, 2012; Peng et al., 2021; J. G. Pickar, 2002; van der Wal, 2009).

2.6.2. One to Zero (OTZ) Chiropractic Technique

The literature indicates that cervical spinal dysfunction alters SMI leading to an increase in head, neck, and shouldet joint impairment due to these changes in central processing (Chen & Treleaven, 2013; Haavik & Murphy, 2012; Falla et al., 2004; 2006; Zabihhosseinian et at., 2017; Zakharova-Luneva et al., 2012). Spinal manipulation in the cervical spine region leads to normalizing afferent input, the restoration of SMI, an increase in head, neck, and shoulder ROM along with a significant decrease in neck pain (Daligadu, Haavik, Yielder, Baarbe, & Murphy, 2013; Haavik, & Murphy, 2007; 2010; 2012; Pikar, 2002; Saavedra-Hernández et al. 2013). A novel spinal manipulation technique called OTZ tension adjustment treats dysfunction of the articulation between the occiput (C0) and the first cervical vertebrae (C1) (Murphy et al., 2012). Given the importance of head orientation and its integration with vestibular and visual orientation in creating an accurate body schema, it is essential to investigate head and neck mobility before and after the OTZ adjustment.

2.7. Methodology of The OTZ Technique

The OTZ approach utilizes visual inspection and motion palpation to detect restricted movement of the atlanto-occipital articulation (F. X. Murphy et al., 2012). The chiropractor first performs a precise skull glide to detect the exact alignment of the problematic joint while seated at the head of the supine patient (F. X. Murphy et al., 2012). At the level of the defective C0-C1 joint, a high-velocity, low-amplitude thrust is supplied in the direction of maximal restriction (F. X. Murphy et al., 2012). The thrust is often from the back to the front, lateral to medial, and slightly superior to inferior (Murphy et al., 2012). The skull glide palpation is repeated after the adjustment to ensure that the joint restriction has been corrected.

2.7.1. Previous Study involving OTZ

There has been one study on the OTZ adjustment focused on the treatment and its impact on patients with frozen shoulder syndrome (F. X. Murphy et al., 2012). In 2012, a retrospective case series of 50 patients between the ages of 40 – 70 years of age, were screened, treated, and reviewed. The primary outcomes of this study resulted in 16 patients regaining full shoulder range of motion without any pain and 25 participants showed 75% – 90% improvement in shoulder range of motion and little to slight pain (F. X. Murphy et al., 2012). In the review it was discussed that these significant findings were likely influenced by the neurophysiology of the cervical spine; specifically, the atlanto-occipital joint, cranial nerve eleven (CNX1) and the spinal accessory nerve (F. X. Murphy et al., 2012). OTZ treatment is suggested to be sourced from altered atlanto-occipital biomechanics from improper neck posture leading to altered shoulder ROM (F. X. Murphy et al., 2012). It is yet to be examined in a randomized trial, whether individuals with a joint dysfunction at the C0-C1 joint complex who have OTZ chiropractic treatment, show improved head and neck and shoulder ROM when compared to an untreated group. OTZ treatment has shown to improve shoulder mobility in a case study but the adjustment not been examined for head and neck proprioception, along with neck and shoulder mobility in a randomized control trial

2.7.2. Gap in Research

Previous research on spinal manipulation focused on adjusting the cervical spine, but did not specifically address the occiput-C1 articulation. The literature proposes that cervical spinal dysfunction alters SMI leading to a decrease in head, neck, and shoulder joint impairment due to changes in central processing (Chen & Treleaven, 2013; Haavik & Murphy, 2012; Falla et al., 2004; 2006; Zabihhosseinian et at., 2017; Zakharova-Luneva et al., 2012). It has also been suggested that spinal manipulation between C1 - C7 leads to normalizing afferent input, which then results in improved SMI, and an increase in head, neck and shoulder ROM, along with a significant decrease in neck pain (Daligadu, Haavik, Yielder, Baarbe, & Murphy, 2013; Haavik, & Murphy, 2007; 2010; 2012; Pikar, 2002; Saavedra-Hernández et al. 2013). A past case study found that OTZ treatment significantly increased shoulder abduction (F. X. Murphy et al., 2012). However, head, and neck proprioception along with neck ROM and shoulder ROM has not been investigated in response to the OTZ treatment.

2.8. Experimental Technique to Measure Sensorimotor Function

2.8.1. Cervical Range of Motion Device

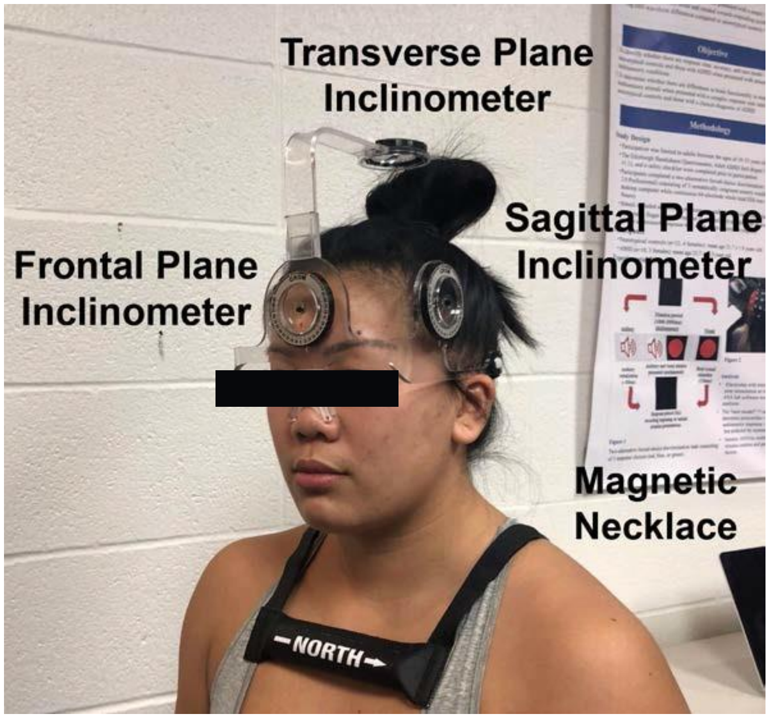

Figure 2.6: Cervical Range of Motion

The Cervical Range of Motion (CROM) Device is a type of goniometer that is used to measure CROM. Plenty of research has shown that the CROM device is a reliable goniometer to accurately measure CROM on symptomatic and control groups (Capuano-Pucci et al., 1991; Chen & Treleaven, 2013; Jordan, 2000; H. Y. Lee, Teng, Chai, & Wang, 2006; Rix & Bagust, 2001; Youdas, Carey, & Garrett, 1991). The apparatus is composed of a plastic helmet with three goniometers measuring three cardinal planes of movement including the transverse (rotation), sagittal (flexion and extension), and frontal (lateral flexion) planes (Rix & Bagust, 2001). It also has a magnetic yoke that rests around the neck on the shoulders for the compass goniometer which is used for the transverse plane (Rix & Bagust, 2001). Gravity goniometers are used for the sagittal and frontal plane (Rix & Bagust, 2001).

2.8.1.1. Validity of Device

There have been studies that have called the CROM device to be superior to other head and neck goniometers because it can measure three planes simultaneously while producing valid measures (H. Y. Lee et al., 2006; Reddy & Alahmari, 2015; Tousignant, de Bellefeuille, O'Donoughue, & Grahovac, 2000; Tousignant et al., 2002). The CROM device was used in an investigation on head repositioning tests to assess neck proprioception (H. Y. Lee et al., 2006; Reddy & Alahmari, 2015). The neutral head position test and target head position test were done using the CROM device and produced valid results (H. Y. Lee et al., 2006). When testing cervical proprioception in a clinical setting, the CROM device was supported and deemed as more valid compared to a laser attached to the head (Wibault, Vaillant, Vuillerme, Dedering, & Peolsson, 2013). The CROM device has the ability to efficiently and accurately quantify head repositioning impairment (Wibault et al., 2013).

2.8.2. Shoulder Joint Range of Motion Device

A shoulder joint ROM device is used to measure shoulder ROM in a clinical and research setting to document and communicate improvements. Wall goniometers can be used to measure shoulder range of motion (F. X. Murphy et al., 2012).

2.8.2.1. Validity of Device

Figure 2.7: Wall Goniometer

The wall goniometer is a valid tool in measuring postural abnormalities in the upper body (Kolber & Hanney, 2012; Tinazzi et al., 2019). In a previous retrospective case study investigating the effects of the atlanto-occipital adjustment on patients with frozen shoulder, a wall goniometer was used to assess and demonstrate the change in shoulder ROM (F. X. Murphy et al., 2012). A wall goniometer is thus a valid, inexpensive, and beneficial tool to provide quantify results to the researcher, patient, and research community (Kolber & Hanney, 2012; Tinazzi et al., 2019).

2.9. Randomized Control Trial

A randomized control trial (RCT) is used to quantify whether or not a novel intervention or treatment is effective. Randomization provides a reliable method for examining cause-and-effect links between an intervention and its outcome while minimizing bias (Hariton & Locascio, 2018). This is done by randomizing the individuals in each group ensuring no control or unconscious bias from the researcher; this design provides a reliable method for examining the cause-and-effect links between an intervention and its outcome (Hariton & Locascio, 2018). After a pilot intervention, or case study has been completed presenting a possible link between a cause and effect, further action will usually lead to an RCT.

2.9.1. Rationale for use of Techniques to Assess Sensorimotor Function

Cervicocephalic kinesthetic sensibility is highly dependent on sensorimotor function of the head and neck and is commonly examined through assessing joint reposition sense (Jull et al., 2007; H. Y. Lee et al., 2006; Reddy & Alahmari, 2015; Treleaven, 2008; Mahboobeh Zabihhosseinian, Michael WR Holmes, & Bernadette Murphy, 2015). Evidence-based research demonstrates that the CROM device is a valid and reliable tool to measure head repositioning error (Chen & Treleaven, 2013; H. Y. Lee et al., 2006; Wibault et al., 2013). The second assessment is on the shoulder joint which indirectly assists in assessing sensorimotor function (Heidi Haavik et al., 2017; Mahboobeh Zabihhosseinian, Michael WR Holmes, & Bernadette Murphy, 2015). Previous research demonstrates the shoulder joint increasing in mobility after a treatment on the cervical spine (F. X. Murphy et al., 2012). This presents a high possibility that the neck adjustment is associated with restoring upper limb sensorimotor function (H. Haavik &

Murphy, 2011; F. X. Murphy et al., 2012). Shoulder ROM can be measured utilizing a wall goniometer, because it's a valid, and reliable tool for verifying shoulder progress (Kolber & Hanney, 2012; Tinazzi et al., 2019).

2.10. Conclusion

2.10.1. General Summary

Neck pain is a serious issue within the global community that is causing severe disability (Hoy et al., 2014). Subclinical neck pain and neck fatigue has been shown to have a negative effect on head, neck and upper limb proprioception (Haavik-Taylor & Murphy, 2007; H. Haavik & Murphy, 2011; Joanna J Knox & Hodges, 2005; H.-Y. Lee et al., 2008; Palmgren, Andreasson, Eriksson, & Hägglund, 2009; Palmgren, Sandström, Lundqvist, & Heikkilä, 2006; Rix & Bagust, 2001). Prolonged neck pain and neck fatigue leads to maladaptive neural plasticity in areas related to sensorimotor integration, which is likely the mechanism that leads to altered proprioception in the head, neck and upper limb (Deborah Falla & Farina, 2007; H. Haavik & Murphy, 2012; Paulus & Brumagne, 2008; Rix & Bagust, 2001; Treleaven, 2008; Zabihhosseinian, Holmes, Ferguson, & Murphy, 2015). Proprioceptive information and movement from the neck and upper limb are processed in the cerebellum (Bhanpuri et al., 2013). The suboccipital region contains highly dense muscle spindles that are related to the multiplex of proprioceptive input involved with head, neck and shoulder-controlled movement (Boyd-Clark, Briggs, & Galea, 2002; Cooper & Daniel, 1963; Kulkarni et al., 2001). Spinal manipulation of the areas of joint dysfunction between C1-C7 improves proprioceptive awareness and causes an increase in head, and neck ROM, along with a significant decrease in neck pain (Daligadu et al., 2013; Haavik-Taylor & Murphy, 2007; H. Haavik & Murphy, 2010; H. Haavik & Murphy, 2012; J. G. Pickar, 2002; Saavedra-Hernández et al., 2013). The external branch of the spinal accessory nerve travels between the atlanto-occipital joint and innervates the trapezius and SCM muscle which control stability and movement in the head, neck and shoulder (D. Campos et al., 2010; de Campos et al., 2017; Walker, 1990). There is a novel treatment called the OTZ adjustment that treats dysfunction of the articulation between the occiput (C0) and the first cervical vertebrae (C1) (F. X. Murphy et al., 2012). A past case series study found that OTZ treatment significantly increased shoulder abduction, but head and neck proprioception has not been investigated in response to the treatment (F. X. Murphy et al., 2012). Due to the physiological location of the adjustments, and deep sensorimotor connections of the cervical spine, treatments of the atlanto-occipital join dysfunction could also have positive effects on neck and should ROM along with head and neck proprioception (Bhanpuri et al., 2013; D. Campos et al., 2010; de Campos et al., 2017; Kulkarni et al., 2001; F. X. Murphy et al., 2012; Peng et al., 2021; J. G. Pickar, 2002; van der Wal, 2009; Walker, 1990).

2.10.2. Research Questions

1) When OTZ Chiropractic treatment is compared with a no treatment control group, will it be effective in improving proprioception of the head and neck?
2) When OTZ Chiropractic treatment is compared with a no treatment control group, will it be effective in increasing shoulder, head and neck range of motion?

2.10.3. Hypothesis

1) After OTZ chiropractic treatment, there will be an improvement in cervical proprioception as measured by an increase in neck joint position sense accuracy and less deviation from their subjective neutral head position using the CROM device.
2) After OTZ chiropractic treatment, there will be an improvement in neck and shoulder range of motion using the CROM device, and a shoulder goniometer.

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CHAPTER 3 MANUSCRIPT

The Effect of Atlanto-Occipital Manipulation on Neck and Shoulder Proprioception and range of motion: A Randomized Controlled Trial

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3.1. Abstract

Introduction: Prolonged neck pain is correlated to maladaptive neuroplastic alterations. One such adaption is altered proprioception of the head and neck. The One to Zero (OTZ) tension technique aims to correct dysfunction between the occiput (C0) and first cervical vertebrae (C1). Due to the physiological location of the adjustment, and deep sensorimotor connections of the cervical spine, the treatment could have positive effect on shoulder range of motion, along with head and neck proprioception.

Methods: 65 participants between the ages of 18 – 65 with dysfunction between the occipito-atlantal (C0-C1) joint complex were randomly arranged into a control group (n=33) or treatment group (n=32). Shoulder flexion, extension, and abduction range of motion were measured using a wall goniometer, and neck rotation range of motion and joint position sense of the head and neck were measured using a Cervical Range of Motion (CROM™) device at baseline and following treatment or control period (2 to 3 weeks). Participants were instructed to rotate their head to a pain free end range on both the right and left side, three times for each side and ROM was recorded. The researcher then moved the individual's head to 50% of their end range, and participants were instructed to reproduce the angle with their eyes closed 3 times for each position. Absolute, constant, and variable error of the average angle was calculated, and all measures compared using a repeated measures ANOVA with baseline and post as the repeated measure, and side (R vs L) and group (treatment or control) as factors).

Results: There was no effect of side, so data was pooled. Shoulder range of motion significantly improved for the treatment group in abduction as indicated by significant group x time interactions ($F_{(1,63)} = 21.235$, $p < 0.001$, $\eta_p^2 = 0.252$, Power = 0.995); flexion ($F_{(1,63)}$ = , p = 0.005, $\eta_p^2 = 0.117$, Power = 0.812;, and extension ($F_{(1,63)} = 7.605$, p =0.008 $\eta_p^2 = 0.108$, Power = 0.775). Neck rotation significantly increased (time by group interaction, $F_{(1,63)} = 14.264$, $p <$ 0.001, $\eta_p^2 = 0.185$, Power = 0.961). There was a significant improvement in head joint position sense, as indicated by a time by group interaction for absolute, constant and variable error ($F_{(1,63)}$ = 7.616, $p < 0.008$, $\eta_p^2 = 0.108$, Power = 0.776 ; F(1,63) =6.853 , p = 0.011, $\eta_p^2 = 0.098$ Power = 0.732, F(1,63) =7.293 , p = 0.009, $\eta_p^2 = 0.104$ Power = 0.758 ; F(1,63)=5.620, p = 0.021, η_p^2 =0.082 Power = 0.646, ; $\eta_p^2 = 0.034$ Power = 0.603).

Conclusion: The OTZ technique improved shoulder and neck range of motion, along with head and neck proprioception.

Key words: Cervical Range of Motion, Cervicocephalic sensibility, proprioception

3.2. Introduction

Neck pain is a globally prominent phenomenon that causes excessive disability (Hoy et al., 2014). Over two thirds of people experience neck pain, and one third of people experience chronic neck pain in a lifetime (Côté et al., 2004). The ability to sense and perceive where the body is in space is a very complex physiological system that involves the process of using multiple afferent sensory inputs (Côté et al., 2004). The body is required to be aware of precise position, balance, and direction within any given environment in order to execute the correct motor output. Proprioception is the awareness that allows an individual to perceive where the body is in three-dimensional space (Standring, 2020). The body relies on sensory input transmitted through specialized receptors known as mechanoreceptors, muscle spindles, and joint receptors and Golgi tendon organs which are involved in relaying information from the peripheral nervous system (PNS) to the central nervous system (CNS) (Joel G Pickar, 2002).

The constant circuit of response and reaction from the CNS to the PNS and vice versa is known as the sensory feedback loop. Feedback is used to keep the CNS updated so that it can provide corrections or identify faults that occur during movement (Kandel, 2013; MacKinnon, 2018). There are two feedback loops that are known to assist in movement (Kandel, 2013; MacKinnon, 2018). The closed loop system is used during novel actions, and is highly dependent on sensory feedback for precision and accuracy (Kandel, 2013). The open loop system is used during learned actions, and relies on previously retained information on the specific movement (Kandel, 2013). The sensory feedback loop, whether it be an open or closed loop, is used to create a constantly updated internal map of the body to be kinesthetically aware and produce accurate movement (Kandel, 2013; MacKinnon, 2018; Peng, Yang, Li, Liu, & Liu, 2021).

The internal reference model of the body is commonly referred to as body schema (Sainburg, Ghez, & Kalakanis, 1999). Proprioceptive signals are interpreted in two ways: one in relation to the body, and the other in relation to the external environment (Lackner & DiZio, 2000; Paulus & Brumagne, 2008). Muscle tissue changes as the body changes its joint position, initiating sensory signals in the periphery to the central processing system (Lackner & DiZio, 2000; MacKinnon, 2018; Slosberg, 1988). The body schema, current motion, and motor output are all determined using the sensory feedback system (MacKinnon, 2018; Sainburg et al., 1999; Slosberg, 1988).

Sensorimotor integration (SMI) is the relationship, coordination, and communication between the CNS and sensory input as the body interacts with the environment to produce an accurate movement (Kandel, 2013). Movement can be negatively affected if there is an impedance between the periphery and CNS (Joanna J Knox & Hodges, 2005; Paulus & Brumagne, 2008; Zabihhosseinian, Holmes, & Murphy, 2015). Subclinical neck pain (SCNP) has been shown to negatively impact the head, neck and upper limb position sense (Joanna J Knox & Hodges, 2005; Paulus & Brumagne, 2008; Zabihhosseinian, Holmes, Howarth, Ferguson, & Murphy, 2017). It is suggested that the altered afferent input created by neck fatigue, and acute and/or chronic neck pain results in altered SMI, and changes motor outputs to the head, neck and upper limb (Joanna Joy Knox et al., 2006; Paulus & Brumagne, 2008; Zabihhosseinian, Holmes, Ferguson, & Murphy, 2015; Zabihhosseinian et al., 2017).

Control of the cervical spine requires the use of cervical proprioceptive cues as well as vestibular input (Mergner, Maurer, & Peterka, 2003). Afferent information from the neck muscles travels to CNS ascends via nerve plexlii in the neck (Campos, Rieger, Mohr, Ellwanger, & Borba, 2010; de Campos, Rieger, Mohr, Ellwanger, & de Borba Junior, 2017). As efferent information is retrieved, the signal travels through the spinal accessory root fibers which form the external ramus and innervate the sternocleidomastoid and trapezius muscle in the neck to create movement (Bordoni, Reed, Tadi, & Varacallo, 2019; Campos et al., 2010; de Campos et al., 2017; Walker, 1990). However, if there are sensory anomalies generated from mechanoreceptors in the neck or from the neck muscles, due to neck fatigue or pain, there will be likely alterations in cervical proprioceptive cues leading to more variable movement (Campos et al., 2010; de Campos et al., 2017; Peng et al., 2021; Walker, 1990). Previous studies demonstrated that individuals with neck pain having a higher neck rotation error in the sagittal plane when preforming cervicocephalic neck repositioning (Pinsault & Vuillerme, 2010; Ravi S Reddy, Maiya, & Rao, 2012). This was also apparent in participants with chronic neck pain, and who had experienced a whiplash injury (Heikkilä & Wenngren, 1998; Revel, Andre-Deshays, & Minguet, 1991; Rix & Bagust, 2001). In 2008, Lee and colleagues found a positive correlation between subclinical neck pain (SCNP), which is recurrent neck dysfunction that has not yet been treated, and cervicocephalic kinesthetic awareness (Lee, Wang, Yao, & Wang, 2008). An increase of neck pain caused an increase in neck repositioning errors (Lee et al., 2008). The authors concluded that the alterations in sensory input from the neck affected the body's ability to process sensory information to update the sensory feedback loop (Lee et al., 2008). This affected the body schema and kinesthetic awareness of the head, neck and upper limb (Paulus & Brumagne, 2008; Zabihhosseinian et al., 2017; Zabihhosseinian, Holmes, & Murphy, 2015). Proprioceptive impairments caused alterations in SMI, unconscious variability in error and an increase in repositioning error (Peng et al., 2021; Ravi Shankar Reddy, Tedla, Dixit, & Abohashrh, 2019; Zabihhosseinian et al., 2017; Zabihhosseinian, Holmes, & Murphy, 2015) .

Altered proprioception impacts the ability to synchronize movement (Peng et al., 2021), making it critical to research therapeutic alternatives to improve neck pain and dysfunction.

Spinal manipulation administered by registered chiropractor may offer a potential intervention to significantly reduce neck pain and improve joint position sense (JPS) error by normalizing firing from muscle spindle afferents (Heidi Haavik, Holt, & Murphy, 2010; H. Haavik & Murphy, 2012; Joel G Pickar, 2002). Muscle spindle and Golgi tendon afferents are stimulated by spinal adjustments (Joel G Pickar, 2002). Through mechanical and chemical changes, spinal manipulation could contribute to restoring a correct body schema, and normalizing SMI, which would then improve the body's ability to perceive and create accurate movement in the head, neck, and upper limb (H. Haavik & Murphy, 2012; Joel G Pickar, 2002). A pilot study was done to assess proprioceptive awareness in individuals with chronic pain (Rogers, 1997). Participants were either put in a spinal manipulation group, or a stretching group to compare the differences. The treatment group improved JPS by 41% compared to the stretching group, which improved by 12% (Rogers, 1997). Another study indicated that over 3-5 weeks of several low-velocity and low-amplitude spinal manipulations on individuals with nontraumatic neck pain, participants displayed a significant reduction of pain and head repositioning error, along with an increase in cervical range of motion (CROM) (Palmgren, Andreasson, Eriksson, & Hägglund, 2009). Even with a single session of spinal manipulation on participants with re-occurring neck pain there was evidence suggesting a relief of pain and restoration of motor functional ability (Heidi Haavik & Murphy, 2008). This research indicates that cervical spine manipulation for participants with enduring neck pain, may restore their proprioception and decrease their pain (Heidi Haavik & Murphy, 2008; H. Haavik & Murphy, 2012; Rogers, 1997). However, many of the researched spinal manipulation techniques focus on

C1 through C7. The novel spinal manipulation called the OTZ technique aims to correct articular dysfunction of the occipito-atlantal (C0-C1) (Murphy, Hall, D'amico, & Jensen, 2012). In the discussion of a case series study of 50 patients, it was suggested that OTZ was likely to have the ability to improve proprioceptive awareness in the upper extremities (Murphy et al., 2012), but this has never been examined in research.

Previous research on OTZ focused on the treatment and its impact on patients with frozen shoulder syndrome. In 2012, a retrospective case series of 50 patients between the ages of 40 – 70 years of age, was screened, treated, and reviewed (Murphy et al., 2012). The primary outcomes of this study resulted in 16 patients regaining full shoulder range of motion without any pain and 25 participants showed a 75% – 90% improvement in shoulder range of motion and little to slight pain (Murphy et al., 2012). In the review it was discussed that these significant findings were likely influenced by the neurophysiology of the cervical spine; specifically, the atlanto-occipital joint, cranial nerve eleven (CNX1) and the spinal accessory nerve (Campos et al., 2010; Murphy et al., 2012).

The sternocleidomastoid (SCM) and trapezius muscles are innervated by the external branch of the CNXI (de Campos et al., 2017). The SCM is a superficial neck muscle at the base of the skull on both sides down the neck; it attaches on the top of the sternum and inserts on the mastoid process (Kenny & Bordoni, 2019). The trapezius is a superficial back muscle that has upper, middle, and lower muscle fibers (Standring, 2020). The trapezius originates on the occiput, ligamentum nuchae, and the spinous processes of C7 to T12 (Standring, 2020). It's insertion points are the clavicle, acromion process and spine of the scapula (de Campos et al., 2017; Standring, 2020). The scapula is elevated and retracted by the upper trapezius fibers, while it is depressed by the lower trapezius fibers (Bordoni et al., 2019). The SCM and Trapezius are essential for functioning bilaterally to extend the skull posteriorly, to flex the neck laterally, and rotate the head about the transverse axis (Bordoni et al., 2019; Marieb, 2000; Standring, 2020). These movements are essential for daily living consequently, and altered SMI from these muscles is likely to result in distorted proprioceptive awareness in the head, neck and shoulder (Falla, Jull, Russell, Vicenzino, & Hodges, 2007; Peng et al., 2021; van der Wal, 2009; Zakharova-Luneva, Jull, Johnston, & O'leary, 2012). As the body adapts to the presence of pain and incorrect posture, it reduces deep cervical neck muscle activation and increases the activation of superficial muscles (Falla et al., 2007; Kim, 2015). The neck's principal source of proprioceptive afferents is provided by the heavily packed muscle spindles located in the deeper cervical musculature (Jull et al., 2007; van der Wal, 2009; Peng et al., 2021). These modifications in muscle coordination causes an irregular decrease in muscle spindle activation resulting in an impairment in proprioception (Falla et al., 2007; Peng et al., 2021). It is appropriate to speculate that altered proprioceptive input from atlanto-occipital articular dysfunction would likely compromise the body's ability to update the body schema resulting in a decrease in proprioceptive awareness. Given the deep kinesthetic connections from the neck to the cerebellum, and the densely packed muscle spindles in the suboccipital region it is probable that sensorimotor connections would be impacted by dysfunction at the atlanto-occipital articulation with concomitant changes in muscle activation (Bhanpuri, Okamura, & Bastian, 2013; Boyd-Clark, Briggs, & Galea, 2002; Cooper & Daniel, 1963; de Campos et al., 2017; Kulkarni, Chandy, & Babu, 2001)

Previous research on spinal manipulation directed between C1-C7 in participants with recurrent neck pain consistently found an increase in kinesthetic awareness, and improved head, neck, and shoulder range of motion (ROM) (Pickar et. al., 2002; Palmgren et. al., 2005; Lin et.

al., 2008; Haavik & Murphy, 2011; Murphy et. al., 2012). Therefore, it is appropriate to hypothesize that delivery of the OTZ tension adjustment between C0-C1 for individuals with articular dysfunction, the results will indicate an increase in proprioceptive awareness, head, neck, and shoulder ROM. As of now there has been no studies considering OTZ treatment and its effects on individuals with SCNP using head repositioning. The objective of this study is to identify the effect of OTZ spinal manipulation on cervical ROM, shoulder ROM, head to target repositioning accuracy and head to neutral repositioning accuracy. A randomized control trial design was conducted to investigate this research question.

3.3. Methods

3.3.1. Participants

The study protocol was authorized by Ontario Tech University's Research Ethics Board (reference number 15908), and the research was done in accordance with the Declaration of Helsinki. Prior to participation, all subjects gave written and oral informed consent. 68 participants presented articular dysfunction in the atlanto-occipital joint after being assessed and screened by a chiropractor at Total Body Chiropractic Health and Wellness in Toronto. A total of 65 patients, 37 females and 28 males (with the mean age of 41.77 ± 14.02 years), completed the study by attending both the baseline and follow-up sessions along with the required chiropractic treatment sessions. The inclusion criteria for the study consists of dysfunction of the articulation between the occiput and first cervical vertebrae, and recurrent unilateral/bilateral musculoskeletal problems that were not clinically diagnosed or treated beforehand. Any identified, or reported neurological conditions were recognized as exclusion. Three individuals withdrew from the study due to time-commitment issues.

3.3.2. OTZ Chiropractic Spinal Manipulation

The OTZ approach utilizes visual inspection of head tilt and neck asymmetry as well as and motion palpation of the skull movement on the condyles of C1 to detect misalignment of the atlanto-occipital articulation (Murphy et. al, 2012). The chiropractor first performs a precise skull glide to detect the exact alignment of the problematic joint while seated at the head of the supine patient. At the level of the defective C0-C1 joint, a high-velocity, low-amplitude thrust is supplied in the direction of maximal restriction (Murphy et al., 2012). The thrust is often from the back to the front, lateral to medial, and slightly superior to inferior (Murphy et al., 2012). The skull glide palpation is repeated after the adjustment to ensure that the malfunction has been corrected.

3.3.3. Treatment Method

Participants who met the criteria reported their medical history and had a physical examination by a trained OTZ practitioner. Once the participant was randomized into the treatment group, they were instructed to obtain treatment immediately after the researcher completed their baseline examination. The practitioner used the OTZ tension adjustment technique on the side that was causing recurrent musculoskeletal difficulties, then, if required, repeated the procedure on the opposite side. There were only a few individuals that received the correction on both the right and left side. The chiropractor recommended the patients to walk for at least 30 minutes within 24 hours after the treatment for optimal fluidity of joint movement. The practitioner performed the OTZ adjustment followed by any additional chiropractic adjustments in the cephalocaudal (top to bottom) direction directed to areas restricted joint movement. The treatment sessions consisted of two to three treatment sessions delivered over a two-to-three-week timeline, until the atlanto-occipital articulation was maintaining normal mobility between treatment sessions.

3.3.4. Experimental Procedure

The chiropractor provided the researcher with eligible participants who met the inclusion criteria. These individuals would each attend a baseline session where they would sign a formal consent form, and allow the researcher to assess and record head, neck, and shoulder proprioception. This experimental protocol follows the procedure and guidelines of a randomized control clinical trial following the CONSORT (Consolidated Standards of Reporting Trials) 2010 checklist. Participants were randomized into either the control group or the treatment group. Randomization was done using an excel random number generator, and the group assignments were put into opaque envelopes. After baseline measures were complete, the researcher selected an envelope to determine the group placement of that participant. If the participant was randomized into the treatment group, they would receive their first OTZ treatment after the baseline measurement, followed by two to three treatment sessions on a two-to-three-week timeline. Once the patient was deemed by the chiropractor to have reached optimal functionality of the C0-C1 dysfunction, they attended their post-treatment follow-up session to re-examine their head, neck, and shoulder proprioception. Contrarily, if the participant was placed into the control group, they would commence a two-week wait period directly after their baseline session. This would include adhering to the same regular routine, with no additional treatments, or alterations in medication and supplements. After the wait period, they would attend their follow-up assessment to re-assess and record head, neck, and shoulder proprioception. (Note: once follow up measurements were complete, the control group participants were offered the same treatment protocol as the treatment group, iff they wished to receive this). During each of the data collection sessions, shoulder ROM, neck ROM and cervical joint position sense (CJPS) were measured (see Figure 3.1). All collection sessions took place the Total Body Chiropractic clinic. The study was single blind, in that data was coded by an individual not involved in the study and returned to the researchers for experimental analysis. At the end of the study the code was broken so that the participants could be placed in the correct group for statistical comparison.

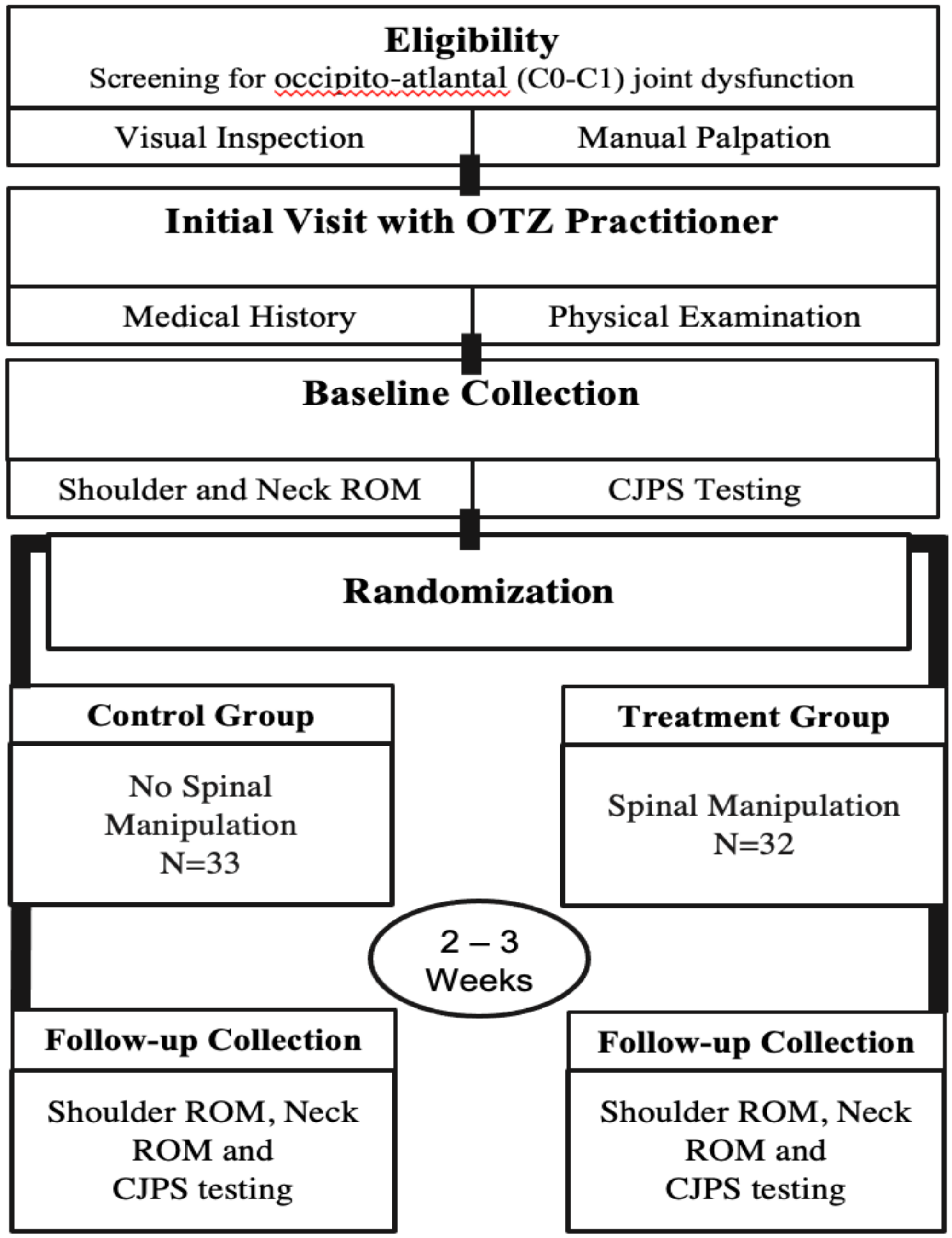

Figure 3.1: Experimental Protocol Diagram

3.3.5. Shoulder Range of Motion

Figure 3.2: Wall Goniometer to measure shoulder ROM

A height adjustable wall goniometer (OTZ Health Education Systems, Dallas, TX) was used to measure shoulder abduction, flexion, and extension once per side. Prior to completing the shoulder ROMs, the participant was instructed to stretch out each shoulder by going through the motions that would be measured to a pain and tension free end range. Once that was completed, they would stand with both feet marked on a specific spot that centers them against the wall goniometer. The researcher would stand at a marked spot directly parallel to the participant and record the motions using an iPhone camera in portrait orientation while the assistant would instruct the individual through the movement for each side.

3.3.6. Neck Range of Motion

All Neck ROM was measured using the CROM device (CROM 3, Performance Attainment Associates, Roseville, MN). The patient was seated with their back against the chair, feet flat on the floor, and arms on their lap, while positioned towards true north with their eyes looking forward indicating their neutral position. The investigator placed the CROM device on the participant's head and documented a portrait-oriented photograph of their front and side profile. After that the researcher measured neck flexion, neck extension, lateral flexion (both sides), and rotation of the head (both sides). In order to establish that the plane of interest was not disrupted by angle changes in other planes, the CROM device was referred to zero in-between each movement. The participants were instructed to move to pain and tension free end range for all neck ROMs. The researcher recorded three trials of each movement and the average of those trials was used for statistical analysis.

3.3.7. Cervical Joint Position Sense

All **Cervical Joint Position Sense** (CJPS) was measured using the CROM device (CROM 3, Performance Attainment Associates, Roseville, MN). Participants were seated with their back against the chair, feet flat on the floor, and arms on their lap. The researcher would instruct them to rotate their head to a pain-free end range on each side then come back to their center looking forward. This would re-calibrate their head to a self-selected neutral positioning which was then called re-calibration. Once they were stationary, the researcher would move the dial to zero degrees on the top of the CROM device on their head. They were instructed to close their eyes and the lights were dimmed to ensure there was no additional visual cues. Throughout this exercise the assistant was seated at the front to make sure the participant did not use vision. This protocol integrates a method developed by Revel and colleagues which contains head-to-target repositioning tests (Revel et al., 1991).

3.3.7.1. Head to Target

The participant would begin this exercise by re-calibrating their head to their self-selected neutral positioning. Then the researcher would passively move their head to 50% of their end range towards one side, announce “here” to confirm the angle, hold for 3 seconds, and then bring the participant back to neutral to have them replicate the angle three times sequentially by focusing on using muscle memory. The participant indicated their position by holding their angle for a few seconds before moving back to their self-selected neutral position. After this, the researcher instructed the individual to re-calibrate their head and re-adjusted the dial to zero degrees. Once this was established the researcher would passively move their head to 50% of the participant’s end range on the opposite side. They followed the same procedure as the first angle and then the researcher would instruct the participant through the same exercise for the opposite side. The researcher would measure 50% and 65% of the participant’s end range of neck rotation for each side, with three trials per angle (a total of 6 neck rotations on each side).

3.3.7.2. Head to Neutral

The participant was instructed to rotate their head at a steady pace to a pain-free end range and proceed back to their self-selected neutral positioning for each side by only using muscle memory. After they had completed the three trials on one side, they would re-calibrate and then, when instructed, they would commence the movement on the opposite side. Each side was measured and recorded three times consecutively.

3.3.8. Statistical Analysis

The mean shoulder ROM of abduction, flexion, and extension at two time points (baseline, and follow-up) was compared between both the control and treatment group, which was conducted through a two-way repeated measures ANOVA. For all statistical analysis, partial eta-squared (p2) was reported to evaluate effect sizes, with 0.01 denoting a small effect, 0.06 denoting a medium effect, and 0.14 denoting a high effect (Richardson, 2011). SPSS® version 26 was used to conduct all statistical tests (Armonk, New York, NY, USA). Shapiro-test Wilk's was used to check for normality, while Mauchly's test was used to check for sphericity.

The mean ROM was calculated for neck flexion, neck extension, lateral flexion, and rotation for each participant. There was no effect of side for neck flexion and extension, so data was pooled. A two-way repeated measures analysis of variances (ANOVAs) was used to assess differences between the two measurement sessions for neck flexion and extension data. Lateral flexion and rotation were calculated with, 2 side (right, left) by 2 time points (baseline, follow-up) two-way repeated measures ANOVAs.

Average (absolute, constant, variable) error of repositioning variability was measured for each participant through the head-to-neutral, and head-to-target proprioceptive tests. A 2 by 2 Repeated Measures ANOVA was conducted with group as a factor: 2 groups vs. 2 time points. SPSS® version 26 was used. All data was tested for normality and transformed if normality not found. There were significant ($p < 0.05$) differences in repositioning error and estimates of effect size.

3.4. Results

All data met assumptions of normality. Error bars on the graph signify standard deviation, and the stars (*) above the bars are intended to flag three levels of significance (p value). If the p- value is less than 0.05 it is flagged as one star (*). If the p-value is less than 0.01 it is flagged as two stars (**), and lastly, if the p-value is less than 0.001 than it is signified using three stars (***). There was no effect of side for the right and left side for lateral flexion, or rotation, or for shoulder abduction, flexion or extension, so the right and left side results were averaged for the ANOVA. There was also no effect of side for neck head repositioning error, so the left and right-side results were averaged for the ANOVA.

3.4.1. Shoulder Range of Motion

Shoulder ROM statistically significantly increased by time, and by time and group interaction (by time ; shoulder abduction, $F(1,63) = 11.864$, $p = 0.001$, $\eta p^2 = 0.158$, Power = 0.924; by time and group; shoulder abduction, $F(1,63) = 21.235$, $p < 0.001$, $\eta p^2 = 0.252$, Power = 0.995; by time; shoulder flexion, $F(1,63) = 4.059$, $p = 0.048$, $\eta p^2 = 0.061$, Power = 0.510; by time and group; shoulder flexion, $F(1,63) = 8.356$, $p = 0.005$, $\eta p^2 = 0.117$, Power = 0.812; by time; shoulder extension, $F(1,63) = 4.419$, $p = 0.040$, $\eta p^2 = 0.066$, Power = 0.544; by time and group; shoulder extension, $F(1,63) = 7.605$, $p = 0.008$, $\eta p^2 = 0.108$, Power = 0.775). The graph (figure 3.3.) illustrates the treatment group increasing by an average of approximately 10° post-adjustment, whereas the control group decreased by an average of about 2°.

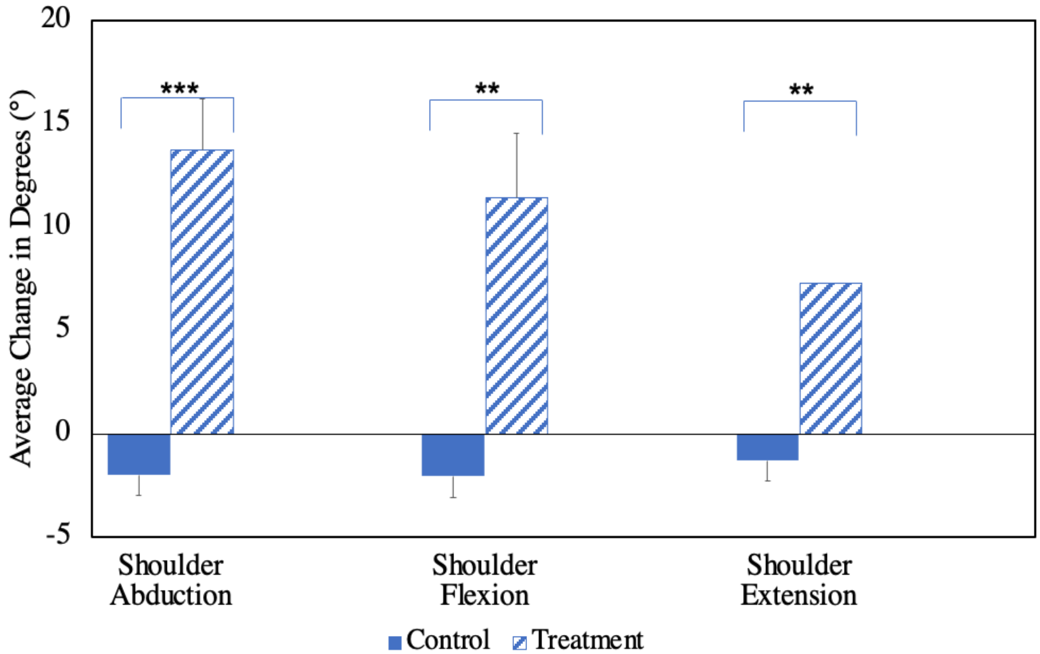

Figure 3.3: Shoulder range of motion for abduction, flexion and extension.

3.4.2. Head and Neck Range of Motion

3.4.2.1. Neck Flexion and Extension

Neck Flexion statistical results reveal a small effect size and a significant effect of time ($F(2,70) = 4.328$, p =0.042, $\eta p^2 = 0.064$ Power =0.535). These findings show a significant increase in neck flexion post OTZ treatment whereas the control group remained relatively constant before and after the 2-3 weeks of no treatment (figure 3.4.). Neck Extension ANOVA results indicate a large effect size and a significant effect on time by group interaction ($F(1.63) = 30.394$, $p < 0.001$, $\eta p^2 = 0.325$ Power = 1). This shows that the participants considerably increased in neck flexion and extension after OTZ treatment compared to the participants in the control group (figure 3.4.). The graph demonstrates that the treatment group increased by an average of 4° in Neck flexion, and by 7° for neck extension. The control group increased by an average of less than 1° for neck flexion, and decreased by an average of 3° for neck extension.

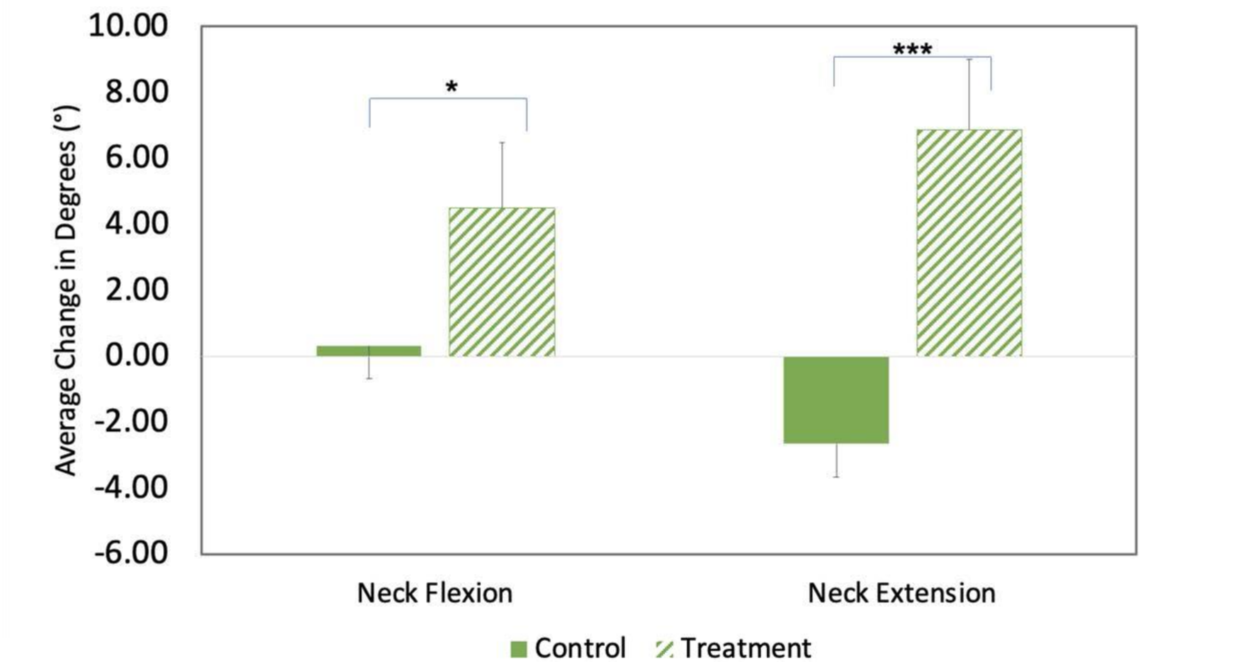

Figure 3.4: Average Change in Neck Flexion and Extension following

3.4.2.2. Lateral Neck Flexion and Rotation

Neck lateral flexion statistical results presented a large effect size and significant effect of time by group interaction ($F(1,63) = 14.545$, $p < 0.001$, $\eta p^2 = 0.188$ Power = 0.964). When comparing the follow- up measurements to the baseline, pairwise comparison reveals a significant difference ($p < 0.0001$). On average, the control group decreased in neck flexion by about 1° after 2-3 weeks of no treatment.

However, after 2-3 weeks with adjustments on the head and neck, they increased in lateral neck flexion on each side by an average of 3° and they increased in rotation on each side by an average of 4.5°. Neck rotation ANOVA results indicate a large effect size and a significant effect on time by group interaction ($F(2,140) = 18.345$, $p < 0.001$, $\eta p^2 = 0.127$). When comparing the follow-up measurements to the baseline, pairwise comparison reveals a significant difference ($p < 0.0001$).

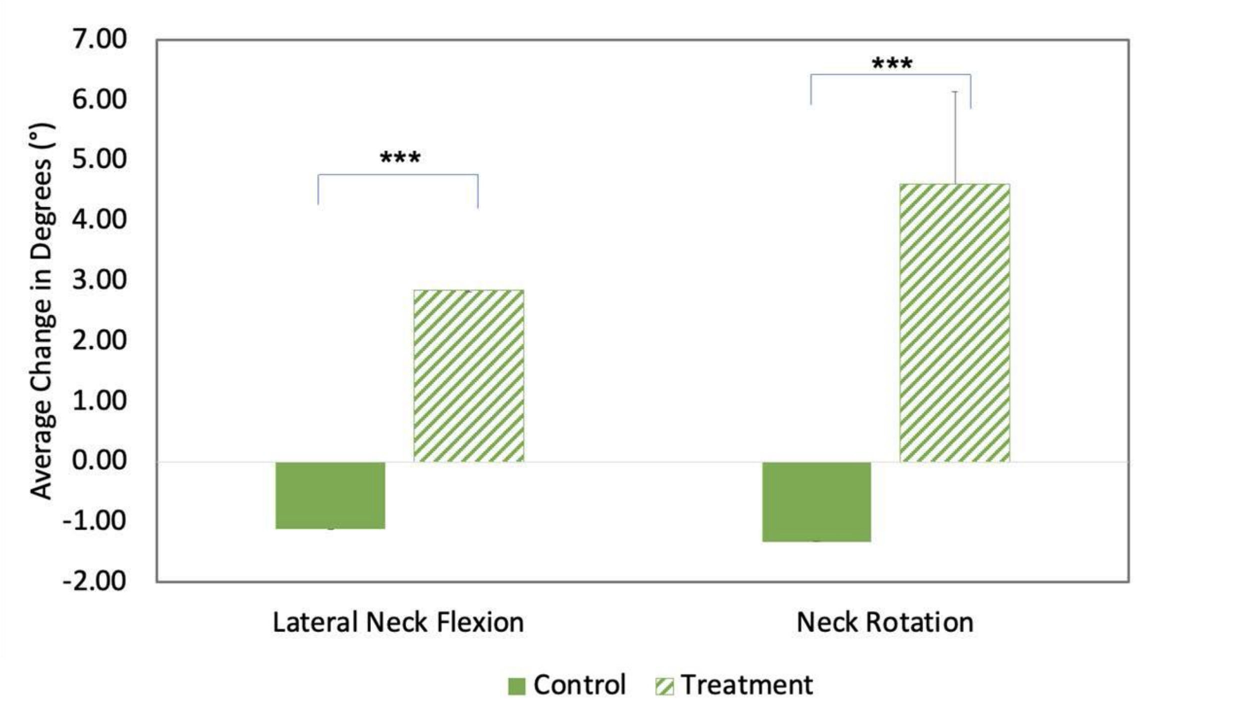

Figure 3.5: Average Change in Lateral Neck Flexion and Rotation

3.4.3. Head and Neck Repositioning

There was a significant improvement in head proprioception, as indicated by a time by group interaction (absolute error, $F(1,63) = 6.867$, $p = 0.011$, $\eta p^2 = 0.098$ Power = 0.733;, constant error, $F(1,63) = 6.853$, $p = 0.011$, $\eta p^2 = 0.098$;, variable error, $F(1,63) = 5.620$, $p = 0.021$, $\eta p^2 = 0.082$, Power =0.646). There was a substantial average decrease in head re-positioning error after 2-3 weeks of the atlanto-occipital adjustment for the treatment group.

Conversely, there was an increase in head re-positioning error after 2-3 weeks of no spinal manipulation. 50% of maximal ROM for the absolute, constant, and variable error of the treatment group significantly decreased post-treatment, whereas the control group increased in error without treatment (Figure 3.6.).

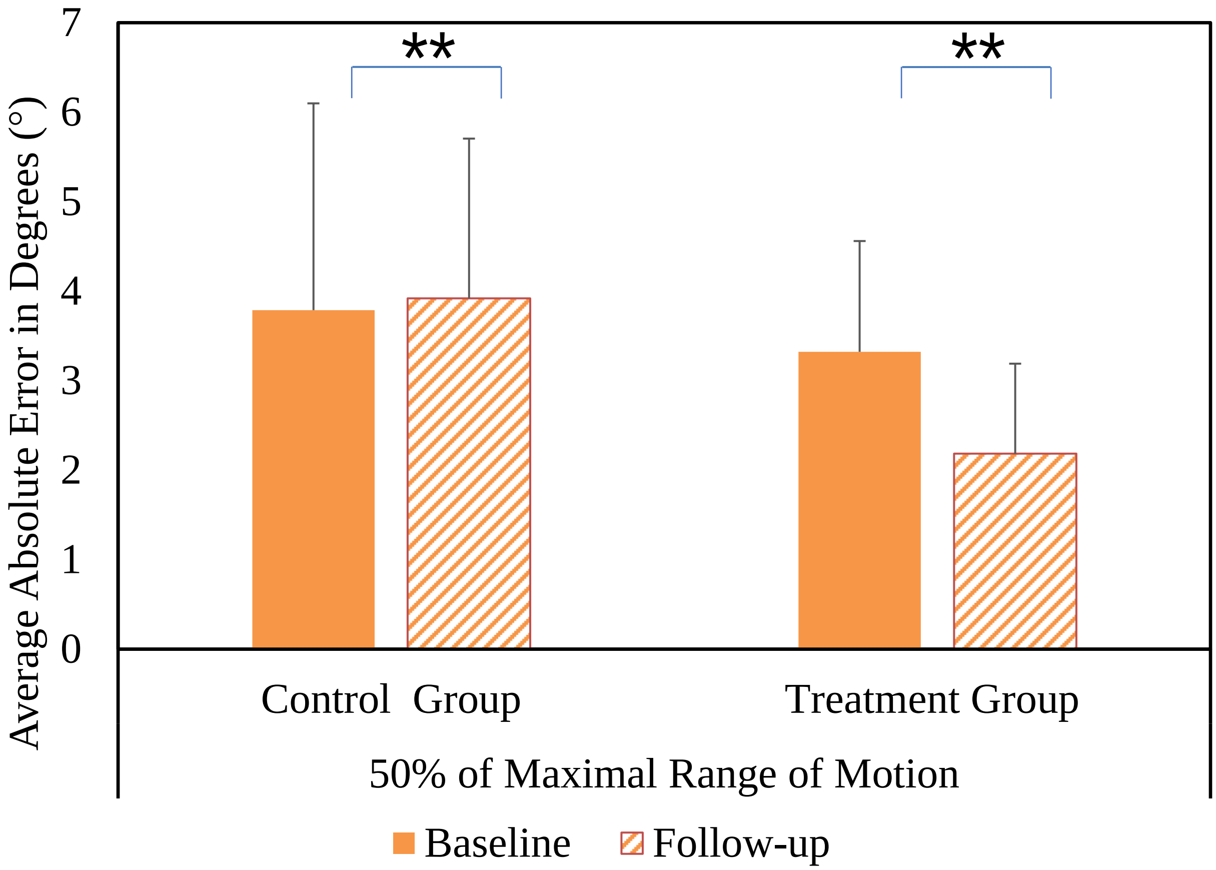

Figure 3.6: Average Absolute Error for Head to Target Testing

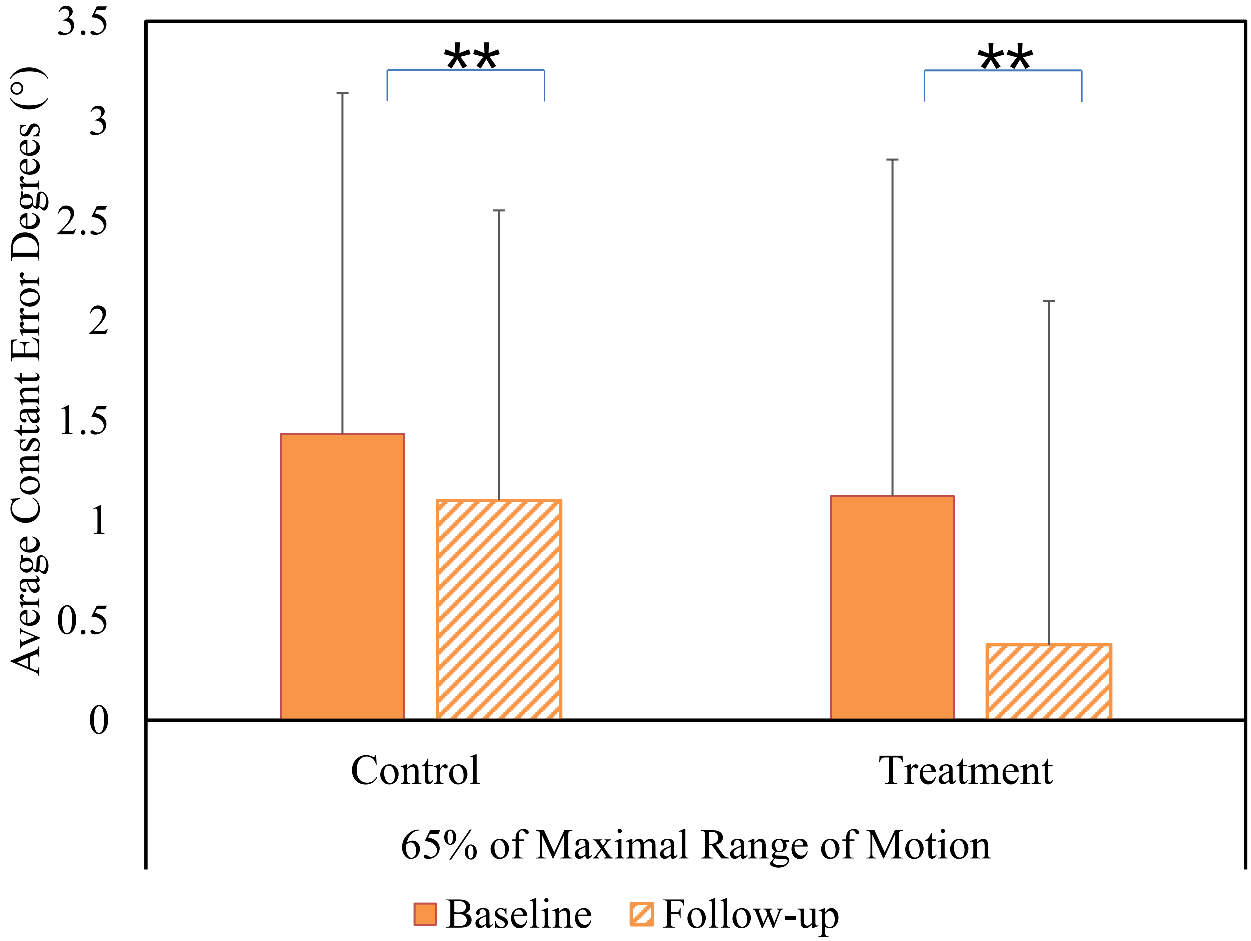

Figure 3.7: Average Constant Error of Head to Target Graph

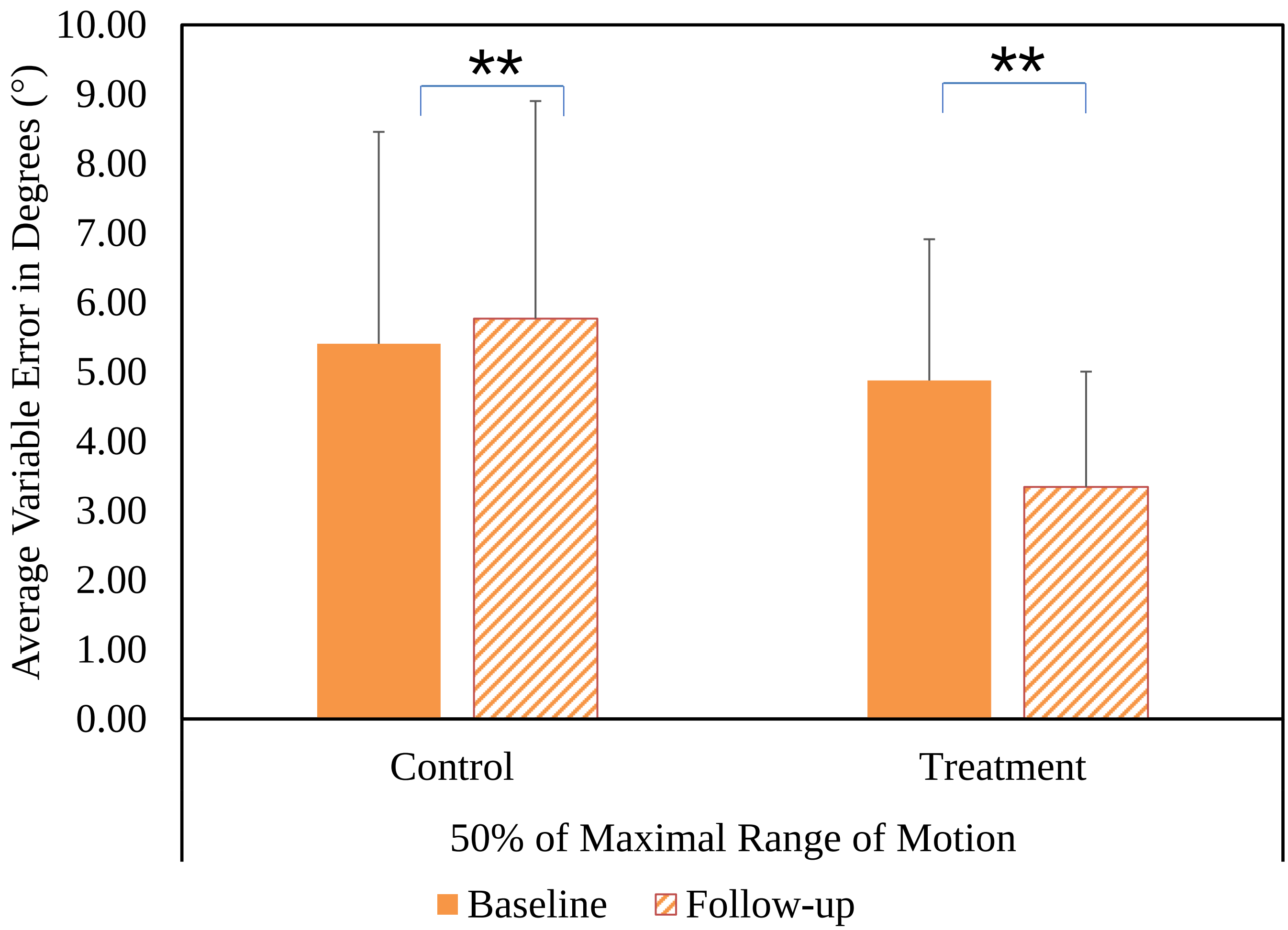

Figure 3.8: Average Variable Error of Head to Target Testing

3.4.4. Head and Neck to Neutral

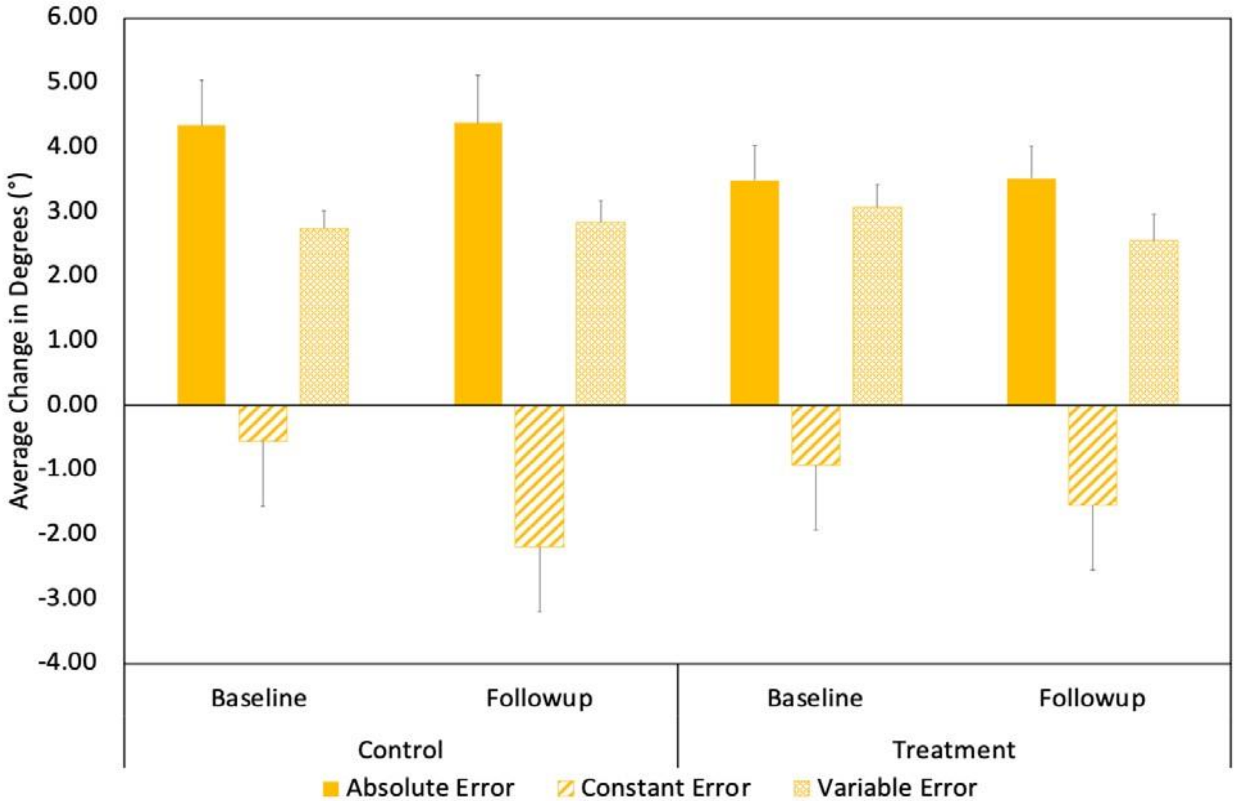

Figure 3.9: Average absolute, constant, and variable error for head to neutral testing

absolute, constant and variable error. The p value was more than 0.05 for all repeated measured ANOVAs.

3.5. Limitations

Safety glasses were taped with black duct tape to use for a blindfold during neck repositioning, however it became too uncomfortable for the participant to wear with the CROM device, and the safety glasses were causing a strain on the plastic sides of the CROM device. A sleep mask could not be used because they are difficult to sanitize efficiently, and are placed too close to the eyes, nose and mouth which causes a high chance of spreading COVID-19. Hence why we decided to dim the lights and had the research assistant supervise the participant while they had their eyes closed.

In this randomized controlled trial the OTZ treatment was followed by subjective treatments for each patient. For future studies it is recommended for the chiropractor to preform the OTZ treatment, with no additional treatments during the period of the trial.

3.6. Discussion

The goal of this study was to discover whether OTZ tension adjustment would significantly affect CJPS in individuals with SCNP. The gross difference in ROM for shoulder and neck following treatment (figure 3.3 – 3.5) is likely due to the removal of the neuromechanical blockage and reduction in pain which results in an increase in mobility (J. G. Pickar, 2002). The improved shoulder ROM is in accord with previous work by Murphy et al. who shows improvements in shoulder abduction following OTZ using a case series design (2012).

These changes in neck proprioception for individuals with atlanto-occipital dysfunction are probably the result of biomechanical changes at the C0 – C1 joint complex and associated structures, after treatment, which change inflow of sensory information to the central nervous system (J. G. Pickar, 2002). Spinal adjustments influence the influx of sensory information to the CNS (Joel G Pickar, 2002). Central facilitation is a process that increases the receptive field of central neurons, allowing subthreshold or benign stimulation to penetrate central pain pathways (Cook, Woolf, Wall, & McMahon, 1987; Joel G Pickar, 2002). The manipulation's potential to modify central sensory processing by removing subthreshold mechanical or chemical inputs from paraspinal tissues could thus be one mechanism underlying the effects of spinal manipulation (Joel G Pickar, 2002).

The results of this study focusing on the spinal manipulation of the C0-C1 joint are consistent with current research focusing on kinesthetic awareness and body schema after spinal manipulation from the C1 – C7 vertebrae (Daligadu, Haavik, Yielder, Baarbe, & Murphy, 2013; Heidi Haavik-Taylor & Murphy, 2006; H. Haavik & Murphy, 2012; Palmgren et al., 2009; J. G. Pickar, 2002; Rogers, 1997; Whittingham & Nilsson, 2001). The improved neck proprioception was not solely due to improved neck ROM because participants were tested at 50% and 65% of their individual ROM at both baseline and follow-up, so there is a genuine improvement in neck proprioception. This study has demonstrated that 2-3 weeks of the atlanto-occipital adjustment notably increased neck flexion, extension, lateral flexion and rotation along with shoulder abduction, flexion and extension mobility.

The treatment and control group, within 65% of maximal neck ROM decreased in absolute, constant, and variable error. The further away the head rotates from the midline the more the parallel SCM muscle stretches. At 65% neck rotation, the participant has greater stretch to reproduce the same movement compared to 50% neck rotation. For 50% of maximal range of motion they are closer to the midline, there is less of a SCM muscular stretch, and therefore they are required to focus on their proprioceptive awareness to locate the correct angle of their head. This may clarify how 50% of maximal neck ROM had statistically significant results when compared to 65% of maximal neck ROM.

The control group had difficulty executing movement by solely focusing on proprioception without neck adjustments, whereas post-adjustment, the treatment group had significantly decreased in variability and absolute error, indicating that they increased in proprioceptive awareness.

A significant decrease in averaged repositioning error indicates an increase in head and neck proprioceptive awareness in response to the atlanto-occipital treatment. Given the deep kinesthetic connections from the neck to the cerebellum, and the densely packed muscle spindles in the suboccipital region it is probable that sensorimotor connections have been positively impacted by the treatment (Bhanpuri et al., 2013; Boyd-Clark et al., 2002; Cooper & Daniel, 1963; de Campos et al., 2017; Kulkarni et al., 2001).

After spinal manipulation there was a significant increase in mobility for lateral neck flexion and extension, compared to a lesser increase in neck flexion. Excessive neck flexion, internally rotated shoulders and a curved spine is becoming increasingly common due to interaction with technology (Mahmoud, Hassan, Abdelmajeed, Moustafa, & Silva, 2019). So, the small effect in neck flexion mobility is likely because of the evolved neutral and perpetual neck flexion that people are regularly positioned into. Naturally there will be greater mobility in neck flexion if people are more frequently moving in that range, unlike neck extension, the opposite movement.

3.7. Conclusion

This randomized control trial confirms that OTZ chiropractic treatment preformed on individuals with atlanto-occipital dysfunction significantly improves their shoulder ROM, neck ROM and neck proprioceptive awareness compared to no treatment. The findings in this study suggest that the OTZ tension adjustment is a statistically reliable technique that can restore normal function of the atlanto-occipital joint, and glenohumeral articulation. This is the first randomized controlled trial examining the impact of treatment specifically addressing the atlanto-occipital joint (OTZ^{TM}) on neck proprioception.

OTZ treatment does address dysfunction in other areas of the spine in addition to the atlanto-occipital articulation however the cervicocephalic region is the primary focus of this technique and improvement of joint dysfunction in this region was used as the treatment endpoint by the OTZ practitioner. Treatments targeting upper neck dysfunction may lead to significant improvements in upper limb proprioception in addition to neck proprioception. Given the rich connections between the upper cervical spine and sensorimotor integration areas, the importance of the atlanto-occipital joint should be considered in patient assessment and treatment.

The major muscle effectors which are the Golgi tendon organs, and muscle spindles within the muscle, along with joint receptors such as mechanoreceptors, work together to gage postural control and movement surrounding and within the joint (Proske & Gandevia, 2012). The mechanoreceptors within the cervical joints indicate that neural input and communication to and from the CNS is essential for head and neck proprioception (McLain, 1993, 1994).

Proprioception is relayed from muscles effectors to the ascending tracts and processed in the cerebellum (Bhanpuri et al., 2013). Cervical spinal dysfunction is associated with proprioceptive impairments within the head and neck (Peng et al., 2021; Joel G Pickar, 2002). Previous research and this randomized control trial show that through spinal adjustment, individuals living with cervical spinal dysfunction significantly improve in head and neck proprioception (Heidi Haavik-Taylor & Murphy, 2006; H. Haavik-Taylor & Murphy, 2007; Heidi Haavik & Murphy, 2008; Lelic et al., 2016; Peng et al., 2021).

In the presence of neck pain and scapular dysfunction there are alterations in trapezius function (Zakharova-Luneva et al., 2012). Spinal manipulation on participants with shoulder pain resulted in an immediate increase in shoulder ROM, similar to this randomized control trial (McClatchie et al., 2009). Through adapting to nociception the body reduces deep muscle activation, which contain an abundance of muscle spindles providing proprioceptive information, and increase superficial muscle activation (Kulkarni et al., 2001; Peng et al., 2021; van der Wal, 2009). These alterations may cause proprioceptive impairments in muscle coordination and communication for the head, neck and upper limb (Jull, Falla, Treleaven, Hodges, & Vicenzino, 2007; Kang et al., 2015; Joanna J Knox & Hodges, 2005; Treleaven, 2008). Evidence indicates that the accessory nerve carries proprioceptive afferents connecting the head, neck and shoulders via arising from the trapezius and SCM. The atlanto-occipital joint communicates to the spinal nerve C1 (de Campos et al., 2017; Orhan, Saylam, Ikiz, Üçerler, & Zileli, 2009; Schneider, Biörnsen, & Hagenah, 1996; Walker, 1990). After spinal manipulation treatment participants decreased in joint position error indicating increased in joint position awareness. This presents a strong correlation between cervical mobilization and increased shoulder ROM, neck ROM, and improved head and neck proprioception.

The neuromusculoskeletal system changes and improves in head and neck JPS as a result of spinal manipulation (Joel G Pickar, 2002). According to previous research, the impulse load of spinal adjustments affects proprioceptive primary afferent neurons in paraspinal tissues (Joel G Pickar, 2002). Furthermore the OTZ treatment and other cervicocephalic adjustments increased neck and shoulder ROM significantly (Joel G Pickar, 2002). This indicates that spinal treatments can influence the motor system, conceivably through modifying the central facilitated state of the cervical facet joints and surrounding musculature (Cook et al., 1987; Joel G Pickar, 2002).

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