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Effect of a Tai Chi Chuan Slow Walking Intervention on Balance and Mobility in Individuals with Multiple Sclerosis

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A Thesis Presented

By

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DEDICATION

To my patient and loving husband, who if I was feeling down would always say “Go to [martial arts] class you will feel better, try not to kill anybody.” Without him this thesis would not be finished, and I would not be training for my black belt in Tae Kwon Do.

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ABSTRACT

EFFECT OF A THREE WEEK TAI CHI INTERVENTION ON STATIC AND DYNAMIC BALANCE IN INDIVIDUALS WITH MULITPLE SCLEROSIS

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In people with Multiple Sclerosis (MS) balance impairments may lead to increased falls and mobility loss. In quiet stance, people with MS display greater postural sway than healthy controls. Tai Chi is a Chinese martial art that has decreased the risk of falling in frail elderly individuals (Wolf et al., 1996). The purpose of this study was to determine if a three week Tai Chi intervention would improve postural stability in people with MS. Seven participants (6F/1M, age 48.5 ± 10.8 years, height 1.66 ± 0.08m, mass 68.6 ± 19.8kg) attended nine one hour training sessions to practice two types of Tai Chi: standing meditation and slow walking. Postural stability was assessed before and after training using average center of pressure (CoP) velocity, total excursion and time to contact (TtC) for the static trials, and dual and single limb support times for the walking trials. To measure postural stability trials of quiet stance (QS), Tai Chi standing meditation with (SMA) and without arms (SM), tandem stance (TS), preferred speed walking (PW) and slow speed walking (SW) were assessed. Kinematic data recorded by a 12 camera motion capture system (Qualysis AB), and kinetic data collected from a single forceplate (AMTI) were used to compute net CoP. Because functional parameters can influence stability, strength obtained from a chair rise test and neural drive obtained from a foot tapping test were obtained. All results were assessed with paired t-tests ($p<.05$). Increased muscular strength ($p=.024$) and neural drive ($p=.025$) were observed after the intervention, with no differences in QS and SM

($p>.05$). For SMA, average CoP velocity ($p=.006$) and excursions ($p=.023$) increased, and average TtC ($p=.020$) was reduced. For TS average CoP velocity ($p=.06$) and excursions ($p=.09$) trended towards decreased values, and average TtC ($p=.045$) increased. With the exception of increased left single limb support time ($p=.009$) PW and SW were not affected by the intervention. In conclusion, the increased neural drive, muscular strength, and postural stability in TS supports the idea that a three week Tai Chi intervention is effective at improving static balance in people with MS.

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GLOSSARY:

Anterior-Posterior (AP): refers to CoP movement from forward to back as the person is standing upright

Anterior-Posterior Medial-Lateral (APML): refers to CoP movement in all directions

Boundaries of Stability (BoS): the area enclosed by the feet

Center of Pressure (CoP): is the average point application of the ground reaction forces between an individual's feet during dual support

1. **CoP Net Excursion**: the total distance traveled by the CoP during data collection.
2. **CoP Velocity**: the speed ($m \cdot s^{-1}$) at which the CoP is moving towards the BoS
3. **CoP TtC**: the time until collision of the instantaneous CoP to the BoS

Center of Mass (CoM): is a representation of the average masses of the individual body segments condensed into a point in three dimensions at the center of the overall body mass (Shumway-Cook & Woollacott, 1995)

Fatigue Severity Scale (FSS): a self-report MS questionnaire which is a measure of general and leg fatigue (Krupp et al., 1989)**.**

Medial-Lateral (ML): refers to CoP movement from side to side as a person is standing upright.

Multiple Sclerosis (MS): a disorder of the central nervous system which is caused by demyelination of neurons.

Multiple Sclerosis Impact Scale-29 (MSIS-29): a self-report MS questionnaire which assesses the physical and psychosocial effects of MS (Hobart et al. 2001).

Patient Determined Disease Steps (PDDS): the gait specific portion of the EDSS which measures how much an individual's mobility is affected by their MS.

PRE: refers to before the Tai Chi intervention, or data collected at the initial data collection.

POST: refers to after the Tai Chi intervention, or data collected at the final data collection.

Quiet Stance (QS): a task in which the person stands with their feet aligned comfortably under their hips for 30s with eyes open, arms relaxed to the sides, gazing into the distance.

Self Report Expanded Disability Status Scale (sEDSS): a self-report questionnaire commonly used in the MS population to measure symptom severity and disability caused by MS.

Tai Chi Standing Meditation without arms (SM): a task in which the person stands with their feet aligned comfortably under their hips, with body relaxed, standing with the least amount of effort necessary, with relaxed gaze, sunken shoulders, and a lowered chin (Chuen, 2003). Upon each inhalation the person is asked to imagine an inflating balloon, allowing their arms to move away from the body slightly, and with every exhalation to imagine that same balloon to be deflating (Chuen,2003). Refer to Figure 7 for an image of without arms meditation.

Tai Chi Standing Meditation with arm movements (SMA): a task in which the person is given the same instructions as above, as well as being asked to perform 'Grasp Sparrows Tail' arm movements along with the stance. Refer to Figure 8 for an image of 'Grasp Sparrows Tail' Tai Chi arm movements.

Tandem Stance (TS): a task in which the person is instructed to stand heel to toe, first with their dominant leg forward then with their non-dominant leg forward for 30s. Participants were allowed to pick their arm position as needed, but had to keep the same arm position for their initial and final data collections. (If arms were relaxed at the sides at the initial visit, they had to repeat for the final visit.)

Time to Contact (TtC): a measure of time until collision of the instantaneous CoM and the edge of the BoS (Hasson et al., 2008).

CHAPTER 1

INTRODUCTION

1.1 Background on Multiple Sclerosis

Multiple Sclerosis is an autoimmune, demyelinating disease of the Central Nervous System (CNS). It is estimated that about 400,000 people are currently diagnosed with Multiple Sclerosis (MS) in the United States (National MS Society, 2011). A higher prevalence of MS has been found in the northern parts of the US, Scandinavia and northern Europe, with an increased rate of occurrence in females compared to males (Koch-Henriksen & Sorensen, 2010). MS often develops at a young age, with the average age of onset ranging from ages 18 to 50 years (Noseworthy et al., 1999). The course of the disease is highly unpredictable, evident by the numerous subtypes of MS as well as the variability in symptoms along with symptom severity (Noseworthy et al., 1999). The most common type of MS is Relapsing-Remitting which is characterized by worsening neurological symptoms known as relapses that are followed by extended periods of remission in which symptoms improve (Noseworthy et al., 1999). The Primary-Progressive form of MS has symptoms that continually worsen from the onset of diagnosis. Secondary-Progressive MS typically begins as Relapsing-Remitting, but then takes on features that are more comparable to the Primary-Progressive form (Tremlett et al., 2008). Progressive-Relapsing patients usually have steadily worsening relapses from the onset, with exacerbations of symptoms (National MS Society, 2006A). Less than 5% of people have Progressive-Relapsing MS; it is quite rare to see this type of progression

(National MS Society, 2006A). For a positive diagnosis of MS, at least two lesions must occur during different time periods within different parts of the brain or spinal cord (Calabresi et al., 2004). That is, the lesions must be separated by time and space.

1.1.1 Functional Systems affected by MS

The variability of lesion location and extent of damage in various CNS structures produces a variety of symptoms, commonly measured by the Expanded Disability Status Scale (EDSS) (Kurtzke, 1983). These functional systems consist of: Visual, Brainstem, Pyramidal, Cerebellar, Sensory, Bowel and Bladder, and other types of symptoms, such as fatigue (Kurtzke, 1983). Depending where the lesion is located in an MS patient, the somatosensory system, visual system, proprioceptive, or vestibular system can be adversely affected (Cameron et al., 2008; Degirmenci et al., 2010; Roodhooft, 2009). Motor impairments are one of the most common complications in MS and may arise due to lesions affecting the pyramidal system, the brain stem, the cerebellum, and the cerebral regions of the cortex.

1.1.2 Mechanisms of Impaired Static Balance in MS

Even in quiet stance, MS patients display greater amounts of postural sway when compared to healthy controls (Soyuer et al., 2006). Postural sway being the amount of Center of Pressure (CoP) displacement over time (Horak et al., 1987). Sosnoff et al. (2010) found that individuals with MS (both with and without spasticity) had increased postural sway in the medio-lateral direction during standing tasks. Some interpret this as a result of decreased postural control. Should a perturbation, or a challenge to balance, occur, it is likely that balance will be lost. Perturbations arise from two sources; internally-generated and externally-generated. Internal perturbations occur when an individual voluntarily displaces their center of mass (CoM), such as seen during reaching, leaning, or walking. External perturbations occur when an external stimulus causes a displacement of the CoM, such as slipping or being pushed. Both types of perturbations reduce stability by accelerating the CoM towards the boundary of stability (bounded by the feet), and a strategy (ankle, hip, or stepping) is needed to redirect the path of the CoM to keep the person from falling. This measure of time until collision of the instantaneous CoM and the edge of the stability boundary is called the Time to Contact (TtC) (Hasson et al., 2008). Karst et al. (2005) found that CoP displacements in mildly impaired MS populations were much smaller during internal perturbation tasks then the healthy controls. This finding was supported by Van Emmerik et al.(2010), who also documented that individuals with MS had reduced stability in the direction perpendicular to the reach or lean.

1.1.3 Alterations in Gait Parameters in Individuals with MS

Because of the large range of functional neurological systems affecting walking in MS, gait impairment has been one of the most commonly diagnosed symptoms (Givon et al., 2008). Several studies have shown that individuals with MS have shorter stride lengths, a longer duration in dual support phase, greater leg asymmetry and lower knee extensor power, and a reduced speed of progression while walking (Benedetti et al., 1999; Chung et al., 2008; Givon et al., 2008; Martin et al., 2006; Sacco et al., 2010). Givon et al. (2008) also found that MS individuals preferred using a wider base of support during walking then their control counterparts. Van Emmerik et al.(2010) documented loading asymmetries between the dominant and non-dominant legs during standing posture in individuals with MS. It has also been shown that individuals with MS have a slower gait initiation velocity, smaller center of pressure shifts, and spent longer time in dual support phase during the gait cycle then their control counterparts (Remelius et al., 2008). Martin et al. (2006) found that individuals with MS walk with limited ankle motion and altered ankle muscle recruitment of the Tibialis Anterior and the Medial Gastrocnemius muscles. Gehlsen et al. (1986) found that individuals with MS had reduced knee and ankle joint rotation, less vertical lift of the center of gravity, and greater trunk lean when compared to controls. Increased levels of kinematic gait variability of the hip, knee, and ankle were found in individuals with MS when compared to controls at preferred speed, but not seen while walking at different speeds (Crenshaw et al., 2006).

One of the larger gaps in the MS walking literature is that most of the studies have compared individuals with MS to other populations only at their preferred walking speeds, and have not examined how the gait parameters may change due to different speeds or under different gait conditions. It is possible that by using a different gait condition, some of the normal compensatory mechanisms used by individuals with MS may not be as effective, allowing us to look more selectively at certain gait alterations. An intervention of Tai Chi Chuan slow walking may be an interesting gait condition to try as the gait is much slower, and may allow individuals to alleviate or reduce the severity of some of the most common gait alterations. By using components of Tai Chi Chuan as an intervention it may be possible to: improve preferred gait speed, reduce dual support times, increase stride length, reduce stride width, and increase somatosensory sensitivity (Cartmell, 2010; Mao et al., 2006B;Richerson &Rosendale, 2007; Wu et al., 2004).

1.2 Background on Tai Chi Chuan

Tai Chi Chuan is an ancient Chinese martial art that has been practiced in different styles dating back to its origin in 13th century China (Man-ch'ing, 1981). Tai Chi Chuan was created with an emphasis placed on the awareness of balance and breathing, and was based on the Yin and Yang ideas of whole body harmony. The original form of Tai Chi Chuan comprised 128 different movements, but was later broken down by grandmaster Cheng Man-ch'ing into a condensed 37 movement form for beginners (Man-ch'ing, 1981).

There are three main styles of Tai Chi Chuan; Yang, Chen, and Wu. Yang style is characterized by deep stances and very slow movements; Chen style is characterized by moderately deep stances with both fast and slow movements; and Wu style is characterized by the most upright stance of the three, with a shorter stance width and a forward lean to the body (Cartmell, 2010). Both the short and long forms of Tai Chi Chuan incorporate fluid movements that involve slow arm, foot, and torso displacements. These movements gradually increase the practitioners' strength and spatial awareness, as the movements are traditionally performed from a semi-crouch to lower the center of gravity and improve stability (Man-ch'ing, 1981). It has been shown that practicing Tai Chi Chuan may be beneficial to one's health by increasing lower limb muscular strength, increasing reflex reaction times (Gatts et al., 2008), reducing fear of falling (Sattin et al., 2005), and improving overall balance and postural control, as reported in diverse populations (Au-Yeung & Hui-Chan, 2009; Hackney & Earhart, 2008).

1.2.1 Tai Chi Slow Walking

In the regular practice of Tai Chi Chuan one of the common exercises is walking with Tai Chi Gait also known as Tai Chi slow walking (See Figure 1). This gait is performed from a deeply flexed knee position, and is made up of exaggeratedly slow single stance, dual support, and swing phases (Wu &Million, 2007). Tai Chi slow walking is performed from this flexed position with the emphasis placed on the slow fluid movements and precise foot placements, at a speed approximately ten times slower than normal walking (Wu et al., 2004). Wu and Hitt (2005), in a comparison of Tai Chi slow walking versus slow normal walking, found that during Tai Chi slow walking initial foot contact forces were low, body weight was evenly distributed across the entire foot region as well as large mediolateral center of pressure (CoP) displacements. Mao et al. (2006A) also found that CoP excursions during Tai Chi slow walking (compared to slow normal walking) were predominately medial and posterior at initial foot contact, and significantly wider in the mediolateral direction during forward, backward, and sideways Tai Chi slow walking. It has also been found that Tai Chi slow walking has longer single stance durations, greater mediolateral excursions of the CoP, higher peak pressure and a longer pressure-time interval of the first metatarsal head and great toe compared to the same individuals' preferred normal walking speed(Mao et al., 2006B). Wu et al. (2004) found that Tai Chi slow walking had an overall longer cycle duration, longer single stance duration, larger joint movements of dorsiflexion/ plantar flexion, increased hip flexion and abduction, as well as a larger lateral body shift in comparison to normal gait. Wu and Ren (2009) found changes in the knee extensor muscles when Tai Chi Chuan movements were increased in speed; the knee extensor muscles performed more isometric contractions at the slower speeds whereas when the speeds increased the contractions became predominantly concentric and eccentric.

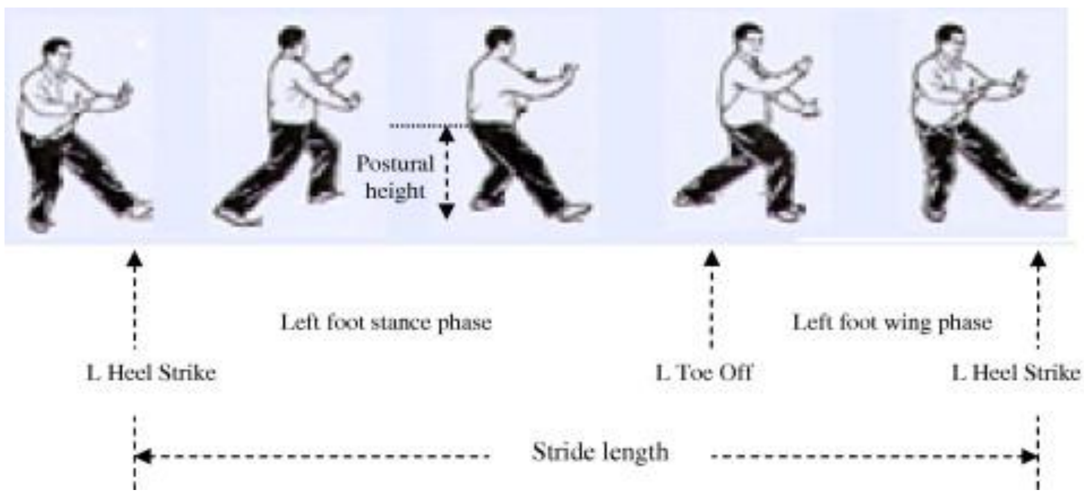

Figure 1: Example of Tai Chi slow walking while performing the hand movements for "Part the Wild Horses Mane." (Wu & Ren, 2009)

Tai Chi slow walking would be a beneficial task to use as an intervention for two reasons. First, Tai Chi Chuan is a gentle and flowing martial art that allows people of all body types and ages to perform the movements safely and comfortably (Cartmell, 2010). Second, while practicing Tai Chi slow walking, the practitioner spends a longer duration in single support stance throughout the gait cycle when compared to normal walking (Wu et al., 2004).

By using the fact that Tai Chi slow walking forces people to spend more time in single stance, Tai Chi slow walking training might be an interesting way to try to alleviate the gait alteration of more time spent in dual support for MS individuals with mild gait impairments. While this adaptation of longer time spent in dual support phase in individuals with MS may increase stability, most people compensate for this longer dual support time by having a faster swing phase (Remelius et al., 2012). By increasing the velocity of the swing phase, this may actually cause the individual to become less balanced, and more likely to fall because of the increased velocity of the CoM towards the boundaries of stability.

1.2.2 Tai Chi Chuan Training in Special Populations

The beneficial impacts of Tai Chi Chuan training have been well documented in healthy elderly populations as well as populations with sensory impairments (Fong & Ng, 2006; Sattin et al., 2005; Xu et al., 2004). Some of the beneficial impacts reported in elderly populations which have occurred within (at most) 1 year of Tai Chi training have been: reduced fear of falling in an ambulatory elderly population, faster reaction times to perturbations with decreased muscular co-contraction, and increased plantar sensation (Gatts et al., 2008; Richerson & Rosendale, 2007; Sattin et al., 2005).

Some of the beneficial impacts that have been reported after 3 years or more of regular Tai Chi practice have been: Increased ankle, knee, and hip proprioception compared to age matched controls, comparable balance control to college students when dealing with reduced or conflicting sensory information, faster gastrocnemius and hamstring reaction times when compared to age matched controls, faster speed and accuracy at pointing and tracking stationary and moving targets, less knee joint positioning error when compared to college students, and increased cutaneous tactile sensitivity in long term practitioners comparable to college aged students (Fong et al., 2006; Fong & Ng, 2006; Kerr et al., 2008; Kwok et al., 2010; Tsang et al., 2004; Xu et al., 2003).

These beneficial impacts could all singularly increase participants' stability and balance. Asano et al. (2009) argued that a more comprehensive intervention program for individuals with MS is needed, and Tai Chi Chuan would certainly be a comprehensive mix of aerobic exercise, flexibility, strength training, and most importantly balance training.

However, it is still unclear as to whether similar benefits may be seen in populations with a wide variety of motor and sensory impairments such as MS. Individuals with MS may display numerous impairments similar to aging populations, diabetic neuropathies, and stroke patients, all populations where Tai Chi Chuan has been used effectively as an intervention program. It is best to start small, so I propose starting with a shorter, three week long Tai Chi slow walking intervention to document any changes to static and dynamic balance. Improvements in static balance would be shown by: decreased postural sway, a smaller sway area, and increased plantar mechanoreceptor sensitivity. Improvements in dynamic balance would be shown by: decreased postural sway, an increase in preferred gait speed, reduced time spent in dual support, increased plantar mechanoreceptor sensitivity, longer stride lengths, and shorter stride widths. These changes will be considered improvements if they occur not only in the post intervention Tai Chi slow walking, but also in the post intervention slow normal or preferred walking conditions.

1.3 Purpose of Master's Thesis

The purpose of this study is to determine if a three weeklong Tai Chi standing meditation and Tai Chi slow walking intervention helps to improve static and/or dynamic balance control in individuals with MS.

Rationale: One week with 15 minutes per day was found to be the minimum amount of time that it would take to teach a healthy individual Tai Chi slow walking (Wu et al., 2004). After consultation with three Tai Chi instructors, it was determined that practicing for 15 minutes for one week may not be enough time to become proficient at Tai Chi slow walking in a population like MS. The amount of training time for practicing the Tai Chi standing meditation and Tai Chi slow walking was therefore increased to nine training sessions each lasting 1 hour in duration which would occur on Mondays, Wednesdays, and Fridays during the three intervention weeks.

Balance and gait impairments have a large effect on the quality of life in individuals with MS. Most of the studies focusing on altered gait parameters in MS populations have examined the differences between the preferred walking speeds of individuals with MS and controls (Benedetti et al., 1999; Martin et al., 2006). Eve et al. (2011) have shown that these same gait alterations in MS populations occur at a variety of gait speeds, and these impairments are especially pronounced as gait speeds become slower. By retraining the body to alleviate some of these gait alterations, balance and stability may increase in MS individuals with mild gait impairments. Tsang and Hui-Chan (2004) found that a four week intensive Tai Chi intervention improved balance control in an elderly population, by improving directional control of CoP movement during different leaning conditions as well as during conflicting sensory conditions. Au-Yeung and Hui-Chan (2009) found that a 12 week Tai Chi intervention improved standing balance in individuals with chronic stroke, both during self-induced perturbation tasks as well as during conflicting sensory conditions. Increased dynamic balance was seen in healthy individuals with a year of Tai Chi training, found by increased gastrocnemius and hamstring reaction times, and better knee joint repositioning (Fong & Ng, 2006).

1.3.1 Specific Aims

Specific Aim #1: Does static balance change after a Tai Chi Chuan intervention in individuals with MS? We hypothesize that: Static balance will improve after a Tai Chi Chuan intervention, shown by:

a.) A decrease in CoP variability and path length in quiet stance after the Tai Chi intervention.

b.) A decrease in CoP variability and path length in tandem stance after the Tai Chi intervention.

c.) A decrease in CoP variability and path length in Tai Chi standing meditation after the Tai Chi intervention.

Specific Aim #2: Does dynamic balance change after a Tai Chi Chuan intervention in individuals with MS? We hypothesize that: Dynamic balance will improve after a Tai Chi Chuan intervention, shown by:

a.) Increased Gait Speed during preferred walking b.) A longer duration spent in single support phase and a shorter duration spent in dual support phase during Tai Chi slow walking after the Tai Chi intervention.

c.) A longer duration spent in single support phase and a shorter duration spent in dual support phase during slow normal walking after the Tai Chi intervention.

d.) Increased knee joint flexion during Tai Chi slow walking after the Tai Chi intervention.

e.) Reduced TtC measures in preferred speed walking after the Tai Chi intervention.

f.) Reduced TtC measures in Tai Chi slow walking after the Tai Chi intervention.

Rationale: Wu et al. (2004) found that during Tai Chi slow walking individuals spent a longer duration in single support stance, and also had a large lateral CoP displacement when compared to their normal walking. Research has shown that individuals with MS have a faster swing phase to allow for more time spent in dual support phase, as well as larger CoP displacements (Remelius et al., 2012).

Specific Aim #3: Does plantar sensation change after a Tai Chi Chuan intervention in individuals with MS? We hypothesize that: Plantar sensation will improve after a Tai Chi Chuan intervention, shown by:

a.) Improved plantar sensitivity to pressure after the Tai Chi intervention as measured by the Von Frey Filaments.

b.) Improved plantar sensitivity to vibration after the Tai Chi intervention measured by the Biothesiometer.

Rationale: A pilot study by Richerson and Rosendale (2007) found that both healthy elderly and elderly adults with diabetes and plantar sensory losses showed significant improvements in cutaneous plantar sensitivity after a six month Tai Chi intervention.

Specific Aim #4: Are there any effects on fatigue and physical functionality after a Tai Chi Chuan intervention in individuals with MS? We hypothesize that: Overall functionality will improve after a Tai Chi Chuan intervention, as shown by:

a.) Improved psychological well-being scores as measured by the Multiple Sclerosis Impact Scale after the Tai Chi intervention.

b.) Decreased general and leg fatigue as measured by the Fatigue Severity Scale after the Tai Chi intervention.

c.) Faster time to complete Chair raises and 25ft walk after the Tai Chi intervention.

d.) Increased neural drive will occur as measured by increased number of Toe taps completed in 15 seconds after the Tai Chi intervention.

1.4 Significance of Master's Thesis

The proposed study would be significant because this intervention of Tai Chi slow walking would attempt to increase balance and stability in individuals with MS by reducing the amount of time spent in dual support phase during walking. Tai Chi slow walking has many similar components to normal walking, but has slight differences that would allow it to be a safe and effective intervention. During regular walking, approximately 75% of the gait cycle is spent in single support and swing phase, with only about 25% spent in dual support (Cuccurullo et al., 2004). In Remelius et al. (2012) it was found that at their preferred speed individuals with MS spent about 36% of time in dual support and 64% in swing and stance phase throughout the gait cycle, compared to the matched controls who spent respectively 32% of time in dual support and 68% in swing and stance phase. By either reducing the amount of time spent in the dual support phase, or by reducing the swing leg velocity by using a Tai Chi slow walking intervention you may increase balance and stability in MS individuals with mild gait impairments.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of MS

MS is a neurological disorder which causes the demyelination of neurons within certain areas of the brain. This demyelination, as shown in Figure 2, is the breakdown of the myelin sheath surrounding the neuronal axon, causing the electrical impulses to be either disrupted or stopped. It is unknown why demyelination begins, but the current thought is that MS is an autoimmune disorder where the body suddenly begins to attack its own myelin sheaths (National MS Society, 2006A).

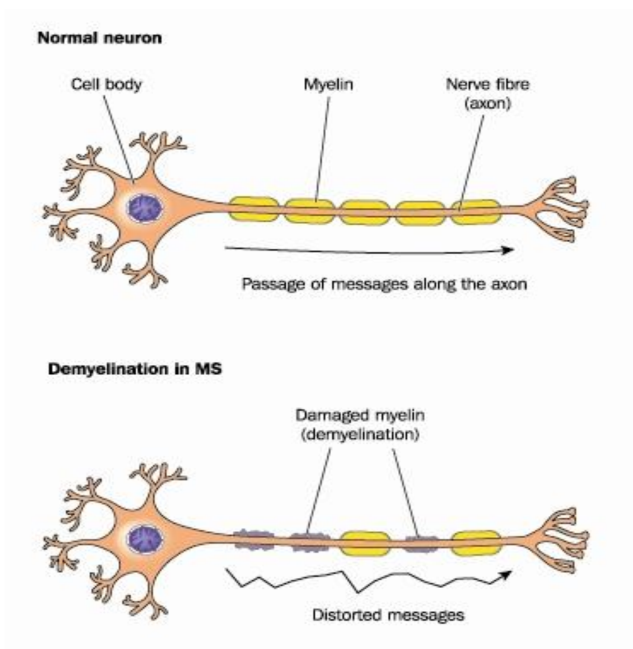

Figure 2: Neuronal Demyelination in MS (SickKids Research Institute, 2012)

Groups of these damaged neurons are called lesions, which are sites of inflammation that occur within the CNS (National MS Society, 2006A). A range of symptoms can occur, depending on where lesions are located. The etiology of MS is unknown, but some of the most common symptoms are: optic neuritis, fatigue, muscular weakness, cognitive impairment, coordination and balance impairments, pain, spasticity, numbness, dizziness, and vertigo (National MS Society, 2006A). While this is only a list of the most common symptoms, most MS symptoms can be broken down into either sensory or motor categories.

2.1.1 Sensory Symptoms of MS

Functional systems that are especially challenging to the MS patient include the visual, vestibular, and somatosensory systems. Impairments of the visual system often result in optic neuritis, blurred vision, diplopia or oscillopsia (Roodhooft et al., 2009). Nearly half of individuals with MS develop optic neuritis, and for 15-20% it is the initial event that leads to a MS diagnosis (Arnold et al., 2005). Vision impairment in MS is associated with poorer performance on visual, non-visual, and motor based tests (Feaster & Bruce, 2011).

Should the vestibular system be impacted, vertigo, dizziness, and equilibrium issues may arise (Achiemere et al., 2006; Degirmenci et al., 2010). Another common vestibular impairment of MS is nystagmus, characterized by inconsistent rates of tracking an object with the eyes. Nystagmus occurs because of a lesion in the central vestibular system, and in one study of 82 MS patients, 60% of the entire participant population had either nystagmus of a single eye or both eyes (Dam et al., 1975).

Impairments in the somatosensory system present unique symptoms, including paresthesias, numbness, and altered sensation (Heron et al., 1989; Sanders & Arts, 1986). Naturally, somatosensory impairments interfere with the ability to detect touch, pressure, and vibration as well as muscle stretch and tension. It has been proposed that the somatosensory losses may be due to slowed nervous impulse conduction in the spinal cord (Cameron et al., 2008). In a study of 127 patients with MS, 40% indicated paresthesia (loss of feeling or numbness) was one of the symptoms from the time of onset, and 84% had paresthesia as a symptom by the time the study began (Sanders & Arts, 1986). In MS patients with plantar somatosensory loss, lower limb muscles have higher activation levels during locomotion; this is thought to be a compensatory mechanism to increase stability because of sensory loss (Thoumie & Mevellec, 2002). In one study looking at the effects of experimentally induced plantar insensitivity in healthy controls, researchers found that during a self-selected walking speed the contact times and duration of contact increased when plantar sensation was dulled, while the force pressures under the foot were redistributed (Taylor et al., 2004). Sensory system impairments present in MS certainly have the potential to cause complications in sensing the environment as well as performing the movements being performed by the individual. The functionality of an individual with MS then depends on how their sensory and motor impairments interact to affect the overall system.

2.1.2 Motor Symptoms of MS

The motor systems in the CNS are also at risk for inflammation and demyelination due to MS. The most notable motor impairments due to MS include muscular weakness, spasticity, and fatigue (Van der Kamp et al., 1991). In MS, muscular weakness and fatigue are two of the most common and debilitating motor symptoms (Freal et al., 1984). Chung et al. (2008) found that individuals with MS have a greater power asymmetry of the knee extensor muscles when compared to controls, which may affect symptomatic fatigue and postural stability. Carroll et al. (2009) suggest muscular weakness is not really an impairment of the muscle, and that MS patients have similar fiber-type amounts as unaffected counterparts. Instead, it is proposed that muscular weakness may occur from reduced motor unit firing rates, decreased motor unit recruitment, and overall increases in the motor conduction times (Garner & Widrick, 2003). Ng et al. (2004) also found that weakness and walking impairments may be caused by central activation impairments upstream in individuals with MS, but not fatigue. Rice et al. (1992) found that, while healthy controls could activate their muscles maximally, MS participants rarely were able to voluntarily activate higher than 60% when trying to achieve maximal activation. Therefore, the problem may be caused by CNS complications upstream of the muscle.

Two other motor symptoms that MS patients may experience include spasticity and clonus. Spasticity is defined as a velocity dependent hyperactivity of stretch reflexes, while clonus is a series of involuntary muscle contractions and relaxations of the flexion reflexes and extensor plantar reflexes (Ashby et al., 1987; Hinderer and Dixon, 2001). Spasticity is usually caused by lesions of the upper motor neurons, which contribute to increased excitability within the spinal cord (Young & Wiegner, 1987).

Fatigue is one of the most difficult symptoms of MS to study, because it is hard to quantify. Many studies have used qualitative measures to try to document the fatigue of their participants, but even this can be difficult as fatigue can be both mental and physical. The Fatigue Severity Scale is one questionnaire that has been used to document fatigue in individuals with MS (Johnson, 2008).

2.2 Balance and Postural Control

The sensory and motor complications due to MS have the potential to manifest in impaired balance. Balance is determined from a relationship between the masses of the body segments and the area enclosed by the feet (Figure 3). The center of mass (CoM) represents the average masses of individual body segments, condensed into a point in three dimensions at the center of the overall body mass (Shumway-Cook &Woollacott, 1995). The CoM is not stationary, but moves depending on the movement and orientation of the limbs, allowing the body to remain stable during different situations. For example, when walking, the CoM makes a sinusoidal movement, with a vertical increase during toe off and a vertical decrease during the heel strike phase of walking. Besides the CoM, another measure that is regularly used is center of pressure (CoP). The CoP is the average point application of the ground reaction forces between an individual's two feet during dual support. (During single support stance the CoP is located underneath the standing foot.) Often, the CoM is referenced relative to the boundaries of stability, defined as the area enclosed by the feet. Naturally, wider stances increase the stability boundaries, while smaller stances serve to decrease the stability boundaries (Saunders et al., 1953). Taken together, balance is considered present when the CoM is within the boundaries of stability.

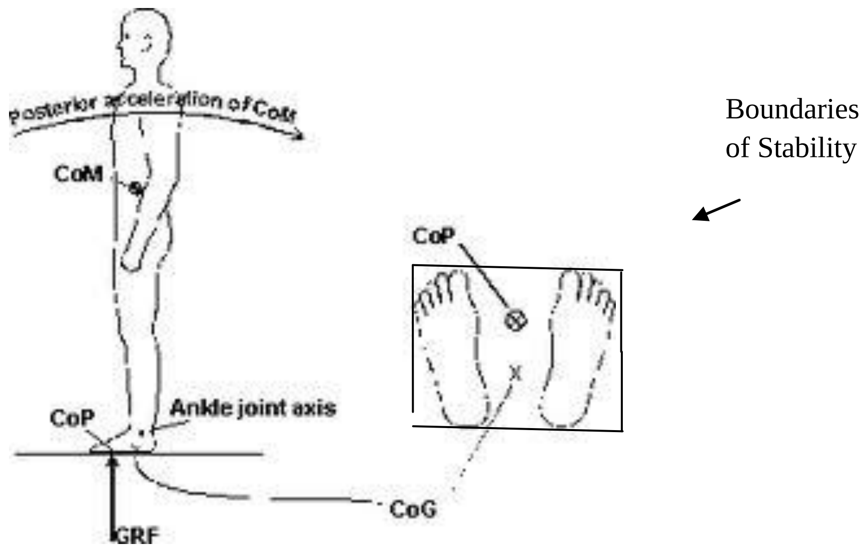

Figure 3: Maintenance of Balance in Relaxed Bipedal Standing (Kirby, 2002). While standing in quiet stance the Center of Pressure (CoP) which is the averaged point of ground reaction force pressure from under both feet is located just anterior to the ankle joints. The Center of Gravity (CoG) in this image is the vertical projection of the Center of Mass (CoM) on the ground; as long as the CoM stays within the Boundaries of Stability (BoS) the person is stable.

In everyday static activities, the CoM tends to stay within the boundaries of stability, allowing the body to stay upright and stable, but there are several factors that may contribute to the CoM progressing outside the stability boundaries. Walking or dynamic activities cause sudden increases in CoM velocity to project the CoM towards the boundaries at a high rate, requiring the body to actively slow the CoM down. The displacement of the CoM also plays a role, as greater displacements toward the boundaries signify a decreased level of balance. Therefore, if the CoM is well within the boundaries and moving at a slow velocity, one is said to have a greater level of balance than if the CoM is close to the boundaries traveling at a faster velocity. The concept of time to contact (TtC) helps to identify this relationship, describing the time (based on the position and velocity) that it will take the CoM to cross the stability boundary (Carello et al., 1985). Lower TtC values indicate a greater level of intervention required to redirect the CoM within the boundaries, while higher TtC values indicate less of a challenge to balance. In one study comparing TtC between healthy young adults, healthy older adults, and elderly fallers when walking at a preferred speeds, it was found that elderly fallers had significantly decreased TtC at heel strike when compared to their healthy peers and healthy young adults (Lugade et al., 2010).

Depending on the criticality of the impending loss of balance, the body has a variety of postural control methods by which it attempts to maintain the CoM within the stability boundaries (Horak et al., 1987). Shumway-Cook and Woollacott (1995) define postural control as one's ability to control the body's position in space to maintain stability and an upright orientation. For the body to maintain postural control during different situations, the body takes in information from the sensory and the motor systems to judge stability and body orientation at any given time (Shumway-Cook & Woollacott, 1995). Several postural control strategies have been identified, including the ankle, hip, and stepping strategies that the body can use to regain postural stability during upright standing (Horak & Nashner, 1986). An ankle strategy is used during small perturbations to adjust the body back to equilibrium by making small dorsiflexion or plantar flexion ankle movements, allowing the CoM to adjust anteriorly or posteriorly from the edge of the boundaries of stability back to the middle (Shumway-Cook & Woollacott, 1995.) Hip strategies are used when a larger or faster perturbation occurs, especially when on an uneven support surface; in this strategy the hips will make a rapid anterior or posterior adjustment to maintain equilibrium by moving the CoM away from the edge of the boundaries of stability and back into the middle (Horak & Nashner, 1986). The stepping strategy usually occurs when the CoM is no longer within the boundaries of stability; when a large or fast perturbation occurs the body will take a step to expand the boundaries of stability to incorporate the new CoM position (Shumway-Cook & Woollacott, 1995).

2.2.1 Balance and Postural Control in individuals with MS

Increased postural sway (i.e., displacement of the CoP) has been documented in MS participants with sensory and motor impairments, which may increase an individual's risk of falling (Daley et al., 1981; Finlayson et al., 2006). Frzovic et al, (2000) found that individuals with MS had reduced balance compared to controls, as shown by reduced times in how long they maintained tandem stance (heel to toe), standing on a single leg, and functional reach tasks. Van Emmerik et al. (2010) showed that individuals with MS during static tasks have increased postural CoP variability, greater loading asymmetries, as well as faster TtC times. During dynamic tasks individuals with MS have smaller CoP shifts and reduced stability in the direction perpendicular to their lean or reach. Karst et al. (2005) found that minimally impaired adults with MS restrict their CoP movements during reaching and leaning tasks, allowing them to stay within their reduced limits of stability.

Though the interactions are complex and the mechanisms are still relatively unexplored, there exists evidence suggesting unique contributions from each sensory and motor system towards postural control. It has been shown that loss of usual vestibular input will affect stability, even if regular visual and somatosensory input is present (Black et al., 1983). This could have large consequences for balance in MS populations with vertigo or other vestibular impairments. While vestibular impairments are not commonly documented in the MS population, they can be difficult to diagnose because of the numerous sensory and motor impairments that occur which create similar symptoms to that of a vestibular impairment (Nelson et al., 1995).

With somatosensory impairments, increased hip strategies are used to maintain equilibrium, whereas vestibular impairment has been shown to result in a lack of hip strategy in healthy populations (Horak et al., 1990). Merchut and Gruener (1993) found that the most common somatosensory impairments in MS were insensitivity to thermal changes and greater difficulty in sensing vibration. Meh and Denslic (2000) found that these abnormalities of thermal sensation and vibratory insensitivity in individuals with MS were positively correlated. Daley and Swank (1981) found that visual impairment in MS populations resulted in increased anteroposterior sway, even if overall impairment level was minimal as measured by the Romberg Neurological test. Rougier et al. (2007) found that individuals with MS who had proprioceptive losses were able to compensate by using more efficient control strategies if visual information was available.

2.2.2 Fall rates in the MS Population

Individuals with MS often have impaired balance when compared to healthy counterparts; it is because of these potential balance complications that they have a greater likelihood of falling (Soyuer et al., 2006). Shumway-Cook and Woollacott (1995) define a fall as when the CoM is displaced outside of the base of support, to the extent that ankle, hip, and stepping strategies cannot work to prevent a collision with the ground. Individuals with neurological disorders are twice as likely to fall then their age-matched control peers (Stolze et al., 2004). MS is no different. Finlayson et al. (2006) determined that over 50% of MS patients experienced a fall within a six-month time period. It is conceivable that as the self report Expanded Disability Severity Scale (sEDSS) score of MS patients increases, so does their risk of falling. The sEDSS is an overall measurement of symptoms and disability in MS, and an sEDSS score over three indicates gait impairments as well as other motor and sensory symptoms that may affect stability during static and dynamic tasks. This notion is supported by Nilsagard et al. (2009). Because of the high prevalence of falls and fear of falling in MS, a treatment needs to be found that can address the balance issues more adequately compared to purely educational programs aiming to reduce risk factors (Finlayson et al., 2009).

2.2.3 Rehabilitation and Training in MS

Several different types of rehabilitation training protocols have been used in the MS population, most of which include exercise to help improve gait impairments in MS. Motl et al. (2005) performed a meta-analysis, documenting that individuals with MS were less physically active then non-MS populations. Ng and Kent-Braun (1997) supported that finding when they documented that individuals with MS were less physically active when compared to sedentary control participants. Several studies have supported the notion that increasing the amount of daily physical activity is beneficial to both the physical and psychological quality of life in individuals with MS (Motl et al., 2005; Ng et al., 1997).

Prakash et al. (2009) documented that individuals with MS who participated in regular aerobic physical activity had increased amounts of gray matter in the midline cortical structures, and faster processing speeds compared to those (with MS) who did not regularly exercise. Wahls et al. (2010) documented faster 25 ft walk times and decreased spasticity in individuals with secondary and primary progressive MS after nine months of daily electrical stimulation of the lower leg muscles. Sosnoff et al. (2009) found after a four week unloaded cycling rehabilitation program that individuals with MS perceived decreased spasticity, as was documented by lower Multiple Sclerosis Spasticity Scale (MSSS-88) scores (this decrease was not found electro-physiologically or clinically). Prosperini et al. (2010) found that after a six week training period individuals with MS who practiced static and dynamic exercises had improved 25ft walk times compared to controls, as well as a significant reduction in the risk of falls in single leg stance with both eyes open and closed.

After a review of eleven different exercise interventions for MS (studies were broken into these four categories: aerobic, flexibility, strengthening/resistance training, or yoga), Asano et al.(2009) concluded that while each program has its own benefits what is really necessary is an exercise intervention which integrates all four categories into one program. Benefits have been documented in each of these four intervention exercise categories, but a more comprehensive exercise intervention is needed that integrates aerobic exercise with increasing overall flexibility, strength, and balance. One intervention that may have great benefits to both static and dynamic balance in individuals with MS would be Tai Chi Chuan.

Husted et al. (1999) found increases in 25ft walking speed, hamstring flexibility, and psychosocial well-being after an 8 week Tai Chi intervention in individuals with MS. (Psychosocial well-being for this study was measured with a Medical Outcomes Study 36 item short form healthy survey.) Unfortunately there has not been any more recent studies published using Tai Chi as an intervention for individuals with MS.

2.2.4 Improvements in populations other than MS using Tai Chi

Tai Chi Chuan as an ancient Chinese martial art has been used for many years as a way to maintain flexibility and aerobic capacity. The gentle flowing movements have made it a very adaptable and efficient exercise for a wide range of people. Regular Tai Chi Chuan practice has been shown to benefit the healthy elderly population. Fear of falling in ambulatory elderly populations (ages 70-97) was significantly reduced after 12 months of a Tai Chi intervention (Sattin et al., 2005). Fong et al. (2006) found that Tai Chi Chuan practitioners with more than three years experience had decreased reaction times of their gastrocnemius and hamstring muscles compared to age matched controls. (A Tai Chi Chuan practitioner is the title for an individual who practices Tai Chi Chuan regularly). Increased proprioception in the ankle and knee joints in a population of elderly (age 65 or older) Tai Chi Chuan practitioners has been documented (Tsang & Hui-Chan, 2004). It has also been shown that long term Tai Chi Chuan practitioners have increased proprioception compared to long term elderly runners and long term elderly swimmers (Xu et al., 2003). One study by Fong and Ng (2006) found that elderly long term Tai Chi Chuan practitioners (1-3 years) had significantly less knee joint repositioning error when compared to healthy college age non-Tai Chi Chuan individuals. A group of elderly long term Tai Chi Chuan practitioners also had faster speed and better accuracy at pointing and tracking stationary and moving targets then their age matched counterparts (Kwok et al., 2010). Besides balance improvements it seems that there are a large number of physiological benefits that occur with a regular Tai Chi Chuan practice in elderly populations.

Many benefits have been shown with a regular Tai Chi Chuan practice in healthy elderly populations, but it is likely that populations with neurological disorders may experience similar benefits. Gatts et al. (2008) found that in a group of older individuals with a history of back, hip, and knee surgeries, a three week Tai Chi Chuan training program resulted in faster ankle neuromuscular responses to perturbations as well as a reduction in perturbed muscle co-contraction. In a study on Type 2 diabetic individuals, increased peripheral nerve conduction velocities were seen after only 12 weeks of Tai Chi Chuan practice (Hung et al., 2009). A pilot study from 2007 found that diabetic participants had improved balance and plantar sensation after only 6 months of a Tai Chi Chuan program (Richerson & Rosendale, 2007). Increased plantar sensation was also seen in 25 individuals with peripheral neuropathies after a 24 week Tai Chi intervention (Li et al., 2010). A study looking at the impact of a 3 month Tai Chi Chuan training program on participants with mild-moderate Parkinson's disease showed faster times in clinical measures such as: the 6 minute walk, timed up and go, and backward walking

(Hackney & Earhart, 2008). Chronic stroke patients who learned the short form of Tai Chi Chuan for 12 weeks had improved standing balance, and were able to have a larger CoP displacement when leaning forward compared to non-Tai Chi stroke controls (Au-Yeung & Hui-Chan, 2009). It seems possible that many other neurological disorders that have symptoms such as balance problems, decreased sensory abilities, and decreased proprioception, may be alleviated or at least modified by a Tai Chi Chuan rehabilitative intervention.

Even short duration Tai Chi Chuan training appears to have a beneficial effect on populations with neurological disorders such as: faster reaction times with less muscle co-contraction during perturbations, increased standing balance, and increased plantar sensation (Gatts et al., 2008; Hung et al., 2009; Richerson & Rosendale, 2007). And as many of the symptoms of MS are similar to the symptoms of these special populations, it is possible that a Tai Chi Chuan intervention may be as beneficial to balance and mobility in individuals with MS as some of the populations listed above.

2.2.5 Alternative Medicine Interventions in MS populations

Balance improvements were seen for single leg stance times and BERG balance scores after six "mindfulness movement" training sessions. Individuals were then given an audiotape and videotape to continue their own practice before a final follow up after 3 months where these same balance improvements were maintained (Mills & Allen, 2000). After a six month Iyengar yoga intervention, significant improvement in measures of fatigue were found when compared to a waiting list MS control group (Oken et al., 2004).

After 8 weeks of Feldenkrais sessions lowered stress and anxiety were reported in individuals with MS, with non-significant trends towards increased self-efficacy (Johnson et al., 1999).

CHAPTER 3

METHODOLOGY

3.1 Introduction

To report if Tai Chi Chuan helps to increase balance and mobility in individuals with MS, I propose completing a short intervention study. This intervention would consist of an initial data collection, followed by a three week group training period, and a final data collection. (See Figure 4) The initial and final data collections will be held at the UMass Biomechanics lab, while the group training sessions will be located at “Studio Helix” in Northampton. At the initial and final data collections both kinematic and kinetic data will be collected to document any changes in balance and mobility post intervention. The nine training sessions will consist of a 10 minute video explaining how to perform Tai Chi standing mediation and Tai Chi slow walking followed by 50 minutes of practice time. As an extra precaution, a “Check in Days” will be held at the beginning of each weekly training period where participants will be assessed by a Tai Chi instructor as to their ability to perform Tai Chi standing meditation and Tai Chi slow walking.

Initial Data Collection (2.5 Hrs, 1 Day)	Intervention			Final Data Collection (2Hrs, 1 Day)
	Week 1	Week 2	Week 3	
	M	M	M	
	W	W	W	
	F	F	F	

Figure 4: Tai Chi Intervention Diagram

3.2 Participants

All participants will be asked to read and sign a University Human Subjects Review Committee approved Informed Consent form (Refer to Appendix C). The study will consist of (n=12) MS individuals between the ages of 21 and 65 years. The decision to recruit twelve individuals is based upon restrictions of the Tai Chi studio where the Tai Chi intervention will take place. All participants will have no to minimal mobility impairments, as assessed through the Patient Determined Disease Steps (PDDS; Hohol, 1995). Participants will be excluded from the study if they have a PDDS score of greater than 3 (scores of 0-3 indicating minimal gait impairment), or if they have participated in a regular Tai Chi Chuan class within the past five years.

3.2.1 Recruitment

Before being accepted into this study participants will be screened with a Telephone Screening Form and the PDDS. The Telephone Screening form asks questions about patient demographics such as: contact information, age, height, body mass, current health status, past martial arts experience, MS subtype, physical limitations, current medications, current physical activity level, etc. If the participants fulfill all requirements to for recruitment, they will be contacted to schedule their initial visit to the collection facility (Refer to Appendix B for PDDS and Telephone Screening forms).

3.3 Research Design

This study will consist of an intervention, with a duration of three weeks, attempting to increase mobility and balance in people with MS by using Tai Chi standing meditation and Tai Chi slow walking. Twelve individuals with MS between the ages of 21 and 65 years will be recruited. The initial visit will consist of questionnaires, an assessment, and a 20 minute Tai Chi Chuan training period. All participants will read and sign the Informed Consent and will fill out a Fatigue Severity Score, an Expanded Disability Status Scale, and a Multiple Sclerosis Impact Scale-29. The assessment will include sensorimotor testing, a functional assessment, four static balance tests, and three gait tasks. At the initial visit participants will be given training in Tai Chi standing meditation and slow walking before completing the Tai Chi specific trials. On each Monday during the three week intervention the participants will also attend a "Group Check in Day." This "Check in" will be used as a time where each participant will be individually assessed in their competency at performing Tai Chi standing meditation and Tai Chi slow walking. At the first "Check in" the participants will be assessed by Tai Chi instructor Jeff Rosen, at the second and third "Check in" days the participants will be assessed by Tai Chi instructor Clint Hartzell. The final visit will consist of only the assessment portion of the initial data collection. All participants will have their final visit and training within three days of their 9^{th} training day (Refer to Figure 5).

Training will be given by an expert instructor, Jeff Rosen, who has been a long term practitioner of Tai Chi Chuan. The instructor will attend the initial visit to train participants in Tai Chi standing meditation and Tai Chi slow walking. Videotaped instructions will be used as the onsite source of instruction for the participants as they go through the three weeks of Tai Chi Chuan training. This video will provide the same information to each of the participants, and by having all the participants practice in Studio Helix we will be able to control the environment and instruction under which the participants will be practicing. The Tai Chi Chuan style that we will be using for this study will be Yang style. Yang style is the most commonly practiced style of Tai Chi in the United States. It also has the lowest and widest stances out of the three styles, which would potentially have the most benefit to individuals with MS to increase stance width and length, and increase lower leg muscular strength for stance depth (Cartmell et al., 2010).

Initial Data Collection (2 Hrs, 1 Day)	Intervention			Final Data Collection (2Hrs, 1 Day)
	Week 1	Week 2	Week 3	
I.)Questionnaires II.) Sensorimotor & Functional Assessment III.) Static Postural & Dynamic Gait Conditions IV.) Initial TCC training period	M (Check in Day)	M (Check in Day)	M (Check in Day)	I.) Sensorimotor &Functional Assessment II.) Static Postural & Dynamic Gait Conditions
	W	W	W	
	F	F	F	

Figure 5: Tai Chi Complete Intervention Diagram

3.3.1 Protocol

Participants will attend two data collection sessions that will occur three weeks apart and last for a duration of two hours. The initial visit will consist of a series of questionnaires and an assessment. All participants will read and sign the Informed

Consent Document and fill out a Fatigue Severity Score, self-reported Expanded Disability Severity Score, and a Multiple Sclerosis Impact Scale. The assessment will include sensorimotor testing, a functional assessment, four static balance tests, and three gait tasks (Refer to Figure 6).

Screening:

- Telephone Screening Form
- Patient Disability Disease Steps (PDDS)

Part I: Informed Consent and Questionnaires

- Informed Consent Document
- Fatigue Severity Score (FSS)
- Self Administered Expanded Disability Severity Scale (sEDSS)
- Multiple Sclerosis Impact Scale (MSIS-29)

Part II: Sensorimotor and Functional Assessments

- Assess Cutaneous Sensitivity (Von Frey Fibers and Biothesiometer)
- Timed Foot Taps
- Timed Chair Rises
- 25 ft Walk (Preferred speed)

Part III: Static Postural and Dynamic Gait Conditions

- Three Quiet Stance Trials
- Three Tandem Stance Trials (Repeated on both sides)
- Five Trials at preferred walking speed
- Five Trials at slowest possible normal walking speed (approximately.84m/s)
- 20 Minutes of Tai Chi Training with Instructor (Jeff Rosen)
- Three Standing Meditation Trials w/o Arms
- Three Standing Meditation Trials with Arms
- Five Trials of Tai Chi slow walking w/o Arms
- Five Trials of Tai Chi slow walking with Arms

Figure 6: Diagram of Tai Chi Study Protocol: parts I-III to be completed at Initial Data Collection, and parts II-III without 20 minutes of Tai Chi training to be completed at Final Data Collection.

3.3.2 Informed Consent and Questionnaires

After the Informed Consent document has been read and signed by the participant, three questionnaires will be administered. These three questionnaires will consist of a Fatigue Severity Scale (FSS; Krupp et al., 1989) a self-reported Expanded Disability Severity Scale (sEDSS; Kurtzke, 1983), and the Multiple Sclerosis Impact Scale-29 (Hobart et al., 2001).

The Fatigue Severity Score (FSS) was developed by Krupp et al. (1989) for use in individuals with MS or Lupus. This scale identifies the amount of fatigue that someone has on a regular basis. This questionnaire has been shown to be valid and reliable (Krupp et al., 1989). In addition to the original FSS, a Fatigue Severity Score that is specific to leg fatigue will also be used (Refer to Appendix D).

The Expanded Disability Status Scale (EDSS) was developed by Kurtzke et al. (1983) to give neurologists a way to qualitatively assess an individual's functional level with MS. The self-report version of this questionnaire (sEDSS) measures the perceived ambulatory ability of the MS participant, their perceived strength, perceived coordination, perceived sensation loss, bladder symptoms, vision symptoms, speech symptoms, swallowing symptoms, thinking/memory symptoms, and MS activity over time (Bowen et al., 2001). This scale has been proven to be valid and reliable (Gold et al., 2003; Kurtzke et al., 1983). (Refer to Appendix D.)

The Multiple Sclerosis Impact Scale (MSIS-29) is a self-report questionnaire that has been shown to be a valid and reliable way to document MS severity (Hobart et al., 2001; McGuigan & Hutchinson, 2004). The MSIS-29 consists of 29 questions that assess both the physical and psychosocial impact of MS (Hobart et al. 2001).

3.3.3 Sensorimotor and Functional Assessments

To assess cutaneous pressure sensation, Semmes-Weinstein monofilaments will be used (North Coast Medical, CA), and to assess cutaneous sensitivity to vibration a Biothesiometer will be used (Armstrong et al., 1998). The sensorimotor testing will be performed on the hallux, ball, arch, and heel of each foot. For the monofilament test, participants are instructed to indicate when and where they feel the filament touching their feet. For the Biothesiometer the participant will be instructed to indicate when they begin to feel the vibration from the different spots on their feet. Both the filaments and the Biothesiometer have been proven to be valid and reliable in healthy populations (Armstrong et al., 1998). Frederiksen et al. (1991) used a Biothesiometer in conjunction with MRI and electrophysiological measures to detect MS in patients who had been diagnosed with optic neuritis.

The Functional testing will include measuring the number of foot taps that can be completed within 15 seconds (a measurement of neural drive), the time it takes for the participant to complete 5 chair rises (a measure of muscular strength), and a timed 25ft walk at both preferred and brisk speeds (Kent-Braun & Ng, 1999; Buatois et al., 2008; Lusardi, 2003) (Refer to Appendix D).

A timed foot tapping exercise will be completed to test motor coordination (Kent-Braun et al., 1998; Larson et al., 2007). The participant will be asked to perform 15 seconds of consecutive foot tapping movements (foot flat, raising toe, back to foot flat; twice for each foot) and will be timed. Next, the participants will be timed while completing five consecutive chair rises. This activity has been used as a clinical measure of strength and balance ability, and has been proven to be valid and reliable (Whitney et al., 2005). One chair rise consists of the person beginning in a seated position with their arms crossed over their chest, standing, and then sitting back in a seated position without use of their arms for balance (Whitney et al., 2005). A 25 foot walk test will be used to test mobility and leg function in individuals with MS. For this measurement the participant will be timed as they walk for 25 feet. This measure is then repeated to get an average of the timed walking, and is performed at both a brisk and a preferred walking pace. This measure has been shown to be valid and reliable (National MS Society, 2006B).

3.3.4 Static Postural and Dynamic Gait Conditions

First, the static postural conditions will be performed; these will include three quiet stance trials followed by three tandem stance trials. For quiet stance participants will be instructed to align their feet comfortably under their hips, an equal distance apart, then to stand comfortably for 30 seconds with their eyes open, arms relaxed at their sides, while looking out in the distance. For the tandem stance trials participants will be asked to stand heel to toe on the forceplate, first with the dominant leg forward then with the non-dominant leg forward for30 seconds (Berg et al., 1989). Three trials with each foot forward will be taken. Tandem stance is a clinical measure used to assess postural sway with a narrow base of support in the medio-lateral direction (Jonsson et al., 2005).

Second, the dynamic gait conditions will be performed. First the participant will be asked to complete five trials at their preferred walking speed. Next the participant will be asked to complete five trials at the slowest normal speed that they would feel comfortable doing; these trials will be timed as the individual walks through the collection area. The participant’s average preferred walking speed and average slow normal walking speed will be retained. The slow normal walking speed average will be used as the speed they need to meet for their Tai Chi slow walking trials. Wu et al., 2004 found that 0.84 m/s slow walking speed was close enough to compare to the Tai Chi slow walking speeds. But from my pilot study on a healthy Tai Chi practitioner, it seems to make more sense to find the slowest normal walking speed that an individual feels comfortable moving at and using that as the bar for how slow their Tai Chi slow walking should be. This way each intervention would be individualized to that participant's comfort level, and we will still be able to see if there are improvements following the Tai Chi intervention (Improvements defined by changes in the person's measures that would show increased balance and/or mobility post Tai Chi intervention.).

Third, the participant will receive instruction for the two types of Tai Chi standing meditation (with and without arms) and the Tai Chi slow walking. For the three Tai Chi standing meditation without arms trials, the participant will be asked to align their feet comfortably under their hips, then will be asked to completely relax their body standing with the least amount of effort necessary, to relax their gaze, sink their shoulders, and lower their chin to maintain the correct standing meditation stance (Chuen, 2003). Participants will then be instructed to concentrate on the core of their body, with each inhalation imagining an inflating balloon, allowing their arms to move away from the body slightly, and with every exhalation imagining that same balloon to be deflating (Chuen, 2003) (Refer to Figure 7).

Figure 7: Tai Chi Standing Meditation (Without Arms): Northwest Fighting Arts 2012

For the three trials of Tai Chi standing meditation with arms, the standing body form will be the same as the previous paragraph. The arms will be held close to the body relaxed with the top hand (left) palm down while bottom hand (right) is palm up with arms rounded as if holding a ball. During inhalation the top hand (left) will be moved palm down to the left hip, while the bottom hand (right) rotates palm up to the right shoulder level. At the end of exhalation the person should have both arms extended, and as inhalation begins the top hand (right) becomes the new top hand while the hand at hip level becomes the new bottom hand for the rounded “holding a ball” position. As inhalation occurs the body weight is shifted minutely back towards the heels, while during exhalation the body weight is shifted minutely towards the midfoot (Refer to figure 7 for leg position during standing meditation with arms, and Figure 8 for arm movement during standing meditation with arms.).

Figure 8:Grasping Sparrows Tail Arm Technique (Ottawa Chinese Martial Arts Association; 2003) This technique will be used for the Standing Meditation with Arms, and this image also shows using "Grasp Sparrows Tail" while using Tai Chi slow walking.

Next, five Tai Chi slow walking trials will be performed on a10 meter walkway. Participants will be instructed to begin by standing in Tai Chi meditation and concentrating on their breathing for a few minutes. While maintaining the full body relaxation of Tai Chi standing meditation, participants will be instructed to slowly shift their body weight from being centered to their left foot (approximately 25% of the body weight on the right foot, and 75% on the left foot). The relatively unloaded right leg can begin by slowly bending at the knee until only the toes of the right foot are on the ground, with all of the body's weight being held by the left leg. Next the left leg bends as the right leg is extended forward with a gently placed heel contact. As the body weight is shifted to the right leg, the right foot goes through a gentle external rotation as the foot is slowly lowered to the ground which places the forefoot 45 degrees outward. At this time 75% of the body weight is being supported through the flat externally rotated right foot, while the toes of the left foot are supporting only 25% of the weight. From here the right leg bends as the left leg is brought up to meet the externally rotated right foot. Weight is held evenly between the two feet here, before the left leg is extended forward with a gently placed heel contact. As the weight is shifted slowly forward to the left foot the external rotation occurs again after heel contact, placing the forefoot 45 degrees to the left. Again, the right knee bends and the right foot is brought up to meet the externally rotated left foot where the weight is held evenly between the two feet. Progression forward in Tai Chi slow walking continues in shifting the weight slowly from foot to foot (as explained above), while the torso is relaxed, gaze is soft, and the upper body glides forward (Chuen, 2003). Arms are relaxed at the side during Tai Chi slow walking. Participants will be asked to at least meet their average slow normal walking speed for these five Tai Chi slow walking trials or to go slower if they can (At the initial data collection so far all participants have been able to walk slower with Tai Chi slow walking then their slowest normal walking speed).

Next, five trials of Tai Chi slow walking with arms will occur. The same gait as described above will be used with the only difference being the addition of the “Grasping Sparrows Tail” arm movement to match the gait. As shown in figure 8, you will see that as the feet are brought together the arms are in the rounded “holding a ball” position (which is also the inhale), when the foot is then placed forwards before the weight is shifted the arms are slowly fully extended to the sides (also the exhalation).

3.3.5 Tai Chi Intervention

The Tai Chi training sessions will occur on Monday, Wednesday, and Fridays over a total of three weeks. Training will consist of 1-hour sessions where the participant will watch an instructional video on how to perform the two types of Tai Chi standing meditation and Tai Chi slow walking, and will then have time to practice these skills. Approximately thirty minutes will be spent on practicing the two types of Tai Chi standing meditation and Tai Chi slow walking, ten minutes total will be given for the instructional video, and twenty minutes of break time will be given throughout the session (Refer to figure 9).

Tai Chi Training Sessions:

- 8:00-8:05am- Arrival time
- 8:05-8:10am- Video on two types of Standing Meditation
- 8:10-8:20am- Practice time for Standing Meditation with/without arms
- 8:20-8:25am- Rest break
- 8:25-8:30am- Video on Tai Chi slow walking
- 8:30-8:40am- Practice time for Tai Chi slow walking
- 8:45-8:50am- Rest break
- 8:50-9:00am- Free Practice time (work on areas where you feel you need more attention.)
- 9:00-9:05am- Class ends

Figure 9: Training Session Protocol

Wu et al. (2004) have shown that healthy individuals can learn Tai Chi slow walking proficiently with 15 minutes of practice time per day for one week. After consultation with three Tai Chi instructors, it was determined that practicing for 15 minutes for one week may not be enough time to become proficient at Tai Chi slow walking in a population like MS. The amount of training time for practicing the Tai Chi standing meditation and Tai Chi slow walking was therefore increased to nine training sessions each lasting 1 hour in duration every other day over a period of three weeks.

As an extra precaution, three “Check in days” will be held (on the Monday of each week) where the participants will receive individual feedback from one of the two Tai Chi Chuan instructors (Jeff Rosen or Clint Hartzell). On this day the participants will be expected to attend the regular training meeting for that day, and after that day’s training will be the group “Check in.” This “Check in” will be a time for the participants to be qualitatively assessed, to make sure that they are correctly learning the Tai Chi standing meditation and Tai Chi slow walking (Refer to the “Check in Day” Assessment located in Appendix D). This time will also allow the participants to receive more input and have their questions answered on accurately performing the Tai Chi standing meditation and Tai Chi slow walking.

3.4 Experimental Set Up

Kinematic data will be obtained by using a Qualysis Motion Capture System, with nine cameras collecting at 240Hz (Qualysis, Sweden). Average trial speeds will be measured by a ten meter optical trap; so that the slow normal walking speed and the comparable Tai Chi slow walking speeds can be recorded. Six calibration markers will be used, as well as a full body marker set up. The calibration markers will be applied to these anatomical landmarks: bilateral greater trochanters, medial/lateral malleoli, and medial/lateral knee. Second, the collection markers (which will be on for the entire data collection period) will be applied to: bilateral big toes, bilateral M1, bilateral M5, bilateral heel clusters, bilateral shank clusters, bilateral thigh clusters, bilateral ASIS, bilateral PSIS, sacrum, bilateral elbows, bilateral wrists, bilateral acromion processes, and a head piece with five markers on it (See figure 10) .

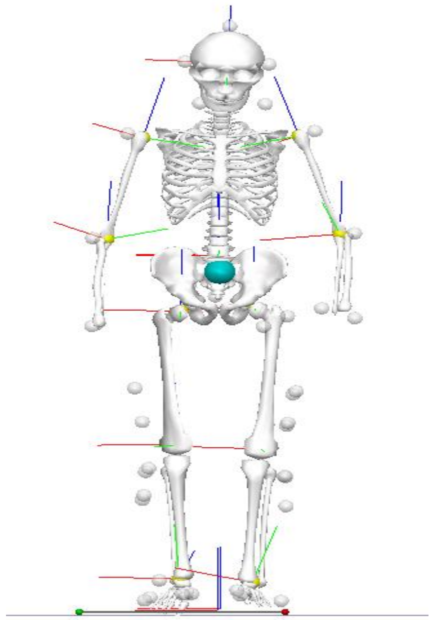

Figure 10: Tracking and Calibration Marker Positioning (Eve et al., 2011)

For the static postural trials, 3 trials will be collected for 20 second data collection periods. The static postural trials will include: quiet stance, tandem stance (leg with greatest neural drive in front), standing meditation with and without arms.For the dynamic gait trials, 5 trials will be collected at the participants preferred and slow walking speeds.

Kinetic data will be obtained by a series of 5 AMTI forceplates embedded in a 10m walkway (AMTI, Watertown, MA). These 5 strain gauge force platforms will be used to assess ground reaction forces and to obtain the CoM displacements during the different static postural and dynamic gait tasks (See Figure 11).

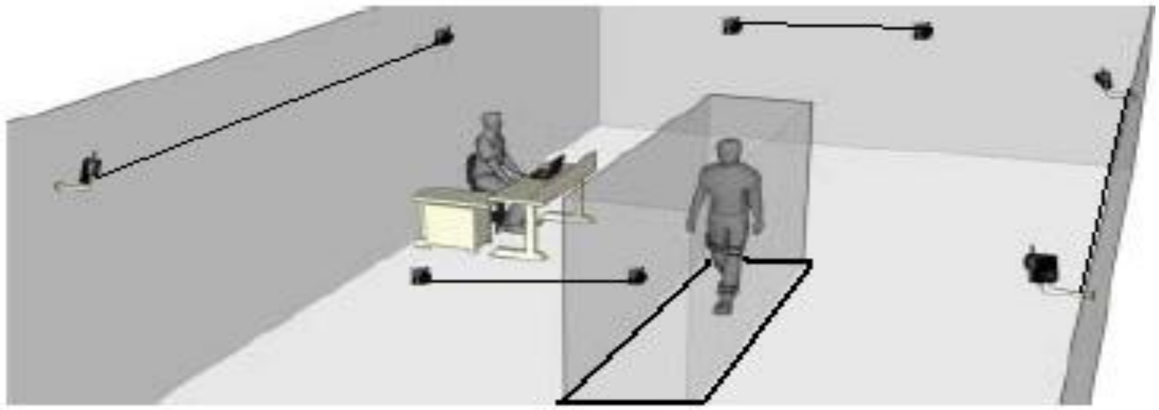

Figure 11: Qualysis Motion Capture System with eight Infrared Cameras (Eve et al., 2011)

Multiple trials will be recorded at each different gait condition to assess within-subject variability. At least five successful trials will be needed for the participant to progress to the next condition. A successful trial will consist of getting at least one foot to hit the AMTI forceplate in the walkway.

3.4.1 Data Analysis

A Qualysis tracking program will be used to track the markers and develop a computer simulation model of the participant's body. Kinematic and kinetic data were filtered using a 2^{nd} order Butterworth low-pass filter at 15Hz (Qualysis Inc; AMTI). A Matlab program was used to calculate the CoP parameters and marker trajectories as well as the trapezoidal BoS to find the TtC values for the static trials. For the dynamic gait trials the gait parameters (gait speed, single limb support, dual limb support, stride width, stride length, etc) were obtained using a "Gait Report" from Visual3D using the gait events gathered from the 5 force plates as well as the foot markers.

3.4.2 Statistical Analysis

For Specific Aim 1, t-tests will be used to compare the CoP parameters (average CoP area, average Path length, and average CoP displacement) and TtC data pre and post intervention for the quiet stance, tandem stance, and Tai Chi standing meditation trials. A separate t-test will compare the post intervention average quiet stance trials versus the post intervention average of Tai Chi standing meditation trials using the aforementioned CoP parameters.

For Specific Aim 2, t-tests will be used to analyze the pre and post intervention TtC data and gait parameter measures(such as :gait timing, gait speed, stride length, stride width, dual support, and swing time)for the preferred walking speed, normal slow walking, and for Tai Chi slow walking gait conditions. A separate t-test will be used to compare these same gait measures between post intervention normal slow walking and post intervention Tai Chi slow walking.

For Specific Aim 3, t-tests will be used to analyze the pre and post intervention measures of Von Frey Fibers and Biothesiometer measurements and quantify if any changes have occurred in plantar sensation after a Tai Chi intervention.

For Specific Aim 4, both the FSS and MSIS-29 questionnaires will be scored and paired T-tests will be used to compare the pre and post intervention scores of both questionnaires to quantify any changes after having taken part in the intervention. T-tests will also be used to quantify changes in the pre versus post intervention measures in the functional assessments such as: chair rise timing and number of Foot Taps produced in a 15 second period.

CHAPTER 4

MODIFICATIONS TO THESIS PROPOSAL

4.1 Modifications

As the study progressed some modifications needed to be made to the thesis proposal to bring it up to date. These modifications are listed below:

4.1.1 Modifications to Specific Aims

For Specific Aim #1, instead of assessing static postural control by the standard deviation of the COP, net CoP excursion and average CoP velocity were calculated. The variable of net CoP excursion was calculated by finding the total path length of the CoP during the 20 second data collection period; this total CoP path length was averaged across all directions as well as medio-laterally and antero-posteriorly. Average CoP excursion and velocity were used instead of the standard deviation of the CoP because the literature indicated that COP velocity and excursion variables are more widely used to quantify postural control in specialized populations (Mancini et al., 2012; Ruhe et al., 2010)

For Specific Aim #2, instead of assessing dynamic balance during preferred speed walking and Tai Chi slow walking, dynamic balance was assessed during preferred speed and slow normal walking. Tai Chi slow walking is a gait all of its own, and any benefits found during Tai Chi slow walking would show that the participants had learned to perform the task without giving additional information about potential changes to preferred or slow normal walking. Even if more time were spent in Tai Chi slow walking in single leg support after the intervention, this result may not cross over to the participants' normal day to day walking. To study dynamic balance changes, the parameters of gait speed, stride length, stride width, single limb support time (time from heel strike foot 1 to heel strike foot 2 in seconds), step length (distance of a step in meters), stance phase duration (heel strike to toe off in seconds), swing phase duration (toe off to heel strike in seconds), dual limb support times (heel strike foot 1 to toe off foot 2), COP velocity, COP net excursions, and Time to Contact data were used as the primary dependent variables to assess changes in dynamic balance (C-Motion, 2004). Knee joint range of motion will not be assessed for either preferred or slow speed walking, as the gait parameters will give more specific information about the effect of Tai Chi on balance strategies during walking. TtC during preferred and slow walking will also not be assessed at this time, because of impending time constraints.

4.1.2 Modifications to Participant Screening Documents

The original inclusion criteria listed an sEDSS score of 4 or less for participant recruitment. Because of how the self-report EDSS is scored, a high sEDSS score can occur because of other symptom severity with no effect to a person's gait and mobility score (e.g. high levels of bladder and bowel impairment). The PDDS is the mobility portion of the EDSS alone and has been shown to be a valid and reliable way to assess mobility in individuals with MS (Learmonth et al., 2013). Gait ability was based on the PDDS scores, and a PDDS score between 0-4 became the main criterion along with the Telephone screening form.

CHAPTER 5

RESULTS

5.1 Demographic Data:

Eight individuals with mild-moderate MS (7F/1M) participated in this research study. This study was completed in two parts, with the first group (n=4) going through the study protocol in August 2012 while the second group (n=4) completed the protocol in January 2013. PDDS score of the individuals recruited for this study ranged zero (mobility not effected) to four (need a cane to ambulate). Refer to Appendix A for a table reporting which side was the ‘more impaired’(right/left) for each of the measures accessed at the initial data collection.

One participant in the 2nd group was unable to complete the study due to flu symptoms which affected her final data collection. By the time she was feeling better from her illness more than three weeks had past. Therefore, data analysis was performed on the remaining 7 participants (see Table 1).

Table 1: Group Characteristics and Functional Assessment

Abbreviation: sEDSS, self report Expanded Disability Status Scale; PDDS, Patient Determined Disease Steps

Characteristics	n	Average
Age (y)	7	50±10.74
Height (cm)	7	166.73±8.76
Body Mass (kg)	7	70.03±22.29
sEDSS	7	3.86±1.88
PDSS	7	2.42±1.51

NOTE. Values are mean ± SD

5.2 Plantar Sensitivity

5.2.1 Plantar Pressure Sensitivity

After the three week Tai Chi intervention, there was no difference in overall sensitivity averaged across feet (p=0.216). A significant increase in pressure sensitivity was found after the Tai Chi intervention when comparing the sensitivity values of the 'more impaired plantar sensitivity foot' pre versus post (p=0.02). In contrast, the 'less impaired plantar sensitivity foot' did not have any pressure sensitivity changes pre versus post the intervention (p=0.207) (Figure 12). The participants' right and left feet were categorized as 'more impaired plantar sensitivity' versus 'less impaired plantar sensitivity' based on plantar sensitivity values attained at the initial data collection. The difference between most and least impaired foot was significantly, both pre and post intervention (p=0.036; table 2B). Of the seven participants, for 4 their left foot was the 'more impaired foot', 1 individual had no difference in sensation between feet, and for the last 2 individuals their right foot was 'more impaired' at the initial data collection. For the remainder of the results section the distinction of 'more impaired plantar sensitivity' and 'less impaired plantar sensitivity' will be used.

Table 2A-B: Plantar Pressure Sensation

Plantar pressure sensitivity PRE vs. POST Tai Chi intervention (A), and comparison across 'more plantar sensitivity impaired' and 'less plantar sensitivity impaired' feet PRE or POST intervention (B). A decrease in pressure threshold shows increased sensitivity. Abbreviation: Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; CI, confidence interval.

Table 2A:

Somatosensory Characteristics	**Pre**	**Post**	**P-value**	**95% CI**
Pressure Threshold (g)	2.84±1.43	2.19±1.80	0.216	-0.50 to 1.80
More Impaired Foot (g)	3.14±0.68	2.37±0.35	0.020	0.23 to 1.31
Less Impaired (g)	2.58±0.81	2.08±0.20	0.207	-0.49 to 1.51
L Foot Pressure (g)	3.12±0.73	2.16±0.25	0.031	0.16 to 1.74
R Foot Pressure Threshold (g)	2.61±0.75	2.28±0.32	0.235	-0.37 to 1.02

NOTE. Values are mean ± SD, 95% CI: difference between means

Table 2B:

	More Impaired Foot Sensitivity (g)	**Less Impaired Foot Sensitivity (g)**	**P-value**	**95% CI**
PRE	3.14±0.68	2.58±0.80	0.036	0.06 to 1.05
POST	2.37±0.35	2.08±0.20	0.036	0.03 to 0.55

NOTE. Values are mean ± SD, 95% CI: difference between means

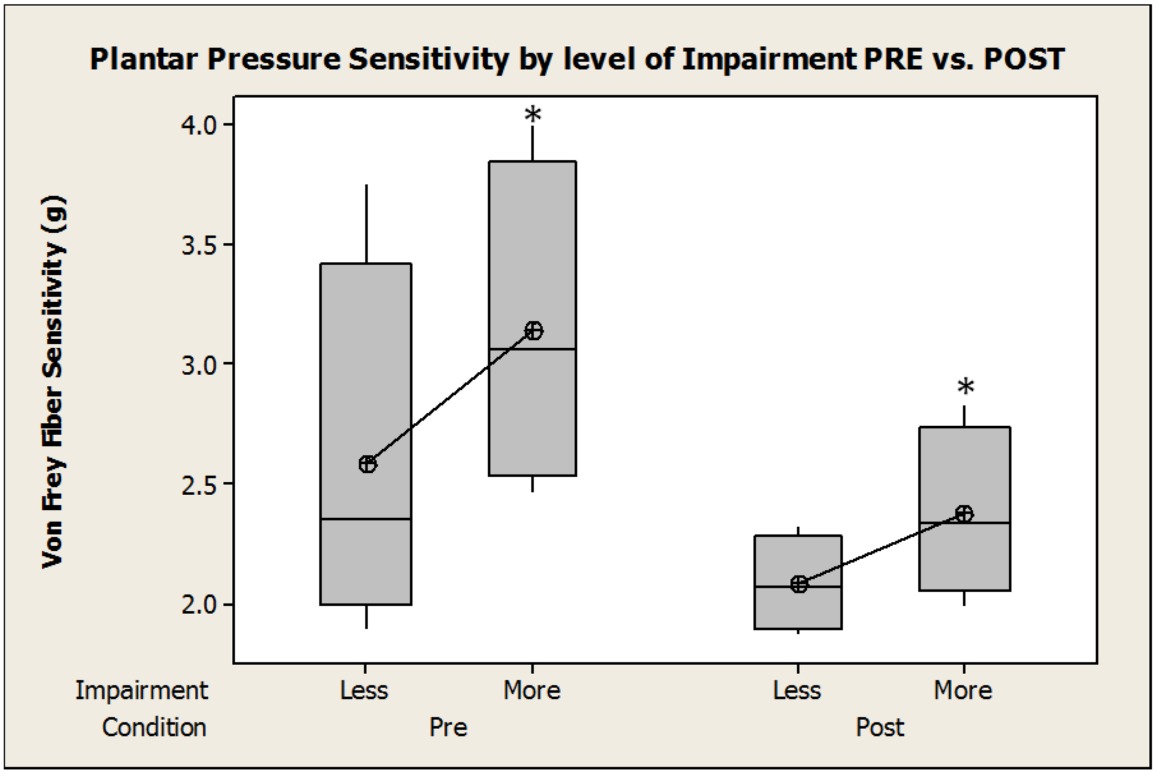

Figure 12: Pressure Sensitivity averaged across all sites for 'more plantar pressure impaired' vs. 'less plantar pressure impaired' feet PRE vs. POST. 'More Impaired' was the foot with the least plantar pressure sensitivity at the initial data collection, 'Less Impaired' was the foot with more plantar pressure sensitivity at the initial data collection. A lower Von Frey fiber diameter sensed indicates higher pressure sensitivity. Means are designated by a target symbol, medians by a line, with the top and bottom whiskers designating the 1st and 3rd Interquartile, an asterix indicates significance within groups, a cross indicates significance between groups.

5.2.2 Plantar Vibratory Sensitivity

After the Tai Chi intervention, no significant changes were found in overall plantar vibratory sensitivity averaged across both feet (see Table 3A). At the initial data collection no statistically significant differences were found between the plantar vibratory sensitivity of the more and less vibratory impaired feet (Table 3B). One participant's data was excluded from the plantar vibratory sensitivity measures as their plantar vibratory sensitivity was greater than was possible to measure with the Biothesiometer on all sites for both feet (>50 volts). There was a significant difference in plantar vibratory sensitivity between the more and less vibratory impaired foot after the intervention (p=0.043), with the less impaired foot having a lower threshold (see table 3B) (Figure 13).

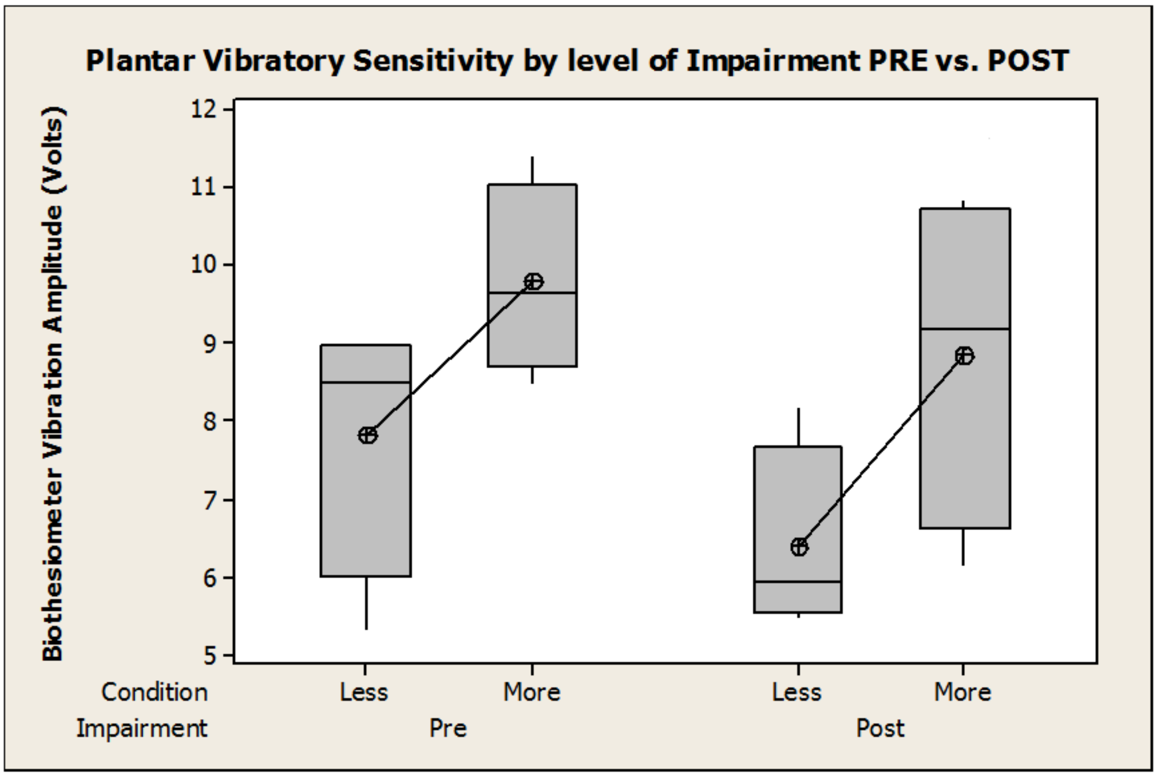

Figure 13: Vibratory Sensitivity averaged across all sites for 'more plantar vibratory impaired' vs. 'less plantar vibratory impaired' feet PRE vs. POST.' More impaired' was the foot which had the least vibratory sensitivity at the initial data collection, 'Less impaired' was the foot with the greatest vibratory sensitivity at the initial data collection. A lower Biothesiometer amplitude sensed indicates higher vibratory sensitivity. Means are designated by a target symbol, Medians by a line, with the top and bottom whiskers designating the 1st and 3rdInterquartiles, an asterix indicates significance within groups, a cross indicates significance between groups.
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Table 3A-B: Plantar Vibratory Sensation

Plantar vibratory sensitivity PRE vs. POST Tai Chi intervention (A), and comparison across 'more plantar vibratory impaired' and 'less plantar vibratory impaired' feet PRE or POST intervention (B). Abbreviation: Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; CI, confidence interval.

Table 3A:

Plantar Vibratory Characteristics	Average Pre	Average Post	P-Value	95% CI
Vibratory Threshold all participants Pre vs. Post (v)	8.87±1.68	7.69±2.26	0.228	-1.02 to 3.38
More Impaired Foot Pre vs. Post (g)	9.81±1.23	8.85±2.18	0.448	-2.54 to 4.46
Less Impaired Foot Pre vs. Post(g)	7.83±1.73	6.38±1.22	0.147	-0.93 to 3.82
R Foot Vibratory Threshold (g)	7.83±1.73	6.38±1.22	0.147	-0.92 to 3.82
L Foot Vibratory Threshold (g)	9.80±1.22	8.85±2.18	0.448	-2.54 to 4.45

NOTE. Values are mean ± SD, 95% CI: difference between means

Table 3B:

	More Impaired Foot Sensitivity (g)	Less Impaired Foot Sensitivity (g)	P-value	95% CI
PRE Intervention	9.80±1.22	7.83±1.73	0.206	-1.93 to 5.88
POST Intervention	8.84±2.18	6.38±1.22	0.043	0.15 to 4.77

NOTE. Values are mean ± SD, 95% CI: difference between means, The 'more vibratory impaired foot' had the same values as the Left Foot, and the 'less vibratory impaired foot' had the same values as the Right Foot.

5.3. Functional Assessments

5.3.1 Neural Drive: Foot Taps

An increase in foot taps (neural drive) was found in both feet after the intervention (p=0.024), with a larger change seen in the more neural drive impaired foot (p=0.005) than the less neural drive impaired foot (p=0.057) (Figure 14) (see Table 4).

Table 4: Functional Characteristics

Neural Drive was calculated as the number of foot taps completed in 15s; Muscular Strength: the time for the person to complete five Chair Rises. MSIS-29 is a psychosocial wellbeing questionnaire (a decreased score signifies decreased symptom severity). FSS is a fatigue severity questionnaire (a decrease in measures signifies a decrease in symptom severity). Abbreviation: MSIS-29, Multiple Sclerosis Impact Scale-29; FSS, Fatigue Severity Scale; CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention.

Functional Characteristics	Average Pre	Average Post	P-Value	95% CI
Average Foot Taps	27.86±8.38	39.25±4.25	0.024	-20.68 to -2.09
More Impaired Foot Taps (in 15s)	24.79±7.64	38.29±5.55	0.005	-21.17 to -5.83
Less Impaired Foot Taps (in 15s)	30.93±10.53	41.36±4.56	0.057	-21.29 to 0.43
Chair Rise Time (s)	13.04±5.08	8.22±2.45	0.025	0.85 to 8.80
MSIS-29 Total Wellbeing Score	67.71±27.38	53.14±20.87	0.032	1.72 to 27.42
MSIS-29 Psychological Score	24.14±10.42	17.86±8.72	0.018	1.55 to 11.02
MSIS-29 Physical Score	43.57±18.31	35.29±13.57	0.060	-0.48 to 17.05
FSS General Score	44.29±11.89	37.86±15.22	0.132	-2.59 to 15.45
FSS Leg Score	29.29±7.11	28.71±10.47	0.855	-6.76 to 7.90

NOTE. Values are mean ± SD, 95% CI: difference between means

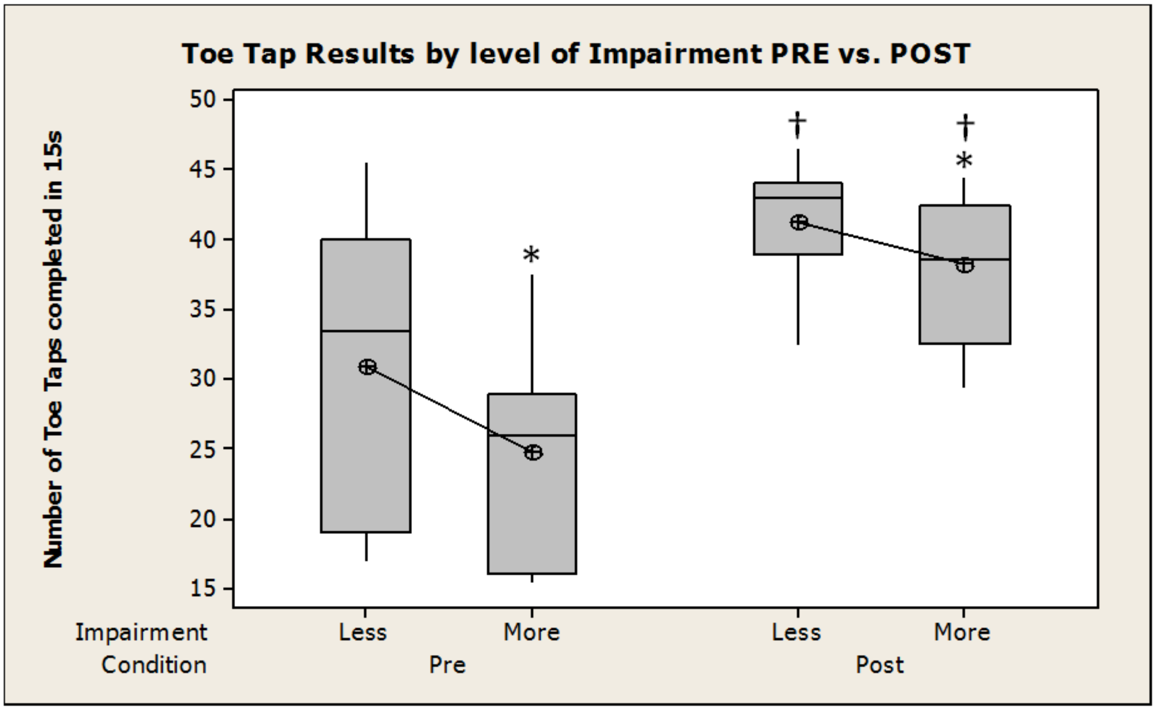


Figure 14: Toe Tap Results by level of Impairment PRE vs. POST. Toe Tap results averaged by foot Pre and Post the Tai Chi Intervention. Neural Drive was calculated as the number of toe taps completed in 15s. 'More impaired' was the foot with the least neural drive at the initial data collection, the "Less impaired' was the foot with the greatest neural drive at the initial intervention. Means are designated by a target symbol, Medians by a line, with the top and bottom whiskers designating the 1st and 3rd Interquartiles, an asterix indicates significance within groups, a cross indicates significance between groups.

5.3.2 Chair Rise

A decrease in the time to complete five Chair rises (a measure of muscular strength) was found after the intervention (p=0.025; Table 4).

5.3.3 Multiple Sclerosis Impact Scale-29

An increase in psychosocial wellbeing was found following the Tai Chi intervention ($p=0.032$) as measured by the MSIS-29 questionnaire. The MSIS-29 can also be broken down into two scores, psychological and physiological wellbeing. Increases in psychological wellbeing ($p=0.018$), and a trend towards an increase in physical wellbeing ($p=0.06$) were found after the Tai Chi intervention (see Table 4).

5.3.4 Fatigue Severity Scale

No changes in fatigue level as assessed by the FSS were found after the Tai Chi intervention, for both general fatigue ($p=0.132$) or leg specific fatigue ($p=0.855$) (see Table 4).

5.4. Standing Balance

5.4.1 Quiet Stance

No significant changes in CoP velocity, net excursions, or average TtC were found in quiet stance after the Tai Chi intervention. All p-values were greater than 0.05 (see Table 5).

Table 5: Quiet Stance Characteristics

Quiet stance CoP characteristics of average velocity, net excursion, and TtC PRE vs. POST Tai Chi intervention. Abbreviation: CoP, Center of Pressure; TtC, Time to Contact of instantaneous CoP to the Base of Support; CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; AP, Antero-Posterior; ML, Medio-lateral; APML, all directions antero-posterior and medio-lateral.

Quiet Stance Characteristics	**Average Pre**	**Average Post**	**P-Value**	**95% CI**
Average CoP Velocity APML (mm/s)	106.07±35.35	101.74±31.41	0.706	-22.44 to 31.11
Average CoP Velocity AP (mm/s)	106.07±35.34	101.735±31.41	0.706	-22.44 to 31.11
Average CoP Velocity ML (mm/s)	56.37±26.60	47.44±17.09	0.440	-17.51 to 35.38
Net CoP Excursion APML (mm)	241.19±85.74	226.41±64.81	0.613	-52.99 to 82.58
Net CoP Excursion AP (mm)	212.20±70.67	203.59±62.80	0.708	-44.93 to 62.16
Net CoP Excursion ML (mm)	112.86±53.18	95.00±34.22	0.440	-35.05 to 70.79
Average TtC APML (s)	1.58±0.18	1.48±0.19	0.310	-0.13 to 0.34
Average TtC AP (s)	2.14±0.19	1.93±0.25	0.132	-0.08 to 0.49
Average TtC ML (s)	3.05±0.42	3.06±0.47	0.953	-0.53 to 0.51

NOTE. Values are mean ± SD, 95% CI: difference between means

5.4.2 Standing Meditation (without arm movements)

No significant changes in CoP velocity, net excursions, and average TtC were found in Standing Meditation after the three week Tai Chi intervention. All p-values were greater than 0.05 (see Table 6).

Table 6: Standing Meditation Characteristics

Standing Meditation without arms average CoP velocity, net excursion, and TtC PRE vs. POST the Tai Chi intervention. Abbreviation: CoP, Center of Pressure; TtC, Time to Contact of instantaneous CoP to the Base of Support; CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; AP, antero-posterior; ML, medio-lateral; APML, antero-posterior and medio-lateral.

Standing Meditation Characteristics	Average Pre	Average Post	P-Value	95% CI
Average CoP Velocity APML (mm/s)	206.13±112.96	274.01±148.46	0.186	-179.19 to 43.43
Average CoP Velocity AP (mm/s)	206.12±112.96	274.01±148.45	0.186	-179.19 to 43.43
Average CoP Velocity ML (mm/s)	107.80±65.18	115.20±58.73	0.587	-38.92 to 24.12
Net CoP Excursion APML (mm)	444.76±247.29	601.14±304.78	0.197	-419.95 to 107.19
Net CoP Excursion AP (mm)	392.18±216.05	548.13±296.93	0.194	-417.00 to 105.11
Net CoP Excursion ML (mm)	205.94±127.79	230.52±117.48	0.417	-93.57 to 44.41
Average TtC APML (s)	1.26±0.26	1.17±0.19	0.171	-0.05 to 0.23
Average TtC AP (s)	1.70±0.34	1.54±0.28	0.095	-0.03 to 0.36
Average TtC ML(s)	2.51±0.47	2.39±0.35	0.317	-0.14 to 0.38

NOTE. Values are mean ± SD, 95% CI: difference between means

5.4.3 Standing Meditation with Arm Movements

For standing meditation with arm movements, there was a significant increase in average CoP velocity (p=0.022) (Figure 15A) and net CoP excursions APML (p=0.023) (Figure 15B), in addition to a reduction in average TtC APML (p=0.020) (Figure 15C) after the intervention. These significant effects were found in the AP direction only, with no effects in the ML direction for each of the variables (see Table 7).

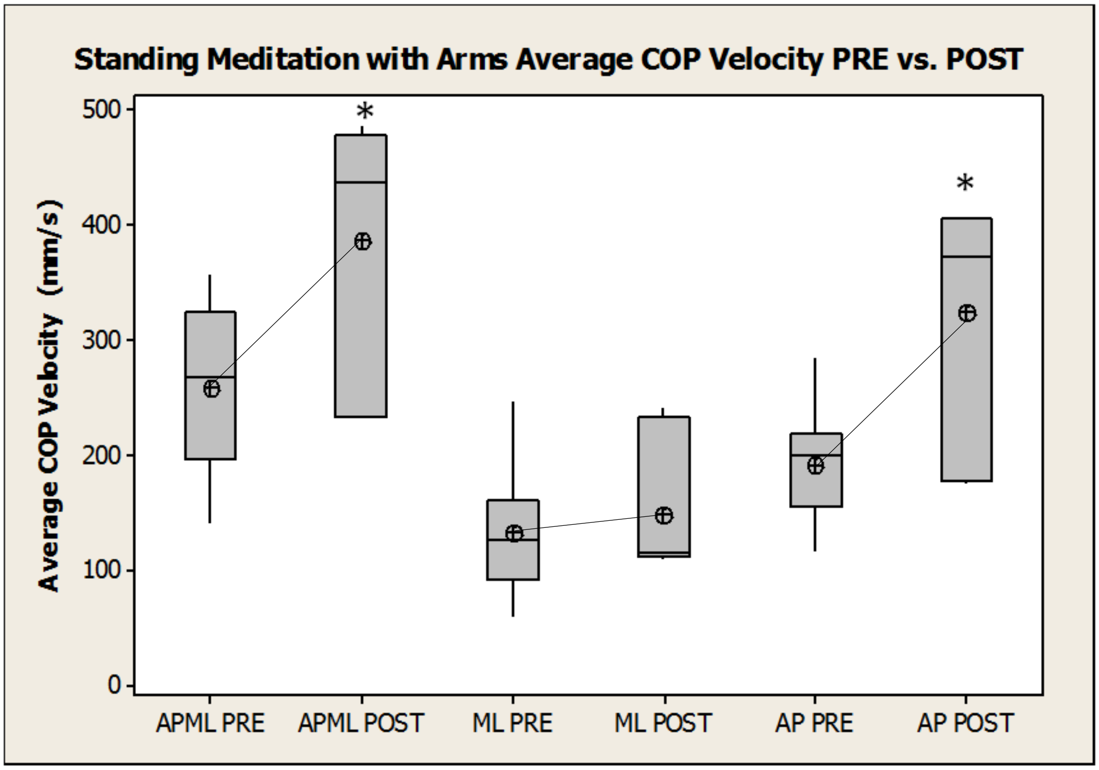
Table 7: Standing Meditation with Arm Movements Characteristics

Standing Meditation with Arms CoP average velocity, net excursion, and TtC PRE vs. POST Tai Chi intervention. Abbreviation: CoP, Center of Pressure; TtC, Time to Contact of instantaneous CoP to the Base of Support; CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; AP, antero-posterior; ML, medio-lateral; APML, antero-posterior and medio-lateral.

Standing Meditation with Arms Characteristics	Average Pre	Average Post	P-Value	95% CI
Average CoP Velocity APML (mm/s)	259.08±73.08	386.57±109.21	0.022	-229.17 to -25.80
Average CoP Velocity AP (mm/s)	192.30±53.21	325.15±102.42	0.006	-211.14 to -54.56
Average CoP Velocity ML (mm/s)	132.90±59.84	148.92±59.98	0.608	-88.52 to 56.48
Net CoP Excursion APML (mm)	474.99±132.71	722.86±209.36	0.023	-446.93 to -48.80
Net CoP Excursion AP (mm)	384.71±106.35	650.39±204.78	0.006	-422.15 to -109.22
Net CoP Excursion ML (mm)	266.01±119.62	298.01±119.95	0.608	-176.97 to 112.95
Average TtC APML (s)	1.22± 0.14	1.03±0.16	0.020	0.04 to 0.33
Average TtC AP (s)	1.66±0.19	1.37±0.16	0.012	0.09 to 0.49
Average TtC ML(s)	2.31±0.30	2.11±0.30	0.174	-0.12 to 0.53

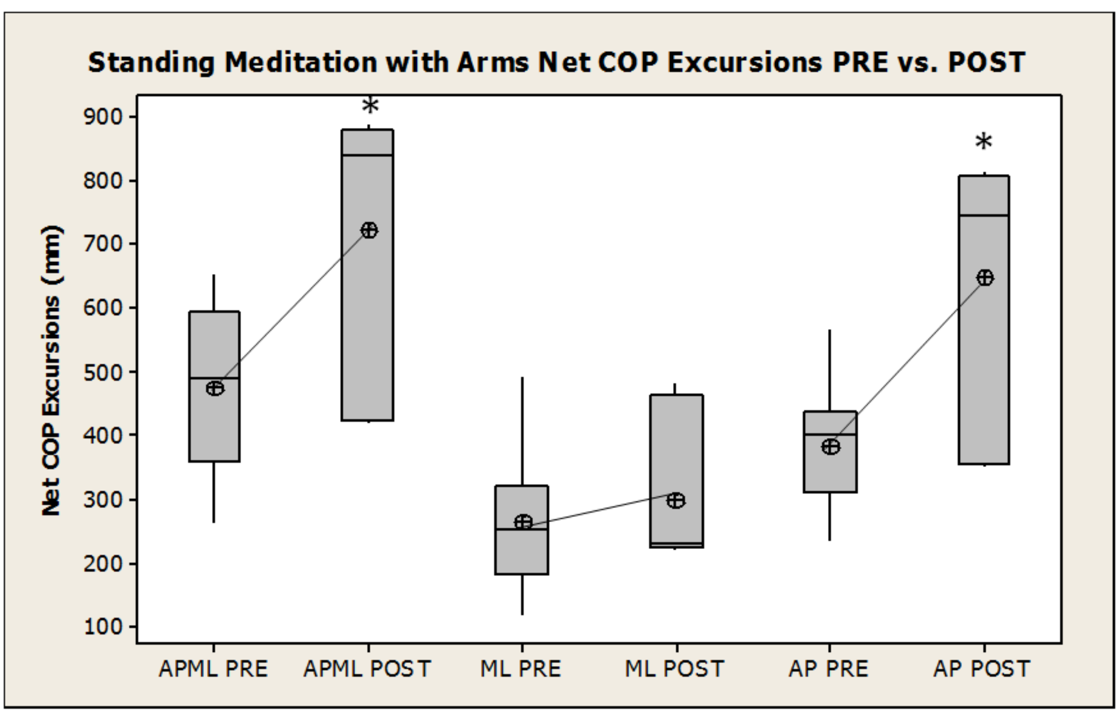
NOTE. Values are mean ± SD, 95% CI: difference between means

15A



Standing Meditation with Arms Average COP Velocity PRE vs. POST
Average COP Velocity (mm/s)
0
100
200
300
400
500
APML PRE
APML POST
ML PRE
ML POST
AP PRE
AP POST
*
*

15B



Standing Meditation with Arms Net COP Excursions PRE vs. POST
Net COP Excursions (mm)
100
200
300
400
500
600
700
800
900
APML PRE
APML POST
ML PRE
ML POST
AP PRE
AP POST
*
*

15C

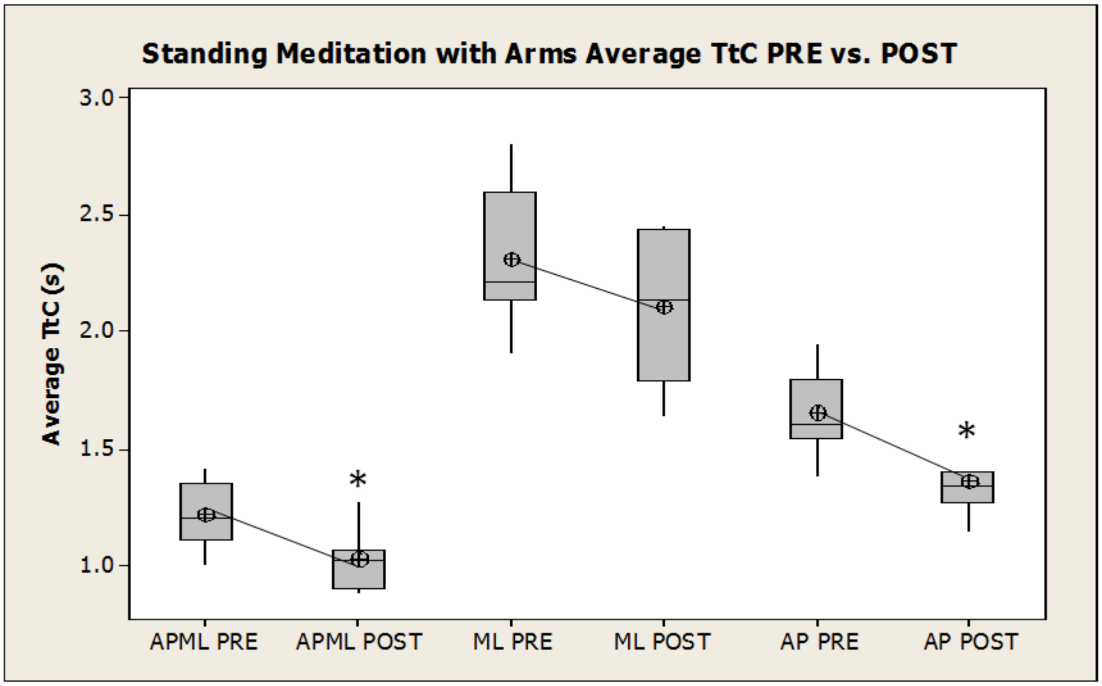


Figure 15: Standing Meditation with Arm movements. The average CoP velocity (A), net CoP excursions (B), and TtC (C) are plotted PRE and POST the Tai Chi intervention for all directions. Means are designated by a target symbol, Medians by a line, with the top and bottom whiskers designating the 1st and 3rdInterquartiles, an asterix indicates significance within groups, a cross indicates significance between groups. Abbreviation: CoP, Center of Pressure; TtC ,Time to Contact of instantaneous CoP to the Base of Support; CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; AP, antero-posterior; ML, medio-lateral; APML, antero-posterior and medio-lateral.

5.4.4 Tandem Stance

Tandem stance statistics were run with the front foot being the one with the greatest neural drive (able to produce the greater number of Toe Taps) after the Tai Chi intervention. Average TtC values increased after the Tai Chi intervention (p=0.045), predominately in the AP range (p=0.005) more so than in the ML range (p=0.045) (Figure 16C) (see Table 8). There were some trends (0.05<p<0.10) within the data, and these included a decrease in CoP average velocity (p=0.066) (Figure 16A), and a decrease in CoP net excursions (p=0.091) (Figure 16B) most specifically in the AP direction (p=0.074) in Tandem stance after the Tai Chi intervention (see Table 8).

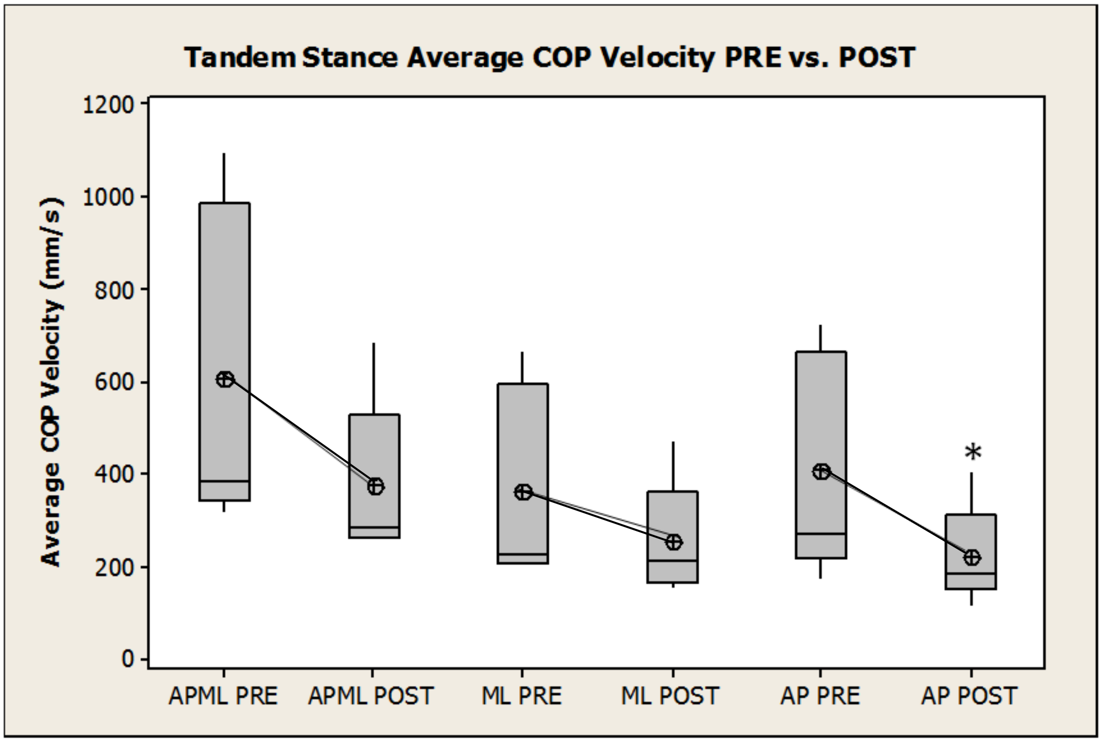
Table 8: Tandem Stance Characteristics

Tandem stance characteristics of TtC, CoP average velocity, and net excursion PRE vs. POST Tai Chi intervention. N=5, excluding the two cane users from this data analysis. Abbreviation: CoP, Center of Pressure; TtC, Time to Contact of CoP to the Base of Support; CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; AP, antero-posterior; ML, medio-lateral; APML, antero-posterior and medio-lateral.

Tandem Stance Characteristics	Average Pre	Average Post	P-Value	95% CI
Average TtC APML (s)	0.62±0.20	0.77±0.16	0.045	-0.31 to -0.01
Average TtC AP (s)	1.369±0.447	1.693±0.431	0.005	-0.484 to -0.16
Average TtC ML (s)	0.616±0.204	0.774±0.163	0.045	-0.31 to -0.01
Average COP Velocity APML (mm/s)	609.49±354.89	375.71±178.93	0.066	-25.23 to 492.80
Average CoP Velocity AP (mm/s)	408.79±240.42	223.86±108.79	0.054	-5.59 to 375.46
Average CoP Velocity ML (mm/s)	366.56±215.04	256.54±125.68	0.095	-30.10 to 250.13
Net CoP Excursion APML (mm)	1330.91±813.1	685.23±323.61	0.091	-163.63 to 1454.90
Net CoP Excursion AP (mm)	995.03±620.45	448.44±218.29	0.074	-85.92 to 1179.10
Net CoP Excursion ML (mm)	879.35±534.95	513.29±251.55	0.115	-140.77 to 872.88

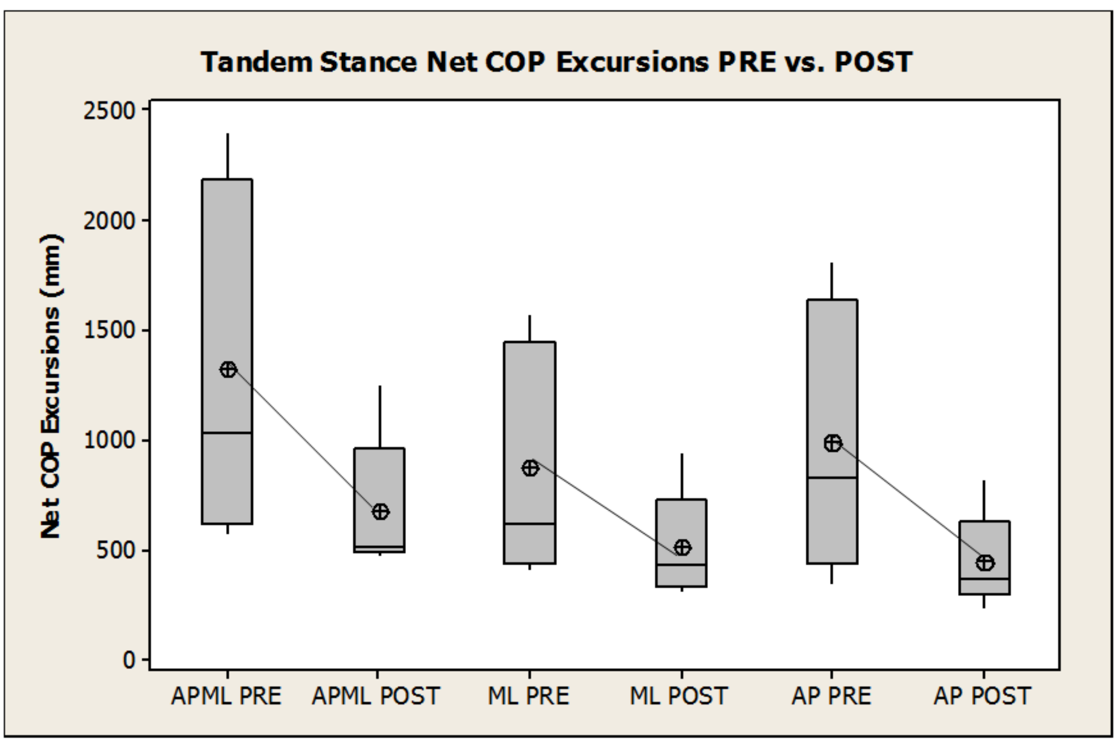
NOTE. Values are mean ± SD, 95% CI: difference between means

16A



Tandem Stance Average COP Velocity PRE vs. POST
Average COP Velocity (mm/s)
0
200
400
600
800
1000
1200
APML PRE
APML POST
ML PRE
ML POST
AP PRE
AP POST
*

16B



Tandem Stance Net COP Excursions PRE vs. POST
Net COP Excursions (mm)
0
500
1000
1500
2000
2500
APML PRE
APML POST
ML PRE
ML POST
AP PRE
AP POST

16C

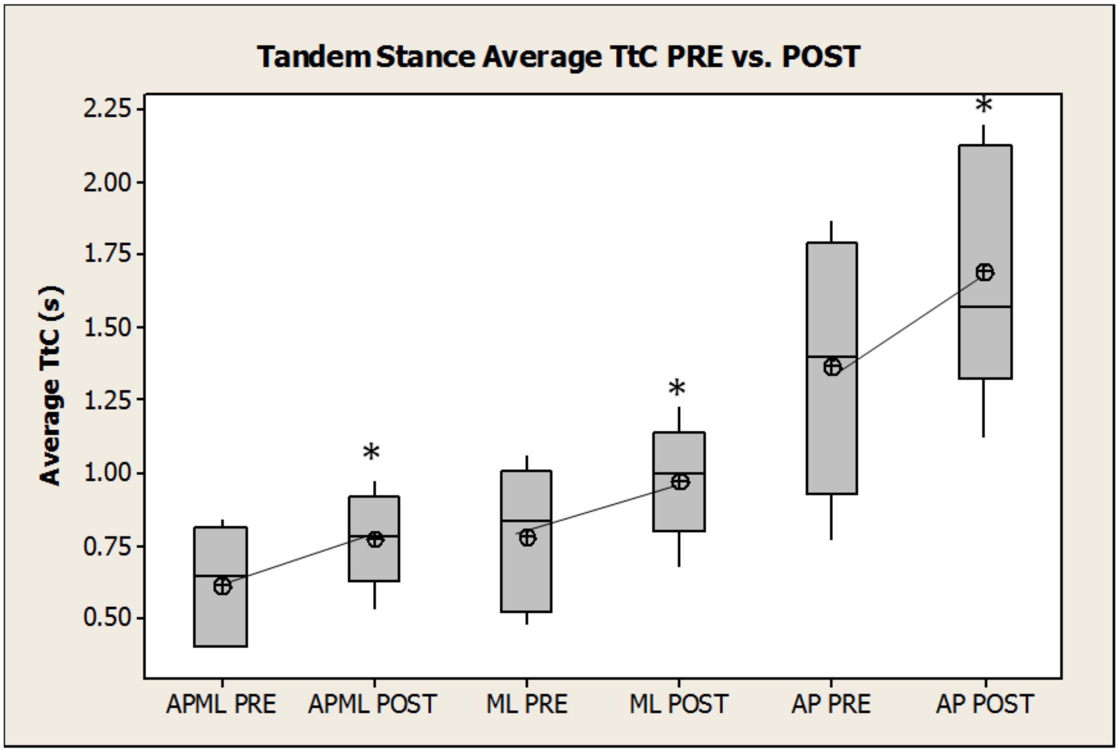


Figure 16: Tandem Stance. Tandem stance average CoP velocity (A), net CoP excursions (B), and TtC (C) are plotted PRE and POST the Tai Chi intervention for all directions. Means are designated by a target symbol, Medians by a line, with the top and bottom whiskers designating the 1st and 3rd Interquartiles, an asterix indicates significance within groups, a cross indicates significance between groups. Abbreviation: CoP, Center of Pressure; TtC,Time to Contact of instantaneous CoP to the Base of Support; CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention; AP, antero-posterior; ML, medio-lateral; APML, antero-posterior and medio-lateral.

5.5. Dynamic Balance

5.5.1 Preferred Speed

No changes in the gait parameters of: gait speed, stride length, stride width, and dual support times (Figure 17A) were found for preferred speed walking after the intervention (see Table 9A). The only change observed was an increase in left foot single limb support time (left heel strike to right heel strike) after the intervention (p=0.009) (Figure 17B). There were no significant differences between right and left single support times before the intervention, but after the intervention there was a trend towards a difference between the left and right foot single limb support times (p=0.084) (see Table 9B). No significant changes in gait parameters were observed after the Tai Chi intervention when separating the feet into a 'more' and 'less' gait impairment category (Table 9D).

Table 9A-D: Preferred Speed Gait Characteristics

Preferred speed gait parameters PRE vs. POST by left or right foot (A), comparison of single limb support times PRE or POST by left or right foot (B); preferred speed gait parameters PRE vs. POST by 'more or less' impaired foot (C), comparison of single limb support times PRE or POST by 'more or less' impaired foot (D). Abbreviation: CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention.

Table 9A:

Preferred Speed Gait Characteristics	**Average Pre**	**Average Post**	**P-Value**	**95% CI**
Speed (m/s)	1.06±0.14	1.09±0.12	0.425	-0.107to 0.05
Stride Width (m)	0.13±0.03	0.12±0.04	0.471	-0.01 to 0.01
Stride Length (m)	1.19±0.18	1.23±014	0.196	-0.11 to 0.02
Left Step Length (m)	0.58±0.10	0.55±0.15	0.470	-0.04 to 0.09
Left Stance Time (s)	0.66±0.06	0.67±0.10	0.798	-0.11 to 0.09
Left Swing Time (s)	0.37±0.04	0.37±0.10	0.965	-0.08 to 0.09
Left Single Limb Support Time (s)	0.54±0.06	0.58±0.07	0.009	-0.07 to -0.01
Right Step Length (m)	0.58±0.11	0.62±0.06	0.394	-0.13 to 0.06
Right Stance Time (s)	0.64±0.04	0.65±0.04	0.668	-0.06 to 0.04
Right Swing Time (s)	0.36±0.06	0.40±0.06	0.216	-0.09 to 0.02
Right Single Limb Support Time (s)	0.52±0.03	0.51±0.06	0.592	-0.03 to 0.05
Double Limb Support Time (s)	0.26±0.05	0.28±0.08	0.732	-0.10 to 0.08

NOTE. Values are mean ± SD, 95% CI: difference between means

Table 9B:

Preferred Speed Gait Characteristics	R Single Limb Support Time (s)	L Single Limb Support Time (s)	P-Value	95% CI
PRE	0.52±0.03	0.54±0.06	0.480	-0.10 to 0.05
POST	0.51±0.06	0.58±0.07	0.084	-0.17 to 0.01

NOTE. Values are mean ± SD, 95% CI: difference between means

Table 9C:

Preferred Speed Gait Characteristics	Average Pre	Average Post	P-Value	95% CI
More Impaired Step Length (m)	0.56±0.10	0.55±0.15	0.923	-0.07 to 0.08
More Impaired Stance Time (s)	0.65±0.06	0.67±0.09	0.706	-0.10 to 0.07
More Impaired Swing Time (s)	0.36±0.05	0.37±0.10	0.888	-0.11 to 0.10
More Impaired Single Limb Support Time (s)	0.50±0.02	0.51±0.06	0.805	-0.04 to 0.03
Less Impaired Step Length (m)	0.61±0.11	0.63±0.06	0.659	-0.11 to 0.07
Less Impaired Stance Time (s)	0.64±0.04	0.65±0.06	0.831	-0.07 to 0.06
Less Swing Time (s)	0.37±0.05	0.40±0.06	0.060	-0.05 to 0.00
Less Single Limb Support Time (s)	0.55±0.05	0.59±0.05	0.214	-0.07 to 0.02

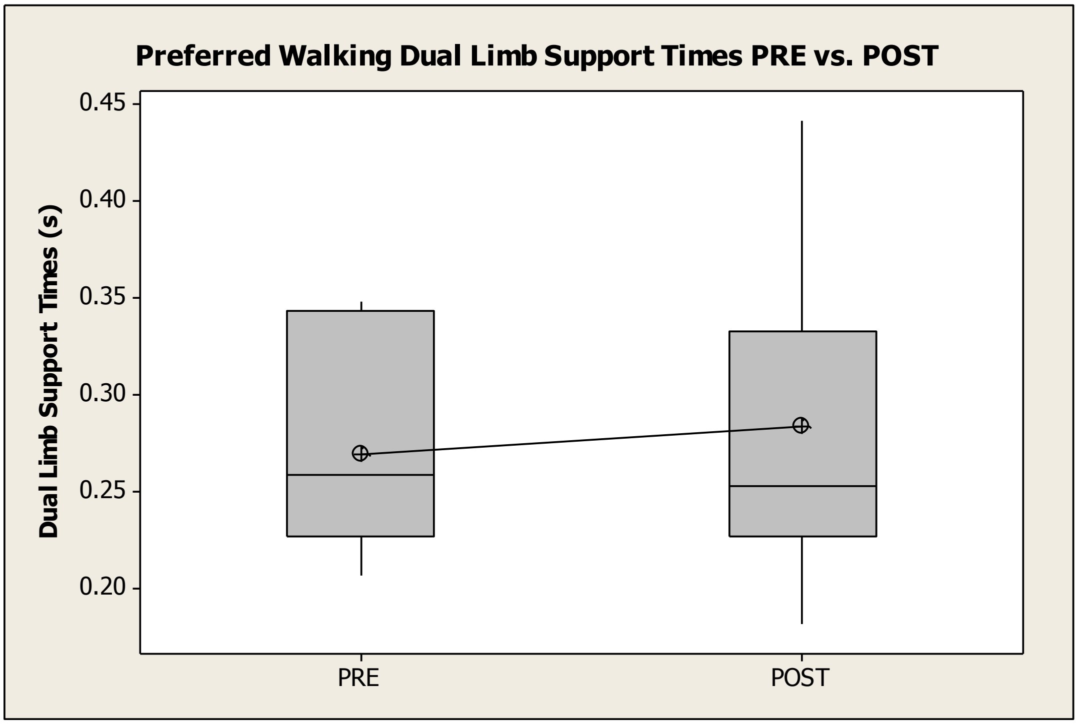
NOTE. Values are mean ± SD, 95% CI: difference between means

Table 9D:

Preferred Speed Gait Characteristics	More Impaired Single Limb Support Time (s)	Less Impaired Single Limb Support Time (s)	P-Value	95% CI
PRE	0.50±0.02	0.55±0.05	0.108	-0.11 to 0.01
POST	0.51±0.06	0.58±0.07	0.119	-0.17 to 0.02

NOTE. Values are mean ± SD, 95% CI: difference between means

17A



17B

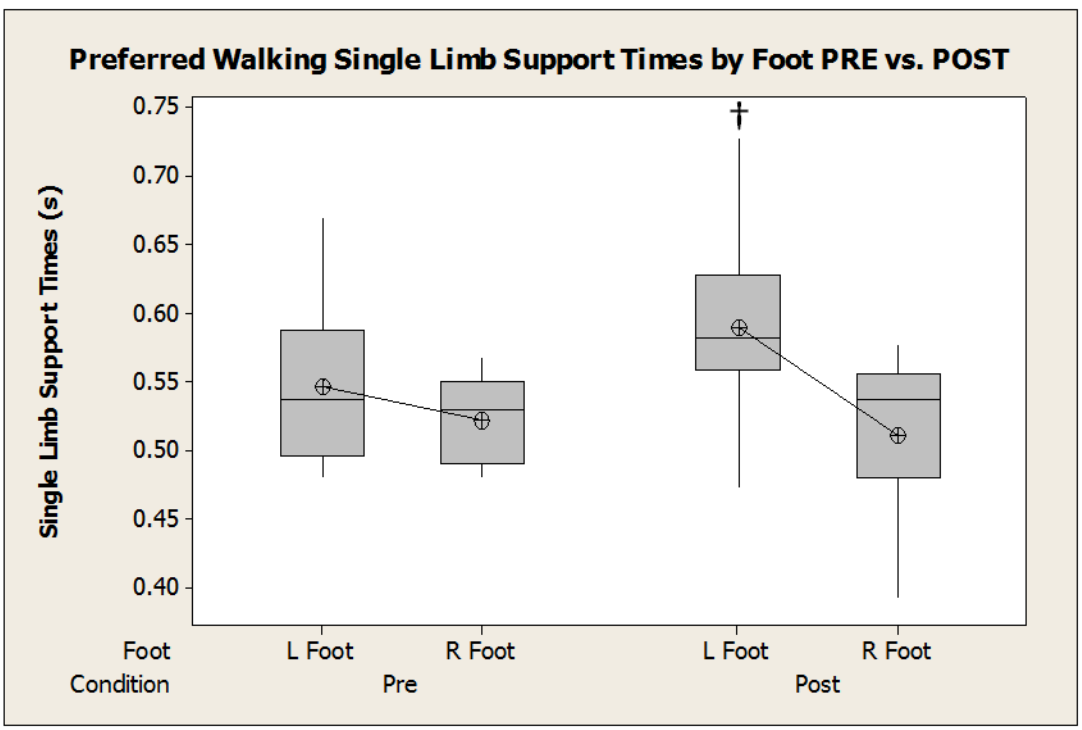


Figure 17: Preferred Speed Support Times. Preferred speed dual limb support times (A) and single limb support times (B) are plotted PRE vs. POST Tai Chi intervention. Means are designated by a target symbol, Medians by a line, with the top and bottom whiskers designating the 1st and 3rdl interquartiles, an asterix indicates significance within groups, a cross indicates significance between groups. Abbreviation:Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention.

5.5.2 Slow Speed

For slow walking a decrease in stride length after the Tai Chi intervention (p=0.008) (figure 18C) was the only gait parameter that changed, with trends towards decreased gait speed (p=0.085). The gait parameters of stride length, stride width, dual support (figure 18A), and single support times (Figure 18B) stayed the same (see Table 10A) and no difference in right and left single support times were observed pre and post intervention (Table 10B).

Table 10A-B: Slow Speed Gait Characteristics

Slow speed gait parameters PRE vs. POST by left and right foot (A), and a comparison of single limb support times by left and right foot PRE or POST the intervention (B). Slow speed walking is cautious walking, like going over ice. Abbreviation: CI, confidence interval; Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention.

Slow Speed Gait Characteristics	**Average Pre**	**Average Post**	**P-Value**	**95% CI**
Speed (m/s)	0.36±0.21	0.23±0.07	0.085	-0.02 to 0.29
Stride Width (m)	0.14±0.04	0.12±0.05	0.517	-0.05 to 0.09
Stride Length (m)	0.79±0.41	0.38±0.15	0.008	0.15 to 0.67
Left Step Length (m)	0.51±0.44	0.11±0.16	0.101	-0.10 to 0.89
Left Stance Time (s)	1.28±0.75	0.89±0.31	0.307	-0.46 to 1.24
Left Swing Time (s)	0.99±0.54	1.37±0.62	0.174	-0.98 to 0.22
Left Single Limb Support Time (s)	1.36±1.00	1.03±0.74	0.142	-0.14 to 0.80
Right Step Length (m)	0.40±0.32	0.35±0.27	0.717	-0.23 to 0.32
Right Stance Time (s)	0.94±0.39	1.12±0.24	0.394	-0.6 to 0.30
Right Swing Time (s)	0.97±0.37	1.07±0.62	0.658	-0.58 to 0.39
Right Single Limb Support Time (s)	1.39±1.31	1.03±0.52	0.541	-1.00 to 1.73
Double Limb Support Time (s)	0.76±0.39	0.84±0.74	0.764	-0.75 to 0.58

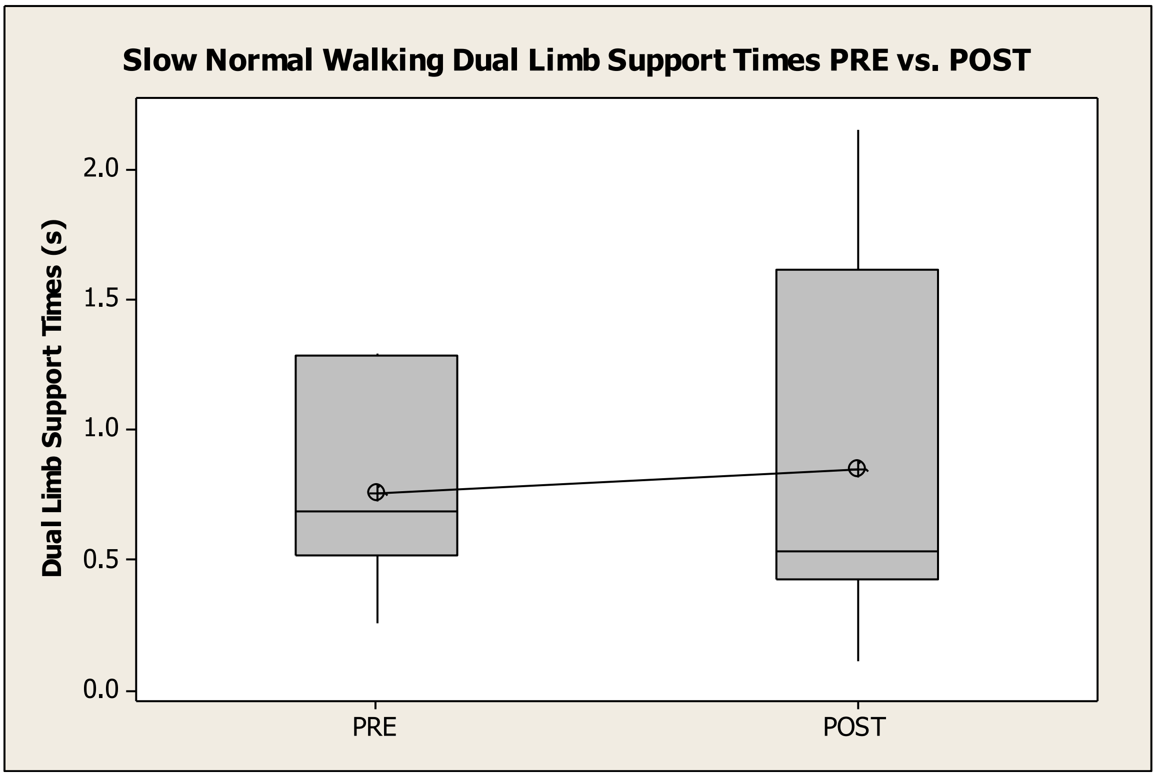
NOTE. Values are mean ± SD, 95% CI: difference between means

Table 10B:

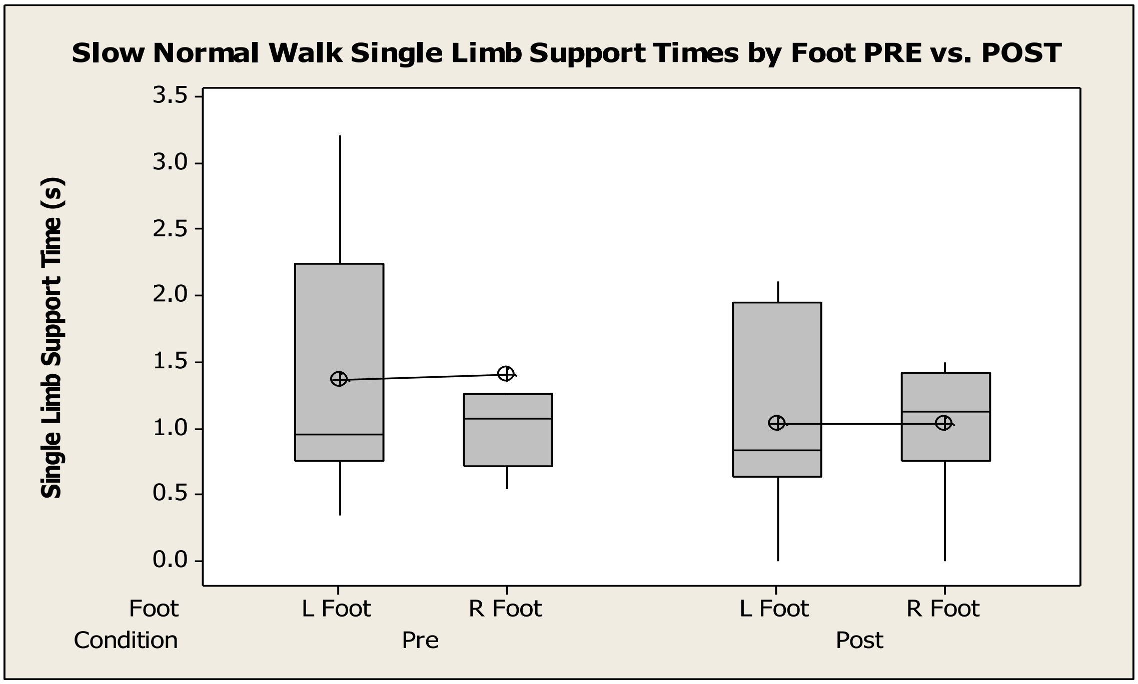
Slow Speed Gait Characteristics	R Single Limb Support Time (s)	L Single Limb Support Time (s)	P-Value	95% CI
PRE	1.39±1.31	1.36±1.00	0.915	-0.79 to 0.87
POST	1.03±0.52	1.03±0.74	0.995	-0.73 to 0.73

NOTE. Values are mean ± SD, 95% CI: difference between means

18A



18B



18C

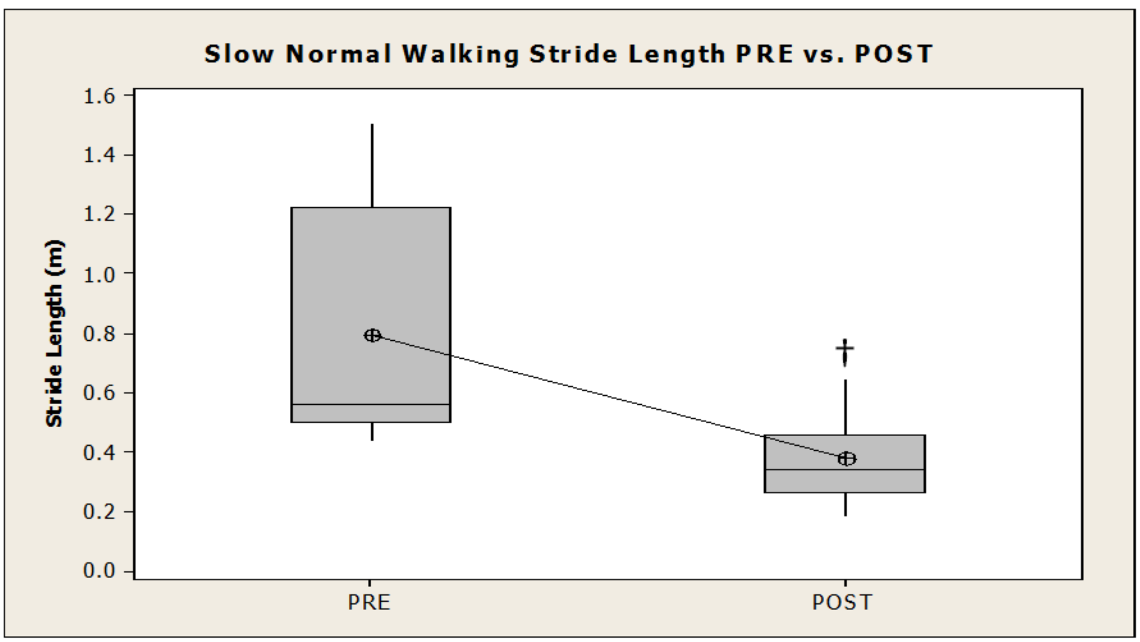


Figure 18: Slow Speed Walk Characteristics. Slow normal walk dual limb support times (A), single limb support times (B), and stride length (C) are plotted PRE vs. POST Tai Chi intervention. Means are designated by a target symbol, Medians by a line, with the top and bottom whiskers designating the 1st and 3rdIinterquartiles, an asterix indicates significance within groups, a cross indicates significance between groups. Abbreviation: Pre, before the Tai Chi intervention; Post, after the Tai Chi intervention.

CHAPTER 6

DISCUSSION

The purpose of this study was to document how a three-week Tai Chi slow walking intervention would affect some of the common gait and balance impairments reported in individuals with MS. Measurements of static and dynamic balance, plantar sensation, and overall physical functionality were assessed for changes after the Tai Chi intervention.

Specific aim #3 predicted that improvements in plantar pressure and vibratory sensitivity would be found after the Tai Chi intervention. Increased plantar pressure sensitivity, as measured by Von Frey fibers, and a trend towards a reduction in the asymmetry of vibratory sensitivity between the feet, as measured by the Biothesiometer were reported after the Tai Chi intervention.

Specific aim #4 predicted that overall functionality would improve after the intervention as assessed by the foot tapping test, chair rise test, and the MSIS-29 and FSS questionnaires. Functionality improved after the Tai Chi intervention as shown by the increased number of foot taps produced in 15 seconds, the decreased time to complete five chair raises, and the increased wellbeing documented by the MSIS-29 scores. No changes in fatigue were reported by the FSS.

Specific aim #1 predicted that static balance would improve after the intervention during each of the postural tasks as measured with CoP velocity, net excursion, and TtC variables. Improvements in static balance during Tai Chi standing meditation with arm movements and tandem stance were found, while no differences were observed for quiet stance or standing meditation without arm movements. Increased CoP velocities and net excursions with decreased TtC times were documented for Tai Chi standing meditation with arms, while decreased CoP velocities and net excursions with increased TtC times were found for the tandem stance condition.

Specific aim #2 predicted that dynamic balance would improve after the intervention for both the preferred and normal slow walking gait conditions. The gait parameters of gait speed, stride width, stride length, single limb support duration, dual limb support duration were used to assess dynamic balance. Overall dynamic balance does not appear to have been effected by the Tai Chi intervention, which may have been because of the shorter intervention duration. Two measures did show significant changes after the intervention such as: increased time was spent in left single limb support during the preferred walking condition, and decreased step length gait during the slow normal walking condition. But because only these few variables were affected these results must be viewed cautiously.

6.1 Plantar Sensitivity and Functional Characteristics

Increased plantar sensitivity, neural drive, muscular strength, and wellbeing scores were found after the Tai Chi intervention. Increased plantar pressure sensitivity was observed in the 'more pressure impaired' foot after the Tai Chi intervention. Similar increases in plantar pressure sensitivity have been reported in older individuals with and without peripheral neuropathies after a Tai Chi intervention (Li & Manor, 2010; Manor et al., 2013; Richerson & Rosendale, 2007).

At the initial data collection a difference in baseline plantar pressure sensitivity was found allowing for a ‘more pressure impaired’ and ‘less pressure impaired’ foot to be designated. No significant difference was found between the ‘more vibratory impaired’ and ‘less vibratory impaired’ feet at the initial data collection. (Left foot more vibratory impaired n=7). Increased plantar pressure sensitivity was reported for the ‘more pressure impaired’ foot after the intervention averaged across all four testing sites. No overall changes in vibratory sensitivity occurred after the intervention, but there was a significant difference in vibratory sensitivity between the ‘more vibratory impaired’ and ‘less vibratory impaired’ feet. This suggests that a greater increase in vibratory sensitivity may have been found if the intervention had continued on for a longer duration.

How do the plantar sensitivity thresholds found in this intervention compare to other MS groups and control groups? At the initial data collection the average plantar pressure sensitivity threshold was 2.84±1.43g, after the intervention average plantar pressure sensitivity had decreased to 2.19±1.80g (refer to Table 2). Remelius et al. (2012) reported an average pressure sensitivity threshold of 4.64±10.23g in individuals with MS (n=19), and an average of 0.65±.70g in controls (n=19). At the initial data collection the average plantar vibratory sensitivity threshold was 8.87±1.68 volts, after the intervention average plantar sensitivity had decreased to 7.69±2.26 volts (these are the values with the one >50 volts outlier removed.). Remelius et al. (2012) reported an average vibratory sensitivity threshold of 17.64±13.01volts in individuals with MS (n=19), and an average of 8.9±6.4 volts in controls (n=19). It appears that the group of MS individuals who participated in this study had slightly lower plantar pressure values (higher pressure sensitivity), and much lower vibratory threshold (greater sensitivity) values than those already reported in individuals with MS. These results could have occurred because of the smaller sample size recruited for the Tai Chi study. With n=19 participants Remelius et al. (2012) reported an sEDSS score median of 3.75; and range of 2.5–6; while the sEDSS scores for this Tai Chi study had a median of 4.20; and a range of 0-6. The range of sEDSS scores for both groups reported similar symptom severity, but the greater sample size in Remelius et al. (2012) may have included more people with plantar sensitivity impairments.

The increased plantar sensation reported after the Tai Chi intervention could have occurred for two reasons. First, the barefoot Tai Chi movements may have increased the amount of blood flow and allowed for more plantar mechanoreceptors to be stimulated. Alfuth and Rosenbaum (2011) found that improvements in plantar sensation occurred over the course of a day in healthy individuals, depending on how much a person had walked that day (more steps better plantar sensation); they hypothesized that the improved plantar sensation was because of increased blood flow and tactile stimulation from the stepping activity. Second, it could be that the actual Tai Chi movements themselves helped to enhance plantar stimulation. Tai Chi slow walking is a gait that has slow weight shifts and very controlled foot placements made up of heel strike, foot flat, and a 45º lateral pivot on the heel. It is possible that the high level of precision needed to control heel strike, foot flat, and weight shifts during Tai Chi slow walking may have caused increased stimulation of the pressure related mechanoreceptors (such as the Meissners corpuscles and Merkels disks). Whereas the vibratory mechanoreceptors (such as the Pacinian corpuscles) would only have been stimulated during the 45º pivot, this might explain why a lesser effect in vibratory sensitivity was found after the intervention because the pivot is only a small component of the overall Tai Chi gait cycle. Hennig and Sterzing (2009) found in healthy subjects that the heel of the foot is the plantar area which is the most sensitive to vibration, which in the case of Tai Chi slow walking is where the 45º pivot would occur. The increased plantar sensation observed after the Tai Chi intervention could be explained by increased blood flow, and/or increased mechanoreceptor stimulation either from practicing barefoot or from the specific Tai Chi movements learned.

Improvements in plantar sensitivity were observed after the Tai Chi intervention in the ‘more impaired’ foot with no changes for in the ‘less impaired’ foot. Asymmetries in plantar sensation have been found between the feet in healthy individuals (Jeng et al., 2000). Not much is known about plantar sensation asymmetries within a healthy population. Most studies will report plantar sensation results as an average of sensation between the two feet and not list individual foot sensation scores, in a healthy population. While there have not been any studies reporting asymmetries in plantar sensation in individuals with MS, there have been a number of studies reporting lower-limb asymmetries.

Not much is known about whether lower-limb loading asymmetries in MS may be linked to asymmetries in plantar sensation and neural drive, perhaps all these lower-limb asymmetries have a common cause. Individuals with MS have greater limb-loading asymmetries of the knee extensors during quiet standing as well as during gait (Chung et al., 2008; Sandroff et al., 2013). Larson et al. (2013) observed that individuals with MS can have bilateral leg strength differences from 2%-30% of maximal strength, and 4%-

66% of cycling work load when compared to controls (who showed no bilateral leg differences in strength or work load). In this intervention plantar pressure asymmetries were observed, and these plantar asymmetries could be one symptom of a larger set of many lower limb asymmetries in people with MS. An interesting future research direction would be to assess whether plantar sensation differences between the feet correspond with the bilateral lower limb-loading asymmetries in individuals with MS.

Neural drive, as measured by a foot tapping test increased in both feet after the Tai Chi intervention, with the greatest increase in the 'more impaired' foot. At the initial data collection the average number of foot taps produced was 27.86±8.38, which then increased to 39.25±4.25 foot taps in 10 seconds after the intervention (Refer to Table 4). Remelius et al. (2012) reported an average of 34.3±9.1 foot taps produced in 10 seconds in individuals with MS (n=19), and an average of 48.4±9.9 foot taps produced in 10 seconds in controls (n=19). The rate of neural drive impairment in the individuals who completed the Tai Chi intervention seems consistent with other MS populations.

The increased neural drive could have been caused by the actual Tai Chi movements themselves. During Tai Chi slow walking, the emphasis is placed on controlled foot placements and slow weight shifts. The Tai Chi slow walking movements may have lead to increased muscular strength of the bilateral Tibialis Anterior muscles which were the ones being tested by the foot tapping test. Increased neural drive after a Tai Chi intervention has been observed in faster Tibialis Anterior reaction times as measured by EMG in elderly populations (Gatts, 2008; Gatts & Woollacott, 2006).

It is interesting that while plantar sensation increases were observed on the 'more impaired side,' the increased neural drive was greater on the 'less impaired side' (refer to Table 4). These plantar sensation and neural drive results point to a deeper question about the symptoms observed in MS. Which symptoms are caused directly by MS or by the secondary reduction in physical activity? The increased level of physical activity may explain the increased neural drive found on both sides, but the different amounts of neural drive increases bilaterally may have been the result of direct asymmetries caused by MS further back in the system. The Tai Chi intervention may have increased the overall amount of physical activity that these individuals were taking part in, and if physical activity had been increased one beneficial aspect could have been increased blood flow during the intervention (Juliano et al., 2011). Another explanation could be that the 'more impaired' side had more room for improvement in comparison to the 'less impaired' side, which could also explain the differences seen.

Muscular Strength was increased after the Tai Chi intervention, as shown by faster chair rise times. The emphasis of slow movements during Tai Chi, and the extended periods of time of standing and Tai Chi slow walking may have helped to build muscular strength and increase coordination. Even though these Tai Chi activities would be considered 'light exercise' for most, the group still practiced for the full hour of standing and walking (people could sit and rest as needed, but most people chose not to). As documented by the sEDSS, these seven individuals were for the most part sedentary and this Tai Chi class was the most active portion of their day. Most likely it was a combination of increased physical activity time as well as the Tai Chi movements themselves that helped to increase muscular strength. Increased muscular strength has been documented after a Tai Chi intervention in elderly populations compared to aged matched controls and a low exercise control group (Wolf et al., 2006; Taylor et al., 2012).

Both overall wellbeing and psychosocial wellbeing scores were increased after the Tai Chi intervention. One component of a Tai Chi practice is to integrate respiration and movement, this practice is known as ‘movement mindfulness.’ The increased wellbeing found after the intervention could have occurred for two different reasons. First, the movement mindfulness of the Tai Chi movements may have worked to relax the participants and give them a ‘better quality of life’ feeling during the intervention. Interventions that promote movement mindfulness have been shown to increase quality of life in individuals with MS (Senders et al., 2012). Second, there could have been a psychosocial wellbeing effect of participating in a MS only exercise group. The supportive group atmosphere may have helped increase both psychosocial wellbeing and intervention adherence. Increased wellbeing has been shown in individuals with MS in a number of interventions similar to Tai Chi (yoga and mindfulness meditation) using questionnaires similar to the MSIS-29 (Mills and Allen, 2000; Oken et al., 2004; Senders et al., 2012).

6.2 Static Balance

No changes in static balance were found for quiet stance or standing meditation after the intervention. In my opinion this could have occurred because quiet stance is the same postural task used during normal upright standing and standing meditation is only a slight variation on this well practiced task; these two static tasks may not have posed enough of a challenge for the participants to have to modify their normal postural strategies.

Static balance changes were found after the Tai Chi intervention for Tai Chi standing meditation with arm movements and tandem stance. In Tai Chi standing meditation with arm movements, decreased TtC times and increased CoP velocities and excursions were observed after the Tai Chi intervention, which was opposite of what had been predicted in the specific aims. This meant that after the Tai Chi intervention in Tai Chi standing meditation with arms, people were moving their CoP closer and/or with higher velocity to their base of support boundaries. Decreased TtC times with increased CoP velocities and excursions in people with MS may reflect poorer postural stability strategies and put the individual at a greater risk of falling (Daley et al., 1981; Finlayson et al., 2006). In tandem stance, increased TtC times and decreased CoP velocities and excursions were observed after the Tai Chi intervention, which was as predicted in the specific aims. This meant that after the Tai Chi intervention in tandem stance, people were keeping their CoP farther from their base of support boundaries and/or moved more slowly. Increased TtC times with decreased CoP velocities and excursions are consistent with increased postural stability in individuals with MS (after balance board training while completing ‘Wii movement games’) (Prosperini et al., 2013). Even though the results of Tai Chi standing meditation with arms and tandem stance differ, the data supports the idea that postural control was improved and stability increased in the more static tandem stance after the Tai Chi intervention. In the more dynamic Tai Chi standing meditation with arm movements, the results indicate that the participants’ postural strategies had also changed after the intervention, arguably to increase postural stability as well.

How could the results of Tai Chi standing meditation with arms be seen as increased postural stability when the participants were moving their CoP at faster velocities closer to their boundaries of stability? First, it is possible that Tai Chi standing meditation with arms could be an example of exploratory CoP sway. Rather than the traditional view of increased postural sway occurring because of less control of the CNS due to aging or disease progression, increased postural sway may actually be a beneficial adaptation to increase the amount of sensory information available to the CNS (Patla et al., 1990; Riccio,1993). This idea is supported by the fact that younger children have increased CoP sway during development which may help solidify the connection between the sensorimotor system and postural control (Chen et al., 2008). Riccio (1993) reported that increased sway variability may be a perception-action strategy used by the system to assist in gathering sensory information from the interaction of the body with its environment. Exploratory CoP sway has also been documented in healthy individuals under circumstances where their center of mass has been locked (stabilized by an external apparatus) and the person is externally stabilized. Studies have shown that when a healthy person's body was externally stabilized, CoP sway was observed to increase instead of decrease even though the person's center of mass was 'more balanced' (Carpenter et al., 2010; Murnaghan et al., 2011; Murnaghan et al., 2013). Second, the increased CoP velocities and excursions may have occurred because the participants felt more confident moving within their balance limits. This is an interesting result as it has been observed that individuals with MS will reduce their CoP displacements as a possible adaptive strategy to maintain balance during postural tasks (Karst et al., 2005; Van Emmerik et al., 2010). It is possible that after the three week training period the participants felt more confident to push their stability limits when performing Tai Chi standing meditation, which in my personal opinion is interesting because this population, with its balance limitations, is not known for risk taking.

The differences in standing meditation with arms and tandem stance trials may have emerged due to limitations of the base of support in the two different postural conditions, and/or the differences could be explained by the stages of motor learning. First, the base of support for Tai Chi standing meditation and tandem stance differed greatly. In Tai Chi standing meditation with arms, the feet were kept in the same position as in regular upright stance while the torso and upper body moved, meaning that there was a wide and stable base of support which could allow for increased CoP velocities and excursions while still being able to maintain stability. Also, in Tai Chi standing meditation with arms the wider stance may have allowed for more movement of the CoP which would correspond with more sensory information having been sent to the CNS. In tandem stance the base of support was limited and narrow, which could have led to the decreased CoP velocities and excursions to maintain stability. As Riccio (1993) states, exploratory CoP variability is dependent on the person and their interaction with the environment, which in the case of tandem stance would be a very narrow base of support. Second, besides limitations of the stance itself, another reason for the different CoP and TtC results between tandem stance and standing meditation with arms could have occurred because of the stages of motor learning. According to Bernstein (1967), there are three stages of motor learning; first, the individual initially freezes the number of degrees of freedom to a minimum; second, there is a gradual releasing of the frozen degrees of freedom so that more degrees of freedom are incorporated into the movement; third, the individual now is able to utilize and exploit all degrees of freedom that arise in movement control. For this intervention Tai Chi standing meditation with arms was a practiced task, whereas standing in Tandem stance was not. After three weeks of having practiced Tai Chi standing meditation with arms the participants would have left the first stage of motor learning and moved on to the second. The gradual releasing of the frozen degrees of freedom may explain the increased CoP velocities and excursions as well as the reduced TtC seen after the Tai Chi intervention in Tai Chi standing meditation with arms. Tandem stance, on the other hand, would still be within the first stage of motor learning, the freezing of different degrees of freedom, because it had not been practiced since the initial data collection.

These results suggest that the Tai Chi intervention increased postural stability during the different static balance tasks. It is unknown whether the differences in the CoP and TtC results of Tandem stance and Standing meditation with arms could be explained by exploratory CoP sway, different stages of motor learning, base of support limitations or a combination of some or all three of these mechanisms.

6.3 Dynamic Balance

No differences were found between the right and left single limb support times during preferred walking at the initial data collection, but after the Tai Chi intervention there was a significant difference in the left single limb support time (p=0.009) when compared to the right single limb support time. Because no other gait parameters for preferred speed walking changed, we need to be cautious when viewing this measure. It appears that left single limb support time may have increased after the Tai Chi intervention, which could be that these individuals had become more comfortable standing in single leg support. Interestingly, the left foot was documented as the ‘more impaired foot’ for most of the participants at the initial data collection and yet the left side also had increased neural drive and plantar pressure sensation after the Tai Chi intervention. No differences were found for single limb support times when separating the feet into ‘more or less plantar pressure impaired’ after the Tai Chi intervention. A greater change was observed when separating the data by foot than by separating the data by gait parameters.

Gait impairments are some of the most common symptoms seen in individuals with MS, and it has been reported that people with MS commonly spend more time in dual limb support as a possible adaptive strategy to increase time with a larger base of support (Benedetti et al., 1999; Martin et al., 2006; Remelius et al., 2008; Remelius et al., 2012). One purpose of this study was to report whether dual limb support times could be reduced or single limb support times increased in individuals with MS, either of these results would mean the MS participants would be moving with a gait strategy more similar to that of healthy controls, and possibly reduce the risk of falling. Throughout this intervention the ‘more impaired foot’ had the greatest increase in plantar sensation, an increase in neural drive, and the greatest increase in single support duration. If this left single limb support timing data is not spurious, it could be that increased somatosensory information was accessed by the ‘more impaired foot’ which would allow the participants to stand on the one side longer.

The ‘more impaired’ side seemed to improve more than the ‘less impaired’ side after the Tai Chi intervention. Possibly the movements practiced during the Tai Chi intervention caused both the ‘more impaired’ and ‘less impaired’ sides of the body to be used equally, not allowing for the ‘less impaired side’ to compensate for the ‘more impaired side.’ The increased blood flow, physical activity, and Tai Chi techniques which trained both strong and weak sides equally may have led to a reduction in the amount of plantar sensation, neural drive, and single limb support time asymmetries found after the Tai Chi intervention.

How impaired was the group of MS individuals who participated in the Tai Chi intervention when compared to other individuals with MS or healthy controls? The average preferred gait speed at the intial data collection was 1.06±0.14 m/s, after the intervention no significant change in average gait speed was found (1.09±0.12 m/s). Remelius et al. (2012) reported an average preferred gait speed of 1.26±0.23 m/s in individuals with MS (n=19), and an average of 1.39±0.21 m/s in controls (n=19). The average slow gait speed at the intial data collection was 0.36±0.21 m/s, after the intervention the average gait speed had decreased to 0.23±0.07 m/s. In preferred walking the slower gait speed for the MS individuals in the Tai Chi study may have been because of the smaller sample size.

No differences were found between the right and left single limb support times during slow normal walking before or after the Tai Chi intervention. For slow normal walking the only changes documented were a decreased step length and a trend towards a decreased cycle time after the Tai Chi intervention. Both of these measures are not unusual, as slow normal walking would be comparable to cautious walking over ice.

No changes in slow walking single limb support times were reported after the Tai Chi intervention, this could have occurred because the adaptations necessary to perform slow normal working versus preferred speed walking may have been different. Tai Chi slow walking emphasized a shorter step length to protect the knees, which would explain why a similar shortened step length strategy would occur in slow normal walking after the Tai Chi intervention. Using a shortened step length adaptation during slow normal walking would also explain why there was a trend towards a decreased gait speed after the Tai Chi intervention, as the participants felt more comfortable going at a slower pace.

CHAPTER 7

CONCLUSION

A three week Tai Chi intervention was shown to improve measures of static balance in a group of individuals with mild-moderate MS. Functional improvements such as increased psychosocial wellbeing, muscular strength, neural drive, and plantar pressure sensation were observed after only three weeks of training. Because of this combination of functional improvements and Tai Chi training the participants were able to demonstrate increased postural stability during static balance tasks.

The purpose of this thesis was to document how a three week Tai Chi intervention would affect some of the common gait and balance impairments reported in individuals with MS. But alleviating impairments in people with MS is complicated (Dalgas et al., 2008). Because the large variety of MS symptoms depends on lesion location, people with MS can have different symptoms depending on where the lesions are located in the CNS. Some of the symptoms in MS may occur because of secondary causes (e.g., decreased physical activity) and not be directly caused by MS lesions. "Impairments seen in MS patients could be a result of the disease process per se (i.e., demyelination and axonal degeneration in CNS, and or it could be a consequence of the reduced physical activity level seen in MS patients compared to matched healthy subjects. It is still unresolved to what extent the impairments can be reversed in MS patients. This may depend on the extent of the impairment being a result of the disease per se, or whether it is a consequence of inactivity secondary to the disease" (Dalgas et al., 2008). The results observed support the idea that the increased physical activity of a Tai Chi intervention along with the inherent benefits of a martial arts practice may be able to reverse some of the secondary symptoms of MS. If reduced plantar sensation, neural drive, and muscular strength were caused by the reduction in physical activity and not directly by an MS lesion, it may explain why improvements in each of these measures were found after the intervention. Improvements in plantar sensation, neural drive, and muscular strength could then allow the participants to use better postural strategies for standing and during walking.

An unforeseen result of this pilot study was a reduction in some of the lower-limb asymmetries which had been found initially for plantar sensation, neural drive, and single limb support times for the 'more impaired' side. More research will need to be done to clarify whether these different asymmetries are caused by the MS, whether these different asymmetries may have a common link, and how a training paradigm like Tai Chi Chuan may be used to reduce lower-limb asymmetries.

The potential of a Tai Chi intervention would be in its generalizability in treating a wide variety of impairments caused by MS. At minimum a Tai Chi intervention may be able to increase quality of life, increase physical activity level, decrease medication costs for secondary symptom treatment, and allow people with MS to retain their independence for as long as possible. More research needs to be done to further our knowledge of using Tai Chi Chuan as an intervention for people with MS, but as this pilot study suggests there may be much to look forward to in the future.

7.1 Limitations

There were a number of limitations to this study. First, the small sample size may have had an impact on the results found, but as this intervention was considered a pilot study the results of a small group are still important. Second, even though medication changes were controlled during this study, actual medication use was not. All participants recruited had not made any changes in their medications or exercise program within 3 months of their initial data collection to their final data collection, but some participants (n=5) were on MS medications and others were not (n=2). It appears that a Tai Chi intervention may be a good supplementary exercise intervention for individuals with MS whether they are on MS medications or not, beneficial effects were observed. Third, the number of MS relapses, date of diagnosis, and MS symptoms (besides mobility) were not controlled for in this study. This is a limitation which is inherent in many MS studies, because lesion location can differ for each individual causing different symptoms and disease progression. Fourth, a control group of either healthy individuals or MS individuals was not used. Because the purpose of this study was to address specific balance and gait impairments in individuals with MS, which are unlikely to be found in healthy age-matched individuals, a control group of healthy individuals would not supply any new information. For future studies, a control group of other individuals with MS who complete a different type of exercise or balance program would provide some very beneficial information. Finally, the study occurred for a short duration of three weeks. While the short duration could easily be seen as a limitation, observing such significant results in only three weeks gives essential information about how even a short duration Tai Chi intervention can increase postural stability and reduce the severity of some functional impairments found in people with MS.

APPENDIX A

Participants ‘More Impaired’ Side at Initial Data Collection

Appendix A: This table reports which side was the ‘more impaired’ for each of the n=7 participants, for each test where the feet were separated into a ‘more/less impaired’ condition. Self-report EDSS comments were included as well. Abbreviations: VF, Von Frey Filaments (pressure sensitivity); Bio, Biothesiometer (vibratory sensitivity); ND: Neural Drive (foot tapping test); R, right; L, left; sEDSS, self report expanded disability status scale.

	VF	BIO	ND	R Side	L Side
S01	R	L	R	R Foot:"can feel very little" R Leg:"moderate loss of sensation"	L Foot:"can feel very little" L Leg:"moderate loss of sensation"
S02	R	L	R	R Foot: "Same as before I had MS" R Leg: "Same as before I had MS"	L Foot: "Same as before I had MS" L Leg: "Same as before I had MS"
S03	L	L	R	R Foot: "Mild loss of sensation" R Leg: "Mild loss of sensation"	L Foot: "Mild loss of sensation" L Leg: "Mild loss of sensation"
S04	L	L	R	R Foot: "Same as before I had MS" R Leg: "Same as before I had MS"	L Foot: "Same as before I had MS" L Leg: "Same as before I had MS"
S06	R	L	R	R Foot: "Can feel very little" R Leg: "Same as before I had MS"	L Foot:"Same as before I had MS" L Leg: "Same as before I had MS"
S07	L	L	R	R Foot: "Mild loss of sensation" R Leg: "Mild loss of sensation"	L Foot: "Mild loss of sensation" L Leg: "Mild loss of sensation"
S08	L	L	R	R Foot: "Same as before I had MS" R Leg: "Same as before I had MS"	L Foot: "Same as before I had MS" L Leg: "Same as before I had MS"

	Other Comments
S01	N/a
S02	Practiced TCC with eyes closed
S03	FSS: "Ongoing pain in R leg Causes Cane use "MS effects R leg more…"
S04	Regularly wears AFO brace on R Foot R Leg: "I wear a mechanical device or brace to help the limb complete movements."
S06	"Neuropathy in L Foot", wears a brace to help for long distance walking. R Leg: "Interferes with some movements, but can eventually complete them w/o help"
S07	Uses a cane to locomote
S08	N/a

APPENDIX B

PDDS Patient-Determined Disease Steps (Learmonth et al., 2013)

Please read the choices listed below and choose the one that best describes your own situation. This scale focuses mainly on how well you walk. Not everyone will find a description that reflects their condition exactly, but please mark the one category that describes your situation the closest.

☐**0** **Normal:** I may have some mild symptoms, mostly sensory due to MS but they do not limit my activity. If I do have an attack, I return to normal when the attack has passed.

☐**1** **Mild Disability:** I have some noticeable symptoms from my MS but they are minor and have only a small effect on my lifestyle.

☐**2** **Moderate Disability:** I don't have any limitations in my walking ability. However, I do have significant problems due to MS that limit daily activities in other ways.

☐**3** **Gait Disability:** MS does interfere with my activities, especially my walking. I can work a full day, but athletic or physically demanding activities are more difficult than they used to be. I usually don't need a cane or other assistance to walk, but I might need some assistance during an attack.

☐**4** **Early Cane:** I use a cane or a single crutch or some other form of support (such as touching a wall or leaning on someone's arm) for walking all the time or part of the time, especially when walking outside. I think I can walk 25 feet in 20 seconds without a cane or crutch. I always need some assistance (cane or crutch) if I want to walk as far as 3 blocks.

☐ **5** **Late Cane:** To be able to walk 25 feet, I have to have a cane, crutch or someone to hold onto. I can get around the house or other buildings by holding onto furniture or touching the walls for support. I may use a scooter or wheelchair if I want to go greater distances.

☐**6** **Bilateral Support:** To be able to walk as far as 25 feet I must have 2 canes or crutches or a walker. I may use a scooter or wheelchair for longer distances.

☐**7** **Wheelchair / Scooter:** My main form of mobility is a wheelchair. I may be able to stand and/or take one or two steps, but I can't walk 25 feet, even with crutches or a walker.

☐**8** **Bedridden:** Unable to sit in a wheelchair for more than one hour.

Name ________________________________

TELEPHONE SCREENING FORM FOR MS STUDIES

1) Name__________________________________

2) Address: ____

____

3) Phone # (Circle preferred contact): Best time/day of contact: ____

   a. Home _____________________________ Message? Yes No ____

   b. Work ______________________________ Message? Yes No ____

   c. Cell _______________________________ Message? Yes No ____

4) Email: ____

5) Age_________ Sex_________ Height _ Weight __________ BMI _

__*(calculate)*

6) Current health status (general)_________________________

7) *MS (subtype)* ____

How long have you had MS? ___________________ *Last Exacerbation*_________

8) Do you have any physical

limitations?____

Have you used ambulatory devices during the last month (i.e., cane, wheelchair, etc.)?_________

If yes, what types of devices have you used? ________________________________

If yes, how often?____

9) Do you smoke or have you ever smoked before?_________ For how long?_______Quit?__________

10) Do you have any allergic reactions?____

11) Do you have any significant past medical history *(other than MS)*? (e.g. hypertension, CAD, etc.)

____

12) Current medications (dose/frequency/duration)____

____

____

13) Current physical activity level (regular exercise, none, UMASS athlete, etc.) _______

_____ ____

14) Considering a 7-day period (a week), how many times on the average do you do the following kinds of exercise for more than 15 minutes during your free time.

a. **Strenuous exercise(Heart beats rapidly)** __________

b. (i.e. running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)

c. Moderate Exercise (Not exhausting) ____________

(i.e., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, alpine skiing, easy swimming, popular and folk dancing)

d. Mild Exercise (Minimal effort) ____________

(i.e., yoga, archery, fishing from river bank, bowling, horseshoes, golf, snowmobiling, easy walking)

15) Has your Doctor ever told you not to exercise?____

16) What was the date of your last doctor's visit?____

17) Is fatigue a problem for you*?*____________________ Leg fatigue?____________________

18) Are you restricted by your vision during daily activities?(20/200)______________________________

19) Are your symptoms exacerbated by heat or cold? ______________________________

20) Would you be comfortable walking on a treadmill for 30 minutes? ________________

*21) Do you have spasticity in your legs?*__________________________________

*Score:*_____________

*22) Do you make use of a care giver?*______ *How often?*_____________________

23) How did you find out about this study?____

24) Have you ever participated in a research study before?__________________________________

25) What type of transportation will you be using?__________ Do you have a handicap permit? Yes No

26) *Physician's name and number?*

____

27) Would you like to be contacted again for future studies? Yes No

28) **Within the last five years have you participated in a Tai Chi class?** Yes No

29) Comments:____

____

____

____

APPENDIX C

Informed Consent Form for Participation in a Research Study

University of Massachusetts Amherst

Principal Investigator: Julianna Averill; Richard Van Emmerik Ph.D

Study Title: Effect of a Tai Chi slow walking intervention on balance and mobility in individuals with MS

Sponsor: None

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1. WHAT IS THIS FORM?

This form is called a Consent Form. It will give you information about the study so you can make an informed decision about participation in this research study.

2. WHO IS ELIGIBLE TO PARTICIPATE?

You are eligible to participate if you are an individual with Multiple Sclerosis who is able to walk and stand. You will be excluded if you have had any Tai Chi Chuan training in the last 5 years or if you have a score higher than 3 on the Patient Determined Disability Score.

3. WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to examine how an intervention of Tai Chi standing meditation and Tai Chi slow walking will affect normal walking gait parameters and measures of balance at both slow and preferred speeds.

4. WHERE WILL THE STUDY TAKE PLACE AND HOW LONG WILL IT LAST?

You will be required to have two (2) visits to the testing laboratory exactly three weeks apart. Each data collection will last for 2 hours.

You will also be asked to attend training meetings occurring on Monday, Wednesday, and Fridays for the three week intervention duration. Training meetings will be located in the Totman building at the University of Massachusetts, each of which will last for 60 minutes. (For a total accumulated amount of training time of 9 hours over twelve days.) Participants will be expected to attend a group “Check in Day” which will occur on the Monday of each intervention week, directly following the normal meeting time where participants will be qualitatively assessed by the Tai Chi instructor on their performance of Tai Chi standing meditation and Tai Chi slow walking. You will be enrolled in this study for a total of three (3) weeks.

5. WHAT WILL I BE ASKED TO DO?

A.) Initial Data Collection Protocol:

1.) First you will read and sign the Informed Consent Documents, Fatigue Severity Score (FSS), Multiple Sclerosis Impact Scale (MSIS-29), and the self report Expanded Disability Severity Scale (sEDSS).
2.) You will be asked to change into comfortable form fitting clothing.
3.) Your body mass and height will be measured.
4.) Sensorimotor tests will be conducted to measure your sensitivity to pressure (Von Frey Fibers) and vibration (Vibrometer) on the ball, arch, and heel of each foot.
5.) A Functional Assessment will be conducted which will include such measures as: a Toe tapping task, timed Chair raises, and a timed 25ft walk at both preferred and brisk speeds.
6.) A functional balance test (Six-Spot-Step-Test) will be performed on each leg twice while being timed. In this test you will be asked to kick five targets out of a series of six circles drawn on the ground by using either the inside or outside edge of whichever foot is being tested.
7.) Reflective markers will then be applied to your full body. These reflective markers allow for 3D motion capture data to be collected.
8.) You will then be asked to perform three trials of Quiet Stance , followed by three trials on each leg of Tandem Stance (standing heel to toe) while standing on the forceplate.
9.) Next you will be asked to walk through the data collection location five times at your normal (preferred) walking speed, then at a slow normal walking speed (as close to .84m/s as possible).
10.) Next you will meet the Tai Chi instructor and be given instruction on how to perform Tai Chi standing meditation and Tai Chi slow walking by a Tai Chi instructor.

11.) After 20 minutes of practice time, six trials of Tai Chi standing meditation will be collected, followed by ten trials of Tai Chi slow walking through the collection location. Next the markers will be removed, and you will be instructed as to the time and location of the daily training meetings, and when your final data collection and training will occur.

B.) Final Data Collection Protocol:

Will consist of all the same measures and training protocol as the initial visit, excluding only the questionnaires. The final data collection day will occur within three days of the ninth training day.

C.) Training Meeting Protocol:

1.) Once all participants arrive at group training site at Studio Helix, participants will be asked to change into comfortable work out attire.

2.) Participants will then be asked to watch a 10 minute video of the Tai Chi instructor explaining how to perform Tai Chi standing meditation and Tai Chi slow walking.

3.) Participants will then be given 50 minutes of practice time. Twenty (20) minutes to practice the Tai Chi standing meditation, and thirty (30) minutes to practice Tai Chi slow walking. (Breaks will be permitted as needed for participants.)

4.) On the Monday of each intervention week a group “Check in Day” will occur after the normal group training protocol. At this time each participant will be individually assessed by the Tai Chi instructor as to how they are progressing with Tai Chi standing meditation and Tai Chi slow walking.

6. WHAT ARE MY BENEFITS OF BEING IN THIS STUDY?

You may not directly benefit from this research; however, we hope that your participation in this study may help to show if Tai Chi standing meditation and Tai Chi slow walking can be used as a beneficial intervention to increase balance and mobility in individuals with Multiple Sclerosis.

7.WHAT ARE MY RISKS OF BEING IN THIS STUDY?

In this study of different gait conditions there is a slight risk to individuals with balance disorders in that the slower walking speed and the Tai Chi slow walking gait may be uncomfortable for some people who may be at a higher risk of falling. All participants recruited for this study should be capable of safely and successfully completing this study, but there is the small chance of falling.

As in many types of exercise you may feel some mild muscular soreness or mild muscular fatigue after participating in this study as the slower walking speed and Tai Chi slow walking gait may impose a different type of gait adjustments. In the unlikely event that medical treatment is required as a result of this study, study personnel will assist you in getting treatment. The University of Massachusetts does not have a program for compensating subjects for injury or complications related to human subjects' research.

8. HOW WILL MY PERSONAL INFORMATION BE PROTECTED?

The researchers will keep all study records in a locked file cabinet within a locked room. Research records will be labeled with a code. A master key that links names and codes will be maintained in a separate and secure location. All electronic files containing identifiable information will be password protected. Any computer hosting such files will also have password protection to prevent access by unauthorized users. Only the members of the research staff will have access to the passwords. At the conclusion of this study, the researchers may publish their findings. Information will be presented in summary format and you will not be identified in any publications or presentations.

9. WILL I RECEIVE ANY PAYMENT FOR TAKING PART IN THE STUDY?

You will not receive any monetary compensation for participating in this study.

10. WHAT IF I HAVE QUESTIONS?

Take as long as you like before you make a decision. We will be happy to answer any question you have about this study. If you have further questions about this project or if you have a research-related problem, you may contact any of the investigators in this study. If you have any questions concerning your rights as a research subject, you may contact the University of Massachusetts Amherst Human Research Protection Office (HRPO) at (413) 545-3428 or humansubjects@ora.umass.edu.

11. CAN I STOP BEING IN THE STUDY?

You do not have to be in this study if you do not want to. If you agree to be in the study, but later change your mind, you may drop out at any time. There are no penalties or consequences of any kind if you decide that you do not want to participate

12. WHAT IF I AM INJURED?

The University of Massachusetts does not have a program for compensating subjects for injury or complications related to human subjects' research, but the study personnel will assist you in getting treatment.

13. SUBJECT STATEMENT OF VOLUNTARY CONSENT

I have read this form and decided that I will participate in the project described above. The general purposes and particulars of the study as well as possible hazards and inconveniences have been explained to my satisfaction. I understand that I can withdraw at any time.

__________________________ ______________________ ___________

Participant Signature: Print Name: Date:

By signing below I indicate that the participant has read and, to the best of my knowledge, understands the details contained in this document and has been given a Copy.

__________________________ ______________________ ___________

Signature of Person Print Name: Date:

Obtaining Consent

APPENDIX D

Patient Administered Expanded Disability Status Scale (Gold et al., 2003; Kurtze et al., 1983)

We would like to know how well your body functions on an average day, not your worst days and not your best days. Please check the box that most closely matches your abilities.

Walking distances: On an **average** day I can:

1. == Walk more than 3 tenths of a mile without stopping to rest.

(This is a little further than 5 football field lengths.)

I would need ☐ no help ☐ a cane ☐ two canes ☐ a walker

2. ☐ Walk 2 tenths of a mile without stopping to rest.

(This is a little further than 3 football field lengths.)

I would need ☐ no help ☐ a cane ☐ two canes ☐ a walker

3. ☐ Walk 600 feet without stopping to rest.

(This is 2 football field lengths.)

I would need ☐ No help ☐ A cane ☐ Two canes ☐ A walker

4. ☐ Walk 300 feet without stopping to rest.

(This is 1 football field length.)

I would need ☐ No help ☐ A cane ☐ Two canes ☐ A walker

5. ☐ Walk 60 feet without stopping to rest.

I would need ☐ No help ☐ A cane ☐ Two canes ☐ A walker

6. ☐ Walk 15 feet without stopping to rest.

I would need ☐ No help ☐ A cane ☐ Two canes ☐ A walker

7. ☐ Walk a few steps.

I would need ☐ No help ☐ A cane ☐ Two canes ☐ A walker

8. ☐ Use a wheelchair

If you use a wheelchair please check one of the following 4 statements:

1. ☐ On an average day, I can bear my weight with my legs (stand up and move) and get myself from one chair to another.
2. ☐ On an average day, I can bear my weight (with the strength in my arms) and lift myself from one chair to another.
3. ☐ On an average day, I cannot bear any weight or get myself from one chair to another.
4. ☐ On an average day, I cannot sit up in a chair.

When answering the following questions, please think about an average day for you (not a particularly good, or bad day) then think of the "best" part of that day. (Maybe the best part of your day is in the morning, or maybe later, after you have moved around a bit.)

<u>Strength</u>:

On an **average** day, at my **best**, my strength is:

	The same as before I had MS	Almost the same as before I had MS	Can barely raise limb in the air	Can move limb, but not raise it in the air	Cannot move limb at all
Right arm	☐	☐	☐	☐	☐
Left arm	☐	☐	☐	☐	☐
Right leg	☐	☐	☐	☐	☐
Left leg	☐	☐	☐	☐	☐

<u>Coordination</u>:

On an **average** day, at my **best**, my coordination:

	The same as before I had MS	Almost the same as before I had MS	Interferes with some movements, though I can eventually complete them without help	I must get help, use a mechanical device, or brace the limb to complete movements	Prevents me from completing movements even with help.
Right arm	☐	☐	☐	☐	☐
Left arm	☐	☐	☐	☐	☐
Right leg	☐	☐	☐	☐	☐
Left leg	☐	☐	☐	☐	☐

<u>Sensation:</u>

*****For touch, pain, cold, or heat, please mark the appropriate box in the table below. Use the worst – the one that has lost the most sensitivity – of the four sensations (touch, pain, cold, or heat) to answer each question. Please think of an average day.***

(For example: your left hand has very little sensitivity to pain, mild sensitivity to touch, and normal for heat and cold, then you would mark "can feel very little" on the line for left hand.)**

	Same as before I had MS	Mild loss of sensation	Moderate loss of sensation	Can feel very little
Right hand	☐	☐	☐	☐
Right arm	☐	☐	☐	☐
Left hand	☐	☐	☐	☐
Left arm	☐	☐	☐	☐
Right foot	☐	☐	☐	☐

Right leg	☐	☐	☐	☐
Left foot	☐	☐	☐	☐
Left leg	☐	☐	☐	☐

Bladder:

On an **average** day, I have:

Yes	No	
☐	☐	A normal bladder
☐	☐	Urgency (once I need to go I have a hard time holding it)
☐	☐	Hesitancy (I feel I need to go but nothing happens)
☐	☐	Accidents (incontinence) occasionally but once a week or less
☐	☐	Accidents (incontinence) twice a week or more, but less than daily
☐	☐	Accidents (incontinence) daily
☐	☐	Use self catheterization
☐	☐	Use continuous catheter (indwelling or condom catheter)

Vision:

1. Which line is the smallest that you can read (you can use glasses if needed).

Left eye only	Right eye only	Both eyes together	
☐	☐	☐	9 3 7 8 2 6
☐	☐	☐	4 2 8 3 6 5
☐	☐	☐	3 7 4 2 5 8

☐	☐	☐	4 2 8 3 6 5
☐	☐	☐	Cannot read any of the lines above

2. I see double (two things, where there is really only one) :

☐ Never ☐ About once a week ☐ Almost daily ☐ constantly

3. On an average day, my eye movements are unsteady

☐ Never ☐ Only when looking to the side ☐ All the time

Speech:

On an average day, my speech is:

☐ Is the same as before I had MS

☐ Slightly Slurred

☐ Moderately Slurred

☐ Severely Slurred

Swallowing:

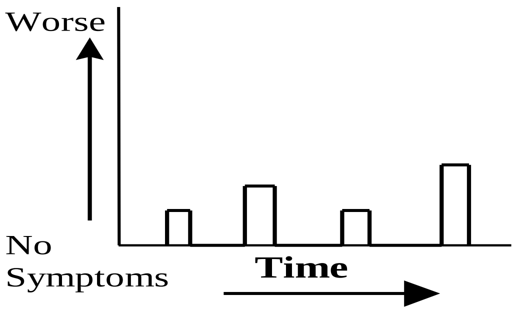
On an average day, my swallowing is:

☐ Normal

☐ Occasional choking

☐ Unable to swallow

Thinking:



On an average day, my thinking and memory is:

*****Although some people may wish to consider thinking and memory separately, we need you to combine them and check one box below.*****

☐ Is the same as before I had MS

☐ Is almost the same as before I had MS

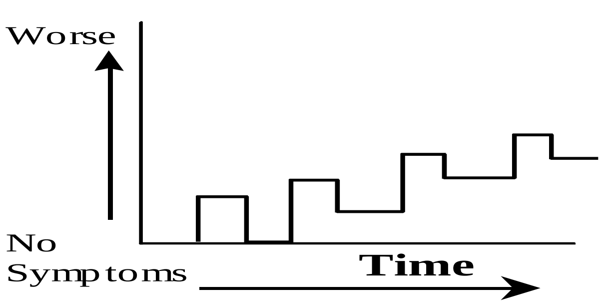
☐ Occasionally causes a problem in my daily life

☐ Frequently causes a problem in my daily life

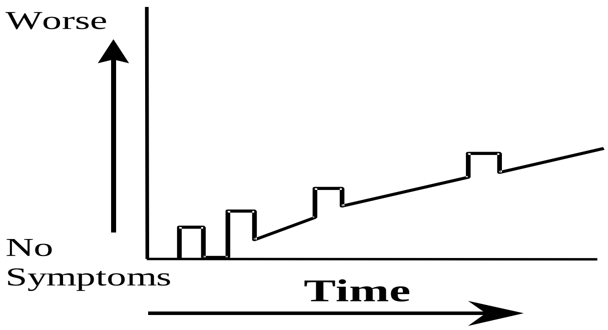
☐ Others have to help me manage my affairs

Check *only* one box that best describes your *MS disease activity over time*

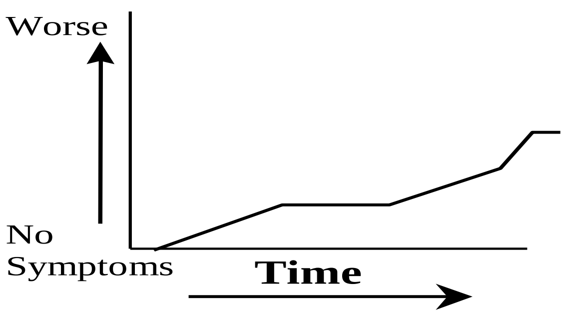
☐ Attacks (exacerbations, relapses) come on over a few hours or days, last from one day to several weeks, but once they are over, you feel the same as you always have.



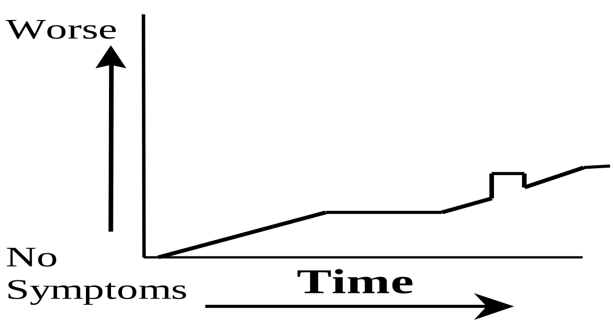
☐ Attacks (exacerbations, relapses) come on over a few hours or days, last from one day to several weeks. After some attacks, your symptoms are worse than before. The symptoms that remain after the attack are stable until a new attack occurs.



☐ At the <u>start</u> of the disease, attacks (exacerbations, relapses) occur. You may feel your symptoms get worse because of these attacks. Then even <u>between</u> the attacks, you feel you are getting worse. In some cases, attacks <u>cease</u>, yet your symptoms continued to worsen.



☐ Symptoms worsen from the beginning. Your symptoms may be stable for a time, gradually worsen, or deteriorate rapidly, but <u>attacks</u> (exacerbations, relapses) <u>have never occurred</u>.



☐ Symptoms gradually worsen from the beginning. Your symptoms may be stable for a time at the beginning, or may deteriorate rapidly. Attacks (exacerbations, relapses) did not occur at the start, but may occur later in the course of the disease.

Fatigue Severity Score – General (Krupp et al., 1989)

Below are a series of statements regarding your fatigue. By fatigue we mean a sense of tiredness, lack of energy or total body give-out. **Please choose a number from 1 to 7 that best indicates your degree of agreement or disagreement with the statement. Please answer these questions as they apply to the past TWO WEEKS**.

Statement:

	Strongly Disagree						Strongly Agree
1. My motivation is lower when I am fatigued.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2. Exercise brings on fatigue.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
3. I am easily fatigued.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
4. Fatigue interferes with my physical functioning.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
5. Fatigue causes frequent problems for me.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
6. My fatigue prevents sustained physical functioning.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

7. Fatigue interferes with carrying out certain **1 2 3 4 5 6 7**

duties and responsibilities.

8. Fatigue is among my most three disabling **1 2 3 4 5 6 7**

symptoms.

9. Fatigue interferes with my work, family or **1 2 3 4 5 6 7**

social life.

Fatigue Severity Score – Leg, Krupp et al., 1989

Please circle the number which most closely approximates your perception of fatigue in the past TWO WEEKS.

Statement:

	Completely Disagree						Completely Agree
1. My sense of fatigue does not involve my legs	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2. When climbing stairs, I have to stop because my legs feel tired.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
3. In the middle of the day, I have difficulties standing because my legs feel weak.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
4. After a period of exertion, my legs feel heavy and more difficult to move.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
5. Exercise lessens the fatigue in my legs.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

6. After a lot walking, I have difficulty lifting my foot when I walk. **1 2 3 4 5 6 7**

7. Fatigue in the muscles of my right leg limits my daily activity. **1 2 3 4 5 6 7**

8. Fatigue in the muscles of my left leg limits my daily activity. **1 2 3 4 5 6 7**

9. Fatigue in the muscles of <u>both</u> my legs limits my daily activity. **1 2 3 4 5 6 7**

MSIS-29, Hobart et al., 2001

The following questions ask for your views about the impact of MS on your day-today life **during the past two weeks**.

For each statement, please **circle** the one number that **best** describes your situation.

Please answer **all** the questions.

In the past two weeks, how much has your MS limited your ability to…	Not at all	A little	Moderately	Quite a bit	Extremely
1. Do physically demanding tasks?	1	2	3	4	5
2. Grip things tightly (e.g. turning on taps)?	1	2	3	4	5
3. Carry things	1	2	3	4	5

In the past two weeks, how much have you been bothered by…	Not at all	A little	Moderately	Quite a bit	Extremely
4. Problems with your balance?	1	2	3	4	5
5. Difficulties moving about indoors?	1	2	3	4	5
6. Being clumsy?	1	2	3	4	5
7. Stiffness?	1	2	3	4	5
8. Heavy arms and/or legs?	1	2	3	4	5
9. Tremor of your arms or legs?	1	2	3	4	5
10. Spasms in your limbs?	1	2	3	4	5
11. Your body not doing what you want it to do?	1	2	3	4	5
12. Having to depend on others to do things for you?	1	2	3	4	5

In the past two weeks, how much have you been bothered by…	Not at all	A little	Moderately	Quite a bit	Extremely
13. Limitations in your social and leisure activities at home?	1	2	3	4	5
14. Being stuck at home more than you would like to be?	1	2	3	4	5
15. Difficulties using your hands in everyday tasks?	1	2	3	4	5
16. Having to cut down the amount of time you spent on work or other daily activities?	1	2	3	4	5
17. Problems using transport (e.g. car, bus, train, taxi, etc.)?	1	2	3	4	5
18. Taking longer to do things?	1	2	3	4	5
19. Difficulty doing things spontaneously (e.g. going out on the spur of the moment)?	1	2	3	4	5
20. Needing to go to the toilet urgently?	1	2	3	4	5
21. Feeling unwell?	1	2	3	4	5
22. Problems sleeping?	1	2	3	4	5
23. Feeling mentally fatigued?	1	2	3	4	5
24. Worries related to your MS?	1	2	3	4	5
25. Feeling anxious or tense?	1	2	3	4	5
26. Feeling irritable, impatient, or short tempered?	1	2	3	4	5
27. Problem concentrating?	1	2	3	4	5
28. Lack of confidence?	1	2	3	4	5
29. Feeling depressed?	1	2	3	4	5

Initial and Final Data Collection Sheet:

Participant Code_________ Date_________ Time_______ Temperature________

Humidity______

Age_____ Height______ Weight______

Anthropometrics (cm)

	Leg length	Foot length	Foot Width	Arm Length	Hand Length
Right					
Left					

Toe Taps

	Trial 1 (#)	Trial 2 (#)
Right toe taps		
Left toe taps		

Chair Raises

Trial 1 (s)	Trial 2 (s)

Filament Test

	Ball (1st met head)	Arch (apex)	Heel	Hallux
Left				
Right				

Biothesiometer

	Ball (1st met head)	Arch (apex)	Heel	Hallux
Left				
Right				

25-Foot Walk

	Walk Time (s)
Trial 1	
Trial 2	

	Apply Marker Setup	

	Zero Forceplates

	Calibration Collections
	Empty_Cal
	Standing_Cal 1
	Standing_Cal 2

	Static Tests		
	Trial Name	**Description**	**Duration**
	Trial_1	Quiet Stance	30s
	Trial_2	Quiet Stance	30s
	Trial_3	Quiet Stance	30s
	Trial_4	Tandem Stance (R leg forward)	30s
	Trial_5	Tandem Stance (R leg forward)	30s
	Trial_6	Tandem Stance (R leg forward)	30s
	Trial_7	Tandem Stance (L leg forward)	30s
	Trial_8	Tandem Stance (L leg forward)	30s
	Trial_9	Tandem Stance (L leg forward)	30s
	Trial_10	Preferred Walk	-
	Trial_11	Preferred Walk	-
	Trial_12	Preferred Walk	-
	Trial_13	Preferred Walk	-

	Trial_14	Normal Slow Walk	-
	Trial_15	Normal Slow Walk	-
	Trial_13	Normal Slow Walk	-
	Trial_14	Normal Slow Walk	-
	Trial_15	Normal Slow Walk	-
		Tai Chi Practice Time	20 min
	Trial_16	Tai Chi Standing M	30s
	Trial_17	Tai Chi Standing M	30s
	Trial_18	Tai Chi Standing M	30s
	Trial_16	Tai Chi Standing M with Arms	30s
	Trial_17	Tai Chi Standing M with Arms	30s
	Trial_18	Tai Chi Standing M with Arms	30s
	Trial_20	Tai Chi Slow Walk	
	Trial_18	Tai Chi Slow Walk	
	Trial_19	Tai Chi Slow Walk	
	Trial_20	Tai Chi Slow Walk	
	Trial_19	Tai Chi Slow Walk	
	Trial_20	Tai Chi Slow Walk with Arms	
	Trial_18	Tai Chi Slow Walk with Arms	
	Trial_19	Tai Chi Slow Walk with Arms	
	Trial_20	Tai Chi Slow Walk with Arms	

* The terminology "with Arms" refers to the participant using the "Grasp sparrow's tail" arm movement along with either the footwork of Tai Chi standing meditation or Tai Chi slow walking.

APPENDIX E

Table 1: Check in Day Instructor Assessment Checklist:

Tai Chi Standing Meditation

- Does the individual have correct head and neck posture?
- Does the individual have correct lower body posture?
- Does the individual appear to be standing equally on each leg?

Tai Chi Slow Walking

- Does the individual maintain correct head and neck posture during gait?
- Does the individual maintain correct lower body posture during gait?
- Is the individual maintaining a constant speed?
- Is the individual correctly loading and unloading the weight of each leg throughout stance?

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