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# Tai Chi and Mindfulness Training to Improve Balance in People with Multiple Sclerosis: A Community-Based Intervention Study

A Dissertation

Presented

By

JULIANNA L. EVE

To be Submitted to the Graduate School of the
University of Massachusetts Amherst in fulfillment
of the requirements for the degree of

Doctor of Philosophy

May 2021

**University of Massachusetts Kinesiology Department**

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# Tai Chi and Mindfulness Training to Improve Balance in People with Multiple Sclerosis: A Community-Based Intervention Study

A Dissertation

Presented

By:

JULIANNA L. EVE

Approved as to style and content by:

__________________________
Richard van Emmerik, Chair

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Krista Gile, Member

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John Sirard, Member

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Jane Kent, Member

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Jane Kent, Member
Department Head of Kinesiology

# DEDICATION

I would like to dedicate this dissertation to my grandfather Arthur W. Eve, PhD who believed in lifelong learning and weekly family dinners.

# ACKNOWLEDGEMENTS

I would like to acknowledge all my teachers, guides, and the MS individuals who believed in this project and made this work possible. Especially my advisor Richard van Emmerik, PhD who has supported my research career since I began as an undergraduate student in the Sensory Motor Control lab in 2008. Special thanks to the two intervention instructors Shalini Bahl, PhD and Jeff Rosen whose invaluable expertise and generosity allowed this study to go forward.

I would also like to acknowledge Niyati Bhatt, Katie Ryder, and Kelly Kalagher for their assistance with recruitment, data collection and data analysis. Jongil Lim, PhD for his assistance with the foot tapping analysis, and Gayatri Guhanarayan, M.S for her sense of humor and always being available to talk. Anna Paskausky PhD, FNP-BC for her guidance and study design support, and Somwang Shephard who designed the online homework application.

Lastly thank you to the National MS Society for the Pilot Grant that supported this project, and my family who supported Vera and me.

# ABSTRACT

TAI CHI AND MINDFULNESS TRAINING TO IMPROVE BALANCE IN PEOPLE WITH MULTIPLE SCLEROSIS: A COMMUNITY-BASED INTERVENTION STUDY

MAY 2021

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**Introduction**: Tai Chi and meditation have led to improved quality of life, and reduced fatigue and depressive symptoms in people with multiple sclerosis (MS). Tai Chi interventions have successfully improved balance, however the few studies evaluating meditation impact on motor skill improvement have reported conflicting results. Benefits of meditation on improving alertness and attention have been reported, but it is unknown whether these benefits might extend to physical balance. **Objective:** determine the impact of an 8-week Tai Chi or Mindfulness Based Stress Reduction (MBSR) intervention on physical balance, psychosocial wellbeing, and sensorimotor function; and whether benefits are retained after a washout period. **Methods:** N=8 participants (7F, 1M) ages 47.3±14, Patient Determined Disease Steps: 2.25±1.3, subtypes (5 RR, 2 PP, 1 SP) were assigned to either the

Tai Chi or MBSR class. Three data collections occurred at: baseline, post 8-week intervention, and post 2-week washout. The average intervention practice time for all participants was 28.9±5.7 hours. **Measures:** Physical balance included quiet standing, narrow standing, forward reach and backwards lean trials, sit-to-stand (STS), and timed-up-and-go (TUG) trials obtained via APDM inertial sensors. Psychosocial data were obtained with fatigue, balance confidence, coping, and MSIS-29 questionnaires, and sensorimotor data included plantar vibration sensitivity and foot tapping performance. **Results:** Both groups improved their forwards reach characteristics, STS, fatigue severity and MSIS-29 disease impact scores. Additionally, Tai Chi may improve backwards lean characteristics, balance confidence, coping, and foot tapping inter-tap interval and coefficient of variance. MBSR may beneficially impact standing with narrow base of support. Both groups retained some beneficial postural characteristics, fatigue scores, MSIS-29 Disease impact, and STS ability. Additionally, Tai Chi retained balance confidence and coping, and some foot tapping parameters. **Conclusion**: Both interventions appear to improve physical balance, psychosocial wellbeing, and sensorimotor function; however further research is needed to clarify if these trends remain within a larger population.

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# CHAPTER 1-INTRODUCTION

## 1.1 Background on Multiple Sclerosis

Over 2.3 million individuals worldwide have Multiple Sclerosis (MS), an autoimmune disease resulting in neuronal demyelination of the central nervous system (National MS Society, 2015). The etiology of MS is still unknown, although factors such as genetics, geographical location, and childhood disease exposure may play a role (National MS Society, 2015). MS is the most common neurological disorder of individuals aged 20-50 years, with a clinical diagnosis occurring after observation of two lesions (areas of damaged neurons) separated by time and location within the central nervous system (Calabresi, 2004).

Four subtypes of MS can be diagnosed, with each subtype characterized by different frequency of relapses and periods of symptom remission. Relapsing-Remitting, the most common type of MS, is characterized by worsening neurological symptoms ('relapses') that are followed by extended periods of remission in which symptoms improve (Noseworthy et al., 1999). Secondary-Progressive MS typically begins as Relapsing-Remitting but then takes on features that are more comparable to the Primary-Progressive form, where symptoms continually worsen from the onset of diagnosis (Tremlett et al., 2008). Less than 5% of people have Progressive-Relapsing MS, where patients have steadily worsening relapses right from disease onset with rapid exacerbations of symptoms (National MS Society, 2006A). MS disease progression and symptom severity vary by individual, but common symptoms include: sensory impairments affecting the visual, somatosensory, or vestibular systems; and motor impairments affecting the pyramidal system, brain stem, cerebellum,

cerebral regions of the cortex, and alpha motor neurons (Cameron et al., 2008; Degirmenci et al., 2010; Kurtze, 1983; Roodhooft, 2009). With ongoing MS progression the accumulation of CNS lesions may contribute to reductions in neuromuscular function, postural stability, mobility, and quality of life (Daley et al., 1981; Fernandez-Jimenez & Arnett, 2014; Kohn et al., 2014).

### 1.1.1 Increased Fall Risk In MS

One study evaluating fall risk in people with MS ages 45 to 90 reported over 50% of their MS participants (n=1,089) experienced a fall within a six-month time period, with falls occurring equally indoors and outdoors. Which contrasts with non-MS individuals where 86% of falls occur outdoors (Finlayson et al., 2006; Mazumder et al., 2014). For our purposes a 'fall' is defined as an unexpected loss of balance resulting in full body contact with the floor (Finlayson et al., 2014). Peterson et al. (2013) attributed falls in MS patients (n=313, aged 55+) to loss of balance 41.5%, lower extremity failure 31%, or assistive technology malfunction 29.7%, while Mazumder et al. (2014) observed level of distraction, heat and fatigue as other factors. Most reported falls in MS occur during walking, turning, and transitioning between body postures (Cattaneo et al., 2014a). This increased fall rate may be due to the combined effects of sensory and motor impairments leading to increased postural sway (i.e., displacement of the center of mass) (Daley et al., 1981; Finlayson et al., 2006; Soyuer et al., 2006).

### 1.1.2 Mechanisms of Impaired Balance in MS

Balance is the ability to maintain the Center of Mass (CoM) within the boundaries of stability in quiet standing (static balance) and during internal/external perturbations (dynamic balance). The boundary of stability is the area enclosed by the feet. Increased postural sway increases the likelihood of the CoM moving outside the boundaries of stability, potentially resulting in a fall during quiet standing (Daley et al., 1981; Pollock et al., 2000). Reductions in postural stability are detectable even in early stages of MS before other physical impairments become apparent (Solomon, 2015; Spain et al., 2012). Postural sway is commonly assessed as movement of the CoM, or movement of the center of pressure (CoP, average of the ground reaction forces between the feet; Haddad et al., 2012). When evaluating postural sway in MS populations the most frequently used posturography methods include calculating the 95% confidence elipse sway area (the elipse that contains at least 95% of the CoP trajectory), CoM velocity, the root mean square of CoM displacement in anteroposterior and mediolateral directions, and time until contact of the CoM to area bounded by the feet (Brincks et al., 2017; Huisinga et al., 2012; Spain et al., 2012; Van Emmerik et al., 2010). Common balance impairments in MS include increased postural sway during quiet standing, reduced ability to control diagonal and backwards body shifts, reduced stability in impaired sensory conditions (e.g., with/without vision, reduced stance width/length, reduced somatosensory input, etc), delayed anticipatory responses to postural perturbations, and larger body displacements during balance restoration phase (Aruin et al., 2015; Fanchamps, 2012; Ganesan, 2015; Soyuer et al., 2006; Van Emmerik et al., 2010). Even though postural instability in MS is primarily related to sensory and motor

impairments, some MS medications may also contribute to balance problems (Chung & Kent-Braun, 2013).

### 1.1.3 Mechanisms of Impaired Mobility in MS

Gait impairment is one of the most commonly diagnosed signs of MS, with reports of shorter stride lengths, a longer duration in dual support phase, greater leg asymmetry and lower knee extensor power, and reduced walking speed in people with MS compared to healthy Controls (Benedetti et al., 1999; Chung et al., 2008; Givon et al., 2009; Martin et al., 2006; Sacco et al., 2011; Remelius et al., 2012). Givon et al. (2009) 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 CoP shifts, and longer time in dual support phase during the gait cycle than their control counterparts (Remelius et al., 2008; 2012). 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 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).

## 1.2 Current Interventions to Improve Balance in MS

There are three ways researchers have attempted to improve balance in MS, and these include medication usage, external aids, and exercise interventions. The first line of defense against MS symptoms is commonly through prescription medication usage, however because balance issues result from a combination of sensory and motor impairments this option may rapidly become complex. Disease-modifying medications have been reported to decrease overall fall risk and may directly impact balance by slowing disease progression (Cameron et al., 2015). However, many MS medications have dizziness as a side effect, and this has been reported for both disease modifying medications and medications to treat individual symptoms (Chung & Kent-Braun, 2013). A second way to improve balance in MS has been through external aids such as canes, ankle foot orthoses, and functional electrical stimulation. While external aids are beneficial as a temporary balance fix, fall risk will increase as soon as the aid is removed or not used (Iezzoni et al., 2010). A third way to improve balance in MS is exercise interventions; interventions that have led to balance improvements in MS include: progressive resistance cycling, yoga, pilates, Tai Chi, strength training, and calisthenics (Aydin et al., 2014; Bronson et al., 2010; Burschka et al., 2014; Coote et al., 2014a; Frank & Larimore, 2015; Guclu-Gunduz et al., 2014; Kjolhede et al., 2012). However, a meta-analysis by Gunn et al. (2015) reported that while balance can be improved through various exercise interventions in MS, the magnitude of change is likely not enough to impact overall fall outcomes.

### 1.2.1 Bridging the Gaps in MS Balance Literature

After reviewing the MS literature, there appears to be a lack of MS specific balance interventions with inclusion of dynamic balance exercises (especially related to turning, walking, or transitioning between postures), exercises tailored to specific sensory impairments, and modifiable exercises for continued use with disease progression. One practice that may provide these elements and potentially result in a reduction in fall outcomes is the field of Mindfulness training. The field of Mindfulness contains a variety of sitting, standing, and moving practices where one maintains non-judgmental monitoring of one's own current state of thoughts, emotions, and body sensations. This can be done within a sitting mindfulness meditation practice, or through a moving mindfulness meditation practice such as Tai Chi or Yoga.

## 1.3 Background on Mindfulness Meditation

Mindfulness meditation is a practice historically rooted in religious tradition, which has since become secularized. Current mindfulness meditation practice is based on the activity of focusing full attention on the present experience in a moment to moment basis (Trousselard et al., 2014). Mindfulness awareness trains people to focus on present sensory input without cognitive elaboration or emotional reactivity, which may reduce negative processing of the past or worrying/fantasizing about the future (Vago & Zeidan, 2016). The benefits of mindfulness meditation on improving anxiety and depression symptoms have been reported across a wide range of populations with differing age, psychological and medical conditions. A meta-analysis which included 39 studies of people receiving

mindfulness-based therapy for diverse conditions reported that mindfulness is moderately effective for improving anxiety and mood symptoms from pre to post treatment (Hofmann et al., 2010).

The benefits of meditation for improving alertness, attention, and reducing anxiety have been well documented (Clark et al., 2015; Williams, 1978). However it is unknown whether these benefits might extend to standing balance or movement, as the few studies researching this topic have led to conflicting results. Some studies have shown no or a detrimental impact of meditation on perceptual-motor tasks such as a pursuit rotor task (Williams & Herbert, 1976; Williams, 1978). Other studies have reported improvements in ability to fit different sized styluses through holes without contacting the sides of the holes after meditation training (Telles et al.,1994), as well as improved performance scores for both a line crossing, and a reaction time task linked to months of meditation practice (Jedrczak et al.,1986). During reaching tasks with limited sensory feedback the participants who had completed an 8-week Mindfulness Based Stress Reduction (MBSR) program were found to have more accurate but slower body movements, which the authors concluded was due to improved movement trajectory adjustments and faster movement detection after the meditation training (Naranjo & Schmidt, 2012). MBSR is a common mindfulness training program which introduces students over an 8-week period to different types of mindfulness meditation training, including body scan, quality of breath training, open awareness sitting meditation, yoga, walking meditation, and sensory system specific meditation (Kabott-Zinn, 1990).

### 1.3.1 Mindfulness Meditation Training in MS

A literature review by Levin et al. (2014a) suggested that mindfulness meditation may improve quality of life in people with MS and has potential benefits for pain and stress management with little to no side effects, the studies published since then have supported this finding. A 12-week skype-based MBSR intervention in with MS resulted in increased levels of self-efficacy, self-compassion, and acceptance with decreased levels of distress (Bogosian et al., 2015). While improvements of quality of life, with reduced fatigue and depression symptoms lasting up to 6 months post intervention have been reported for an 8-week MBSR MS group compared to no treatment (Grossman et al., 2010; Cavalera et al., 2018) or a psycho-education group (Carletto et al., 2017). Tavee et al. (2011) reported that an 8-week MBSR intervention for people with neurological impairments (n=10 MS, n =12 people with peripheral neuropathy) was found to have significant improvements in bodily pain compared to a no treatment control group (n=7 MS, n= 11 peripheral neuropathy). Other MBSR benefits in MS populations include increased self-directedness and cooperativeness character traits, as well as increased mindfulness, conscientiousness, and decreased trait anxiety (Crescentini, et al., 2018); and reduced fatigue and sleep problems (Cavalera, et al., 2018).

The MBSR curriculum does include 1-week of mindfulness movement practices (walking meditation, and yoga) where people are instructed to bring gentle awareness to the body flow during walking or while moving and holding different yoga postures, however specific balance related instruction is not given (Kabott-Zinn, 1990). Tai Chi is an ancient Chinese martial art that has been practiced in different styles dating back to its origin in 13th century China, and is a form of moving mindfulness training (Man-ch'ing, 1981). Tai Chi

practitioners are instructed 1) to bring gentle awareness to their center of mass moving through space allowing for greater stability while walking or transitioning between Tai Chi postures, and 2) to sustain correct body alignment to maintain stability while practicing individually or with a partner.

## 1.4 Background on Tai Chi

Tai Chi is a form of moving mindfulness training created with an emphasis placed on the awareness of balance and breathing, and based upon the Yin and Yang ideas of whole body harmony. The original form of Tai Chi 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; 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 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 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).

In the regular practice of Tai Chi 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). When compared to slow normal walking, Tai chi slow walking has lower initial foot contact forces, an even distribution of body weight across the entire foot region, and larger mediolateral CoP displacements (Wu and Hitt., 2005; Mao et al., 2006A). When compared to preferred speed walking 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, larger joint movements of dorsiflexion/plantarflexion, and increased hip flexion abduction compared to the same individual’s preferred normal walking speed (Mao et al., 2006B; Wu et al., 2004). Wu and Ren (2009) found changes in the knee extensor muscles when Tai Chi 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.

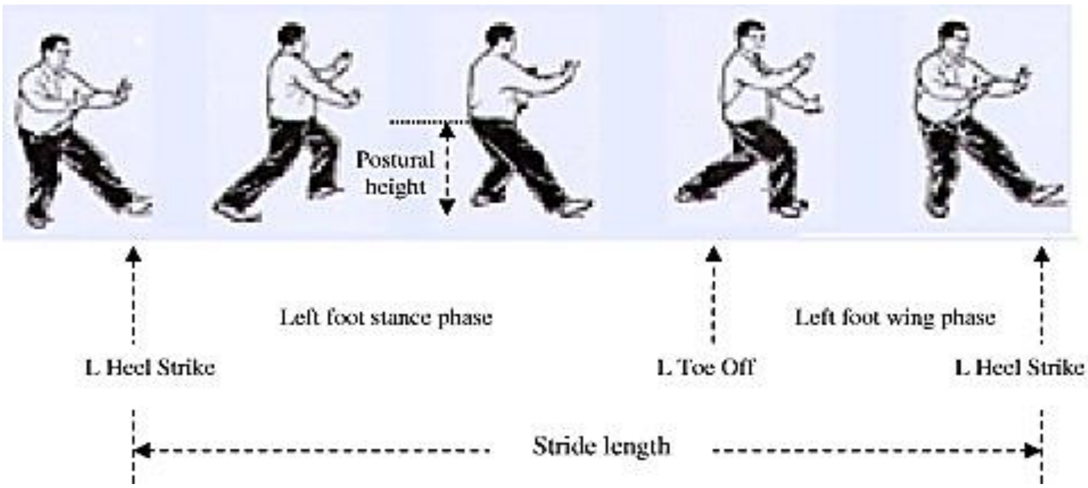



*Figure 1:Tai Chi Gait with "Part the Wild Horses Mane" Hand Techniques (Wu & Ren, 2009)*

Tai Chi would be a beneficial task to use as an intervention for two reasons. First, Tai Chi 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, which may lead to improved single leg standing balance (Wu et al., 2004).

### 1.4.1 Balance and Mobility Improvements in Diverse Populations with Tai Chi

The benefits of a Tai Chi intervention on mobility may include improved preferred gait speed, reduced dual support times, increased stride length, reduced stride width, and increased somatosensory sensitivity (Cartmell, 2010; Mao et al., 2006B; Richerson & Rosendale, 2007; Wu et al., 2004). Besides static balance and strength improvements, practicing Tai Chi has also resulted in improved dynamic balance conditions within diverse populations. This is important as the International MS Falls Prevention Research Network

(2014) recommendations to reduce fall risk in MS have prescribed that dynamic balance measures, such as the Berg Balance Scale and Timed Up and Go (TUG), must be used for evaluating efficacy of MS balance interventions (Cattaneo et al.,2014). Dynamic balance conditions are defined here as the ability to maintain balance while performing complex postural tasks, such as self-generated postural transitions, mobility trials, and functional tasks of everyday life including standing from a seated posture or reaching for an item off a shelf (Frzovic et al., 2000).

Common dynamic balance trials used in Tai Chi studies include 1) the TUG where participants are timed for going from sitting to standing, walking 3 meters around a cone, and returning back to their original seat (Podsiadlo et al.,1991); 2) Sit to Stand test (STS) where participants are timed for the duration it takes to go from seated to standing five times (Nilsagard et al.,2017); 3) the 6-minute walk where the total distance walked in 6 minutes is measured; 4) 25ft walk tests how fast a participant can walk (Kiesier & Pozzilli, 2012); and 5) Functional Reach tasks where the participant's baseline arm position is set at 90 degrees and the participant is instructed to perform a maximal reach forward, while the distance between baseline and final index finger position is measured (Duncan et al., 1990; Frzovic et al., 2000). Improvements in 6 minute walk times and TUG times in an MS population after practicing 8-weeks of pool-based Tai Chi have been reported by Bayraktar et al. (2013). In the TUG test, Hackney and Earhart (2008) found that after 6 months of Tai Chi training Parkinsonian patients had improved TUG times, tandem stance durations, and 6-minute walk times compared to a Parkinsonian control group. Shumway-Cook et al. (2007) found improvements in TUG times, STS test, and Berg balance scores after a 12-month community

based Tai Chi intervention for older adults. A recent meta-analysis by Wayne et al. (2017) to quantify the effects of Tai Chi/Qigong on aspects of balance and mobility in Parkinsonian patients found that fixed effect models showed significant improvements of Tai Chi/Qigong on balance, TUG times, 6-minute walk times, and 6-month fall history; however Wayne et al. (2017) reported that there was some degree of publication bias as only Tai Chi studies with beneficial results are likely to be published. Gallant et al. (2017) found that a 12-week Tai Chi intervention in older adults resulted in improved TUG times and functional forward reach distance.

### 1.4.2 Tai Chi Training in MS

The current Tai Chi and MS literature includes: nine primary source articles using Tai Chi as an intervention in MS, one case study (Achiron et al., 1997), and one review study. An 8-week Tai Chi intervention improved 25ft walking speed, hamstring flexibility, and wellbeing in relapsing remitting MS (Husted et al., 1999). In people with secondary progressive MS, an 8-week group and home-based Tai Chi practice improved single leg standing times and reduced depression symptoms (Mills et al., 2000). An 8-week swimming MS Tai Chi program improved single leg standing times, faster TUG and 6-minute walk times, fatigue, and muscular strength more so than an MS control group with breathing and abdominal exercises alone (Bayraktar et al., 2013). A 6-month MS Tai Chi program improved balance, coordination, and depression measures compared to an MS control group with treatment as usual (Burschka et al., 2014). A 3-week Tai Chi intervention was found to

improve postural stability during tandem stance and standing meditation with arms, improve neural drive (increased speed of foot taps produced), increase muscular strength (faster STS times), improve psychological wellbeing, with no change in fatigue in a relapsing-remitting MS group (Averill, 2013). Kaur et al. (2014) found that their Tai Chi and Tai Chi with mental practice groups had significant improvements in dynamic gait index, functional reach, TUG, and balance confidence (ABC) scores. Mohali et al. (2013) had improved berg balance scores after an 8-week Tai Chi intervention for people with MS, compared to the MS control group. Tavee et al. (2011) found that their meditation group (who practiced Tai Chi and Qigong techniques for an 8-week intervention) had significant improvements in pain, cognitive and psychosocial fatigue scores, and mobility after the intervention compared to a MS control group. Finally, a 12-week MS Tai Chi intervention improved Berg balance scores compared to the MS treatment as usual control group whose balance scores did not change (Azimzadeh et al., 2015). Taylor & Taylor-Pillae (2017) in their review found that even when allowing for differing Tai Chi styles, practice durations, and differing MS subtypes that overall Tai Chi interventions led to improvements in both physical and psychosocial function in people with MS.

### 1.5 Dissertation Purpose

**The purpose of this study** is to determine whether a Tai Chi or Mindfulness Meditation intervention will have a greater effect on physical balance, psychosocial wellbeing and sensorimotor function in people with MS, and whether benefits are retained after a 2-week washout period. The Tai Chi and Mindfulness Meditation (delivered via a

Mindfulness Based Stress Reduction; MBSR) interventions will be delivered via community-based classes for a period of 8 weeks.

## 1.6 General Study Description and Specific Aims

To evaluate the impact and retention of a mindfulness intervention on postural stability in people with MS, individuals will be recruited and attend three data collections in the Motor Control lab over a period of 6 months. At the data collections physical balance, sensorimotor function, and psychosocial measures will be collected. The overall study design is presented in Figure 2. After the initial data collection (#1), participants will be intentionally assigned into either the Tai Chi group (n=18) or the MBSR group (n=18), to match MS disability status, for the 8-week intervention period. After the middle data collection (#2) the 2-week washout period will begin where participants are asked to not practice their art. The final data collection (#3) will occur within a week of the washout period ending. For the training portions of this study we will be partnering with local businesses to lead the interventions. The Tai Chi intervention will be led by Jeff Rosen (and instructors) of Yang’s Martial Art Association (YMAA) Western Massachusetts, while the Meditation intervention will be led by Dr. Shalini Bahl at Downtown Mindfulness. Both the interventions will be at no financial cost to study participants, participation dues will be paid with a National MS Society Pilot grant.

| Data Collection 1 | Intervention | Data Collection 2 | Washout | Data Collection 3 |
|---|---|---|---|---|
| Physical Balance<br><br>Psychosocial Measures<br><br>Sensorimotor Function Measures | Tai Chi Training (n=20)<br><br>MBSR Training (n=20) | Physical Balance<br><br>Psychosocial Measures<br><br>Sensorimotor Function Measures | No Practice<br><br>No Practice | Physical Balance<br><br>Psychosocial Measures<br><br>Sensorimotor Function Measures |

*Figure 2: General Study Design*

## 1.7 Conceptual Framework

With each new lesion postural stability may be impacted in people with MS. The conceptual framework below visually represent how an individual MS lesion may lead to postural instability (Figure 3), how a Tai Chi (Figure 4) or Mindfulness Meditation (Figure 5) intervention could potentially improve postural stability in MS, and how Tai Chi and Mindfulness Meditation differ in their possible effects on postural stability (Figure 6).

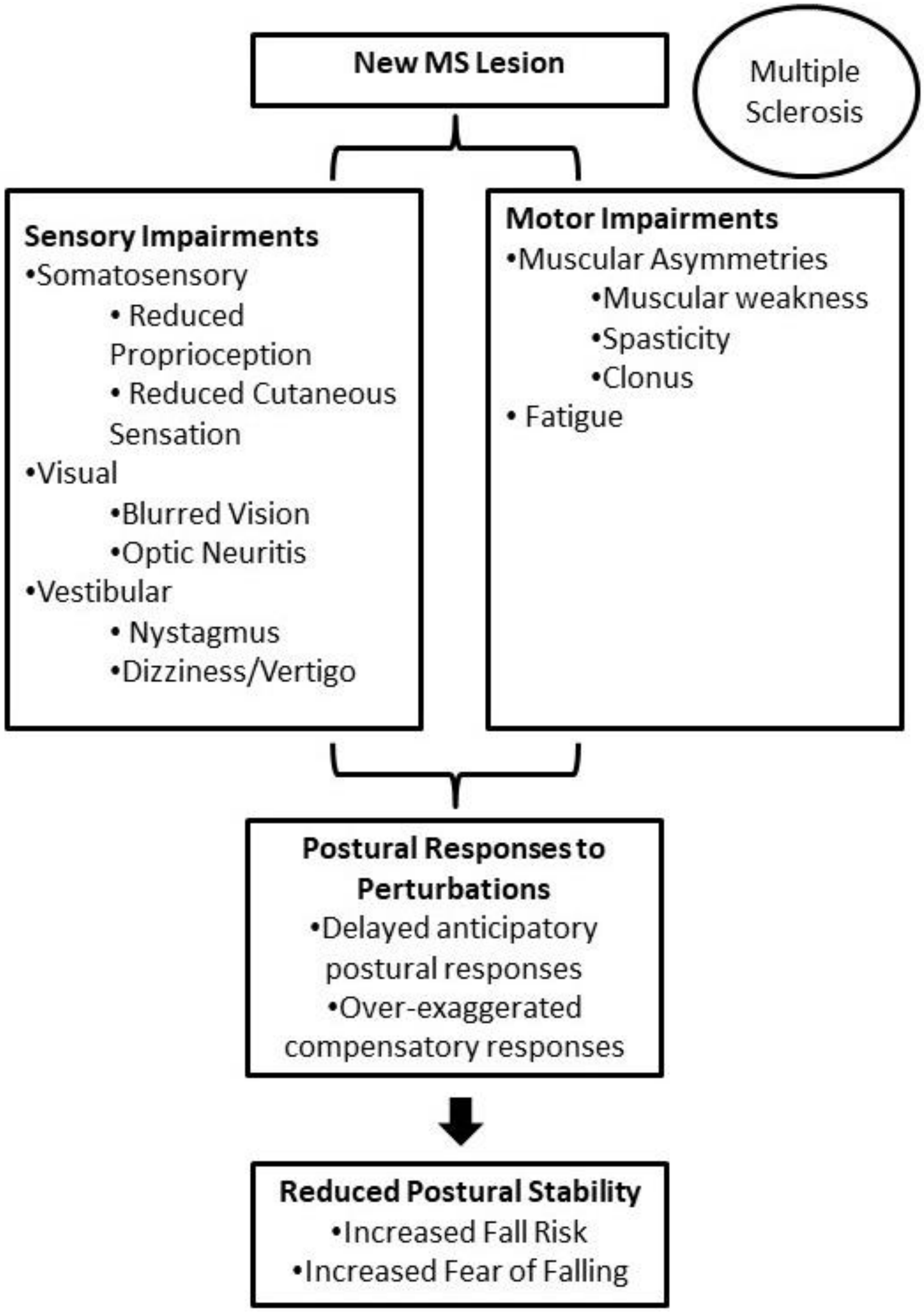



*Figure 3: Conceptual Framework of the Impact of an MS Lesion on Postural Stability. Sensorimotor impairments and postural problems due to MS are indicated in black.*

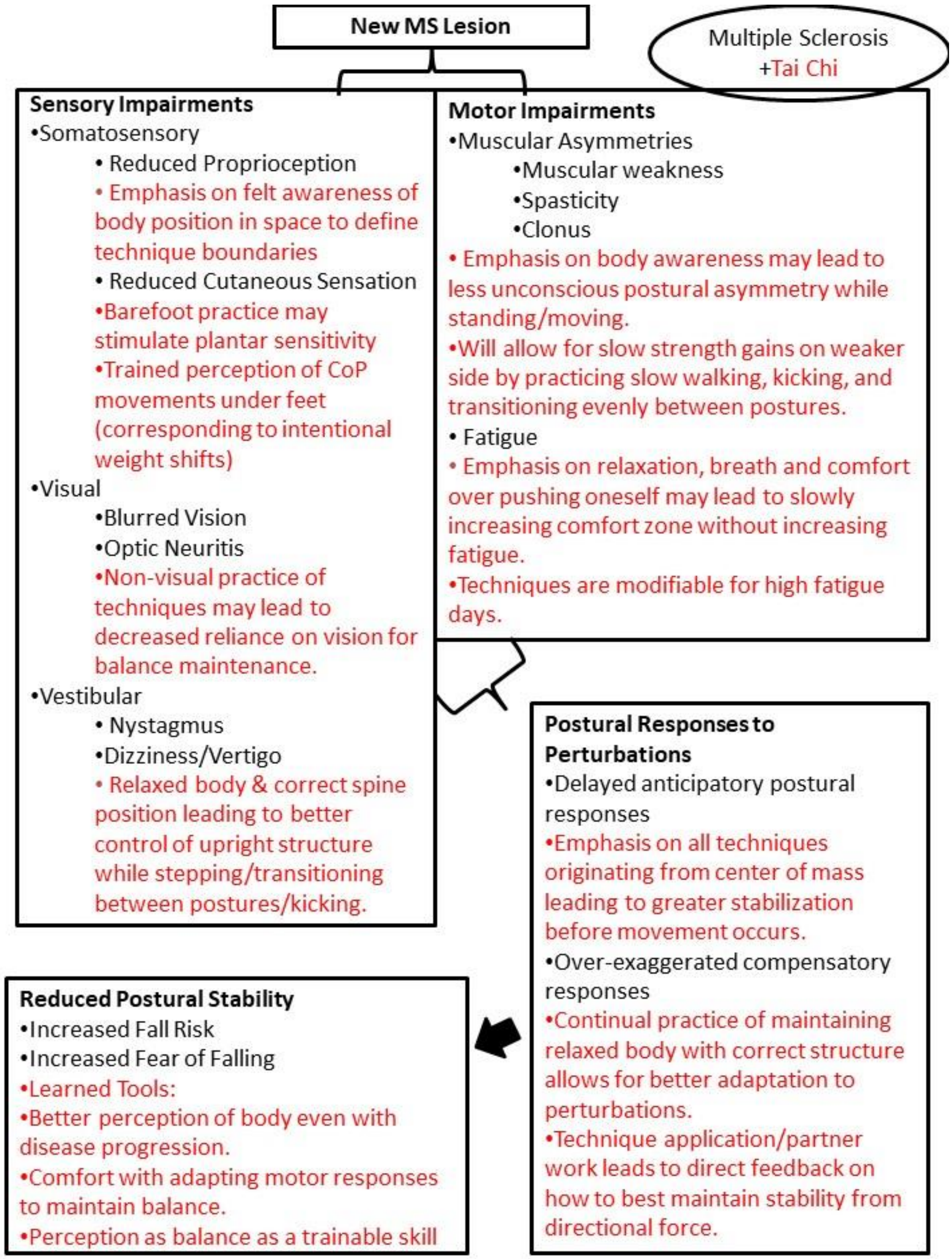



*Figure 4: Conceptual Framework of Tai Chi on MS Postural Stability. Sensorimotor impairments and postural problems due to MS are indicated in black, while potential Tai Chi improvements are red.*

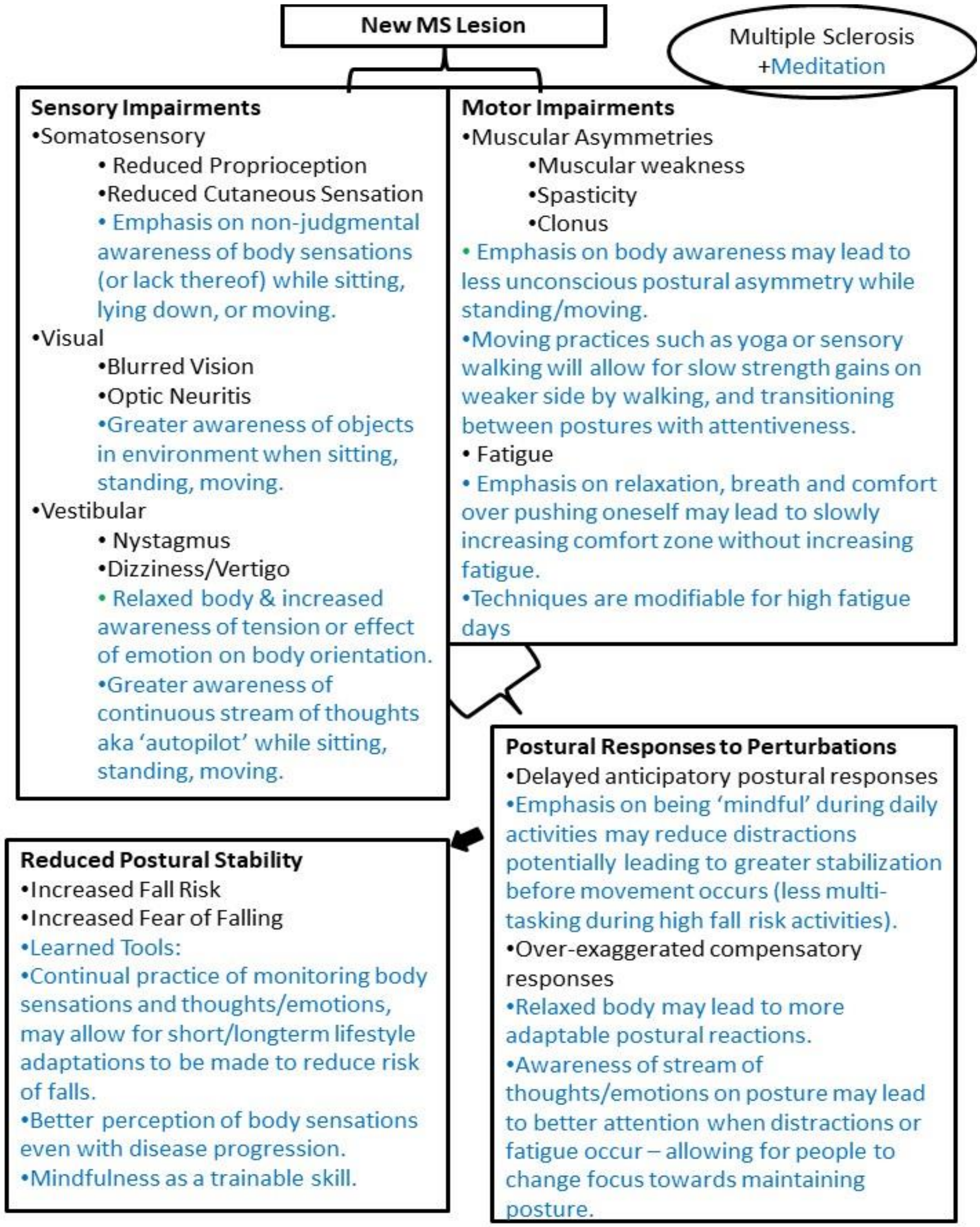



*Figure 5: Conceptual Framework of Meditation on MS Postural Stability*. *Sensorimotor impairments and postural problems due to MS are indicated in black, potential meditation improvements are in blue.*

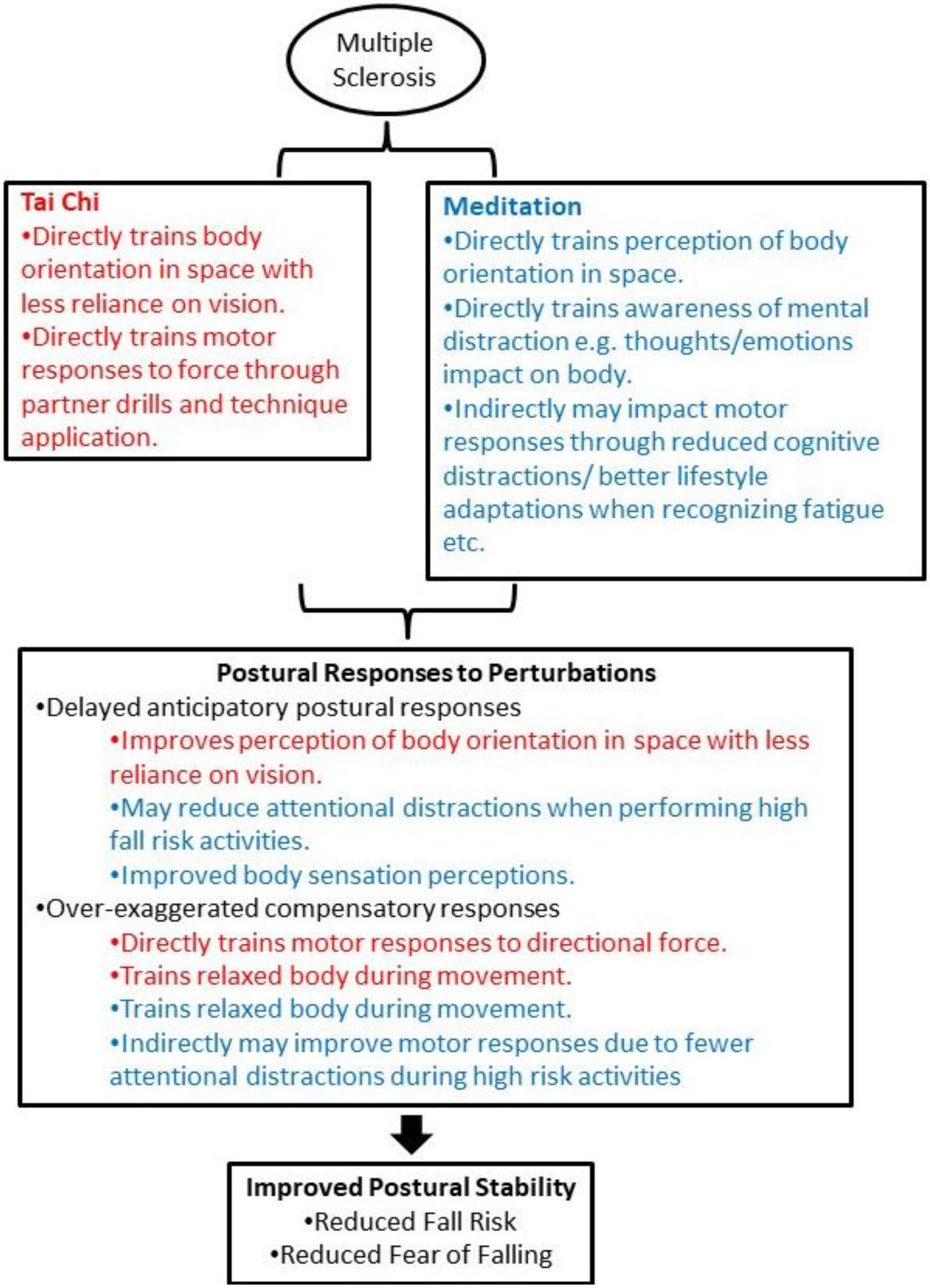



*Figure 6: Conceptual Framework Comparison of Tai Chi vs. Meditation. Sensorimotor impairments and postural problems due to MS are indicated in black, improvements indicated in red for Tai Chi, and blue for Meditation.*

1.8 Dissertation Specific Aims

**The purpose of this study** is to determine which 8 week intervention (Tai Chi or Mindfulness Based Stress Reduction, MBSR) will have a greater effect on physical balance, psychosocial wellbeing and sensorimotor function in people with MS, and whether benefits are retained after a 2-week washout period. Both interventions will be delivered via community-based classes for a period of 8 weeks. The specific aims include:

**Specific Aim 1:** To evaluate (1.1) which intervention Tai Chi or MBSR will yield the greatest improvements in physical balance; and (1.2) whether improvements are retained after a washout period. We hypothesize (1.1) that the Tai Chi group will have the greater improvements in physical balance than the MBSR group, and that (1.2) these benefits will be retained to a greater degree. For the static balance trials the postural variables of interest will include 95% ellipse sway area and center of mass mean velocity in quiet standing, narrow standing, forwards reach, backwards lean. For the dynamic balance trials the postural variables of interest will include trial duration for the Sit to Stand (STS) and Timed Up and Go (TUG) tests, and gait speed for the 25ft walk.

Our rationale for hypothesis 1.1 is based on the previous Tai Chi literature which has reported consistent physical/motor benefits of Tai Chi (Averill, 2013; Li et al., 2008), with contradictory motor benefits found for meditation/MBSR literature (Clark et al., 2015; Williams, 1978; Williams & Herbert, 1976; Telles et al., 1994; Jedrczak et al., 1986; Naranjo et al., 2012). For hypothesis 1.2 we expect better physical balance retention with the Tai Chi group compared MBSR group due to the motor skills learned directly from the Tai Chi practice, specifically the aspects of learning correct structure of Tai Chi movements and continually testing one’s own physical balance limits.

**Specific Aim 2:** Examine (2.1) which intervention (Tai Chi or MBSR) will yield the greatest improvements in psychosocial function (quality of life, coping and adaptation) in people with MS; and (2.2) whether psychosocial improvements are retained after a 2 week washout period. We hypothesize (2.1) both groups will improve but that the MBSR group will improve on psychosocial measures to a greater extent then the Tai Chi group, and (2.2) that these improvements will be retained to a greater degree in MBSR after the 2 week washout period. The psychological variables of interest will include balance confidence, abbreviated profile of mood states, coping and acceptance of MS, fatigue, and psychosocial wellbeing (Powell & Meyers, 1995; Hobart et al.,2001; Krupp et al.,1989); Roy et al.,2016; Grove & Prapavessis, 1992).

Our rationale for 2.1 and 2.2 is based on the findings of Averill (2013) and Simpson et al., 2014. Simpson et al. (2014) in their review of mindfulness interventions (Tai Chi, MBSR, yoga, etc) for people with MS reported improvements in mood (anxiety and depression scores), wellbeing, and health related quality of life as common benefits of mindfulness interventions; with benefits lasting 3 to 6 months post intervention. Averill (2013) found improvements in psychosocial wellbeing with no change in fatigue levels after a 3-week Tai Chi intervention. We theorize that the MBSR skills which lead to improvements in psychological wellbeing can be practiced at any time, whereas the mindfulness during Tai Chi is trained only during Tai Chi practice. Therefore with the 2 week washout period, similar to the literature we expect greater retention of psychosocial wellbeing in the MBSR group.

**Specific Aim #3:** Evaluate (3.1) which intervention (Tai Chi or MBSR) will yield the greatest improvements in sensorimotor function; and (3.2) whether improvements are retained after a washout period. We hypothesize (3.1) that Tai Chi will lead to the greatest improvements in sensorimotor function, and that (3.2) these benefits will be retained after the washout period. The sensorimotor variables of interest will include plantar cutaneous vibration sensitivity assessed with a Biothesiometer, and motor drive assessed via a foot tapping test.

Our predictions for 3.1 is based on the previous Tai Chi literature which has reported some sensorimotor benefits of Tai Chi (Averill, 2013; Richerson and Rosendale, 2007), versus the contradictory motor benefits found for the meditation literature (Clark et al., 2015; Williams, 1978; Williams & Herbert, 1976; Telles et al., 1994; Jedrczak et al., 1986; Naranjo et al., 2012). Improvements in foot tapping ability are expected based on Averill (2013), where improvements were found with 3-weeks of Tai Chi training in an MS population. While plantar vibratory improvements were found by Richerson and Rosendale (2007) in diabetic individuals with peripheral neuropathies after a 6-month Tai Chi intervention. For 3.2 we expect greater retention with the Tai Chi group compared to the MBSR group due to the skills learned directly from the Tai Chi practice, specifically the aspects of correct structure of Tai Chi movements and continually testing one's own functional limits.

## 1.9 Dissertation Significance

This study will add to the current literature on physical balance and psychological wellbeing in MS by: 1) confirming the previous literature regarding the beneficial impacts of

Tai Chi and MBSR as interventions, 2) comparing effectivity of a Tai Chi versus MBSR intervention, and 3) by determining the retention capacity of Tai Chi and MBSR after a 2 week washout period. Lastly, this study is novel as the community-based intervention design would allow participants to have a full student experience within regular classes (Tai or MBSR), and would allow participants to continue their practice after the study ended if the classes are beneficial.

# CHAPTER 2 -LITERATURE REVIEW

2.1 History of MS

Even though MS is the most common neurological disorder observed in people aged 20-50 years old, historically it has been notoriously difficult to diagnose (National MS Society, 2015). MS occurs when neuronal demyelination causes breakdown of the myelin sheath surrounding the axons (Figure 7) resulting in either disruption or loss of electrical impulses; groups of demyelinated neurons are called plaques or lesions (Figure 8; National MS Society, 2006A). Individual MS symptom severity differs depending on lesion location and rate of progression, meaning that people with MS may have very different symptoms and rates of disease progression (National MS Society, 2015).

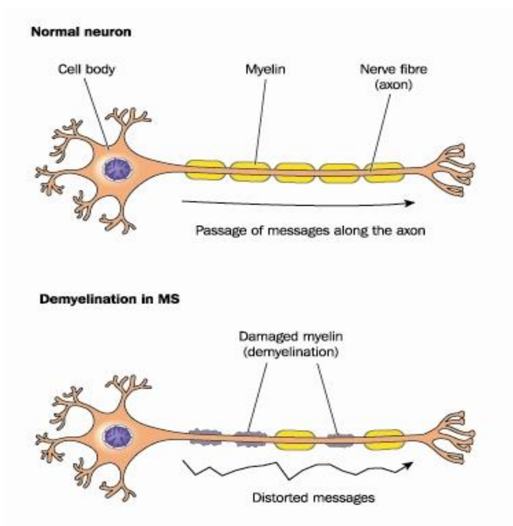



*Figure 7: Neuronal Demyelination in MS (SickKids Research Institute, 2012)*

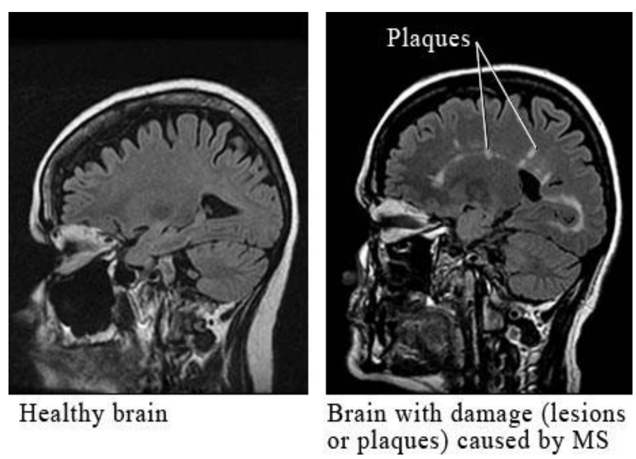



*Figure 8: Plaques/Lesions in MS: Magnetic Resonance Imaging (InterMountain Medical Imaging, Boise Idaho, 2017)*

Because of the diversity of MS symptoms and variable rate of progression, early cases of MS (pre-1800's) were commonly diagnosed as paraplegia with progressive neurological deterioration (Murray, 2009). One of the earliest documented MS cases was that of Sir Augustus D'Este (grandson of King George III) who kept diaries of his progressive neurological illness from 1822-1848, documenting his first visual symptoms at the age of 28 until his death at the age of 54 (Pearce, 2005). In 1868, the first clinical-pathological example of MS was given by Jean-Martin Charcot with his illustrations of MS lesions in the brain and spinal cord, and diagnostic criteria of nystagmus, intention tremor, and scanning speech (Pearce, 2005; Poser & Brinar, 2004). From 1931-1961 numerous diagnostic criteria were developed for MS with varied accuracy, and it was not until the mid-1960's that MS research and diagnostic accuracy improved with better designed clinical trials, improved disease classification and usage of disability scales (Murray, 2009). In 1981 the usage of MRI imaging in MS revolutionized disease diagnosis and allowed for very accurate MS and clear diagnoses to be given (Poser & Brinar, 2004). For a person to be diagnosed with MS in 2017, two lesions separated by time and location within the central nervous system need to be found with MRI or CT imaging (Calabresi, 2004).

## 2.2 Etiology of MS

Current research suggests that the worldwide incidence of MS is increasing, especially among women; nevertheless the etiology is still unknown (Koch-Henriksen & Sorenson, 2010; Noonan et al., 2010). Several factors that may increase MS risk include genetics, geographical location, and childhood disease exposure (National MS Society,

2015). Potential genetic risk factors for MS are chromosomal variants in IL2RA and IL7RA which effect immunoregulatory ability (Rittenhouse et al., 2009), expression of proinflammatory cytokines (Kallaur et al., 2016), level of oxidative stress (Adamczyk & Adamczyk-Sowa, 2016), impaired or reduced quantity of immunoglobulin receptors (Shahsavar et al., 2016), and levels of human leukocyte antigen (Nakamura et al., 2016). As for geographic factors, several studies have supported the Latitude Effect, which is based on findings of an inverse association between quantity of ultraviolet light and prevalence of MS within a geographical region (Brola et al., 2016; Nakamura et al., 2016; Noonan et al., 2010). Lastly, childhood disease exposure to tobacco smoke, Epstein-Barr or Mononucleosis, low levels of vitamin D, and obesity have also been linked to MS onset later in life (Gianfrancesco & Barcellos, 2016).

### 2.3 MS Signs and Symptoms

Common measurable signs of MS include optic neuritis, vertigo, muscular weakness, cognitive impairment, coordination and balance impairments, spasticity, with common individual symptoms including fatigue, dizziness, pain, and numbness (National MS Society, 2006A). However, MS signs and symptoms are diverse and specific occurrence will depend on lesion location and severity. While this list contains only the most common signs and symptoms of MS most can be broken down into predominately sensory or motor categories.

### 2.3.1 Sensory Symptoms of MS

Functional systems that are frequently impacted by MS 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 n=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) as 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 evaluating 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 and accomplishing everyday 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.

### 2.3.2 Motor Symptoms of MS

The motor systems in the CNS are also at risk for inflammation and demyelination, with the most frequent and debilitating motor symptoms of MS being muscular weakness, spasticity, clonus, and fatigue (Freal et al.,1984; Van der Kamp et al., 1991). Even though people with MS have similar fiber-type amounts as healthy controls (Carroll et al.,2005), and the energetic demand of muscular contraction is the same as controls (Castro et al., 1998), muscular weakness is still an issue. Rice et al. (1992) observed that MS participants were rarely able to voluntarily activate higher than 60% when trying to achieve maximal activation, while Chung et al. (2008) found that individuals with MS have a greater power asymmetry of the knee extensor muscles when compared to controls. Therefore, muscular weakness and asymmetry is proposed to occur from upstream central activation impairments

and/or an impaired intramuscular response.  Upstream impairments may consist of reduced motor unit firing rates, altered motor unit recruitment, and overall increases in the motor conduction times (Garner & Widrick, 2003; Ng et al., 1997). While intramuscular impairments leading to muscular weakness may include a blunted metabolic response, impaired excitation-activation coupling, and changes to inherent skeletal muscle characteristics, namely smaller muscle fibers with a greater reliance on anaerobic energy supplies (Ng et al., 2000; Ng et al., 2004; Kent-Braun et al., 1994; Sharma et al.,1995).

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 & 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). According to Rizzo et al. (2004) over one-third of MS patients eliminate or modify activities of daily life due to spasticity, and yet spasticity still may lead to an increased risk of falling due to larger center of pressure velocities and greater mediolateral postural sway (Sosnoff et al., 2011; Sosnoff et al.,2010).

Fatigue is estimated to effect 65-80% of people with MS, however it is one of the most difficult symptoms to quantify (Lerdal et al.,2003; Minden et al., 2006). Fatigue pathophysiology is complicated and may be due to a cumulative impact of medication side effects, musculoskeletal issues, sleep disorders, psychological disorders leading to central and peripheral impairments (Rottoli et al., 2017) 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 defines fatigue as “A sense of tiredness, lack of energy, or total body give-out,” and this questionnaire is one of the most commonly used to document fatigue in individuals with MS (Johnson, 2008). Fatigue in MS starts from higher baseline, typically peaks in late afternoon, and is exacerbated by physical exertion, whereas fatigue in healthy controls starts at a lower baseline, typically increases in a slow linear manner throughout the day, and is exacerbated by reduced quality of sleep (Powell et al., 2017). A higher prevalence of severe fatigue has been found for progressive-relapsing MS (relapsing-remitting with increased frequency of exacerbations) compared to relapsing-stable MS (relapsing-remitting MS with stabilized or lower frequency of exacerbations) or primary progressive MS (Hadjimichael et al., 2008), and there is conflicting evidence whether women experience more fatigue then men with MS (Anens et al., 2014; Lerdal et al., 2003). Wood et al. (2013) when evaluating n=198 individuals with MS found that 44.5% of individuals had anxiety, 18.5% depression, and 53.7% fatigue, they observed that these three symptoms may have shared causal pathways as they tend to cluster together.

Besides qualitative fatigue analyses, MS motor fatigue can be evaluated by measuring muscular force decline over time during sustained muscle activation (Surakka et al., 2004; Kent-Braun & Sharma, 1994). Motor fatigue is increased in MS compared to controls even when adjusting for age, body mass, and fat free mass; likely due to either a reduced ability to activate muscle tissue or lower quality muscle activation due to motor unit impairment (Lambert et al., 2001; Surraka et al., 2004). Even short-term increases in muscle activation

may lead to motor fatigue, reducing postural stability while leaning or reaching (Van Emmerik et al. 2010).

### 2.3.3 Fear of Falling in MS

Besides an increased overall fall risk, fear of falling has also been reported in people with MS. One MS study reported fear of falling in 63.5% of their participants (n=1,064) and within that fearful group 82.6% had modified daily tasks to protect against falling (Peterson et al., 2007). In MS a nonlinear relationship between fall status and mobility function has been observed, similar to that found in older adult and stroke populations (Matsuda et al.,2012; Studenski et al.,1994; Yates et al., 2002). Risk of falling increases as mobility function declines until a threshold of severe mobility function is met and fall risk drops off rapidly, likely due to participants severely limiting their exposure to situations that may lead to a fall (Matsuder et al., 2012). Fear of falling in MS has been linked to reduced cognitive capacity (especially executive function), greater muscle strength asymmetry, and is predictive of reduced physical activity one year after initial fear was reported (Kalron, 2014; Kasser et al., 2014). Management of fear of falling in MS would include addition of mobility aids, modification of the home environment, and improvement of strength, balance, attention span, and problem-solving skills (Peterson et al., 2016a).

### 2.3.4 Altered Cognitive Function in MS

In people with MS, cognitive function (e.g., executive function and processing speed) has been found to be a predictor of variability in motor function even after controlling for

disease duration and physical disability (Benedict et al., 2011). A literature review by Trenova et al. (2016) reported that current prevalence of cognitive dysfunction varied from 40% up to 75% in the MS literature, with potential variation occurring from differing study design, neuropsychological tests used, and disease severity. Cognitive impairments have been observed with increasing T1 and T2 lesion load, atrophy of the cerebral cortex and subcortical areas, including thalamus, putamen, hippocampus, amygdala, and nucleus accumbes (Trenova et al., 2016; Horakova et al., 2012). A common hypothesis is that cognitive impairment in MS is due to functional disconnection between cortical gray matter regions (Rossi et al., 2012). Cognitive dysfunction is not uniform across MS, but the most frequent impairments occur in recent memory, attentional resources/sustained attention, processing speed, verbal fluency, conceptual reasoning, and visuospatial perception (Rao et al., 1995; Rao et al.,1991; Schulz et al., 2006). Even in the early stages of MS it appears that there is an ‘attentional resources deficit’ when cognitive load is high and precise actions are required (Dujardin et al., 1998). Improvements in cognitive function in people with MS have been found by increasing baseline level of physical fitness, with higher levels of exercise leading to improved cognitive function (Beier et al., 2014; Sandroff et al., 2014).

## 2.4 Pharmacological Treatment of MS

While no treatments are available to prevent or cure MS, currently ten disease-modifying medications are FDA approved to delay progression. In the Sonya Slifka longitudinal MS study it was found 52.6% (n=1,231) of people with MS reported a change in disease activity within the previous year, and that within this group the average relapse rate

was 2.3 relapses per person within one year (Minden et al., 2006). No information on medication use was listed for Minden et al. (2006).

Disease-modifying medications in MS work to minimize the frequency of relapses, reduce the number of CNS lesions, and slow progression of disability (Chung & Kent-Braun, 2013). These medications can be divided into two groups, immunosuppressive medications and immunomodulatory medications. Immunosuppressive medications act on mechanisms to suppress the body's immune response (MS is an autoimmune disorder) to reduce the risk of a relapse. Medications in the Beta-Interferon family (1a &1b; Pegylated Interferon B-1a) are the oldest and most well-established immunosuppressive medications for MS care. Beta-Interferons act to reduce IFN-gamma production, T-lymphocytes activity, and T-cell adhesion and ability to cross the blood-brain barrier. The adherence rates to this medication, however, are relatively low as it needs to be injected 3 times a week (Cross & Naismith, 2014; Wingerchuck & Carter, 2014). Natalizumab is an immunosuppressive injected medication which is a monoclonal antibody, and this antibody blocks inflammatory cell movement from location to location in the CNS; however there is an increased risk of developing progressive multifocal leukoencephalopathy, a progressive opportunistic infection of white matter in the brain (Cross & Naismith, 2014; Brooks & Walker, 1984; Wingerchuk & Carter, 2014). Mitoxantrone is an immunosuppressive medication commonly prescribed for progressive forms of MS, which acts to inhibit T-cell activation and reduce proliferation of B and T-cells, however there is a risk of cardiotoxicity or acute leukemia if the dose is not carefully adjusted (Cross & Naismith, 2014; Havla et al., 2016). Alemtuzumab is a monoclonal antibody that binds to CD52 proteins on lymphocytes causing

the lymphocytes to be destroyed, but common side effects include injection site reactions as well as secondary autoimmune diseases (Havla et al., 2016; NMSS, 2016). Daclizumab is also a monoclonal antibody which upregulates CD56 bright NK (natural killer) cells to have a regulatory effect on the immune system, and common side effects are influenza like symptoms (Cross & Naismith, 2014; NMSS, 2016).

Immunomodulatory medications act through indirect pathways to reduce the immune response without directly suppressing the immune system. Glatiramer Acetate is a well-established immunomodulatory medication which is an amino-acid based synthetic copolymer which acts by stimulating neural re-myelination, however injection site reactions are common (Cross & Naismith, 2014; Havla et al., 2016). Fingolimod is an immunomodulatory medication which binds to lymphocytes and keeps them in the lymph nodes (away from CNS to cause lesions), as well as enhancing brain-derived neurotrophic factor to support myelination, however cardiovascular complications are a common side effect (Cross & Naismith, 2014; Wingerchuk & Carter, 2014). Teriflunomide is an immunomodulatory medication which blocks high levels of lymphocyte proliferation by inhibiting an enzyme essential for lymphocyte production; by maintaining low lymphocyte levels there the immune system is strong enough to resist infection without increasing relapse risk, however there is a risk of hepatoxicity and prenatal issues while on this medication (Cross & Naismith, 2014; Havla et al., 2016). Dimethyl fumarate is an immunomodulatory medication that counteracts oxidative stress by modifying the RNA transcriptional pathways, with a common side effect of gastrointestinal issues (Cross & Naismith, 2014; Wingerchuk & Carter, 2014). Overall, these FDA approved MS disease-modifying medications are

relatively effective at slowing disease progression, however a multitude of side effects may occur due to these medications.

### 2.4.1 Medication Side Effects and Fall Risk

Disease-modifying medications have been reported to decrease overall fall risk, and may directly impact balance beneficially by slowing disease progression (Cameron et al., 2015). However, many MS medications have dizziness as a side effect, and this has been reported for both disease-modifying medications and medications to treat individual symptoms (Chung & Kent-Braun, 2013). If dizziness is reported in MS then Meclizine is prescribed, but increasing overall quantity of medications has also been linked to an increased fall risk (National MS Society, 2015). One study (n=248 MS) reported a median of three medications and two supplements per MS participant, with falls risk probability increasing by 13% for each medication, 11% for each supplement, and by 43% for a neurologically active medication such as antidepressants or anti-epileptics (Cameron et al., 2015; Gunn et al., 2013a). Pharmaceutical means may slow disease progression and improve individual MS symptoms, but treating postural instability pharmaceutically is not enough to reduce fall risk in MS.

## 2.5 Balance and Postural Control

Postural control is the ability to regulate one’s body position in space to maintain stability and an upright orientation. To accomplish this a feedback loop of continuous sensory information about body orientation is needed, followed by rapid motor adjustments

to regulate moment-to-moment body orientation (Shumway-Cook & Wollacott, 1995). Balance is determined from a relationship between the masses of the body segments and the area enclosed by the feet (Figure 9). The CoM represents the average masses of individual body segments, condensed into a three-dimensional point at the center of the overall body mass (Shumway-Cook & Wollacott, 1995). Static equilibrium is when the CoM stays located over the base of support allowing for static postural stability to occur; during dynamic equilibrium the CoM can move towards or even outside of the stability boundaries. During dynamic equilibrium 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 used to evaluate balance is CoP. The CoP is the average point application of the ground reaction forces between an individual's two feet during dual support. (Figure 9; during single support 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, stability is considered present when the CoM is within the boundaries of stability.

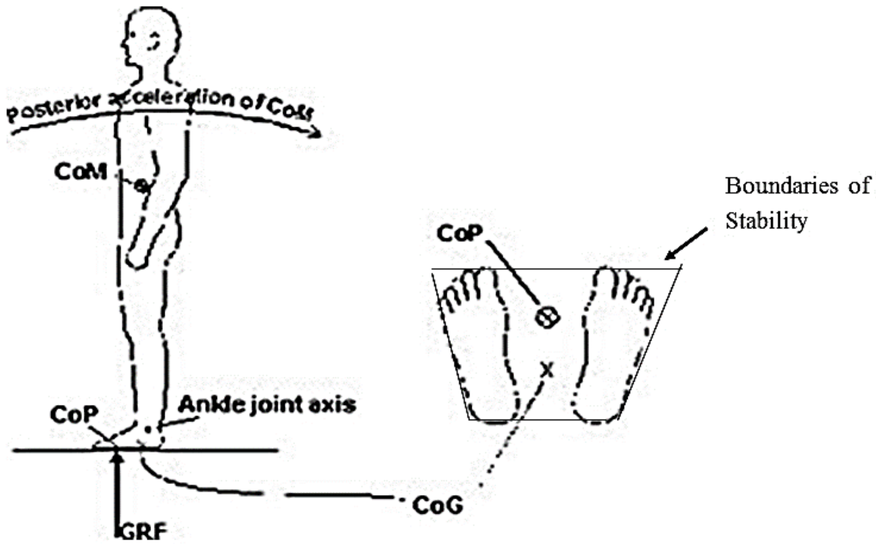



*Figure 9: Maintenance of Balance in Relaxed Bipedal Standing (Kirby, 2002) While standing in quiet stance the Center of Pressure (CoP) which is the averaged point of ground reaction force pressure from under both feet is located just anterior to the ankle joints. The Center of Gravity (CoG) in this 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.*

During static activities, the CoM tends to stay within the boundaries of stability, allowing the body to stay upright and stable; whereas during dynamic activities the CoM can move towards or even outside of the stability boundaries-- potentially perturbing balance. Common dynamic activities include fast movements while standing (e.g. bending, reaching, turning), manipulating an external object, and during walking. In these dynamic activities, postural perturbations occur where the CoM is projected towards the stability boundaries at a high rate, requiring the body to actively slow the CoM down or take a step (Aruin et al., 2015). 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; Haddad et al., 2012; Van Emmerik et al., 2010). 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 young adults, healthy older adults, and elderly fallers when walking at preferred speeds, it was found that elderly fallers had significantly decreased TtC at heel strike when compared to their healthy peers and young adults (Lugade et al., 2010).

When evaluating postural sway in MS populations the most frequently used posturography methods include calculating the 95% confidence ellipse sway area (the ellipse that contains at least 95% of the CoP trajectory), CoM velocity, the root mean square of CoM displacement in anteroposterior and mediolateral directions, and time until contact of the CoM to area bounded by the feet (Brincks et al., 2017; Huisinga et al., 2012; Spain et al., 2012; Van Emmerik et al., 2010).

The body has two postural control strategies to maintain/redirect the CoM within the stability boundaries, depending on the criticality of impending balance loss (Horak et al., 1987). Proactive postural strategies to maintain balance are called Anticipatory Postural Adjustments (APAs), which adjust the CoM position prior to or at the same time as making a voluntary movement (Tresilian, 2012). One common APA is when a person goes from standing to taking a step, where the CoM is shifted over the standing leg to maintain stability before the stepping leg is lifted off the ground (Tresilian, 2012). Reactive postural strategies to maintain balance are called Compensatory Postural Responses (CPRs), and these adjust

the CoM position to regain stability after a perturbation has occurred (Aruin et al., 2015). These CPRs are not automated responses and will vary based on perturbation magnitude and velocity (Diener et al., 1988; Park et al., 2004; Runge et al., 1999).

Three CPRs have been identified that the body can use to regain postural stability during upright standing, and these include the ankle, hip, and stepping strategies (Horak & Nashner, 1986). An ankle strategy is used to maintain balance during small perturbations by causing dorsiflexion or plantar flexion ankle movements to adjust the CoM anteriorly or posteriorly (Shumway-Cook & Wollacott, 1995). Hip strategies are used for larger or faster perturbations, especially on uneven support surfaces; for this strategy, the hips make rapid anterior or posterior adjustments to move the CoM back into equilibrium (Horak & Nashner, 1986). A stepping strategy will occur when the CoM moves past the boundaries of stability due to a large or fast perturbation; in this case the body will take a step to expand the boundaries of stability to incorporate the new CoM position (Shumway-Cook & Wollacott, 1995).

### 2.5.1 Balance Impairments in MS

Increased postural sway (i.e., displacement of the CoM) has been documented in MS participants with and without sensorimotor 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 reduced TtC relative to the stability boundaries. During dynamic tasks individuals with MS have smaller CoP shifts and reduced stability in the direction perpendicular to their lean or reach (Van Emmerik et al., 2010). 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.

In healthy populations APAs are used to proactively stabilize the body, followed by a small CPR to maintain balance after perturbation. MS participants have a similar response to perturbations as blindfolded controls with unexpected perturbations: a smaller or non-existent APA followed by an overexaggerated CPR to regain balance (Santos et al., 2010a; Santos et al., 2010b). People with MS are reported to have smaller APA CoP movements and delayed onset of APA muscle activity (especially when initiating a step), as well as a delayed stepping CPR with multiple steps needed to regain balance compared to healthy controls (Aruin et al., 2015; El-Gohary et al., 2017; Jacobs & Kasser, 2012; Peterson et al., 2016b). Similar to healthy controls, people with MS are able to improve postural responses with

practice (i.e, are able to re-stabilize their CoM faster); however not with the same capacity as controls potentially due to reduced reliance on proprioceptive and cerebellar information to maintain posture (Fling et al., 2015; Kanekar & Aruin, 2015).

### 2.5.2 Mechanisms of Impaired Balance in MS

The maintenance of postural control is dependent on accurate and fast sensory information to allow for active alignment of trunk and head in relation to the environment, and effective coordination of movement responses to deal with balance perturbations (Horak, 2006). The balance impairments observed in MS are likely due to the combination of delayed sensory information, followed by an exaggerated motor response.

Sensory impairments are common in MS, and may lead to delays in body orientation information. Loss of vestibular input will affect stability, even if regular visual and somatosensory input is present, which could have large consequences for balance in MS populations with vertigo or other vestibular impairments (Black et al., 1983). While vestibular impairments are not commonly documented in the MS population, accurate diagnosis can be difficult with sensory and motor impairments creating similar symptoms to that of a vestibular impairment (Nelson et al., 1995).

Common somatosensory impairments in MS include temperature and vibration insensitivity, and reduced proprioception. Delayed information from the plantar surfaces or position of limbs in space would directly impact balance and perception of body orientation (Fling et al., 2014; Meh and Denslic, 2000; Merchut and Gruener,1993). With somatosensory impairments, hip strategies are used to maintain equilibrium in healthy participants with their

feet and ankles anaesthetized; whereas individuals with bilateral vestibular impairment have a lack of hip strategy when compared to healthy populations (Horak et al., 1990).

Visual impairment is often the first symptom of MS, and Daley and Swank (1981) found that anteroposterior sway was increased with visual impairment even in early MS before any other symptoms occurred. Rougier et al. (2007) found that ataxo-spastic and spastic individuals with MS compensated for their proprioceptive losses by using more efficient control strategies if visual information was available. Ataxo-spastic MS individuals lack coordination, have poor balance, and impaired depth perception stemming from cerebellar impairments in combination with the increased spasticity (velocity dependent hyperactivity of stretch reflexes). Spastic MS individuals do not have the cerebellar impairments, and have only the velocity dependent stretch reflex hyperactivity. The control strategies differed between the ataxo-spastic and spastic MS groups with a larger center of gravity horizontal displacement found for the ataxo-spastic MS group to counteract their initial postural responses, which the spastic MS group did not have (Rougier et al., 2007).

Motor symptoms in MS may detrimentally impact the ability to regain balance after the CoM has been perturbed. Motor impairments may lead to reduced balance by either exacerbating balance perturbations due to involuntary motor responses (asymmetry, weakness, fatigue, etc) or by consistently increasing daily fatigue levels. MS symptoms that would detrimentally impact CPRs include leg power and strength asymmetries, plantar flexor and hip flexor weakness, spasticity, ankle joint stiffness, and fatigue level (Chung et al., 2008; Neamtu et al., 2014; Reich et al., 2008; Wagner et al., 2014; Nielsen & Sinkjaer, 2000).

2.5.3 Dynamic Balance and MS

Most falls in MS occur during dynamic balance activities involving transitions between body postures, during walking and turning (Cattaneo & Jonsdottir, 2014a). It has been hypothesized that this may stem from impairment in the collection/ integration of sensory inputs or when executing movements in moments of distraction (Cattaneo et al., 2014; Gunn et al., 2013b). To target fall reduction, the 2014 International MS Falls Prevention Research Network has recommended that besides static measures of balance future MS fall prevention research needs to include dynamic balance measures, such as the Berg Balance Scale, TUG, and STS (Cattaneo et al.,2014). Many of the dynamic balance measures include some aspect of walking, due to the high frequency of gait impairment in MS (Givon et al., 2009). Several studies have shown that individuals with MS have shorter stride lengths, a longer duration in dual support phase (Givon et al., 2009; Remelius et al., 2012), greater leg asymmetry and lower knee extensor power, and a reduced speed of progression while walking (Benedetti et al., 1999; Chung et al., 2008; Martin et al., 2006; Sacco et al., 2011). People with MS prefer to use a wider base of support while walking compared to controls, as well as slower gait initiation velocity, and smaller CoP shifts then their control counterparts (Givon et al.,2009; Remelius et al., 2008).

However, the regular 25ft walk and other straight line walking tests may not adequately measure an individual's true functional mobility which would include turning or posture transitions such as those seen in dynamic movement tasks (e.g, TUG, Six Spot Step Test, STS,  and Functional Reach/leaning tasks; Sebastia et al., 2016). Sebastia et al. (2016), testing the validity of the TUG as a functional mobility test, found that TUG times were

strongly associated with ambulatory mobility, moderately to strongly associated with balance confidence, weakly associated with postural control, and moderately associated with cognitive processing in individuals with MS. In individuals with minimal gait impairment due to MS who performed the TUG, the overall test time did not differ compared to healthy controls; however the body worn inertial sensors measured a greater trunk angular range of motion when standing and a longer 180 degrees turning duration compared to healthy controls (Spain et al.,2012). MS individuals also have a larger variation in TUG times when compared to healthy controls as a function of EDSS disability level, with greater disability resulting in slower TUG times (Allali et al., 2012). Individuals with MS have been shown to have slower Six Spot Step Test (SSST) scores then healthy controls (Nieuwenhuis et al., 2006; Pavan et al., 2010), and similar to the TUG test, EDSS disability level has a significant effect on SSST speed with faster scores for EDSS less than 4 and slower scores for those over 4 (Fritz et al., 2015; with EDSS scores greater than 4 indicating mild to moderate walking disability).

When evaluating the SSST as a measure of ambulation in MS, it was found to be more precise at discriminating between disability levels, MS disease course, and fall risk due to balance confidence compared to the 25ft walk or TUG test (Sandroff et al., 2015). For the STS test, Bowser et al. (2015) found that MS individuals with leg weakness displayed decreased leg strength, greater trunk flexion, faster trunk flexion velocity, and decreased knee extensor power and increased times to perform the STS task when compared to an MS group and Control group without leg weakness (who had equal STS times). While Cattaneo et al. (2014b) reported that people with MS have greater CoP translational sway when

forward reaching and performing STS, had a greater stabilization time when standing up or siting down, and greater quiet standing sway compared to healthy controls. For the maximal functional reach task, people with MS have been found to move their CoP over a smaller distance with a trend towards increased CoP mediolateral sway compared to the healthy controls (Van Emmerik et al., 2010). For the maximal backwards lean, MS individuals trended towards moving their CoP over a smaller distance compared to controls, had a shorter TtC of CoM in the mediolateral direction, with significant limb loading asymmetry compared to healthy controls (Van Emmerik et al., 2010).

When performing four directional leans (forwards, mediolateral and backwards leans), diminished cutaneous sensation was found to be linked to reduced CoP complexity in the antero-posterior direction in people with MS (Busa et al., 2016). While people with MS have similar consistency of maximal functional reach scores as healthy controls when tested morning and afternoon, a significant decrease in functional reach distance has been found for people with MS versus age-matched controls (Frovzic et al., 2008). In older adults functional reach distance has been linked with physical frailty to a greater extent than age; a similar impact of MS disability and functional reach distance may be expected (Weiner et al., 1992).

## 2.6 Balance Interventions in MS

One means to improve balance in MS is with use of external aids in an attempt to beneficially reduce either the sensory information delay or the motor response to balance perturbations. External aids that have improved balance in MS include canes, walkers, ankle foot orthoses, and functional electrical stimulation. Balance improvements in MS have been shown when wearing dynamic ankle foot orthoses for both static and dynamic postures by reducing tripping risk (Cattaneo et al., 2002), for functional electrical stimulation during walking (improving balance by reducing dropfoot), and for using canes or a walker to increase ones base of support area (Bulley et al., 2014; Mayer et al., 2015; Tresilian, 2012). Currently there are conflicting results on the benefits of full body vibration and textured insoles in MS to improve static and dynamic balance, and further research is warranted (Alguacil et al., 2012; Broekmans et al., 2010; Dixon et al., 2014; Kalron et al., 2015; Kelleher et al., 2010). Five days of full body vibration was found to improve reaction time to postural perturbations in an MS group compared to an MS control group (Alguacil et al., 2012). Broekmans et al. (2010) reported no changes in leg muscle performance for maximal isometric and dynamic contractions (measured with a dynamometer) or functional capacity (including: Berg Balance Scale, TUG, 2-min walk, 25ft walk) after 10 or 20-weeks of whole body vibration training. Kelleher et al. (2010) found improved plantar cutaneous sensitivity for both an MS and healthy control group while walking with textured insoles, however no changes in MS gait patterns were seen from the improved sensitivity. Dixon et al. (2014) found no immediate improvements in plantar cutaneous sensitivity or gait in people with MS wearing textured insoles. After 2-weeks of wearing the insoles no changes in static balance

were reported, but there was an increase in stride length when walking at preferred speed. Kalron et al. (2015A) reported immediate reductions in CoP sway rate in both people with MS and healthy controls while wearing textured insoles during eyes closed static balance, but no changes in static balance or gait parameters were found after 4-weeks of wearing the insoles besides the initial immediate change for eyes closed standing. While external aids are beneficial as a temporary balance fix, fall risk will increase as soon as the aid is removed or not used (Iezzoni et al., 2010; Aadfwk et al, 2021).

Another possible way to improve balance in MS is through exercise interventions. Exercise balance interventions may be classified into three categories, all with the goal of improving balance via better postural strategies or sensorimotor adaptations. These three categories are: traditional balance exercises, balance biofeedback, and general exercises. Traditional balance exercises consist of posture specific exercises (e.g., single leg standing, feet together narrow standing) usually led by a physical therapist, and have been shown to improve single leg standing times and Berg balance scores in MS (Hogan et al., 2014; Sosnoff et al., 2014; Tarakci et al., 2013; Wiles et al., 2001). The Berg balance score is a balance measure developed for aging populations and frequently used in MS, with balance criteria based on 14 timed balance tasks such as turning 360 degrees, sitting to standing without using hands, and single leg standing duration (Berg et al., 1989). Balance biofeedback exercises provide external balance information to the participant to modify their body position while accomplishing tasks; these commonly include Nintendo Wii balance boards or playing video games where a variety of body positions must be obtained to achieve task goals (Kramer et al., 2014). Balance biofeedback exercises have been found to reduce

fear of falling and improve Berg balance scores, dynamic posturography and postural sway characteristics for the trained tasks (Brichetto et al., 2015, Cattaneo et al., 2014b; Prosperini et al., 2010; Robinson et al., 2015).

Exercise interventions such as progressive resistance cycling, yoga, pilates, Tai Chi, strength training, calisthenics, and hippotherapy have also been reported to improve balance measures in MS (Aydin et al., 2014; Bronson et al., 2010; Burschka et al., 2014; Coote et al., 2014a; Frank & Larimore, 2015; Guclu-Gunduz et al., 2014; Kjolhede et al., 2012). Finally, a meta-analysis by Gunn et al. (2015) reported that while balance can be improved through various exercise interventions in MS, the magnitude of change is likely not enough to impact overall fall outcomes.

## 2.7 Development of a Successful Balance Intervention in MS

A successful MS balance intervention would reduce fall risk by training balance in a safe, non-fatiguing manner to allow for movement adaptation and development of new balance strategies without reducing quality of life (Tresilian, 2012; Petajan & White, 1999). Furthermore, active participation and integration into everyday life are key aspects of successful falls prevention interventions (Finlayson et al., 2014). Therefore, an intervention is needed that could train balance in a safe non-fatiguing manner allowing balance skills to be learned and integrated into everyday life, in a manner that people find interesting enough to continue for a lifetime. Two mindfulness interventions that may fit this description and improve balance and quality of life in MS are Tai Chi and Mindfulness Meditation training.

## 2.8 Mindfulness Training in Special Populations

Development of a mindfulness meditation practice is based on the activity of focusing attention on the present experience in a moment to moment basis (Trousselard et al., 2014). Mindfulness awareness trains people to focus on present sensory input without cognitive elaboration or emotional reactivity, which may reduce negative processing of the past or worrying/fantasizing about the future (Vago & Zeidan, 2016). Long term benefits of mindfulness meditation include improved ability to deal with negative emotions (by reducing intensity of emotional arousal), a slower baseline respiration rate independently of age and gender, reduced pain awareness due to the decoupling of the sensory experience (somatosensory activation) from contextualizing it as pain (deactivation of ventral-medial prefrontal cortex), and increased gray matter in the lower brain stem regions compared to non-meditating controls (Aftanas & Golosheykin, 2005; Wielgosz et al., 2016; Vestergaard-Poulsen et al., 2009; Zeidan & Vago, 2016).

Short term mindfulness meditation such as that commonly taught in an 8-week MBSR class has resulted in increased mindfulness and wellbeing with decreased stress and depression symptoms (Carmody & Baer, 2008), beneficial changes in gray matter involved with emotional regulation (Holzel et al., 2011), improved cardiovascular characteristics such as reduced blood pressure, increased pain tolerance (in migraineurs and people with chronic pain; Zeidan & Vago, 2016), attenuated cortisol responses to stress (Carlson et al., 2004; Palta et al., 2012; Sibinga et al., 2013), and positive immunological changes with reduced inflammatory gene expression (Creswell et al., 2009; Cresswell et al., 2012; Rosenkranz et al., 2013; Witek-Janusek et al., 2008). Short term meditation training has been especially

beneficial for reducing pain in chronic migraineurs (Day et al., 2014; Zeidan & Vago, 2016). Short term meditation training (less then 1 week) has been found to significantly reduce pain intensity and unpleasantness ratings more so than a sham meditation and placebo group in migraneurs (Zeidan et al., 2015). Four days of mindfulness meditation training while meditating in the presence of noxious stimulation resulted in measures of unpleasantness reduced by 57% and pain intensity by 40% when compared to a resting control group as assessed through fMRI. The mechanism through which this change occurred was thought to occur because of increased inhibitory control of cortico-thalamo-cortical activation (Zeidan et al., 2011).

### 2.8.1 Mindfulness Meditation Practices

Meditation practices can be categorized in different ways, but the most common classification is based on the number of objects of attention. Focused Attention meditation consists of focusing your attention on one object, such as breath, heartbeat, body sensations, thoughts, or specific sensory information (e.g., visual, auditory). While in Open Monitoring meditation the meditator allows multiple objects into their attentional field without focusing on one individually (Manna et al., 2010; Marciniak et al., 2014). Tsai and Chou (2016) reported that, when comparing the effects of 3 months of Focused Attention training versus Open Monitoring practice, the Focused Attention meditators improved executive control abilities while the Open Monitoring meditators improved both executive control abilities and attentional orienting abilities. The commonly taught 8-week MBSR class has a curriculum including both Focused Attention and Open Monitoring meditation sitting and moving

practices (Kabott-Zinn, 1990). No matter the type of meditation practiced, the literature has shown that regular meditation practice has resulted in increased cortical thickness of the prefrontal cortex and right anterior insula, putamen, hippocampus, medulla oblongata, cerebellum, superior and inferior frontal gyrus, cingulo-frontal-parietal network, anterior cingulate cortex, and somatosensory cortex (Grant et al., 2010; Lazar et al., 2005; Holzel et al., 2008; Pagnoni & Cekic, 2007; Shao et al., 2016; Taren et al., 2017; Vestergaard-Poulsen et al., 2009). One explanation for the beneficial cortical changes seen with meditation training may be due to cardiorespiratory synchronization leading to a decreased parasympathetic body response, which indirectly impacts neural activity leading to beneficial changes in functional connectivity (Jerath et al., 2014).

### 2.8.2 Potential Benefits of Meditation Training on Balance in MS

People with MS are known to have delayed sensory input followed by overexaggerated motor responses to perturbations. Potential benefits of meditation training may include faster pick up of sensory information preceding a perturbation and a more relaxed/adaptive motor response when a perturbation occurs. The types of meditation taught within MBSR classes train people to anchor their attentional focus on one point in the body (e.g., sensation in the big toe), or to expand their awareness to include the whole body (e.g., path of breath as it moves through inhalation/exhalation). While neuronal demyelination in MS may limit the quality of sensory information available, with meditation training MS individuals may increase their awareness of available sensory information---which may be enough to improve balance. The same hypothesis holds for improving balance in MS

individuals with reduced cognitive capacity, that potentially meditation training would allow people to allot their available resources in ways to improve stability.

## 2.9 Tai Chi Training in Special Populations

The beneficial impacts of Tai Chi 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 and Rosendale, 2007; Sattin et al., 2005).

Beneficial impacts that have been reported after 3 years or more of regular Tai Chi practice in older populations include 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., 2004).

### 2.9.1 Tai Chi Training and MS

Tai Chi training appears to have a beneficial effect in several studies on people with MS and has resulted in improved balance, function, mobility, and depression scores with interventions varying in duration from 3-weeks to one year (Averill, 2013; Azimzadeh et al., 2015; Bayraktar et al., 2013; Burschka et al., 2014; Mills et al., 2000).

An 8-week Tai Chi intervention improved 25ft walking speed, hamstring flexibility, and wellbeing in relapsing remitting MS (Husted et al., 1999). In people with secondary progressive MS, an 8-week group and home based Tai Chi practice improved single leg standing times and reduced depression symptoms (Mills et al., 2000). An 8-week swimming MS Tai Chi program improved single leg standing times, faster TUG and 6-minute walk times, fatigue, and muscular strength more so than an MS control group with breathing and abdominal exercises alone (Bayraktar et al., 2013). A 6-month MS Tai Chi program improved balance, coordination, and depression measures compared to an MS control group with treatment as usual (Burschka et al., 2014). A 3-week Tai Chi intervention was found to improve postural stability during tandem stance and standing meditation with arms, improve neural drive (increased quantity of foot taps produced), increase muscular strength (faster STS times), improve psychological wellbeing, with no change in fatigue in a relapsing-remitting MS group (Averill, 2013). Finally, a 12-week MS Tai Chi intervention improved Berg balance scores compared to the MS treatment as usual control group whose balance scores did not change (Azimzadeh et al., 2015).

In Averill (2013) a group of n=7 people with MS took part in a 3-week Tai Chi intervention to determine whether postural stability and function in MS would improve with short term Tai Chi training. With function being factors that would influence postural stability such as muscular strength, neural drive, cutaneous sensation, fatigue, and wellbeing. Participants attended two data collections 3-weeks apart, with the intervention occurring in between. At the initial data collection, a Tai Chi instructor taught the participants how to perform Tai Chi meditation and gait. Pre and post intervention assessments consisted of Multiple Sclerosis Impact Scale-29 (MSIS-29; a measure of psychological wellbeing), the Fatigue Severity Score, the Sit to Stand test (rise and sit back in a chair five times), neural drive measured by number of foot taps produced in 15 seconds, and vibratory plantar sensitivity on the hallux, first metatarsal, arch, and heel of both feet. Postural assessments consisted of quiet stance, tandem stance, and Tai Chi standing meditation (SM) with arms relaxed at the sides  or with standing meditation with grasp sparrows tail arm movements (SMA).

The intervention consisted of nine 1-hour training sessions scheduled every other day following the initial data collection for 3-weeks. Training sessions included: ten minutes watching Tai Chi instructional videos, forty minutes practice time, and ten minutes of break time. Check in days were held once per week where a Tai Chi instructor assessed the participants' progress and gave personalized feedback. No significant changes in postural stability were measured pre to post intervention for quiet standing or standing meditation (Table 1). However for SMA the average CoP velocity (p=0.022, large effect: 1.372) and net CoP excursion (p=0.023, large effect: 1.414) significantly increased, while time-to-contact

decreased (p=0.020, large effect: 1.263) (Figure 10, Table 1). This decrease in TtC during dynamic balance may indicate increased comfort moving towards the base of support boundaries with exploratory postural sway for SMA in people with MS after the 3-week Tai Chi intervention. For tandem stance the average time-to-contact increased after the intervention (p=0.045, moderate effect: 0.828, Figure 10), with a trend for CoP excursion (p=0.091, large effect: 1.043) and velocity (p=0.066, moderate effect: 0.832) to decrease. These static balance results under challenging conditions indicate more controlled postural sway in tandem stance after the 3-week intervention, likely due to the narrow base of support size with feet in heel to toe posture.

*Table 1: Postural Stability Characteristics from Averill (2013)*

| *Postural Stability Characteristics*<br>*Quiet Standing* | *Average Pre* | *Average Post* | *P-Value* | *95% CI* | *Cohen's d* |
|---|---|---|---|---|---|
| *Average Time-to-contact (s)* | *1.58±0.18* | *1.48±0.19* | *0.310* | *-0.13 to 0.34* | *0.540* |
| *Average CoP Velocity (mm/s)* | *106.07±35.35* | *101.74±31.41* | *0.706* | *-22.44 to 31.11* | *0.129* |
| *Net CoP Excursion (mm)* | *241.19±85.74* | *226.41±64.81* | *0.613* | *-52.99 to 82.58* | *0.203* |
| *Postural Stability Characteristics*<br>*Standing Meditation (SM)* | *Average Pre* | *Average Post* | *P-Value* | *95% CI* | *Cohen's d* |
| *Average Time-to-contact (s)* | *1.26±0.26* | *1.17±0.19* | *0.171* | *-0.05 to 0.23* | *0.395* |
| *Average CoP Velocity (mm/s)* | *206.13±112.96* | *274.01±148.46* | *0.186* | *-179.19 to 43.43* | *0.515* |
| *Net CoP Excursion (mm)* | *444.76±247.29* | *601.14±304.78* | *0.197* | *-419.95 to 107.19* | *0.563* |
| *Postural Stability Characteristics*<br>*Standing Meditation with Arms (SMA)* | *Average Pre* | *Average Post* | *P-Value* | *95% CI* | *Cohen's d* |
| *Average Time-to-contact (s)* | *1.22± 0.14* | *1.03±0.16* | *0.020* | *0.04 to 0.33* | *1.263* |
| *Average CoP Velocity (mm/s)* | *259.08±73.08* | *386.57±109.21* | *0.022* | *-229.17 to -25.80* | *1.372* |
| *Net CoP Excursion (mm)* | *474.99±132.71* | *722.86±209.36* | *0.023* | *-446.93 to -48.80* | *1.414* |
| *Postural Stability Characteristics*<br>*Tandem Stance* | *Average Pre* | *Average Post* | *P-Value* | *95% CI* | *Cohen's d* |
| *Average Time-to-contact (s)* | *0.62±0.20* | *0.77±0.16* | *0.045* | *-0.31 to -0.01* | *0.828* |
| *Average COP Velocity (mm/s)* | *609.49±354.89* | *375.71±178.93* | *0.066* | *-25.23 to 492.80* | *0.832* |
| *Net CoP Excursion (mm)* | *1330.91±813.1* | *685.23±323.61* | *0.091* | *-163.63 to 1454.90* | *1.043* |

*NOTE. Averill 2013, n=7 MS participants in Pre vs. Post a 3-week Tai Chi intervention. All values based upon antero-posterior and medio-lateral center of pressure (CoP) movement. Abbreviations: QS, quiet stance; SM, standing meditation; SMA, standing meditation with tai chi arm movements; TS, tandem stance. Values are mean ± SD, 95% CI: difference between means.*

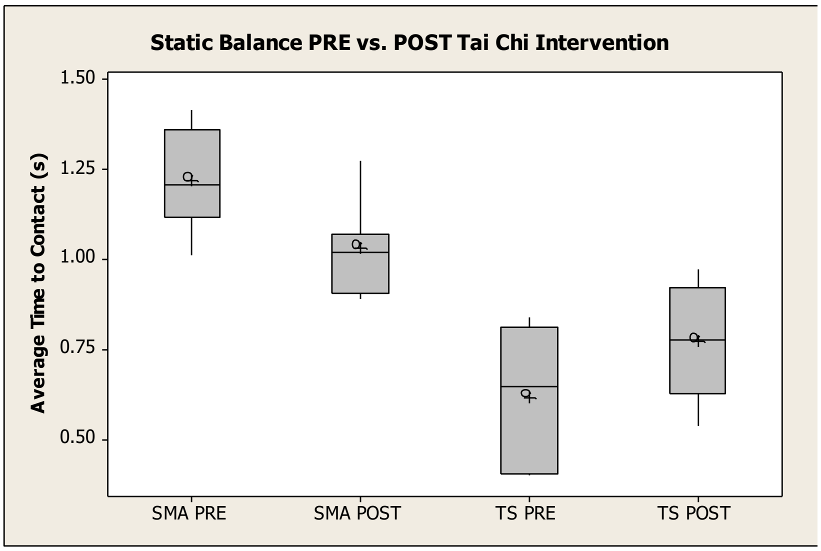



*Figure 10: Postural Stability Changes Pre versus Post for Averill (2013) Tai Chi Intervention. Postural stability data averaged across all directions for standing meditation with arms (SMA) and tandem stance (TS) pre and post the Tai Chi intervention. Means are designated by a target symbol, medians by a line, with the top and bottom designating the 1st and 3rd interquartiles.*

Wellbeing measured by the MSIS-29 increased post intervention (p=0.032, moderate effect: 0.60). The MSIS-29 has subcategories of psychological and physiological wellbeing, in which psychological wellbeing increased (p=0.018, moderate effect: 0.654), and physical wellbeing trended towards an increase (p=0.06, moderate effect: 0.514) post intervention. These findings indicate improvements in overall psychosocial wellbeing after the 3-week Tai Chi intervention. Fatigue was unchanged post intervention (p=0.132; low effect: 0.471), which is an important result as this was one hour practicing Tai Chi three times per week

with no added fatigue for the MS participants. Sit-to-Stand time decreased significantly from pre to post intervention (p=0.025; large effect: 1.21) while average number of foot taps increased (p=0.024, large effect: 1.714), indicating increased muscular strength and improved bilateral neural drive after 3-weeks of Tai Chi. No change in overall cutaneous sensitivity was found post intervention (p=0.674; low effect: 0.176).

In other neurological populations Tai Chi training has resulted in: 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). However more research needs to be completed to better understand the duration, dosage, and type of Tai Chi intervention necessary to optimize balance improvements in MS.

### 2.9.2 Conclusion

Both Tai Chi and mindfulness meditation training have led to improved quality of life, and reduced fatigue and depressive symptoms in MS (Mills et al., 2000; Levin et al., 2014b; Grossman et al., 2010). While the benefits of using Tai Chi as a balance intervention in MS have been reported, only a handful of studies have evaluated the effect of meditation practice on motor skill improvement and these few studies have reported conflicting results (Clark et al., 2015; Williams, 1978; Williams & Herbert, 1976; Telles et al., 1994; Jedrczak et al., 1986; Naranjo et al., 2012). Benefits of meditation training on improving alertness, attention, and anxiety reduction have been reported (Clark et al., 2015), however it is unknown whether these benefits might extend to standing balance or movement. Therefore research is needed to compare the impact of a Tai Chi versus MBSR intervention on physical

balance, sensorimotor function, and psychological wellbeing in MS, and determine if benefits are retained post intervention. This study will add to the current literature on physical balance and psychological wellbeing in MS by: 1) confirming the previous literature regarding the beneficial impacts of Tai Chi and MBSR as interventions, 2) comparing effectivity of a Tai Chi versus MBSR intervention, and 3) by determining the retention capacity of Tai Chi and MBSR after a 2 week washout period. Lastly, this study is novel as the community-based intervention design would allow participants to have a full student experience within regular classes (Tai or MBSR), and would allow participants to continue their practice after the study ended if the classes are beneficial.

# CHAPTER 3- METHODOLOGY

## 3.1 Study Design

**The purpose of this study** is to determine which 8 week intervention (Tai Chi or Mindfulness Based Stress Reduction, MBSR) will have a greater effect on physical balance, psychosocial wellbeing and sensorimotor function in people with MS, and whether benefits are retained after a 2-week washout period. The study design is presented in Figure 2. This study will consist of three data collections taking place over a 6-month period, with the intervention portion (Tai Chi or MBSR) lasting for an 8-week period. After the initial data collection (#1), participants will be intentionally assigned based on MS disability status into either the Tai Chi group (n=20) or the Meditation group (n=20) for the 8-week intervention period. After the middle data collection (#2) the 2-week washout period will begin where participants are asked to not practice their art. The final data collection (#3) will occur within one week after the washout period ends. All three data collections will be held in the UMass Motor Control lab, and will consist of questionnaires, sensorimotor testing, balance assessments, and reported fall history.

Data collections (1-3) will occur over 2-week collection periods ensuring that all participants begin and end the Interventions (1 and 2) at the same date. For the intervention periods 1 and 2 we will be partnering with local businesses to lead the interventions. The Tai Chi intervention will be led by Jeff Rosen (and instructors) of Yang's Martial Art Association (YMAA) of Western Massachusetts in Florence MA, while the Mindfulness Meditation intervention will be led by Dr. Shalini Bahl at Downtown Mindfulness Center in

Amherst MA. There will be no cost to the participants for the 8-week Tai Chi or Meditation training, all practitioner fees will be paid via a National MS Society Pilot Grant.

### 3.2.1 Intervention Components: Tai Chi Group

Participants will become active members of YMAA Western MA Tai Chi, and will be expected to accumulate 5 hours of Tai Chi practice time per week. Within those 5 hours per week, a minimum of 2.5 hours of class work is expected with a YMAA approved Tai Chi instructor while the remaining time will be accumulated through homework. Tai Chi classes typically last one hour, with a general schedule of 10 minutes of stretching, 15 minutes of Qigung (standing meditation), 20 minutes of form training, followed by 15-20 minutes of free practice. The free practice includes centering training, applications, or individual technique work. Beginner Tai Chi classes are offered six times per week and participants will choose which classes to attend depending on their schedule. Remaining practice time will be accumulated through homework; for example, if a student attends 3 hours total class time they would need to accumulate 2 hours homework to achieve the 5 hour weekly practice goal. The YMAA Western MA Tai Chi group was chosen due to instructor excellence, convenient location, and well-developed curriculum. Jeff Rosen is the school director of YMAA Western MA who has practiced Tai Chi for over 36 years, has had 20+ years of Tai Chi teaching experience, and is one of only ten individuals worldwide who have received the title of Instructor in the YMAA Tai Chi school from Dr. Yang Jwing-Ming. The YMAA is a highly respected, international organization dedicated to spreading the benefits of Tai Chi through a highly-codified training system, publications and multi-channel, distributed, digital

media. Dr. Yang's life work has been to connect traditional Chinese mind-body practice to Western principles of science as a means for providing evidence-based support for the benefits of studying Tai Chi. The YMAA has schools on four continents and through these schools, seminars and publications, Dr. Yang's teachings have reached and inspired hundreds of thousands of individuals.

### 3.2.2 Intervention Components: MBSR Group

Participants will join a MBSR class with a goal of accumulating 5 hours total practice time per week. Class time will consist of 2.5 hours curriculum led by an MBSR approved instructor, and the remaining 2.5 hours practice time will be accumulated through homework guided meditation podcasts. A typical MBSR class consists of 1.5 hours of mindfulness lecture and group discussion followed by 1 hour of guided meditation practice for a total of 2.5 hours. The Downtown Mindfulness Center was chosen to lead the Mindfulness classes due to instructor excellence, convenient location, and well-developed curriculum. Shalini Bahl, PhD, is a mindfulness consultant, researcher, and founder of the Downtown Mindfulness meditation center. She received her Mindfulness Based Stress Reduction (MBSR) teacher training from The Center for Mindfulness at the UMass Medical School, and has worked as a mindfulness consultant and a teacher to various companies and individuals. Her research on the transformative potential of mindfulness to enhance consumer, societal, and environmental well-being has been published in premier marketing journals such as the Journal of Public Policy & Marketing. She is also trained in Search

Inside Yourself the mindfulness-based emotional intelligence program that started at Google (Siyli, 2017).

### 3.2.3 Rationale for usage of a Community Based Intervention

Delivering interventions directly through local businesses will allow participants to have a full student experience within regular Tai Chi classes or the MBSR program, complete with any corollary social benefits. By positioning these interventions in the local community participant retention may improve as participants will both become a part of a community and choose class days/times that fit best within their schedule. Lastly, if the participants find the classes to be beneficial then taking classes within the local community would allow participants to continue their health-promoting practice after the study has ended.

### 3.2.4 Assessment of Intervention Practice Time

Participants of both groups are expected to meet a goal of 5 hours practice time per week. A sign in/out sheet will be used to accurately assess class attendance, and a novel data tracker application will be used to evaluate homework time. The data tracker application is currently under development, and when finalized will allow for accurate assessment of Tai Chi video or Mediation podcast usage. During the intervention periods participants will access the data tracker application via a secure individual login to the study website, and can then access media specific to their intervention group. The group specific media will consist

of either Tai Chi videos of 10 and 40 minute durations, or MBSR audio podcasts of 10, 20, or 40 minute durations. The tracker application will allow for weekly reports to be generated, listing dates/times that media files were accessed, duration of media watched/listened to, and which media files were accessed.

## 3.3 Participants

All participants will be asked to read and sign a University Human Subjects Review Committee approved Informed Consent form. The study will consist of n=40 MS individuals between the ages of 21 and 70 years. Sample size calculations with a power of 80% estimated a total population of n=36.8 based on previous balance studies; including a 10% attrition rate would increase the total population size to n=40 people with MS (n=20 per group; Table 2). Final sample size estimations will be calculated based on piloting the study on a group of n=5 participants. All participants will have no to minimal mobility impairments, as assessed through the Patient Determined Disease Steps (PDDS; Hohol, 1999). Participants will be excluded from the study if they have a PDDS score of greater than 4 (scores of 0-4 indicating minimal gait impairment), or if they have participated in a regular Tai Chi or meditation class within the past year.

*Table 2: Sample Size Calculations.*

| Primary Author | Year | MS Tai Chi (n) | Measure of Balance | Pre Mean (Mu) | SD Pre | Post Mean (M1) | 1 or 2 Tailed | Alpha | Power | Sample Size |
|---|---|---|---|---|---|---|---|---|---|---|
| Averill | 2017 | MS, TCC | Time to Contact (ms) | 0.62 | 0.2 | 0.77 | 2 | 0.05 | 0.8 | 14 |
| Azimzadeh | 2014 | MS, TCC | Berg Balance Scale (unit) | 52.25 | 3.39 | 53.94 | 2 | 0.05 | Unlisted (used .80 for calculations) | 32 |
| Brichetto et al. | 2013 | MS | CoP sway area (mm2) | 95.6 | 44.5 | 59.3 | 2 | 0.05 | … | 12 |
| Burschka | 2014 | MS, TCC | Balance (units unlisted) | 5 | 1.89 | 6.5 | 2 | 0.05 | … | 55 |
| Mills & Allen | 2000 | MS, TCC | Single Leg Stand Duration (sec) | 5.63 | 3.96 | 11.88 | 2 | 0.05 | … | 4 |
| Pau et al. | 2015 | MS | CoP sway area (mm2) | 340.68 | 197.82 | 275.85 | 2 | 0.05 | … | 74 |
| Prosperini et al. | 2013 | MS | CoP path (mm) | 597 | 370 | 485 | 2 | 0.05 | … | 86 |
| Zhou & Chang | 2015 | Old Adults, TCC | Cop path length (mm) | 1256.9 | 289.85 | 1061.3 | 2 | 0.05 | … | 18 |
| | | | | | | | | | **Avg Sample Size** | **36.875** |

*Note--The study sample size is based on previous sample sizes calculated from the balance literature using 1 sample Z tests. For example, with Mu(0) being 5.63, Mu(1) being 11.88, 2 sided, with an alpha of 0.05 and a power of 80%. A final sample size of n=36 with a 10% attrition rate would indicate n=40 MS individuals are needed for this study. The units of balance for Burschka et al. 2014 were unlisted in the full paper written in German. Averill (2013) TtC was for Tandem stance. Acronyms: Tai Chi (TCC), Standard Deviation (SD),*

### 3.3.1 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 and/or meditation experience, MS subtype, physical limitations, current medications, current physical activity level, etc. If the participants fulfill all requirements for

recruitment, they will be contacted to schedule their initial visit to the data collection facility. To view the Informed Consent document, PDDS and sEDSS documents refer to Appendix A.

**Recruitment/Screening:**

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

**Part I: Informed Consent and Questionnaires**

- Informed Consent Document
- Self Administered Expanded Disability Severity Scale (sEDSS)
- Activities Balance Confidence Scale (ABC)
- Multiple Sclerosis Impact Scale (MSIS-29)
- Fatigue Severity Score (FSS)
- Coping & Adaptation Processing Scale (CAPS)
- Abbreviated Profile of Mood States-40 (POMS-40)

**Part II: Sensorimotor Assessments**

- Plantar Vibration Sensitivity (Biothesiometer)
- Neural Drive (Foot Tapping)

**Part III: Physical Balance Measures**

- Quiet Standing
- Narrow Standing
- Maximal Forward Reach
- Maximal Backwards Lean
- Sit To Stand (STS)
- Timed Up and Go (TUG)
- 25ft Walk

*Figure 11: Diagram of Data Collection Protocol*

## 3.4 Data Collection Protocol

This study will consist of three data collections separated by two intervention periods as seen in Figure 2, with the data collection protocol shown above in Figure 11. At the first data collection participants will read and sign the Informed Consent and self-report Expanded Disability Status Scale (to attain information about individual MS progression and

symptoms), after which the same data collection protocol will be followed each time. First, psychological wellbeing will be measured via questionnaires to attain self-report measures of balance confidence, wellbeing, fatigue, coping and adaptation, and mood (Appendix B). The questionnaires will include: balance confidence via Activities Balance Confidence Scale (ABC; Powell & Meyers, 1995); psychosocial wellbeing via Multiple Sclerosis Impact Scale-29 (MSIS-29; Hobart et al.,2001); fatigue via Fatigue Severity Scale (FSS; Krupp et al.,1989); coping/adaptive abilities via the Coping and Adaptation Processing Scale (Roy et al.,2016); and Abbreviated Profile of Mood States (POMS-40; Grove & Prapavessis, 1992).

Second, sensorimotor function will be measured with a Biothesiometer and an instrumented foot tapping test (quantity of foot taps performed in 10 seconds). The Biothesiometer will be used to measure plantar vibration sensitivity at the Hallux, Metatarsals 1 and 5, and heel. The participant will be instructed to indicate when they begin to feel the vibration from the different spots on their feet. The Biothesiometer has been proven to be valid and reliable in healthy non-MS populations, and has been used in conjunction with MRI and electrophysiological measures to detect MS in patients who had been diagnosed with optic neuritis (Armstrong et al., 1998; Frederiksen et al., 1991). The foot tapping test will be instrumented with inertial sensors (APDM, Opal System) to assess changes in motor drive (Kent-Braun et al., 1998; Larson et al., 2007). Participants will be instructed to perform 10 seconds of rapid foot tapping movements, with the primary variable of interest being the intertap interval of the foot tap movement.

Third, physical balance will be measured by assessing postural variables from APDM inertial sensors in both static and dynamic balance tasks. Static tasks will include two 30-

second trials of quiet standing, narrow standing (standing with feet together and parallel), and maintaining a static maximal reach forwards and maximal lean backwards. The primary variables collected for static postural stability will be the 95% CoM ellipse sway area (calculated from the lumbar sensor movement in both coronal and sagittal planes), and as well as reach or lean distance from baseline to maximum for the forwards reach and backwards lean trials.

For the dynamic perturbation trials the inertial sensors will be used to evaluate dynamic balance while performing three trials of Sit to Stand (STS), Timed Up and Go (TUG), and two trials of preferred speed 25ft walk. For the STS and the TUG the primary variable of interest will be trial duration, and for the 25ft walk the primary variable will be gait speed. For the STS participants will be instructed to go from sitting to standing five times in a row as fast as they safely can without using their arms for support, this test has been used before to discriminate between MS individuals with asymmetrical leg weakness, MS with symmetrical leg strength, and healthy controls (Bowser et al., 2015). The TUG test was originally developed for frail elderly populations to evaluate balance and mobility, and has been shown to be valid and sensitive enough to distinguish between fallers and non-fallers in MS (Kalron et al., 2017). Three TUG trials while instrumented with APDM sensors will be collected; for these trials participants will be instructed to go from seated to standing at the sound of a tone, walk a 3 meter walkway, turn around a cone, walk back 3 meters, and return to a seated position back in the starting chair (Posiadlo & Richardson, 1991). For the 25ft walk the primary variable of interest will be gait speed, for these three trials participants will be instructed to walk at their preferred speed across a 25ft space. Gait speed in the 25ft

walk test has been found to be effected by knee extensor strength in MS, and declinations in preferred walking speed over time have been found with increasing disease progression (Chung et al., 2008; Fritz et al., 2015).

### 3.5 Experimental Set Up

Inertial sensors (APDM, Opal System) applied to bilateral wrists, bilateral in-step of feet, the sternum, and lumbar spine will be used to collect the variables of interest for this study (Figure 12).

Each APDM inertial sensor is built with a 3D accelerometer, gyroscope, and magnetometer allowing for accurate and reliable body motion to be captured (Horak et al., 2015). While Motion Capture data are the current gold standard for postural evaluation, usage of wearable inertial sensors has been validated with respect to Motion Capture data and has been found to be reliable and sensitive (Bonato et al., 2010; de Bruin et al., 2008; Mariani et al.,2010). Usage of wearable inertial sensors to evaluate postural and sensorimotor functional data was decided upon for three reasons. First, wearable inertial sensors are easy to apply and comfortable for participants to wear whereas the retro-reflective markers necessary for Motion Capture collection are bulky and may inhibit natural movement especially during the TUG and dynamic postural trials. Second, the inertial sensors are less likely to be detrimentally impacted by movement---whereas the retro-reflective markers for Motion Capture analysis may fall off and need to be reapplied during the collection of the dynamic postural trials. Third, the ability to generate immediate APDM reports (TUG, foot tapping, postural variables for both static and dynamic tasks) and to export raw data

immediately following data collections would allow for great reductions in overall data processing time and potential processing errors (Horak et al., 2015). Wearable inertial sensors (Opal, APDM) have been used for collecting postural and functional data in MS and Parkinsonian populations (Brodie et al., 2016; Godinho et al., 2016; Horak et al.,2016).

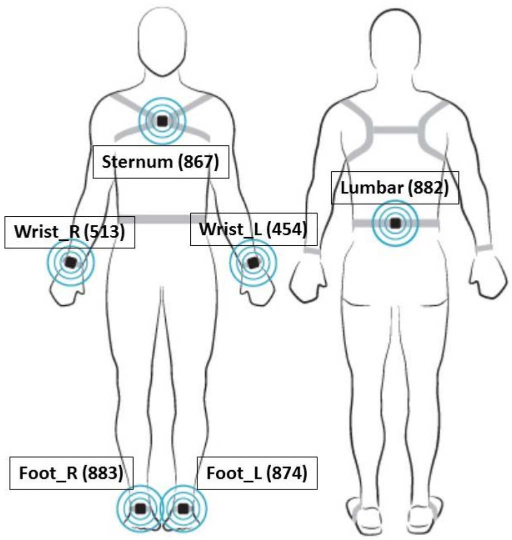



*Figure 12: APDM Inertial Sensor placement.*

3.6 Data and Statistical Analysis

Physical and sensorimotor functional data will be collected using the Opal APDM software, with APDM reports as well as raw data to be exported to excel files for analysis (excluding vibration sensitivity measured via a biothesiometer). Psychological questionnaire data will be scored and entered manually into an excel spreadsheet for analysis. Statistical variance from different durations of practice time will be taken into effect by analyzing participants via time chunks of low, medium, and high practice times. Statistics will be run to

evaluate the impact of differing practice durations (weekly class & homework combined, as well as the overall practice duration).

Specific Aim 1: To evaluate (1.1) which intervention Tai Chi or MBSR will yield the greatest improvements in physical balance; and (1.2) whether improvements are retained after a washout period.

We expect hypothesis 1.1 will be supported if the physical balance measures are greatest for Tai Chi compared to MBSR at Data Collection 2. Hypothesis 1.2 will be supported if the physical balance measures from Tai Chi Data Collection 2 = Data Collection 3 after the washout period. The static balance tasks analyzed will include quiet standing, narrow standing (feet together, parallel), the maximal reach forwards, standing holding a self-generated backwards lean. The dynamic balance tasks (combined balance and mobility trials) analyzed will include Timed Up and Go, Sit to Stand, and 25ft walk. To evaluate Specific Aims 1.1 & 1.2, a mixed-model ANOVA with unequal variance will be run to evaluate the interaction of physical balance benefits by group (Tai Chi, MBSR) and time (data collection 1, 2, 3).

Specific Aim 2: Examine (2.1) which intervention (Tai Chi or MBSR) will yield the greatest improvements in psychosocial function (quality of life, coping and adaptation) in people with MS; and (2.2) whether psychosocial improvements are retained after a 2 week washout period.

We expect hypothesis 2.1 to be supported if the psychological measures for MBSR are greater when compared to Tai Chi for Data Collection 2. 'Greater' or improved results would be expected if Data Collection 2 > Data Collection 1 for balance confidence, coping and acceptance of MS, and psychosocial wellbeing, while we expect Data Collection 2 < Data Collection 1 for fatigue and negative mood states. Hypothesis 2b will be supported if the psychological measures from MBSR Data Collection 2 = Data Collection 3 after the washout period. Psychological measures will include: Activities Balance Confidence Scale, Multiple Sclerosis Impact Scale-29, Fatigue Severity Scale, and the Coping and Adaptation Processing Scale. To evaluate Specific Aims 2.1 & 2.2, a mixed-model ANOVA with unequal variance will be run to evaluate the interaction of physical balance benefits by group (Tai Chi, MBSR) and time (data collection 1, 2, 3).

Specific Aim #3: Evaluate (3.1) which intervention (Tai Chi or MBSR) will yield the greatest improvements in sensorimotor function; and (3.2) whether improvements are retained after a washout period.

We expect hypothesis 3.1to be supported if the sensorimotor function measures are greatest for Tai Chi for foot tapping and smallest for Tai Chi for vibration sensitivity at Data Collection 2. Hypothesis 3.2 will be supported if the sensorimotor function measures from Tai Chi Data Collection 2 = Data Collection 3 after the washout period. To evaluate Specific Aims 3.1 & 3.2, a mixed-model ANOVA with unequal variance will be run to evaluate the interaction of physical balance benefits by group (Tai Chi, MBSR) and time (data collection 1, 2, 3).

# CHAPTER 4- RESULTS

4.1 Demographic Data

Fourteen individuals were recruited for this study, three withdrew due to time constraint issues leaving eleven participants. Of those eleven, eight participants successfully completed the intervention and all three data collections, while the last three participants finished their intervention period at the time when most research at UMass was suspended due to the Covid-19 pandemic. Two of these three final participants were able to remotely complete data collection 3 measures, however the third participant lost their data when the session on Qualtrics timed out before it was submitted. The data presented below will include 8 total data sets (S01-S09) that were recorded before the pandemic.

These eight participants (n=7 female, n=1 male) included four in the Tai Chi group and four in the Meditation group with all subtypes of MS. Participants were matched for PDDS across the two groups at baseline as best as possible; the TC group had an average PDDS of 2 and MBSR an average PDDS of 2.5. The TC group had an average age of 35.5 years ±10.8, height 64.7 ±2.5” inches, weight of 150.4 ±24 lbs., and an average practice time (home and class combined) of 28 ± 7.1 hours. The Meditation group were older at 59.3 years ± 5.2, had a height of 65.8 ± 2.1 inches, weight 147.3±27 lbs., and an average practice time of 30 ± 5.1 hours. Because of the age and mobility differences that occurred between groups with the small sample size, the data to follow will be presented as pilot study data—and not as a comparison between groups for effectivity. Refer to Table 3 for detailed group characteristics.

*Table 3: Group Characteristics*

| Participant Demographics | Tai Chi Group | Age | PDDS | Sex | Hgt (inches) | Wgt (lbs) | MS Subtype | Intervention Practice Time (Hours.Min) |
|---|---|---|---|---|---|---|---|---|
| | S01 | 34 | 2 | F | 62 | 140 | RR | 37.5 |
| | S03 | 38 | 3 | F | 68 | 145 | PP | 29.5 |
| | S05 | 48 | 2 | F | 64 | 185 | RR | 24.5 |
| | S08 | 22 | 1 | F | 64.7 | 131.5 | RR | 21.3 |
| **Average** | | **35.5** | **2.0** | | **64.7** | **150.4** | | **28.2** |
| **Standard Deviation** | | **10.8** | **0.8** | | **2.5** | **23.7** | | **7.1** |
| | **MBSR Group** | **Age** | **PDDS** | **Sex** | **Hgt (inches)** | **Wgt (lbs)** | **MS Subtype** | **Intervention Practice Time (Hours.Min)** |
| | S02 | 57 | 3 | F | 63.5 | 110 | PP | 34.4 |
| | S09 | 63 | 3 | F | 64.5 | 156.25 | RR | 28.5 |
| | S04 | 53 | 0 | F | 67 | 150 | RR | 33.1 |
| | S06 | 64 | 4 | M | 68 | 173 | SP | 23.1 |
| **Average** | | **59.3** | **2.5** | | **65.8** | **147.3** | | **29.8** |
| **Standard Deviation** | | **5.2** | **1.7** | | **2.1** | **26.7** | | **5.1** |

*Note: Demographics Table. Abbreviations include: Patient Determined Disease Steps (PDDS); Height (Hgt); Weight (Wgt), Standard Deviations (St Dev). MS Subtypes of: Relapsing-Remitting (RR), Primary-Progressive (PP), and Secondary-Progressive (SP). Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR).*

## 4.2 Sample Size Acknowledgement

We acknowledge the high risk of Type II error that might occur for these data, where results might not reach significance due to the limitations of having a small sample size. However the benefits of participant safety outweigh the need for statistical power during this Covid-19 pandemic (MS is an immunocompromised population), so no new participants will be recruited for this study until the CDC changes their current community health restrictions. In the meantime, these data will be presented as two uncontrolled pilot interventions with Cohen's d effect sizes and percent change both by group and participant as the main statistical measures. This data will give us a snapshot of improvements/declines for each

group due to the intervention and washout period. ANOVA calculations and individual percent change figures are listed in Appendix C for those interested. Percent change calculations will be used to evaluate the differences in both group and individual participant scores for each measure, with the equation presented below. Percent change is calculated as: **(V2-V1)/(V1)) *100** where V1 is the original value and V2 is the secondary value. To analyze the effect of the intervention then V2 would be the post intervention data and V1 the baseline data. For the effect of the washout period then V2 would be post washout data and V1 the post intervention data.

## 4.3 Specific Aim 1 results:

To evaluate (1.1) which intervention Tai Chi or MBSR will yield the greatest improvements in physical balance; and (1.2) whether improvements are retained after a washout period. We hypothesize (1.1) that the Tai Chi group will have the greater improvements in postural control and balance confidence than the MBSR group, and that (1.2) physical balance improvements in Tai Chi will be retained to a greater degree.

### 4.3.1 Static Balance Trials

For the static balance trials (Quiet Stance, Narrow Stance, Forwards Reach, Backwards Lean) the postural variables of interest include the CoM 95% ellipse sway area and mean sway velocity. These variables will be evaluated with descriptive stats, Cohen’s d effect sizes, as well as individual and group percent change analyses. Interpretation of

Cohen's d effect sizes for postural sway and mean sway velocity variables are as follows: Positive effect sizes are indicative of postural improvements with a reduction in sway area and velocity, while negative effect sizes are indicative of an increase in sway area and velocity which may put people at greater risk of falling. The group percent change values on the other hand are interpreted in the opposite direction as the Cohen's d effect size; for these values a negative percent change indicates an improvement (reduced sway/velocity) in the postural trials while positive values indicate a decline (increased sway/velocity).

*Table 4: Static Postural Effect Sizes Across Visits*

| | Tai Chi | | | | MBSR | | | |
|---|---|---|---|---|---|---|---|---|
| | Intervention V1 to V2 | | Washout V2 to V3 | | Intervention V1 to V2 | | Washout V2 to V3 | |
| | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** |
| **QS 95% Ellipse Sway (m^2/s^4)** | 0.189 | -12.88 | -0.456 | 59.48 | 0.468 | -35.37 | 1.83 | -89.38 |
| **QS Mean Velocity (m/s)** | 0.170 | -3.89 | -0.820 | 53.6 | 0.247 | -21.63 | 0.974 | -46.62 |
| **NS 95% Ellipse Sway (m^2/s^4)** | 0.307 | -20.20 | -0.286 | 19.83 | 0.824 | -46.80 | 0.550 | -38.84 |
| **NS Mean Velocity (m/s)** | 0.440 | -16.69 | -0.290 | 14.60 | 0.544 | -32.27 | 1.008 | -40.49 |
| **FR 95% Ellipse Sway (m^2/s^4)** | 0.709 | -49.27 | -0.214 | 23.33 | 0.981 | -73.88 | 0.116 | -9.51 |
| **FR Mean Velocity (m/s)** | 0.062 | -2.82 | -0.751 | 59.37 | 1.41 | -76.87 | -1.30 | 61.83 |
| **BL 95% Ellipse Sway (m^2/s^4)** | 0.206 | -18.89 | -0.073 | 7.04 | -0.058 | 4.54 | -0.299 | 46.7 |
| **BL Mean Velocity (m/s)** | 0.910 | -26.24 | -0.499 | 27.59 | 0.317 | -15.28 | -0.474 | 38.24 |

*Note: Cohen's d effect sizes are interpreted as: 0-0.2 as no effect; 0.2-0.49 as small, 0.5 to 0.8 as moderate, and 0.8 and above as a large effect. Positive Cohen's d effect sizes for the static postural variables are indicative of postural improvements with a reduction in sway area and velocity, while negative effect sizes are indicative of an increase in sway area and velocity which may put people at greater risk of falling. Negative group % change is indicative of an improvement in postural characteristics (reduced sway/velocity), while positive group % change is indicative of a decline. Abbreviations include: Quiet Stance (QS), Narrow Stance (NS), Forward Reach (FR), and Backwards Lean (BL). Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

*Table 5: Static Postural Variables Individual Percent Change Visual Summary*

| | Static Postural Variables Percent Change after the Intervention | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | QS | | NS | | FR | | BL | |
| PT | Group | 95% CI | Mean Velocity | 95% CI | Mean Velocity | 95% CI | Mean Velocity | 95% CI | Mean Velocity |
| S01 | TC | | | | | | | | |
| S02 | MBSR | | | | | | | | |
| S03 | TC | | | | | | | | |
| S04 | MBSR | | | | | | | | |
| S05 | TC | | | | | | | | |
| S06 | MBSR | | | | | | | | |
| S08 | TC | **NA** | **NA** | | | | | | |
| S09 | MBSR | | | | | | | | |
| | | | | | | | | | |
| | Postural Variables Percent Change after the Washout | | | | | | | | |
| | | QS | | NS | | FR | | BL | |
| PT | Group | 95% CI | Mean Velocity | 95% CI | Mean Velocity | 95% CI | Mean Velocity | 95% CI | Mean Velocity |
| S01 | TC | | | | | | | | |
| S02 | MBSR | | | | | | | | |
| S03 | TC | | | | | | | | |
| S04 | MBSR | | | | | | | | |
| S05 | TC | | | | | | | | |
| S06 | MBSR | | | | | | | | |
| S08 | TC | | | | | | | | |
| S09 | MBSR | **NA** | **NA** | **NA** | **NA** | **NA** | **NA** | **NA** | **NA** |

*Note: The table above includes the individual participants static postural variables color coded to show an overview on postural stability after the intervention and washout periods. Green tiles indicate reduced 95% ellipse sway and slower mean sway velocity values which indicates an improvement as it puts people at less risk of hitting their boundaries of stability, while red tiles indicate larger 95% ellipse sway and faster mean sway velocities which may put participants at greater risk of hitting their boundaries of stability. Abbreviations include: Quiet Stance (QS), Narrow Stance (NS), Forward Reach (FR), and Backwards Lean (BL). Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR), Confidence Interval (CI).*

Quiet Stance:

When evaluating Cohen's d effect sizes some differences between the two groups were noted. The Tai Chi group had no change in quiet standing 95% ellipse sway or mean sway velocity after the intervention, with only a small change in group percent change. However, after the washout period the Tai Chi group had a moderate increase in 95% ellipse

sway (d=-0.456) and a large increase in mean sway velocity (d=-0.820), which may indicate that the intervention while not improving postural characteristics may have had a protective component that disappeared after the washout period. The MBSR group had a moderate reduction in 95% ellipse sway (d=0.468) during quiet standing and a small reduction in mean sway velocity after the intervention, both of which were supported by the group percent change results. However the moderate effect may be due to participant S06 who greatly improved their postural characteristics from V1 to V2, with the beneficial trend continued through the washout period with additional small improvement in ellipse sway and mean sway velocity (d=0.974). Refer to Figures 13 and 14 for boxplots of quiet stance average ellipse sway and average mean sway velocity by group across visits, and Figures 15 and 16 for line graphs showing individual trends of ellipse sway and mean sway velocity. For the static postural trials all Cohen's d effect sizes and group percent change calculations can be found in Table 4, individual postural trends in Table 5, and quiet stance descriptive statistics in Table 6. ANOVA p-values and graphs of individual percent change can be referenced in Appendix C.

*Table 6: Quiet Stance Descriptive Statistics. Mean, Standard Deviation, Median and 95% Confidence Interval for mean data are presented.*

| **QS 95% Ellipse Sway (m^2/s^4)** | **Visit** | **n** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Tai Chi Group | 1 | 3 | 0.0357 | 0.0266 | 0.0384 | -0.0302 to 0.1016 |
| | 2 | 4 | 0.0311 | 0.0216 | 0.0295 | -0.0032 to 0.0655 |
| | 3 | 4 | 0.0496 | 0.0531 | 0.0317 | -0.0348 to 0.1340 |
| MBSR Group | 1 | 4 | 0.175 | 0.170 | 0.1186 | -0.0969 to 0.4469 |
| | 2 | 4 | 0.1131 | 0.0778 | 0.1268 | -0.0107 to 0.2369 |
| | 3 | 2 | 0.0120 | 0.006 | 0.012 | 0.0036 to 0.0203 |

| **QS Mean Velocity (m/s)** | **Visit** | **n** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Tai Chi Group | 1 | 3 | 0.1386 | 0.0338 | 0.1451 | 0.0547 to 0.2225 |
| | 2 | 4 | 0.1332 | 0.0292 | 0.1336 | 0.0867 to 0.1796 |
| | 3 | 4 | 0.2046 | 0.1184 | 0.2156 | 0.0161 to 0.3930 |
| MBSR Group | 1 | 4 | 0.416 | 0.490 | 0.197 | -0.3462 to 1.196 |
| | 2 | 4 | 0.326 | 0.1579 | 0.3556 | 0.0754 to 0.5779 |
| | 3 | 2 | 0.174 | 0.0762 | 0.1745 | 0.0683 to 0.2796 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is post Intervention, Visit 3 is post washout. Abbreviations: Quiet Stance (QS), Standard Deviation (StDev), Confidence Interval (CI).*

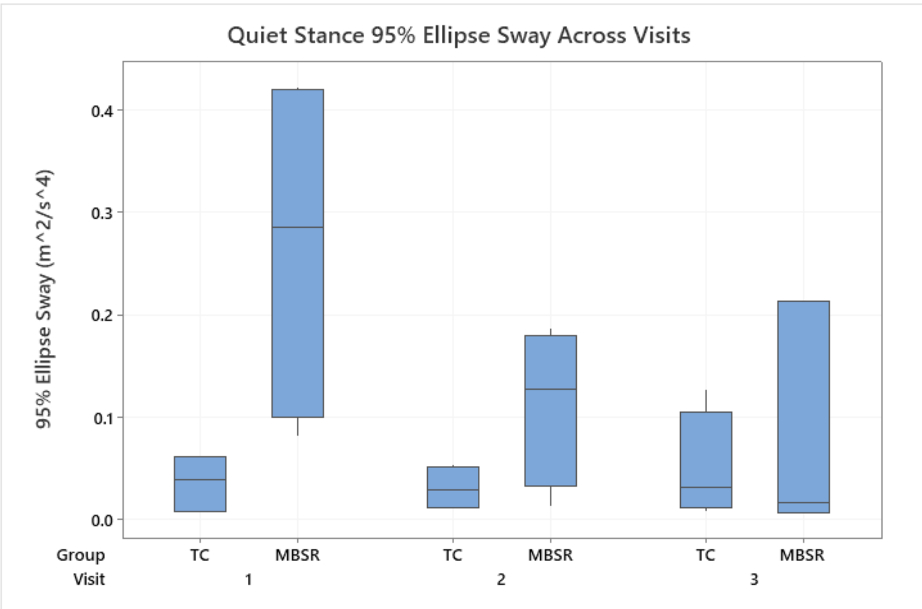



*Figure 13: Quiet Stance Average 95% Ellipse Sway. Medians are designated by a horizontal with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

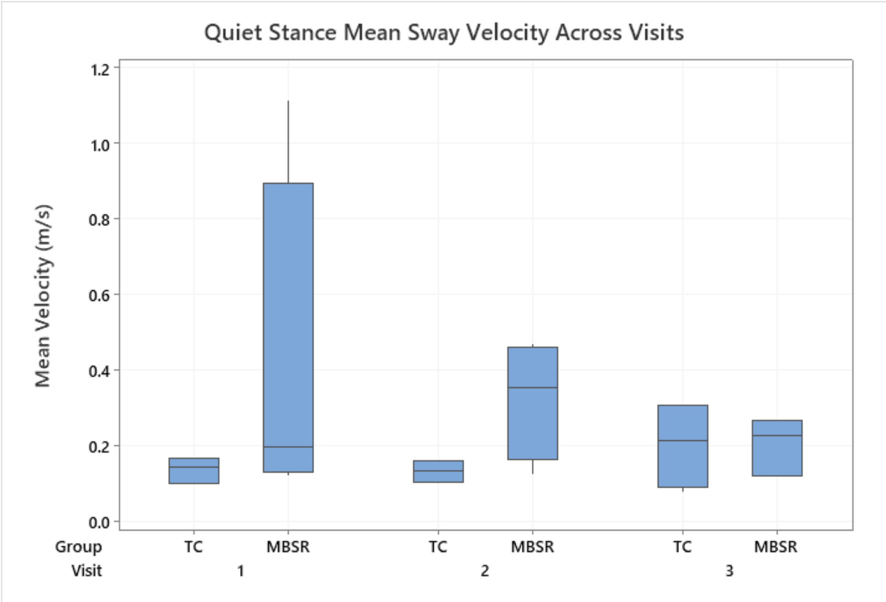
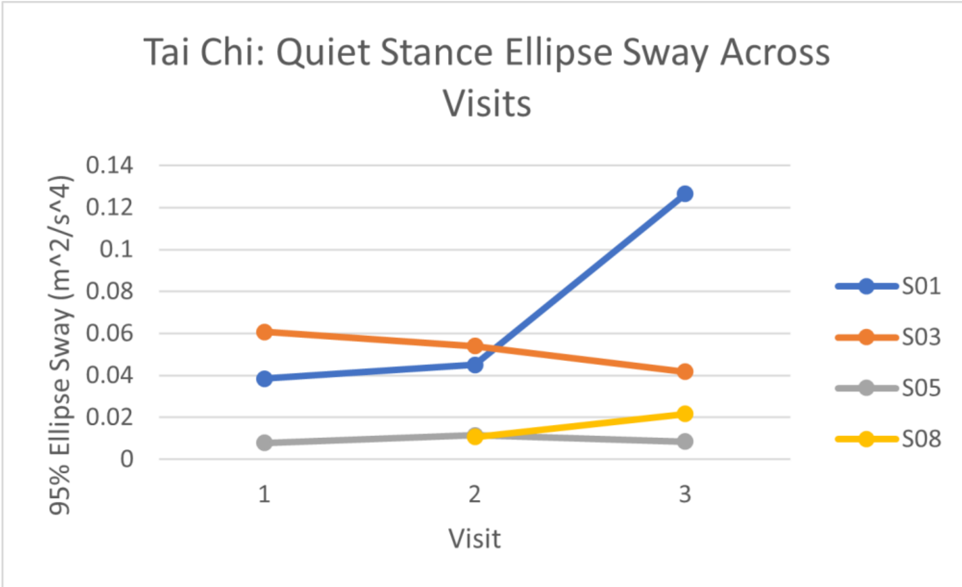



*Figure 14: Quiet Stance Average Mean Sway Velocity. Mean sway velocity is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

When evaluating individual trends using percent change the data was less clear. Of the seven individuals evaluated, 4 participants (2 TC, 2 MBSR) increased their sway area potentially increasing fall risk, while the other 3 participants (1 TC, 2 MBSR) had reduced sway area after the intervention potentially indicating improved postural stability. After the washout period 4 participants (2 TC, 2 MBSR) had increased sway area (greater fall risk), while the other 3 participants (2 TC, 1 MBSR) had reduced sway area (lessened fall risk). These percent change data highlight some of the individual differences between the participants for quiet standing sway. Refer to Table 5 for a visual overview of improvement vs. decrement.



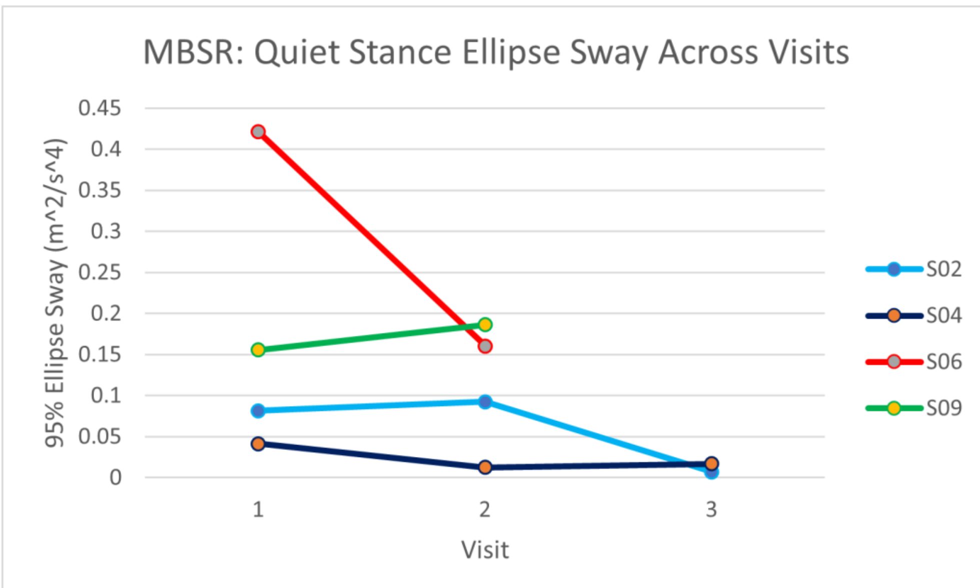




*Figure 15: Quiet Stance Individual Trends of 95% Ellipse Sway Across Visits. Individual trends are plotted as a line graph. S08 V1 and S09 V3 data were unable to be collected at the time for QS. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

For mean sway velocity after the intervention, 4 participants (2 TC, 2 MBSR) increased their mean sway velocity (increased fall risk) while the other 3 decreased their sway velocity (decreased fall risk; 1 TC, 2 MBSR) after the intervention. After the washout period, 3 participants (3 TC) increased their mean sway velocity (potentially increasing fall risk), while the other 4 decreased their sway velocity (1 TC, 3 MBSR). These individual percent change results highlight the differences in how participants control their sway velocity during quiet standing; what is interesting to note is that participants S02, S05 and S09 increased both their postural sway and velocity characteristics (greater fall risk), while participants S04 and S06 reduced both their postural sway and velocity characteristics (less fall risk) after the intervention. The individual trends did not clarify the differences shown by the effect size data that, specifically that the MBSR group had a moderate improvement in 95% ellipse sway after the intervention with large improvements in postural sway and sway velocity after the washout period, and that the Tai Chi group had a large increase in sway after the washout period.

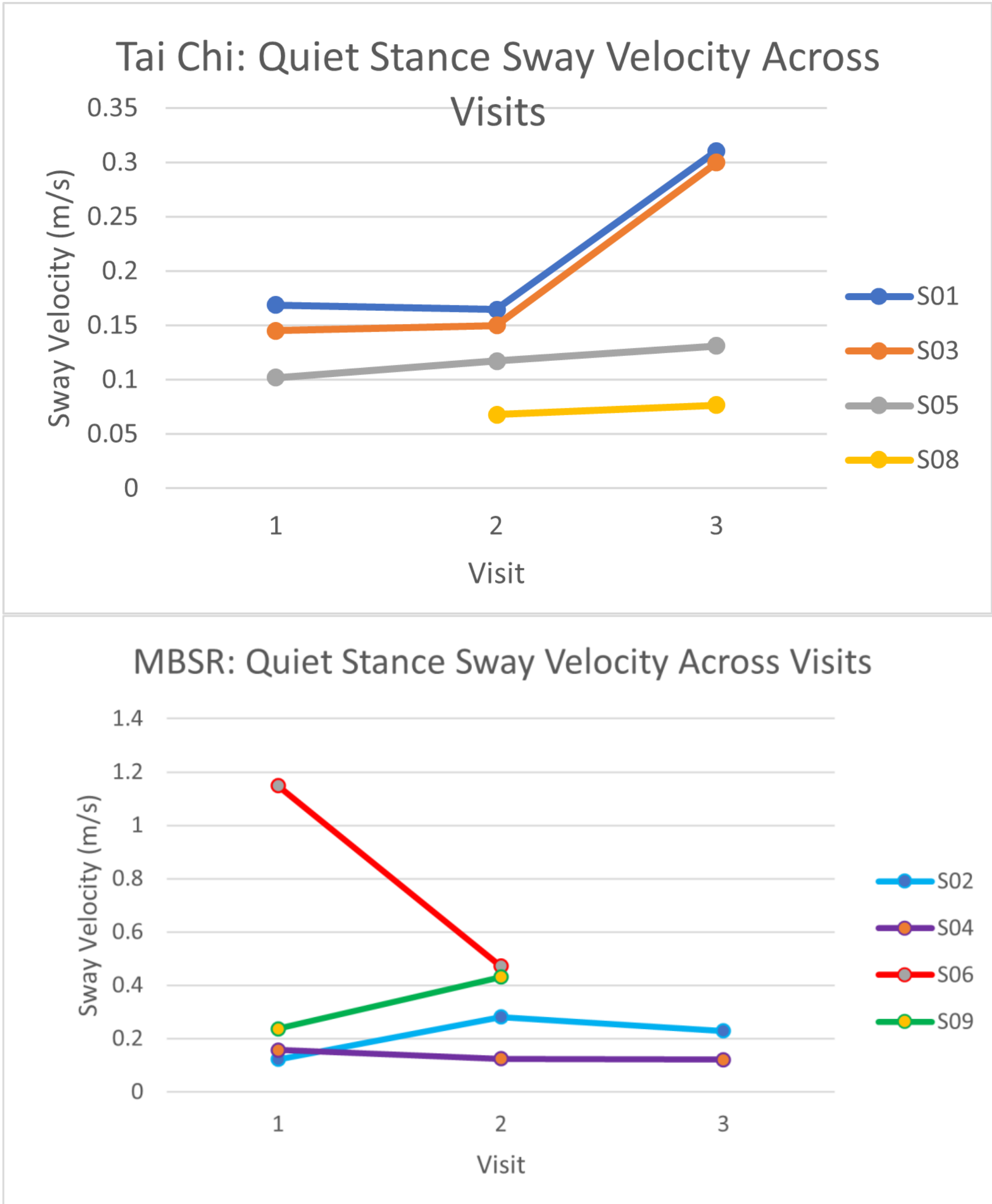



*Figure 16: Quiet Stance Individual Trends of Mean Sway Velocity Across Visits. Individual trends are plotted as a line graph, S08 V1 and S09 V3 data points were unable to be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Narrow Stance:

The narrow stance descriptive statistics are presented in Table 7. The Cohen's d effect size analysis (Table 4) showed that the Tai Chi group had a small reduction in 95% ellipse sway and mean sway velocity during narrow standing, and this along with the group percent change trends might be indicative of small postural improvements after the intervention. After the washout period there was a small increase in 95% ellipse sway and mean velocity for the Tai Chi group; based on these small changes it is likely there was no effect of the intervention or washout periods on postural parameters. For the MBSR group there was a large reduction in 95% ellipse sway (d=0.824) and a moderate reduction in mean sway velocity (d=0.544) after the intervention, indicating improved postural stability. These benefits were retained through the washout period, with moderate improvements in 95% ellipse sway (d=0.550) with a large reduction in mean sway velocity (d=1.008). Refer to Figures 17 and 18 for boxplots of narrow stance average ellipse sway and average mean sway velocity by group across visits, and Figures 19 and 20 for line graphs showing individual trends of ellipse sway and mean sway velocity.

*Table 7: Narrow Stance Descriptive Statistics. Mean, Standard Deviation, Median and 95% Confidence Interval for mean data are presented.*

| **NS 95% Ellipse Sway (m^2/s^4)** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Tai Chi Group | 1 | 4 | 0.1188 | 0.0862 | 0.0907 | -0.018 to 0.2558 |
| | 2 | 4 | 0.0948 | 0.0689 | 0.0715 | -0.0148 to 0.2044 |
| | 3 | 4 | 0.1136 | 0.0623 | 0.1258 | 0.0144 to 0.2128 |
| MBSR Group | 1 | 4 | 0.422 | 0.291 | 0.355 | -0.0412 to 0.8846 |
| | 2 | 4 | 0.2245 | 0.1736 | 0.2164 | -0.0518 to 0.5007 |
| | 3 | 3 | 0.1373 | 0.1413 | 0.1074 | -0.2137 to 0.4882 |
| **NS Mean Velocity (m/s)** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| Tai Chi Group | 1 | 4 | 0.2384 | 0.1501 | 0.1993 | -0.0004 to 0.4773 |
| | 2 | 4 | 0.1986 | 0.1075 | 0.1770 | 0.0275 to 0.3695 |
| | 3 | 4 | 0.2276 | 0.0912 | 0.2332 | 0.0824 to 0.3726 |
| MBSR Group | 1 | 4 | 0.431 | 0.335 | 0.311 | -0.1017 to 0.9633 |
| | 2 | 4 | 0.2919 | 0.1347 | 0.2408 | 0.0775 to 0.5063 |
| | 3 | 3 | 0.1737 | 0.0967 | 0.1194 | -0.0665 to 0.4138 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Narrow Stance (NS), Standard Deviation (StDev), and Confidence Interval (CI).*

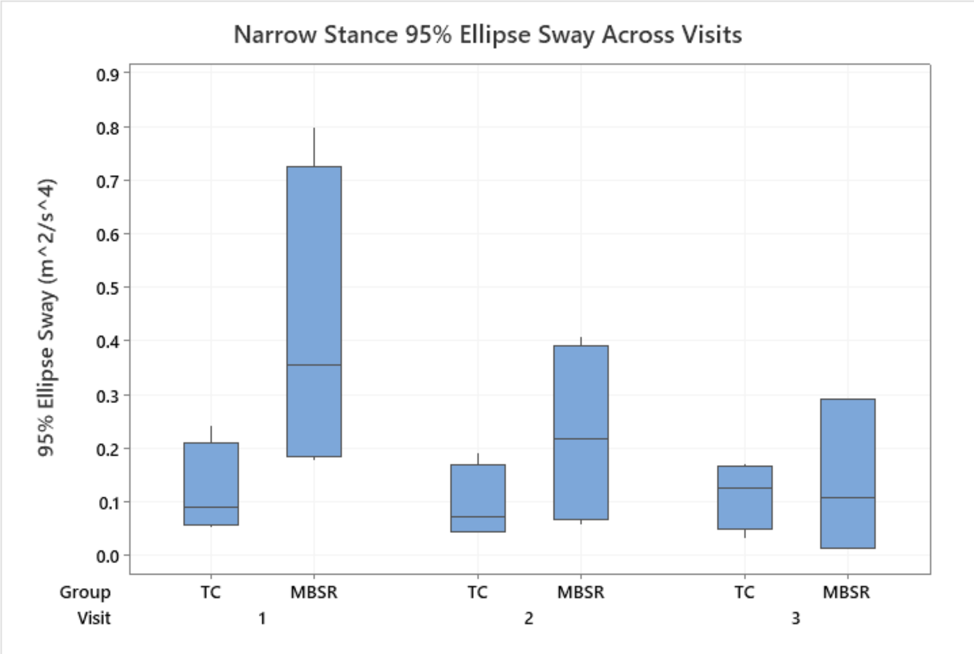



*Figure 17: Narrow Stance Average 95% Ellipse Sway. Narrow Stance (NS) ellipse sway is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

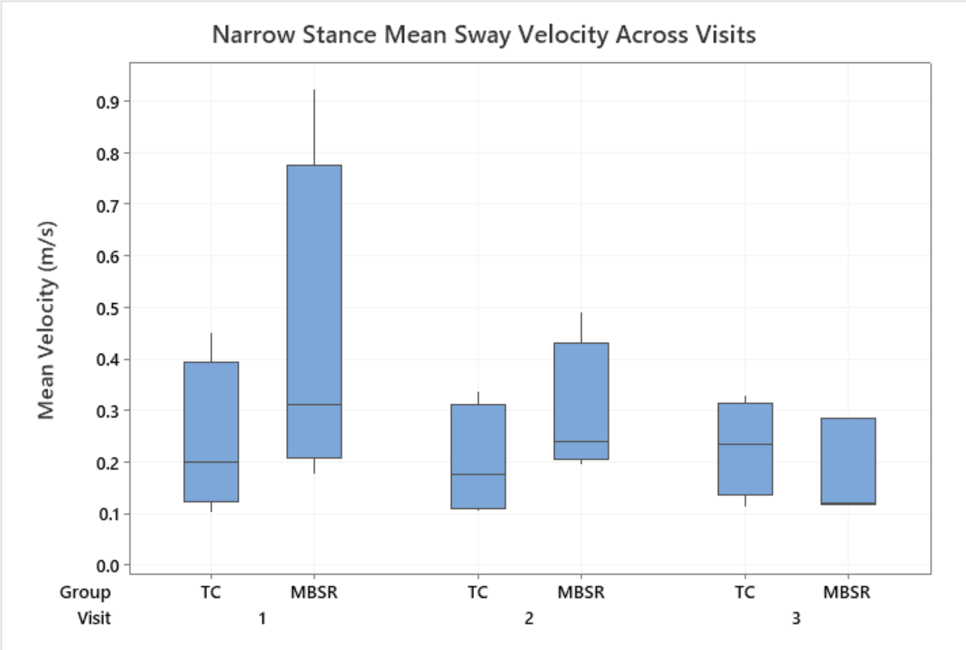



*Figure 18: Narrow Stance Average Mean Sway Velocity. Narrow Stance (NS) sway velocity is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

When evaluating individual percent change trends for 95% ellipse sway during narrow stance 7 of the 8 individuals (3 TC, 4 MBSR) had reduced sway after the intervention, which is indicative of improved postural stability. Only 1 Tai Chi participant increased their sway after the intervention (Table 5; Figure 19). After the washout period, three of the seven individuals (2 TC, 1 MBSR) had increased 95% ellipse sway (increased fall risk), while the other four individuals had reduced sway during narrow standing (2 TC, 2 MBSR).

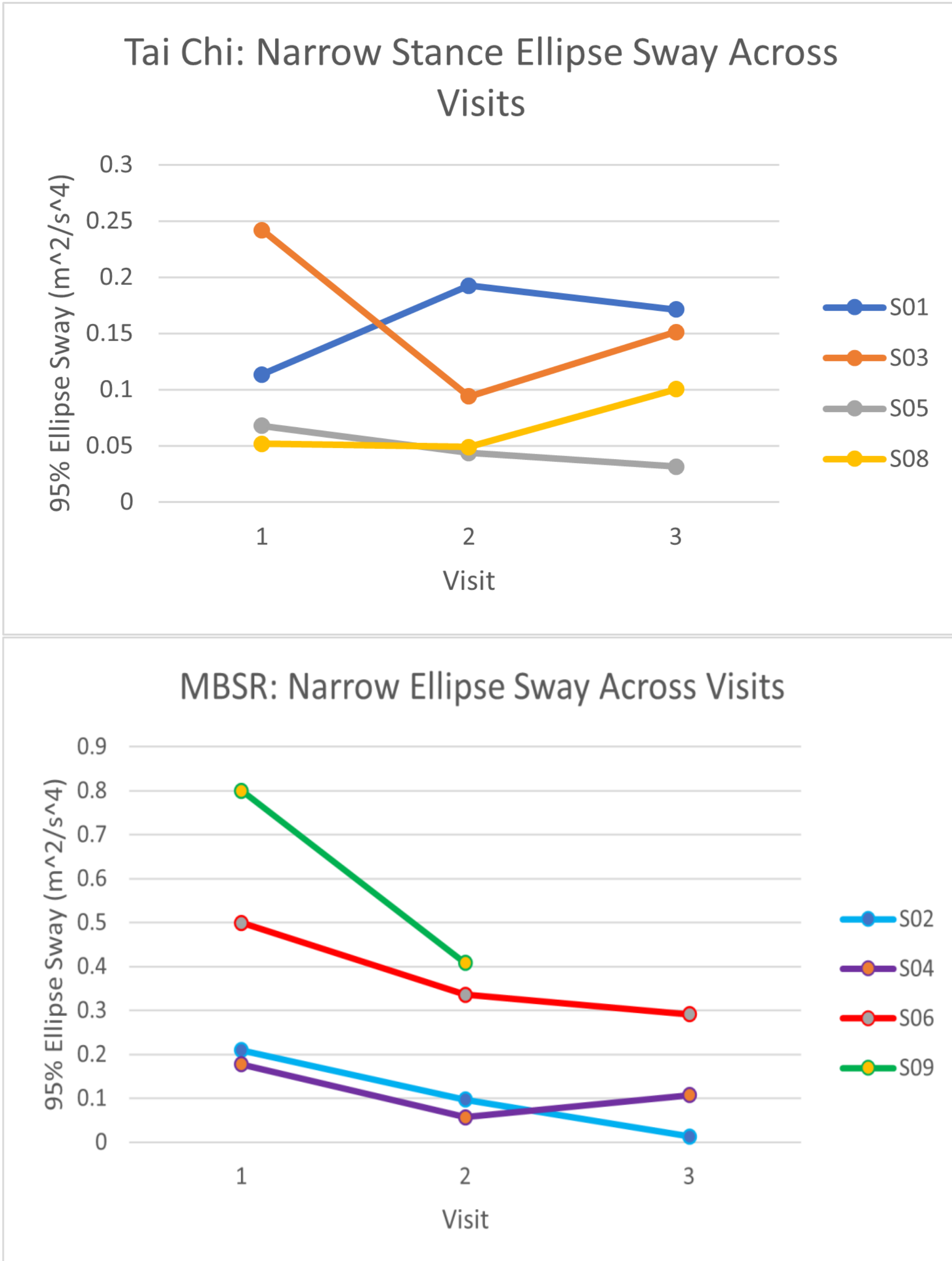
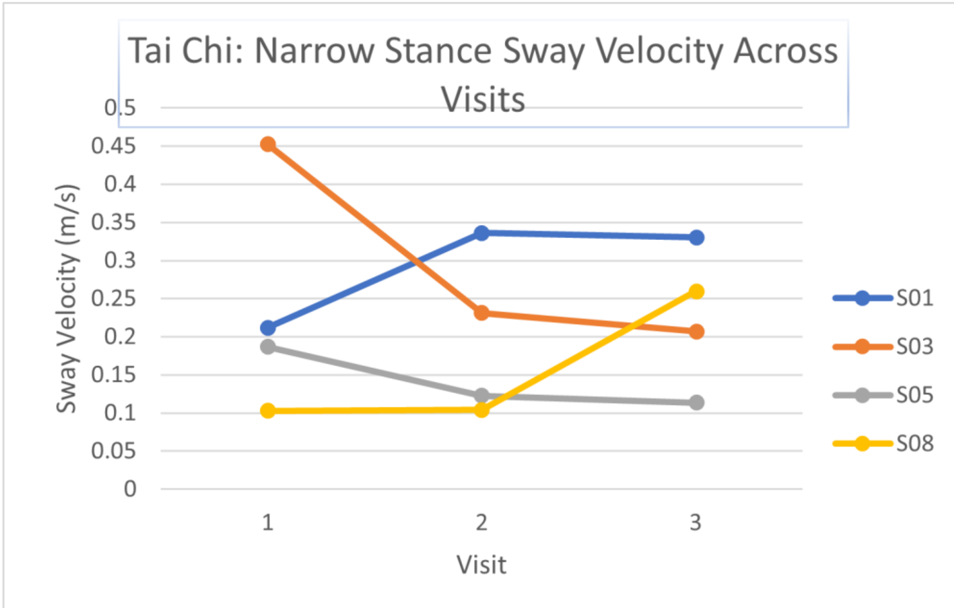



*Figure 19: Narrow Stance Individual Trends of 95% Ellipse Sway Across Visits. Individual trends are plotted as a line graph, S09 V3 data point was unable to be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

When evaluating individual percent change 4 of the 8 individuals (2 TC, 2 MBSR) had reduced mean sway velocity after the 8 week intervention (decreased fall risk), while the other 4 individuals (2 TC, 2 MBSR) increased their sway velocity (increased fall risk). After the washout period 6 of the 7 individuals (3 TC, 3 MBSR) had reduced mean sway velocity, and 1 participant (TC) increased their mean sway velocity. These individual trends show how both interventions had a beneficial impact on postural sway immediately following the intervention, but that individuals had different strategies for controlling sway velocity. After the washout period ellipse sway increased for 3 participants, however the mean sway velocities were reduced in 6 of the 7 participants after the washout potentially showing a delayed improvement response.



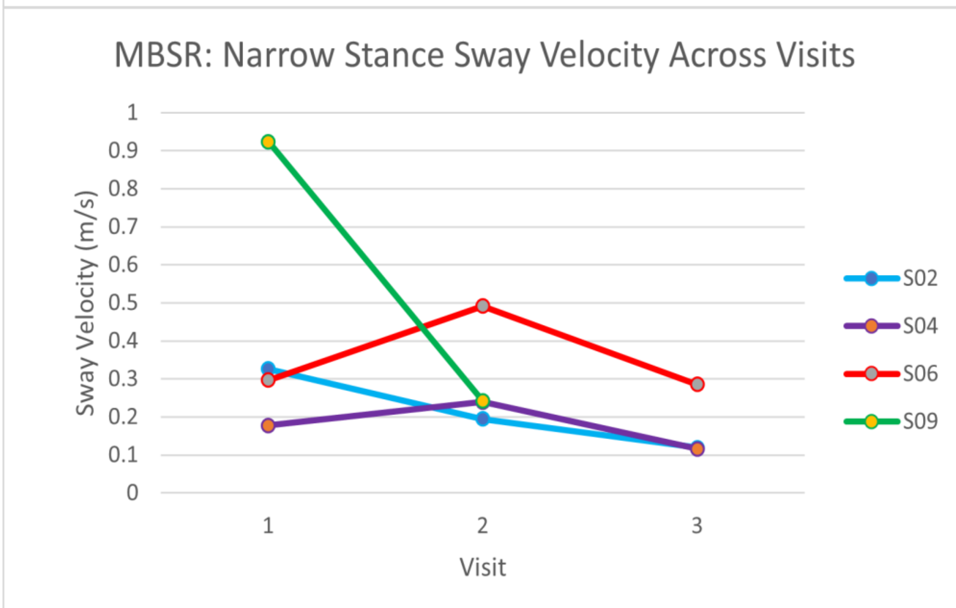




*Figure 20: Narrow Stance Individual Trends of Mean Sway Velocity Across Visits. Individual trends are plotted as a line graph, S09 V3 data could not be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Forwards Reach:

When evaluating the Cohen's d effect size and group percent change it appears that both groups had improvements in their maximal forwards reach (see Table 4; and Table 8 for descriptive statistics). For the Tai Chi group there was a moderate reduction in forwards reach 95% ellipse sway (d=0.709) with no change in mean sway velocity after the intervention. The reduction in 95% ellipse sway may indicate improved postural stability during the forwards reach posture, even though mean sway velocity was unchanged. After the washout period the Tai Chi group had a small increase in forwards reach 95% ellipse sway and a moderate increase in mean sway velocity (d=-0.751) at V3. The MBSR group had large reductions in both forwards reach 95% ellipse sway (d=1.41) and mean sway velocity (d=1.41) after the intervention, indicating improved postural stability characteristics after the intervention. After the washout period there was no change in 95% ellipse sway but a large increase in mean sway velocity (d=-1.30) for the MBSR group at V3, which was still better than the baseline sway velocity values. Refer to Figures 21 and 22 for boxplots of forwards reach average ellipse sway and average mean sway velocity by group across visits, and Figures 23 and 24 for line graphs showing individual trends of ellipse sway and mean sway velocity.

*Table 8: Forwards Reach Descriptive Statistics. Mean, Standard Deviation, Median, 95% Confidence interval of the mean are presented.*

| **FR 95% Ellipse Sway (m^2/s^4)** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Tai Chi Group | 1 | 4 | 0.1098 | 0.0919 | 0.1163 | -0.0364 to 0.2559 |
| | 2 | 4 | 0.0557 | 0.0565 | 0.0467 | -0.0342 to 0.1456 |
| | 3 | 4 | 0.0687 | 0.0642 | 0.0551 | -0.0335 to 0.1708 |
| MBSR Group | 1 | 4 | 0.237 | 0.245 | 0.159 | -0.1529 to 0.6278 |
| | 2 | 4 | 0.0620 | 0.0596 | 0.0414 | -0.0327 to 0.1567 |
| | 3 | 3 | 0.0561 | 0.0395 | 0.0507 | -0.0421 to 0.1542 |
| **FR Mean Velocity (m/s)** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| Tai Chi Group | 1 | 4 | 0.1558 | 0.0626 | 0.1595 | 0.0561 to 0.2554 |
| | 2 | 4 | 0.1514 | 0.0783 | 0.1533 | 0.0268 to 0.2759 |
| | 3 | 4 | 0.2413 | 0.1500 | 0.2515 | 0.0025 to 0.4800 |
| MBSR Group | 1 | 4 | 0.600 | 0.456 | 0.500 | -0.1262 to 1.325 |
| | 2 | 4 | 0.1386 | 0.0737 | 0.1212 | 0.0213 to 0.2559 |
| | 3 | 3 | 0.2243 | 0.0566 | 0.2046 | 0.0836 to 0.3649 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Forwards Reach (FR), Standard Deviation (StDev), Confidence Interval (CI).*

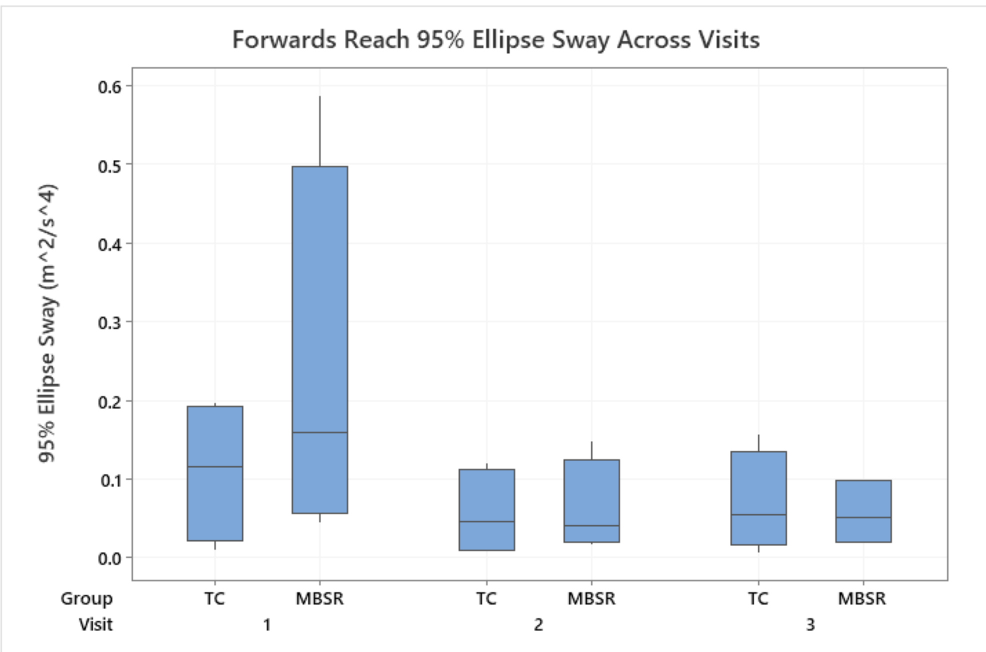



*Figure 21: Forwards Reach Average 95% Ellipse Sway. Forwards Reach (FR) ellipse sway is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

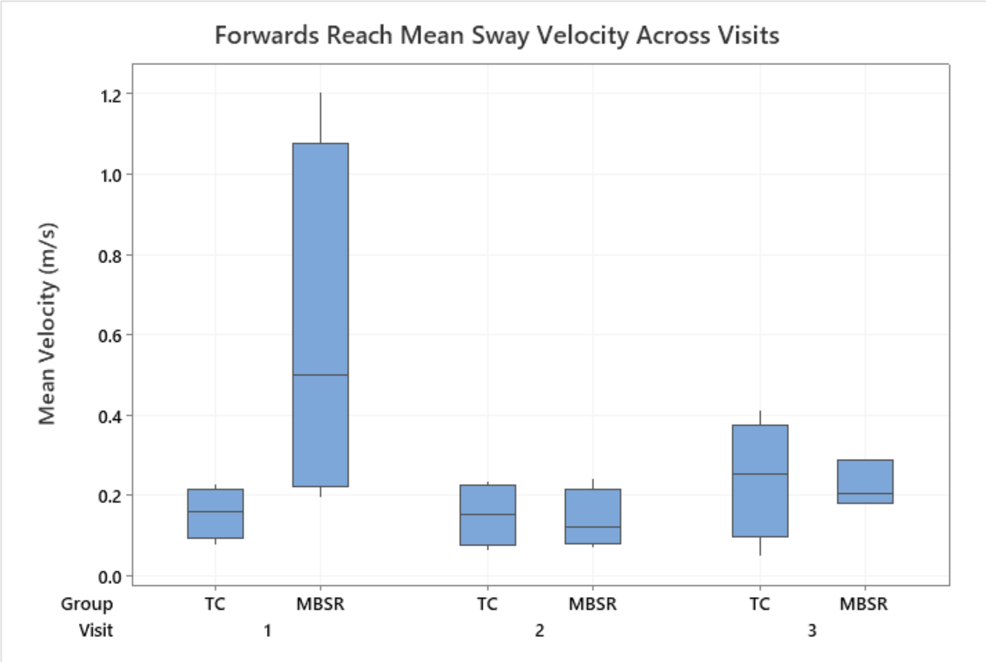



*Figure 22: Forwards Reach Mean Sway Velocity. Forwards Reach sway velocity is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

When evaluating measured forwards reach distance, five of the eight participants (4 MBSR, 1 TC) increased their reach distance at V2, while the other three (TC) decreased their maximal forwards reach. When evaluating individual percent change, seven of the eight individuals (3 TC, 4 MBSR) had reductions in their 95% ellipse sway area after the intervention, and one person (TC) increased their sway area. It appears that both groups improved their postural stability and total reach distance in the forwards reach posture after the intervention. After the washout period five of the seven individuals (2 TC, 3 MBSR) increased their sway area, while the other two participants reduced their sway area (2 TC). Refer to Table 5 for a visual overview of percent change for each participant.

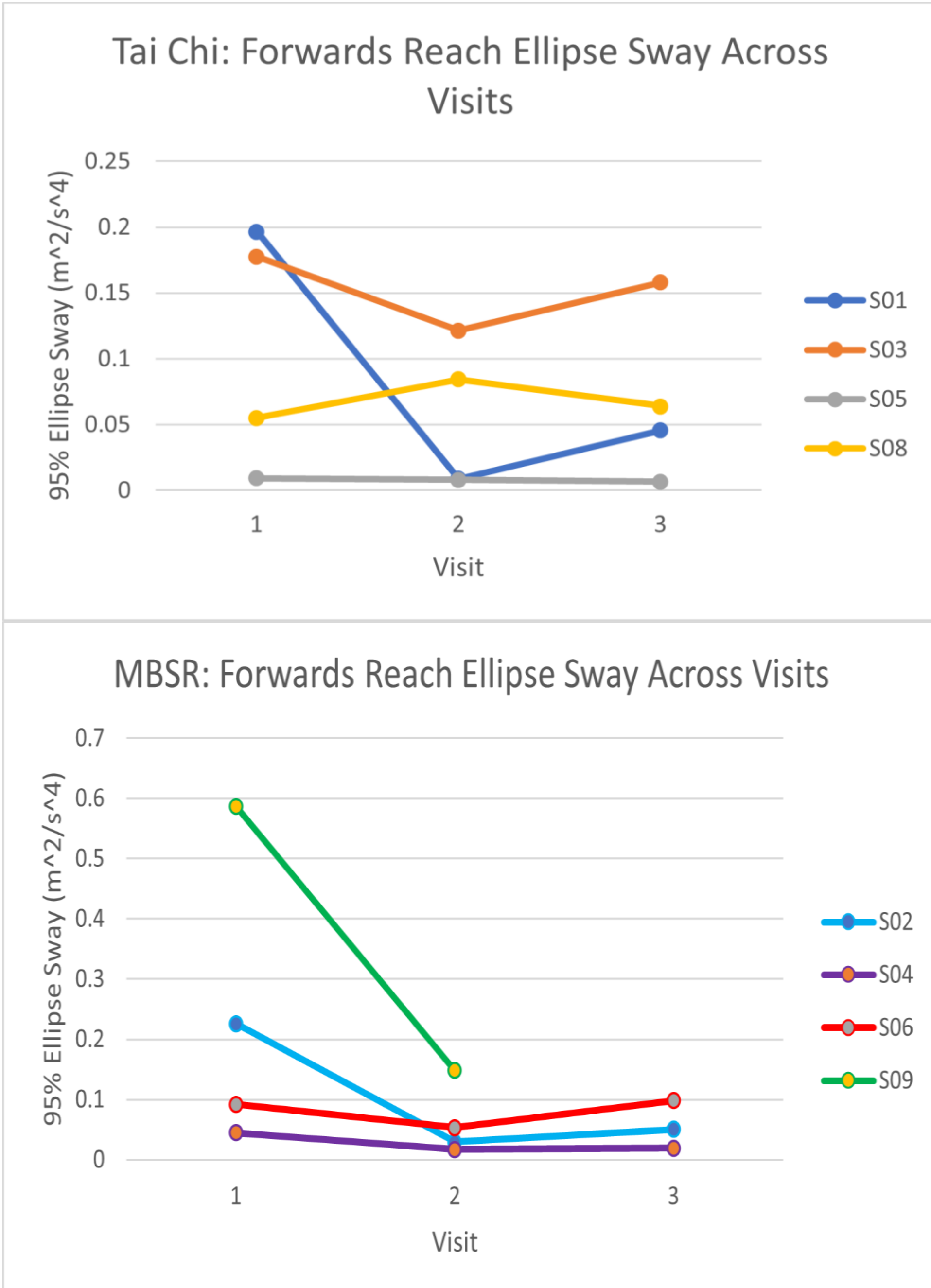
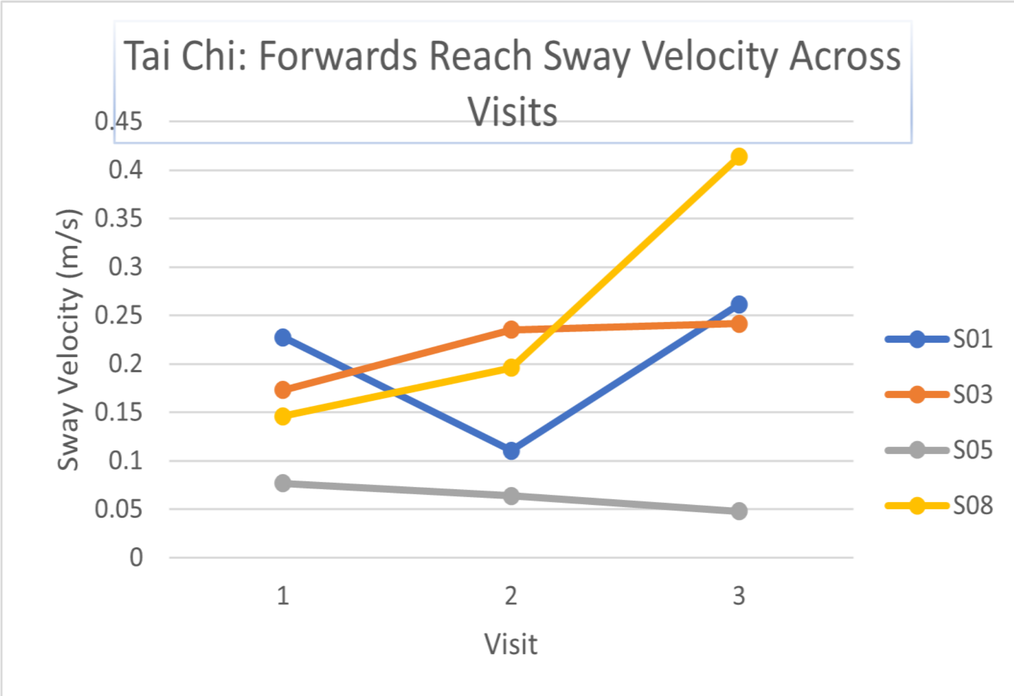



*Figure 23: Forwards Reach Individual Trends of 95% Ellipse Sway Across Visits. Individual trends are plotted as a line graph, S09 V3 data point could not be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

When evaluating forwards reach mean sway velocity the individual trends showed that 6 of the 8 individuals (2 TC, 4 MBSR) had a reduction in mean sway velocity while the other two participants had increased mean sway velocity (2 TC) after the intervention. These 6 individuals with reduced mean sway velocity were the same ones who reported reduced 95% ellipse sway, excluding participant S03 who had reduced sway but an increased mean sway velocity. Participant S08 had both an increase in 95% ellipse sway and an increase in mean sway velocity. These data support the Cohen's d effect size data that both groups improved 95% ellipse sway values after the intervention, but that only the MBSR group had a change in mean sway velocity after the intervention. After the washout period 5 of the 7 individuals had an increase in mean sway velocity (2 TC, 3 MBSR), and the other two participants decreased their mean sway velocity (2 TC). This indicates that the benefits to postural sway and velocity were minimally retained by the MBSR group after the washout period (Figure 24).



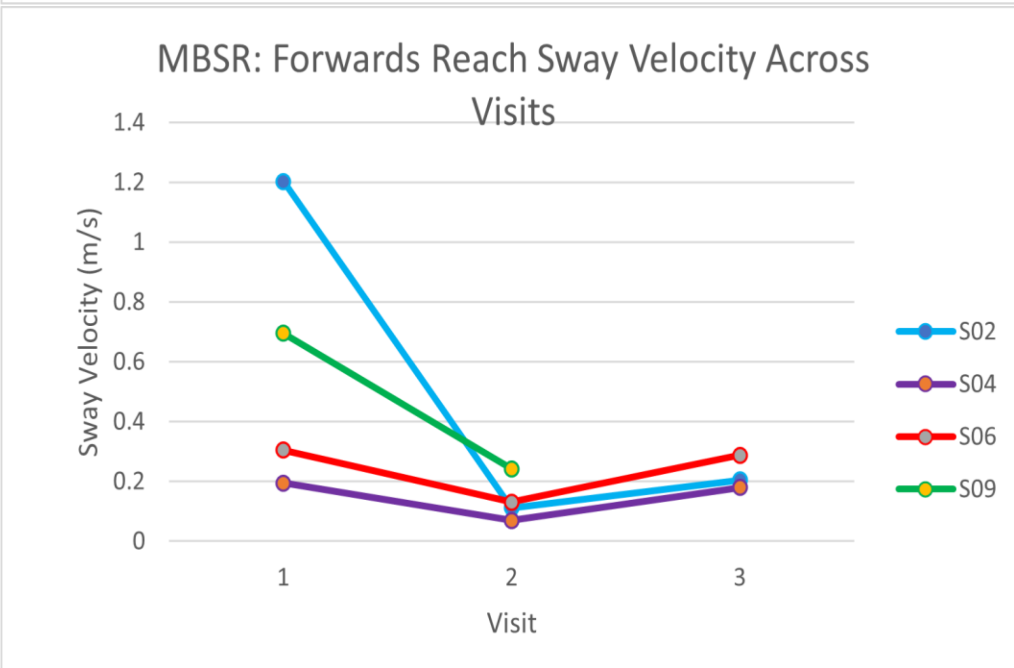




*Figure 24: Forwards Reach Individual Trends of Mean Sway Velocity Across Visits. Individual trends are plotted as a line graph, S09 V3 data point could not be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Backwards Lean:

For the Tai Chi group there was a small reduction in backwards lean 95% ellipse sway and a large reduction in mean sway velocity (d=0.910) after the intervention (see Table 4; and Table 9 for descriptive statistics). After the washout period no change was found for 95% ellipse sway however there was a moderate increase in mean sway velocity (d=0.499) in the Tai Chi group at V3. For the MBSR group there was no effect on backwards lean 95% ellipse sway and a small reduction in mean sway velocity after the intervention. After the washout period there was a small increase in 95% ellipse sway and mean sway velocity at V3. Refer to Figures 25 and 26 for boxplots of forwards reach average ellipse sway and average mean sway velocity by group across visits, and Figures 27 and 28 for line graphs showing individual trends of ellipse sway and mean sway velocity.

*Table 9: Backwards Lean Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence Interval of the mean are presented.*

| **BL 95% Ellipse Sway (m^2/s^4)** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Tai Chi Group | 1 | 4 | 0.1085 | 0.1043 | 0.0754 | -0.0574 to 0.2744 |
| | 2 | 4 | 0.0880 | 0.0947 | 0.0583 | -0.0627 to 0.2387 |
| | 3 | 4 | 0.0942 | 0.0741 | 0.0791 | -0.0236 to 0.2121 |
| MBSR Group | 1 | 4 | 0.1343 | 0.0942 | 0.1109 | -0.0155 to 0.2841 |
| | 2 | 4 | 0.1404 | 0.1141 | 0.1341 | -0.0412 to 0.3220 |
| | 3 | 3 | 0.206 | 0.288 | 0.054 | -0.5097 to 0.9212 |
| **BL Mean Velocity (m/s)** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| Tai Chi Group | 1 | 4 | 0.2393 | 0.0690 | 0.2457 | 0.1295 to 0.3489 |
| | 2 | 4 | 0.1765 | 0.0689 | 0.2062 | 0.0667 to 0.2861 |
| | 3 | 4 | 0.2252 | 0.1195 | 0.1928 | 0.0349 to 0.4154 |
| MBSR Group | 1 | 4 | 0.2997 | 0.0996 | 0.2975 | 0.1412 to 0.4581 |
| | 2 | 4 | 0.2539 | 0.1783 | 0.2591 | -0.0297 to 0.5375 |
| | 3 | 3 | 0.351 | 0.228 | 0.307 | -0.2145 to 0.9166 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Backwards Lean (BL), Standard Deviation (StDev), Confidence Interval (CI).*

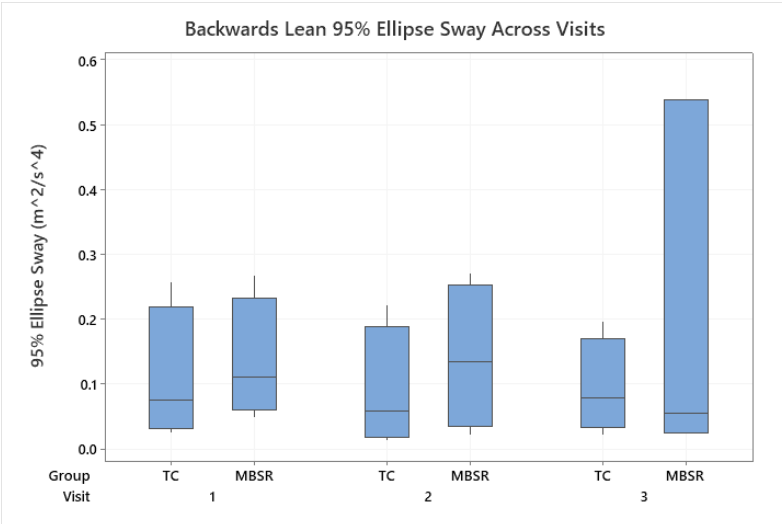



*Figure 25: Backwards Lean Average 95% Ellipse Sway. Backwards Lean (BL) ellipse sway is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

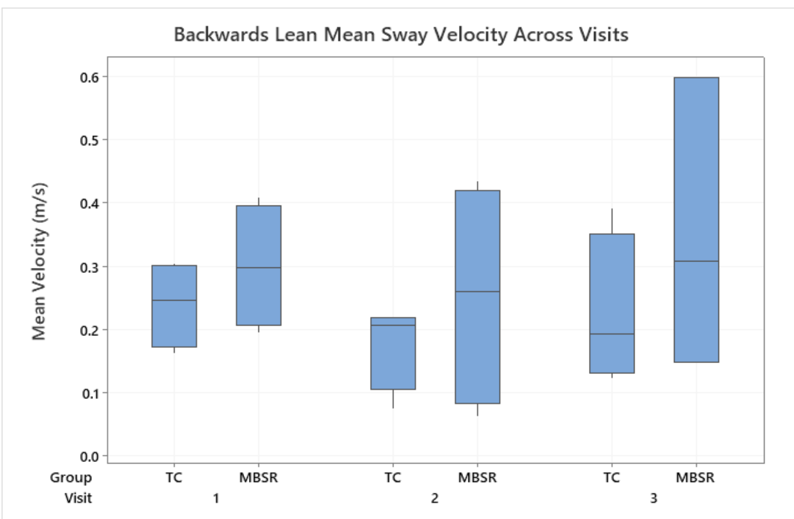



*Figure 26: Backwards Lean Average Mean Sway Velocity. Backwards Lean (BL) mean sway velocity is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the washout period.*

The individual percent change data showed that 6 of the 8 individuals (4 TC, 2 MBSR) had reductions in 95% ellipse sway area after the intervention (decreased fall risk), while 2 individuals (MBSR) increased their sway area (increased fall risk). After the washout period two of the eight individuals (1 TC, 1 MBSR) had reductions in their 95% ellipse sway area (decreased fall risk), and five of the seven (3 TC, 2 MBSR) had increases in their 95% ellipse sway area (increased fall risk). Five of seven participants (3 TC, 2 MBSR) increased their measured lean distance after the intervention, while the other two showed reduced lean distance (the same two MBSR participants who increased sway area). Refer to Table 5 for a visual overview of the individual percent change data.

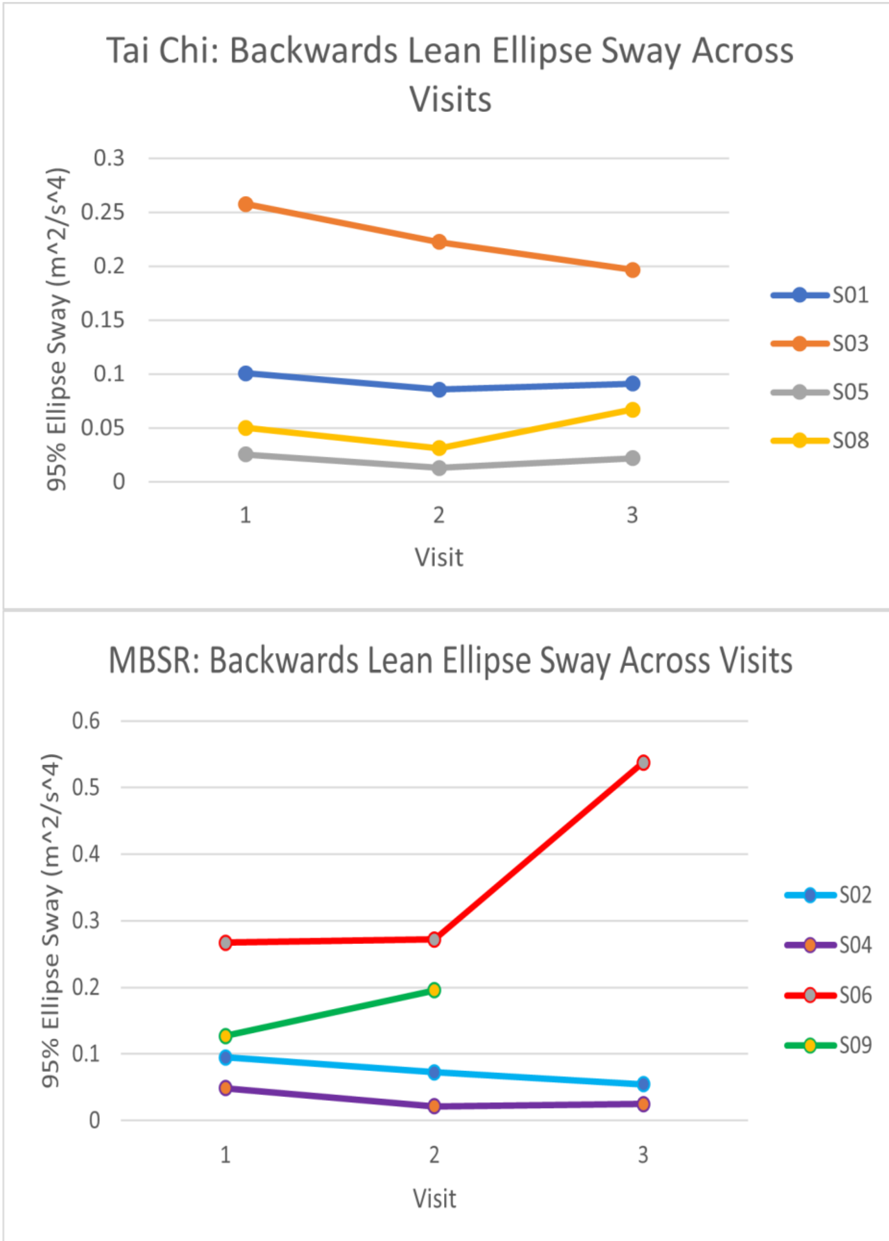



*Figure 27: Backwards Lean Individual Trends of 95% Ellipse Sway Across Visits. Individual trends are plotted as a line graph, S09 V3 data could not be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

For percent change of mean sway velocity, 6 individuals (3 TC, 3 MBSR) showed a reduction in sway velocity after the intervention (decreased fall risk), while 2 participants (1

TC, 1 MBSR) increased their sway velocity at V2 (increased fall risk). After the washout period six of the seven individuals (3 TC, 3 MBSR) had increases in their mean sway velocity, and 1 participant (TC) had a reduction in their mean sway velocity. Even though the trends seen within the individual data were towards the direction of reduced 95% ellipse sway and some reductions in mean sway velocity, the effect size data did not show a larger impact outside of a large reduction in mean sway velocity for the Tai Chi group after the intervention, with increased 95% ellipse sway and mean sway velocity after the washout period.

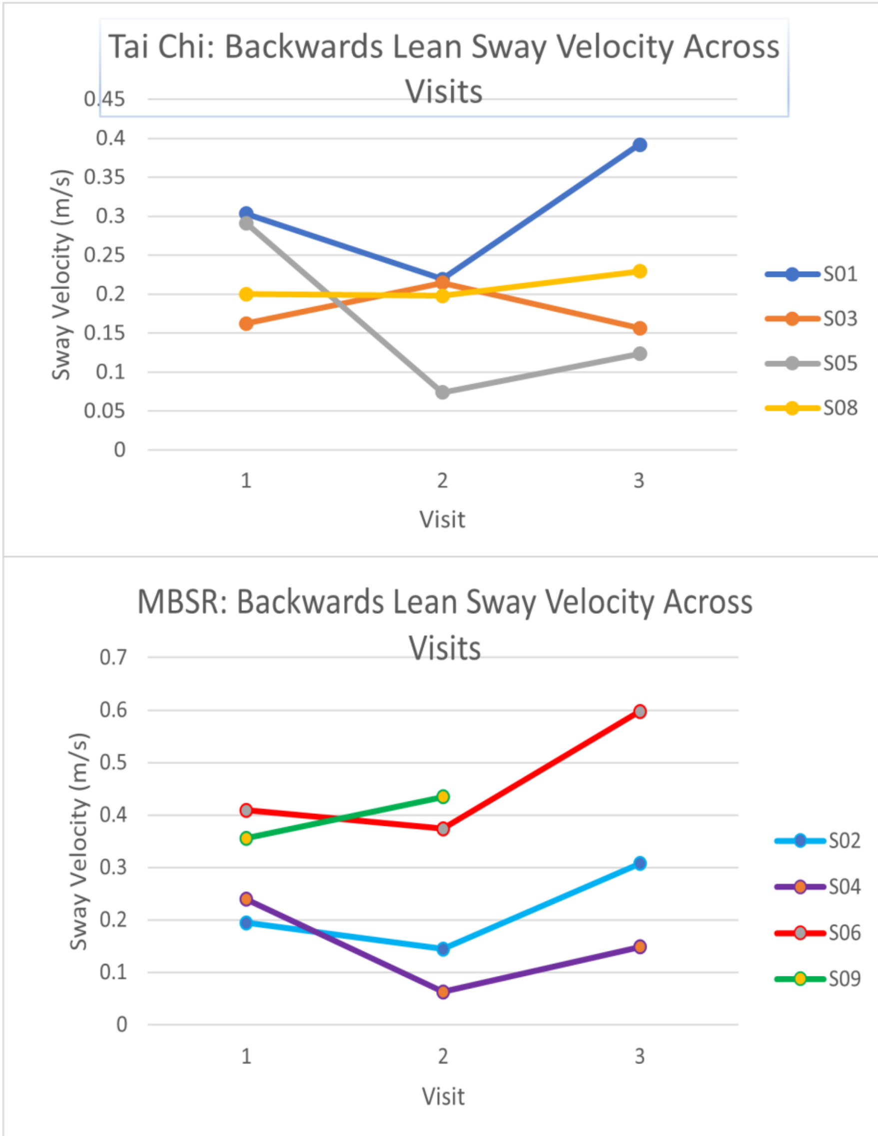



Figure 28: Backwards Lean Individual Trends of Mean Sway Velocity Across Visits. *Individual trends are plotted as a line graph, S09 V3 data could not be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

### 4.3.2 Dynamic Balance Trials

For the dynamic balance trials the postural variables of interest included trial duration for the Timed Up and Go test, Sit to Stand and 25ft walk. As well as the additional 25ft walk variables of dual support time and stride length. Table 12 includes a visual summary of the dynamic postural results. Descriptive statistics, Cohen's D effect sizes and the group percent change for the specific tests are presented below. Positive effect sizes for the dynamic postural variables show reduced time to trial completion which means greater strength/mobility, whereas negative effect sizes indicate increased time to trial completion which may indicate a loss of strength/mobility. The group percent change values on the other hand are interpreted in the opposite direction as the Cohen's d effect size; for these values a negative percent change indicates an improvement in strength/mobility while positive values indicate a decline.

Timed Up and Go (TUG):

For the TUG trials both the Tai Chi and the MBSR groups had only small changes in trial times (Cohen's d), however the direction of the trends differed. Descriptive statistics are presented for the TUG in Table 10, refer to Figure 29 for a boxplot of average TUG duration by group across visits, and Figure 30 for line graphs showing individual trends of TUG duration by group.

For the Tai Chi group there was a small increase in TUG average trial duration after the intervention, and no effect of the washout period at V3 based on the effect size analysis (Table 11). Even though there was only a small increase in TUG average trial time, when

breaking the TUG test down into its components the Tai Chi group showed: a large increase in Sit to Stand Time (d=-1.327), a small increase in Stand to Sit Time, and no effect of Turn Duration after the intervention. After the washout period there was no effect on average trial duration, a small reduction in Sit to Stand time, a large increase in Stand to Sit time (d=-1.348), and no change in Turn Duration. Based on these data it appears that while the Tai Chi group became slower at performing the test, it was mainly in the Sit to Stand component of the test. The slower TUG times and slower Sit to Stand component may have occurred due to the Tai Chi training itself where deliberateness of a movement is trained not speed. Participants may have performed the Sit to Stand portion of the TUG test in a similar way to how the Tai Chi form was practiced, with controlled and deliberate movements from center.

For the MBSR group there was a small decrease in TUG average trial duration after the intervention, and no effect of the washout period at V3. Even though there was only a small effect on TUG average trial duration, when breaking the TUG test down into its components the MBSR group showed: a large reduction in Sit to Stand Time (d= 0.889), a small increase in Stand to Sit Time, and no effect on Turn Duration after the intervention. After the washout period there was a moderate increase in Sit to Stand time (d=-0.662), a moderate reduction in Stand to Sit time (d=0.735), and at large increase in Turn Duration (d=-1.206). When evaluating TUG performance at baseline the MBSR group did perform the TUG trials slower on average (see Figure 29). One reason for the difference in group effect could be due to the MBSR training attention to body sensations and focus on the movement itself that allowed participants to move faster and be more attentive to the components of the TUG test.

*Table 10: TUG Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Average TUG Trial Duration (s) | 1 | 4 | 7.343 | 1.410 | 7.248 | 5.099 to 9.587 |
| | 2 | 4 | 7.875 | 1.014 | 7.702 | 6.26 to 9.48 |
| | 3 | 4 | 8.096 | 1.234 | 8.277 | 6.132 to 10.05 |
| Average TUG Sit to Stand – Duration (s) | 1 | 4 | 0.8163 | 0.0655 | 0.8042 | 0.712 to 0.920 |
| | 2 | 4 | 0.9592 | 0.1315 | 1.0067 | 0.749 to 1.168 |
| | 3 | 4 | 0.9117 | 0.1260 | 0.9067 | 0.711 to 1.112 |
| Average TUG Stand-Sit Duration (s) | 1 | 4 | 0.6925 | 0.0808 | 0.6817 | 0.563 to 0.821 |
| | 2 | 4 | 0.7100 | 0.0864 | 0.7050 | 0.572 to 0.847 |
| | 3 | 4 | 0.8383 | 0.1031 | 0.8533 | 0.674 to 1.002 |
| Average TUG Turn Duration (s) | 1 | 4 | 2.115 | 0.229 | 2.148 | 1.75 to 2.47 |
| | 2 | 4 | 2.073 | 0.238 | 2.008 | 1.694 to 2.451 |
| | 3 | 4 | 2.077 | 0.369 | 2.055 | 1.489 to 2.664 |

| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Average TUG Trial Duration (s) | 1 | 4 | 13.58 | 5.51 | 14.63 | 4.813 to 22.34 |
| | 2 | 4 | 11.83 | 5.16 | 11.95 | 3.623 to 20.03 |
| | 3 | 3 | 12.17 | 5.01 | 12.59 | 4.208 to 20.14 |
| Average TUG Sit to Stand – Duration (s) | 1 | 4 | 1.137 | 0.221 | 1.061 | 0.784 to 1.488 |
| | 2 | 4 | 0.9925 | 0.0628 | 1.0033 | 0.892 to 1.092 |
| | 3 | 3 | 1.0389 | 0.0765 | 1.0033 | 0.848 to 1.228 |
| Average TUG Stand-Sit Duration (s) | 1 | 4 | 0.8933 | 0.1619 | 0.9283 | 0.635 to 1.150 |
| | 2 | 4 | 0.958 | 0.229 | 0.880 | 0.592 to 1.322 |
| | 3 | 3 | 0.8111 | 0.1652 | 0.7567 | 0.400 to 1.221 |
| Average TUG Turn Duration (s) | 1 | 4 | 2.778 | 0.949 | 2.862 | 1.267 to 4.288 |
| | 2 | 4 | 2.738 | 0.328 | 2.742 | 2.215 to 3.261 |
| | 3 | 3 | 3.192 | 0.419 | 3.270 | 2.151 to 4.232 |

*Note: The average trial duration is the overall time measure, with each of the individual components listed: Sit to Stand, Stand to Sit, and Turn duration. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Timed Up and Go (TUG), Standard Deviation (StDev), Confidence Interval (CI).*

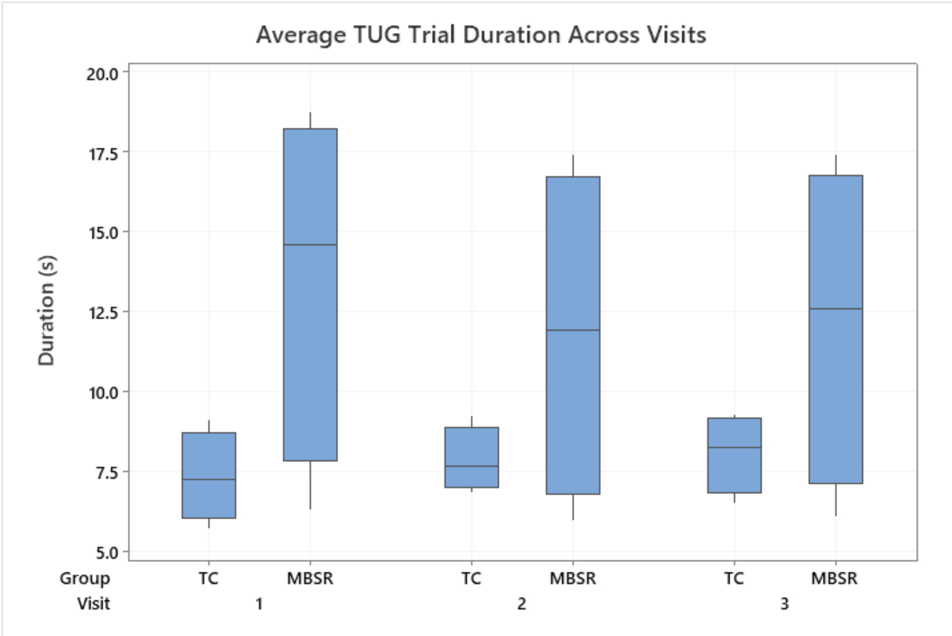



*Figure 29: TUG Average Trial Duration. Trial duration (s) is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

*Table 11: TUG Effect Size Table*

| | Tai Chi | | | | MBSR | | | |
|---|---|---|---|---|---|---|---|---|
| | Intervention V1 to V2 | | Washout V2 to V3 | | Intervention V1 to V2 | | Washout V2 to V3 | |
| | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** |
| **TUG Duration (s)** | -0.433 | 5.92 | -0.195 | 2.79 | 0.327 | -12.88 | -0.066 | 2.87 |
| **Sit to Stand Duration (s)** | -1.327 | 17.50 | 0.368 | -4.95 | 0.889 | -12.70 | -0.662 | 4.67 |
| **Stand to Sit Duration (s)** | -0.209 | 2.52 | -1.348 | 18.07 | -0.326 | 7.24 | 0.735 | -15.33 |
| **Turn Duration (s)** | 0.179 | -1.98 | -0.012 | 0.192 | 0.056 | -1.43 | -1.206 | 16.58 |

*Note: Cohen's d effect sizes are interpreted as: 0-0.2 as no effect; 0.2-0.49 as small, 0.5 to 0.8 as moderate, and 0.8 and above as a large effect. Positive effect sizes for the TUG variables show reduced time to trial completion which means greater strength/mobility, whereas negative effect sizes indicate increased time to trial completion which may indicate a loss of strength/mobility. Negative group % change is indicative of an improvement in strength/mobility, while positive group % change is indicative of a decline. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Timed Up and Go Test (TUG).*

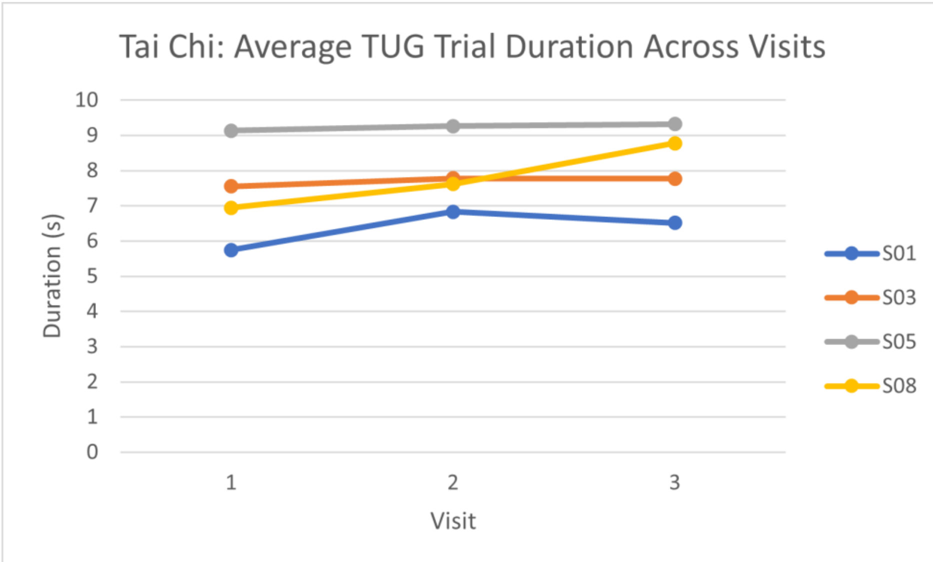
When evaluating the individual percent change trends the same divide between groups was found. Of the seven individuals evaluated, the 4 MBSR participants performed the TUG trials faster after the intervention, while the 4 TC participants performed the TUG trials slower than at V1. After the washout period one participant (TC) had a faster TUG time, 3 participants stayed the same (2 TC, 1 MBSR), and 3 participants had slower TUG times (1 TC, 2 MBSR) than V2. It is important to note as seen in Figure 29 that the Tai Chi group had faster TUG times at baseline then the MBSR, but it does appear that the differences in training may have impacted these results. However the two groups responded to the training differently. The TC group had a small increase in TUG average trial duration

after the intervention, while the MBSR group had a small reduction in TUG average trial duration. After the washout period both groups remained unchanged from V2 to V3 (Table 11). The Tai Chi group was trained to practice slowed deliberate movements which added to an already mobile group may have resulted in the small increased trial time, whereas the increased mindfulness of the more immobile MBSR group may have resulted in the faster trial time. Refer to Table 12 for a visual summary of percent change results.

*Table 12: Dynamic Postural Variables Percent Change Visual Summary*

| | Dynamic Variables Percent Change after the Intervention | | | |
|---|---|---|---|---|
| | | TUG | STS | 25ft Walk |
| PT | Group | Avg Trial Time | Avg Trial Time | Avg Trial Time |
| S01 | TC | | | |
| S02 | MBSR | | | |
| S03 | TC | | | |
| S04 | MBSR | | | |
| S05 | TC | | | |
| S06 | MBSR | | | |
| S08 | TC | | | |
| S09 | MBSR | | **NA** | |
| | | | | |
| | Dynamic Variables Percent Change after the Washout | | | |
| | | TUG | STS | 25ft Walk |
| PT | Group | Avg Trial Time | Avg Trial Time | Avg Trial Time |
| S01 | TC | | | |
| S02 | MBSR | | | |
| S03 | TC | | | |
| S04 | MBSR | | | |
| S05 | TC | | | |
| S06 | MBSR | | | |
| S08 | TC | | | |
| S09 | MBSR | **NA** | | **NA** |

*Note: The table above includes the individual participants static postural variables color coded to show an overview on postural stability after the intervention and washout periods. Green tiles indicate faster TUG, STS, and 25ft walk values indicating an improvement in strength and mobility, yellow tiles indicate no change, and red tiles indicate slower TUG, STS, 25ft walk times indicating a decline of strength and mobility. Abbreviations include: Quiet Stance (QS), Narrow Stance (NS), Forward Reach (FR), and Backwards Lean (BL), Non applicable-(NA) is when there were errors with the trial. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR).*



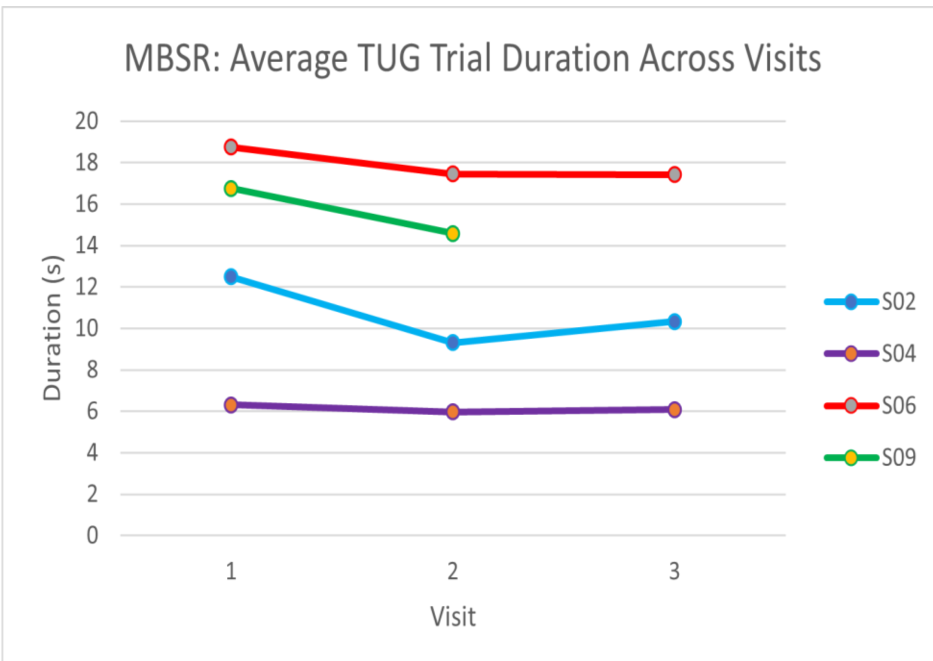




*Figure 30: TUG Individual Trends of Trial Duration Across Visits*. *Individual trends are plotted as a line graph, S09 V3 data could not be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Sit to Stand (STS):

Based on the Cohen's d effect sizes both groups had small to moderate improvements in STS parameters after the intervention with small to negligible changes after the washout period. Descriptive statistics can be found in Table 13, Cohen's d effect sizes in Table 14, Figure 31 is a boxplot of average STS duration by group across visits, and Figure 32 line graphs showing individual trends of STS duration by group. For the Tai Chi group there was a small reduction in STS average trial duration after the intervention, and no effect of the washout period at V3. When breaking the STS test down into its components the Tai Chi group saw: no effect on Sit to Stand time and a small reduction in Stand to Sit Time after the intervention, with no effect on Sit to Stand time and a small increase in Stand to Sit time after the washout period. It appears that the Tai Chi group, which had faster STS times compared to the MBSR group at baseline was not impacted by the intervention or washout period.

For the MBSR group there was a moderate reduction in STS average trial duration (d=0.612) after the intervention, and a small reduction after the washout period. When breaking the STS test down into its components the MBSR group saw: a moderate reduction in Sit to Stand Time (d=0.608) and a large reduction in Stand to Sit Time (d=0.987) after the intervention. After the washout period there was a small reduction in Sit to Stand and a small increase in Stand to Sit time. It appears that the MBSR group was positively impacted by the intervention resulting in faster STS trial times.

*Table 13: STS Descriptive Statistics. Mean, Standard Deviation, Median and 95% Confidence Interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **Total Count** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Average STS Duration (s) | 1 | 4 | 12.12 | 5.07 | 10.51 | 4.049 to 20.19 |
| | 2 | 4 | 10.21 | 2.40 | 9.89 | 6.386 to 14.03 |
| | 3 | 4 | 9.91 | 2.53 | 9.54 | 5.886 to 13.92 |
| Sit to Stand - Duration (s) | 1 | 4 | 0.815 | 0.245 | 0.723 | 0.424 to 1.204 |
| | 2 | 4 | 0.803 | 0.213 | 0.733 | 0.464 to 1.142 |
| | 3 | 4 | 0.7967 | 0.1913 | 0.8033 | 0.492 to 1.100 |
| Stand to Sit - Duration (s) | 1 | 4 | 0.861 | 0.222 | 0.807 | 0.507 to 1.214 |
| | 2 | 4 | 0.8075 | 0.1478 | 0.8100 | 0.572 to 1.042 |
| | 3 | 4 | 0.874 | 0.235 | 0.883 | 0.499 to 1.248 |
| **MBSR Group** | **Visit** | **Total Count** | **Mean** | **StDev** | **Median** | **95% CI** |
| Average STS Duration (s) | 1 | 4 | 16.56 | 8.79 | 15.75 | 2.570 to 30.54 |
| | 2 | 4 | 11.85 | 6.40 | 10.52 | 1.674 to 22.03 |
| | 3 | 3 | 9.56 | 4.34 | 8.87 | -1.21 to 20.329 |
| Sit to Stand - Duration (s) | 1 | 4 | 1.335 | 0.515 | 1.402 | 0.515 to 2.155 |
| | 2 | 4 | 1.023 | 0.511 | 0.883 | 0.210 to 1.836 |
| | 3 | 3 | 0.833 | 0.232 | 0.817 | 0.256 to 1.409 |
| Stand to Sit - Duration (s) | 1 | 4 | 0.8758 | 0.1806 | 0.8600 | 0.588 to 1.163 |
| | 2 | 4 | 0.7292 | 0.1069 | 0.7150 | 0.559 to 0.899 |
| | 3 | 3 | 0.762 | 0.189 | 0.717 | 0.292 to 1.232 |

*Note: The average STS duration is the overall time measure, with each of the individual components listed including: Sit to Stand and Stand to Sit. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Sit to Stand (STS), Standard Deviation (StDev), Confidence Interval (CI).*

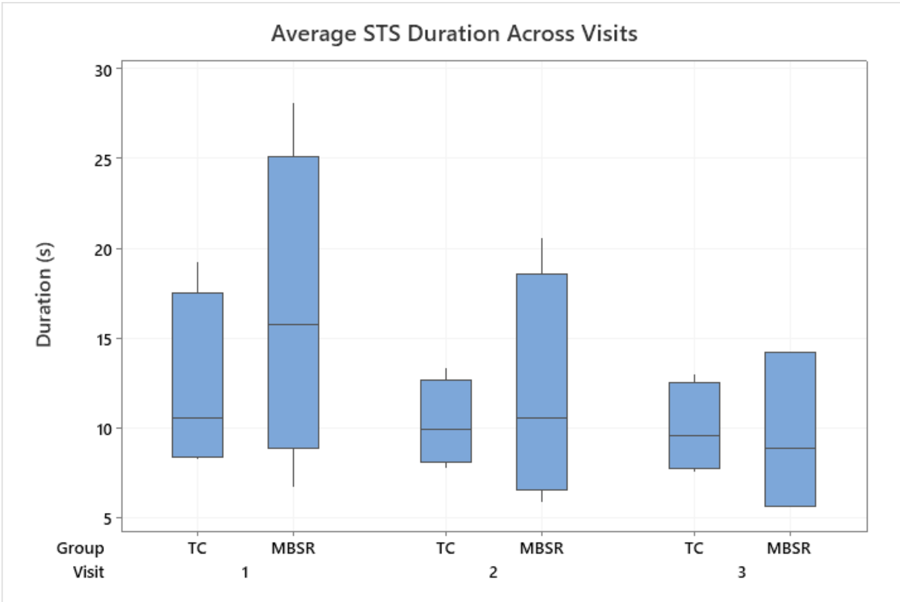



*Figure 31: STS Average Trial Duration. Trial duration (s) is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

*Table 14: STS Effect Sizes Across the Visits*

| | **Tai Chi** | | | | **MBSR** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Intervention V1 to V2** | | **Washout V2 to V3** | | **Intervention V1 to V2** | | **Washout V2 to V3** | |
| | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** |
| **Average STS Duration (s)** | 0.481 | -15.75 | 0.121 | -2.93 | 0.612 | -28.44 | 0.418 | -19.32 |
| **Sit to Stand Duration (s)** | 0.052 | -1.47 | 0.031 | -0.784 | 0.608 | -23.37 | 0.478 | -18.57 |
| **Stand to Sit Duration (s)** | 0.283 | -6.21 | -0.338 | 8.23 | 0.987 | -16.73 | -0.213 | 4.49 |

*Note: Cohen's d effect sizes are interpreted as: 0-0.2 as no effect; 0.2-0.49 as small, 0.5 to 0.8 as moderate, and 0.8 and above as a large effect. Positive effect sizes for the STS variables show reduced time to trial completion which means greater strength/mobility, whereas negative effect sizes indicate increased time to trial completion which may indicate a loss of strength/mobility. Negative group % change is indicative of an improvement in strength/mobility, while positive group % change is indicative of a decline. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

When evaluating the individual participant trends, of the 7 individuals evaluated, 4 participants (1 MBSR, 3 TC) performed the STS trials faster after the intervention, while 3 participants (2 MBSR, 1 TC) performed the trials slower than at V1. After the washout period where eight participants results were measured, 7 participants had faster STS times (4 MBSR, 3 TC) and one participant (TC) was slower.

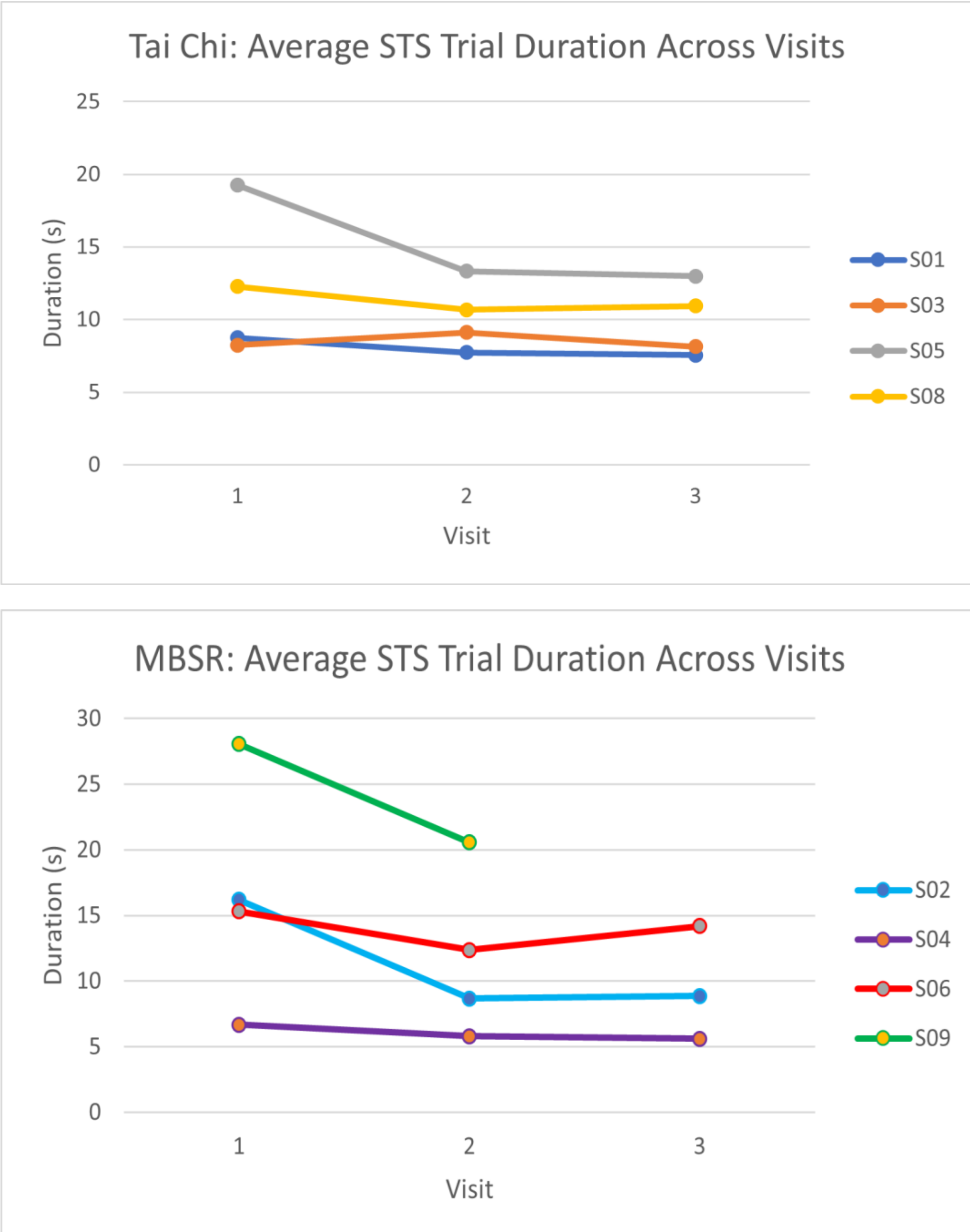



*Figure 32: STS Individual Trends of Trial Duration Across Visits. Individual trends are plotted as a line graph, S09 V3 data could not be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

25ft Walk:

The descriptive statistics for the different walking parameters are shown in Table 15, with Cohen's d effect sizes and group percent change in Table 16. Figure 33 is a boxplot of average 25ft walk duration by group across visits, and Figure 34 is line graphs showing individual trends of 25ft walk duration. The Tai Chi group had a faster average 25ft walk time to start at baseline then the MBSR group (TC: 8.93±1.29s, MBSR: 11.27±1.33s), longer stride lengths (TC: 1.3±0.17m, MBSR: 1.06±0.18m) and less time spent in dual support (TC: 20.9s±4.2, MBSR: 21.6s±3.6). These differences occurred even though the two groups were matched for PDDS mobility scores from the telephone screening. Note that the PDDS scores are based on distance for mobility and not on time to walk a set distance. The 25ft walk data has been organized into 'more versus less function' legs based on foot tapping ability, instead of 'right versus left' legs. The leg with 'more function' (MF) is the one that could produce the most foot taps at the baseline visit, and the leg with 'less function' (LF) was the leg with fewer taps. By arranging the data in this manner it clarifies leg asymmetry, common to MS, which is not as clear when sorted 'right versus left' alone.

*Table 15: 25ft Walk Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence Intervals of the mean are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Avg 25ft Walk Duration (s) | 1 | 4 | 8.936 | 1.292 | 9.140 | 6.880 to 10.99 |
| | 2 | 4 | 8.536 | 0.806 | 8.457 | 7.253 to 9.817 |
| | 3 | 4 | 7.986 | 0.989 | 7.611 | 6.412 to 9.560 |
| Stride Length LF (m) | 1 | 4 | 1.3137 | 0.1806 | 1.3725 | 1.026 to 1.601 |
| | 2 | 4 | 1.3013 | 0.1692 | 1.3600 | 1.032 to 1.570 |
| | 3 | 4 | 1.2913 | 0.1121 | 1.3375 | 1.112 to 1.469 |
| Stride Length MF (m) | 1 | 4 | 1.3125 | 0.1560 | 1.3625 | 1.064 to 1.560 |
| | 2 | 4 | 1.3225 | 0.1370 | 1.3650 | 1.104 to 1.540 |
| | 3 | 4 | 1.2862 | 0.0820 | 1.3100 | 1.155 to 1.416 |
| Gait Dual Support LF (%GCT) | 1 | 4 | 20.92 | 4.20 | 21.63 | 14.232 to 27.608 |
| | 2 | 4 | 21.59 | 2.95 | 21.41 | 16.897 to 25.365 |
| | 3 | 4 | 21.81 | 3.17 | 22.27 | 16.767 to 26.846 |
| Gait Dual Support MF (%GCT) | 1 | 4 | 20.97 | 4.32 | 21.90 | 14.102 to 27.846 |
| | 2 | 4 | 21.34 | 3.03 | 21.63 | 16.516 to 26.162 |
| | 3 | 4 | 22.31 | 2.42 | 22.37 | 18.454 to 26.166 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| Avg 25ft Walk Duration (s) | 1 | 4 | 11.277 | 1.359 | 11.695 | 9.115 to 13.440 |
| | 2 | 4 | 10.95 | 2.69 | 11.13 | 6.672 to 15.228 |
| | 3 | 3 | 10.83 | 4.44 | 8.83 | -0.195 to 21.850 |
| Stride Length LF (m) | 1 | 4 | 1.0775 | 0.1842 | 0.9975 | 0.784 to 1.370 |
| | 2 | 4 | 1.038 | 0.202 | 1.045 | 0.716 to 1.358 |
| | 3 | 3 | 0.9033 | 0.1527 | 0.8950 | 0.524 to 1.282 |
| Stride Length MF (m) | 1 | 4 | 1.0575 | 0.1991 | 0.9700 | 0.740 to 1.374 |
| | 2 | 4 | 1.045 | 0.216 | 1.030 | 0.701 to 1.388 |
| | 3 | 3 | 0.8967 | 0.1298 | 0.9250 | 0.574 to 1.219 |
| Gait Dual Support LF (%GCT) | 1 | 4 | 21.55 | 3.67 | 20.73 | 15.702 to 27.393 |
| | 2 | 4 | 21.21 | 5.36 | 18.69 | 12.676 to 29.739 |
| | 3 | 3 | 23.63 | 6.72 | 19.98 | 6.942 to 40.321 |
| Gait Dual Support MF (%GCT) | 1 | 4 | 21.83 | 3.57 | 20.85 | 16.153 to 27.499 |
| | 2 | 4 | 21.08 | 5.47 | 18.65 | 12.381 to 29.787 |
| | 3 | 3 | 23.26 | 6.87 | 20.11 | 6.183 to 40.337 |

*Note: Average 25ft walk duration (s) is the main trial variable, also included are stride length and dual support times of the gait cycle. Both stride length and dual support measures have been organized so the data represents the participants 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Abbreviations include: Global Cycle Time (GCT) %, Standard Deviation (StDev), Confidence Interval (CI). Groups: Tai Chi (TC), Mindfulness Based Stress Reduction (MBSR). Time includes data over 3 visits: baseline, after the 8-week Intervention, after the 2 week washout period.*

For the Tai Chi group there was a small reduction in 25ft walk time after the intervention, with no effect on stride length, or dual support times. After the washout period, there was a moderate reduction in walk speed (d=0.609), a small reduction in the MF leg stride length (no change to LF stride length), and a small increase spent in dual support time. For the MBSR group there was no change in 25ft walk times after the intervention, with a small reduction in LF stride length, and no change to dual support time. After the washout period there was no effect on 25ft walk times, but for stride length moderate (LF, d=0.752) to large (MF, d=0.832) reductions were seen, with a small increase in dual support time. The 25ft walk variables did not appear to be impacted by either intervention. However, after the washout period it does appear that the MBSR group had some reductions in stride length which may indicate a worsening effect of the washout period.

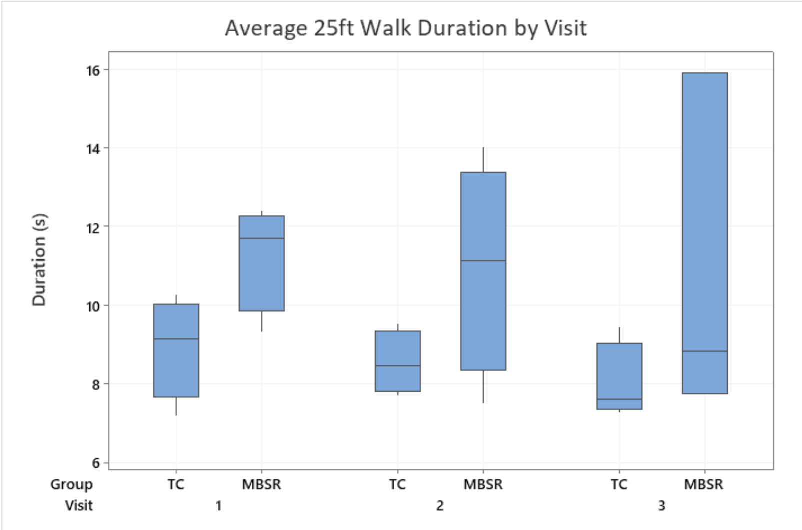


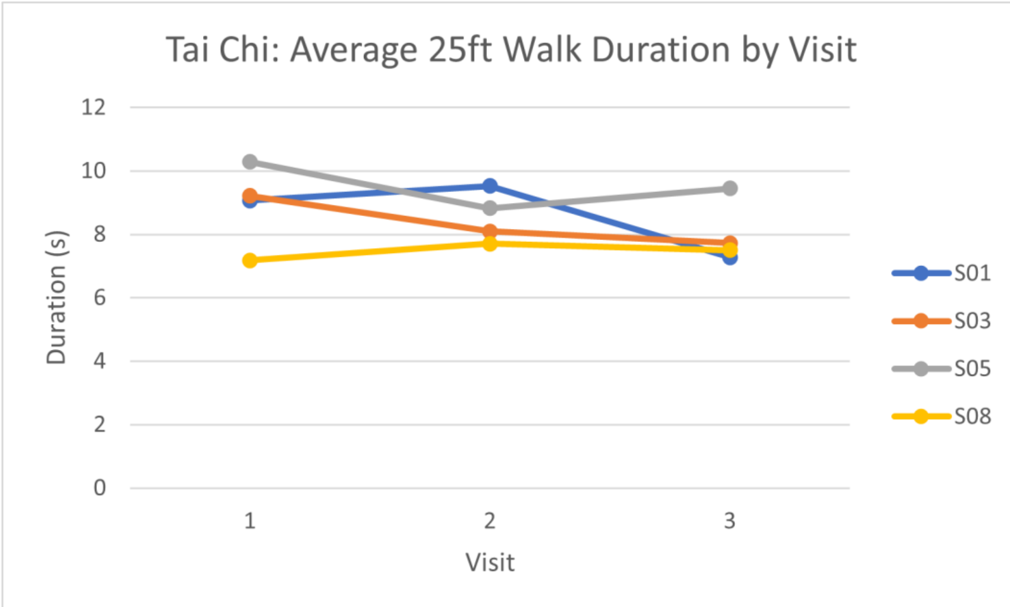

*Figure 33: 25ft Walk Average Trial Duration. Trial duration (s) is plotted by group and visit above. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

*Table 16: 25ft Walk Effect Sizes Across the Visits*

| | **Tai Chi** | | | | **MBSR** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Intervention V1 to V2** | | **Washout V2 to V3** | | **Intervention V1 to V2** | | **Washout V2 to V3** | |
| | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** |
| **Average 25ft Walk Duration (s)** | 0.371 | -4.47 | 0.609 | -6.44 | 0.153 | -2.89 | 0.032 | -1.09 |
| **Stride Length LF (m)** | 0.070 | -0.943 | 0.069 | -0.768 | 0.204 | -3.66 | 0.752 | -12.97 |
| **Stride Length MF (m)** | -0.068 | 0.761 | 0.321 | -2.74 | 0.060 | -1.18 | 0.832 | -14.19 |
| **Dual Support LF (GCT%)** | -0.184 | 3.20 | -0.071 | 1.01 | 0.074 | -1.57 | -0.398 | 11.40 |
| **Dual Support MF (GCT%)** | -0.099 | 1.76 | -0.353 | 9.23 | 0.162 | -3.43 | -0.351 | 10.34 |

*Note: Cohen's d effect sizes are interpreted as: 0-0.2 as no effect; 0.2-0.49 as small, 0.5 to 0.8 as moderate, and 0.8 and above as a large effect. Positive effect sizes for the 25ft walk variables show reduced time to trial completion which means greater mobility, whereas negative effect sizes indicate increased time to trial completion which may indicate a loss of mobility. Negative group % change is indicative of an improvement in mobility, while positive group % change is indicative of a decline.*

When evaluating the individual trends, the percent change showed that of the eight individuals evaluated, 4 participants (2 TC, 2 MBSR) performed the 25ft walk trials faster after the intervention (indicative of improved mobility), while the other 4 (2 TC, 2 MBSR) were slower. After the washout period, 4 of the 7 participants had faster 25ft walk times (3 TC, 1 MBSR) while the other three had slower 25ft walk times (1 TC, 2 MBSR). It is important to note as seen in Figure 33 that the Tai Chi group did have faster 25ft walk times to start with compared to the MBSR group.



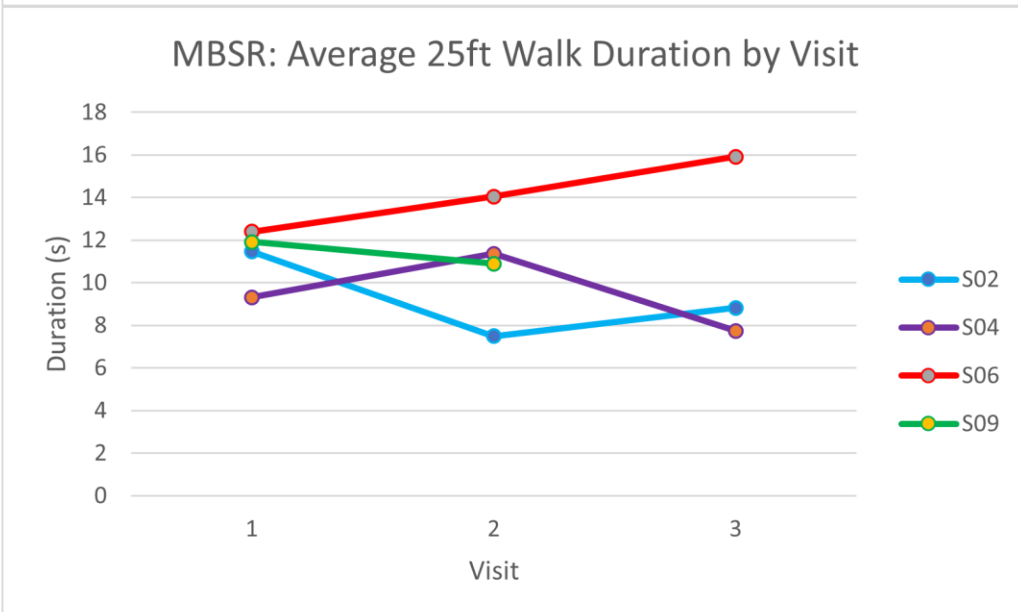




*Figure 34: 25ft Walk Individual Trends of Trial Duration Across Visits. Individual trends are plotted as a line graph, S09 V3 data was unable to be collected. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

## 4.4 Specific Aim 2 Results:

Specific Aim 2: Examine (2.1) which intervention (Tai Chi or MBSR) will yield the greatest improvements in psychosocial function in people with MS; and (2.2) whether psychosocial improvements are retained after a 2 week washout period. We hypothesize (2.1) both groups will improve but that the MBSR group will improve on psychosocial measures to a greater extent than the Tai Chi group, and (2.2) that these improvements will be retained to a greater degree in MBSR after the 2 week washout period. The psychological variables of interest will include balance confidence (subjective balance confidence which is different from the Aim 1 objective balance measures), abbreviated profile of mood states, coping and acceptance of MS, fatigue, and psychosocial wellbeing (Powell & Meyers, 1995; Hobart et al.,2001; Krupp et al.,1989); Roy et al.,2016; Grove & Prapavessis, 1992).

To evaluate psychosocial function the variables of interest included: balance confidence, profile of mood states, coping adaptation and processing of crises, fatigue, and psychosocial wellbeing. To evaluate these variables descriptive stats, Cohen's d effect sizes, and both individual and group percent change analyses will be used. Positive effect sizes for the POMS, FSS, and MSIS-29 measures indicate psychosocial improvements while negative effect sizes indicate a worsening of symptoms; in contrast, negative effect sizes for the ABC and CAPS indicate psychosocial improvements and positive effect sizes a decline. The group percent change values are interpreted in the opposite direction as the Cohen's d effect size, and for these values a sign opposite to the Cohen's d values indicate an improvement in psychosocial variables. Listed below are tables of Cohen's d effect sizes and group percent change (Table 17), and individual percent change (Table 18) for all psychosocial variables.

*Table 17: Psychosocial Effect Sizes Across the Visits*

| | Tai Chi | | | | MBSR | | | |
|---|---|---|---|---|---|---|---|---|
| | Intervention V1 to V2 | | Washout V2 to V3 | | Intervention V1 to V2 | | Washout V2 to V3 | |
| | Cohen's d | Group % Change | Cohen's d | Group % Change | Cohen's d | Group % Change | Cohen's d | Group % Change |
| **Activities Balance Confidence Scale*** | -2.127 | 8.59 | 0.296 | -1.06 | 0.061 | -1.37 | -0.276 | 6.09 |
| **Abbreviated Profile of Mood States[α]** | -0.091 | 1.98 | -0.141 | 3.46 | -0.208 | 3.41 | -0.141 | 2.10 |
| **Coping and Adaptation Processing Scale*** | -1.63 | 37.31 | -0.447 | 4.34 | -0.068 | 1.64 | -0.352 | 5.58 |
| **Fatigue Severity Scale[α]** | 0.763 | -23.87 | -0.299 | 13.55 | 0.867 | -25.17 | 0.223 | -8.05 |
| **MSIS-29 Total Score[α]** | 0.531 | -36.85 | 0.041 | -3.39 | 0.845 | -40.18 | 0.081 | -5.98 |
| **MSIS-29 Psychological Score[α]** | 0.540 | -34.19 | 0.056 | -2.21 | 0.677 | -23.81 | 0.053 | -18.02 |
| **MSIS-29 Physical Score[α]** | 0.497 | -41.2 | 0.027 | -5.28 | 0.479 | -31.87 | 0.298 | -3.01 |

*Note: Cohen's d effect sizes are interpreted as: 0-0.2 as no effect; 0.2-0.49 as small, 0.5 to 0.8 as moderate, and 0.8 and above as a large effect. Questionnaires with an asterisk (*) denote when a negative effect size is indicative of symptom change resulting in psychosocial improvements. Questionnaires with an alpha (α) denote when a positive effect size is indicative of symptom change resulting in psychosocial improvements. The group percent change values are interpreted in the opposite direction as the Cohen's d effect size, for these values a sign opposite to the Cohen's d values indicate an improvement in psychosocial variables. Abbreviations include: Multiple Sclerosis Impact Scale- 29 (MSIS-29), Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

*Table 18: Psychosocial Variables Percent Change Visual Summary*

| | Psychosocial Percent Change after the Intervention | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PT | Group | ABC | POMS | CAPS | FSS | MSIS-29 Total | MSIS-29 Psych | MSIS-29 Physical |
| S01 | TC | | | | | | | |
| S02 | MBSR | | | | | | | |
| S03 | TC | | | | | | | |
| S04 | MBSR | | | | | | | |
| S05 | TC | | | | | | | |
| S06 | MBSR | | | | | | | |
| S08 | TC | | | | | | | |
| S09 | MBSR | | | | | | | |

| | Psychosocial Percent Change after the Washout | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PT | Group | ABC | POMS | CAPS | FSS | MSIS-29 Total | MSIS-29 Psych | MSIS-29 Physical |
| S01 | TC | | | | | | | |
| S02 | MBSR | | | | | | | |
| S03 | TC | | | | | | | |
| S04 | MBSR | | | | | | | |
| S05 | TC | | | | | | | |
| S06 | MBSR | | | | | | | |
| S08 | TC | | | | | | | |
| S09 | MBSR | | | | | | | |

*Note: The table above includes the individual participants static postural variables color coded to show an overview on psychosocial wellbeing after the intervention and washout periods. Green tiles indicate improvements in the psychosocial variables, yellow indicates no change, and red indicates a decline in psychosocial wellbeing. Abbreviations include: Quiet Stance (QS), Narrow Stance (NS), Forward Reach (FR), and Backwards Lean (BL), Non applicable-(NA) is when there were errors with the trial. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR).*

Activities Balance Confidence Scale (ABC):

The ABC is a scale used to evaluate subjective level of balance confidence (as a percentage). Higher scores are indicative of greater percentage of balance confidence and can be broken into: 80% and above is a high level of physical functioning, 50-80% moderate level of function, below 50% being a low level of physical function (Myers et al., 1998). For the Tai Chi group there was a large increase in balance confidence (d=-2.12) after the

intervention, and a small reduction in balance confidence after the washout period which was still larger than the baseline values reported at V1. For the MBSR group there was no effect of the intervention on balance confidence, and a small increase in balance confidence after the washout period. One interesting note is that LaJoie et al., 2004 found that older adults with ABC scores < 67% were at risk of falling and possibly predictive of a future fall. ABC specific descriptive statistics are shown in Table 19, for Cohen's d effect sizes and group % change in Table 17, boxplots of average ABC score by group across the visits in Figure 35, and line graphs showing individual ABC score trends over time in Figure 36.

*Table 19: ABC Scale Descriptive Statistics. Mean, Standard Deviation, and 95% Confidence interval for the mean.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| ABC Score (% Balance Confidence) | 1 | 4 | 85.56 | 3.27 | 85.50 | 80.36 to 90.76 |
| | 2 | 4 | 92.91 | 3.63 | 91.75 | 87.13 to 98.67 |
| | 3 | 4 | 91.92 | 3.02 | 92.15 | 87.11 to 96.72 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| ABC Score (% Balance Confidence) | 1 | 4 | 70.50 | 16.92 | 69.69 | 43.57 to 92.00 |
| | 2 | 4 | 69.53 | 14.91 | 67.85 | 45.80 to 93.25 |
| | 3 | 4 | 73.77 | 15.80 | 76.86 | 48.62 to 98.91 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Activities Balance Confidence Scale (ABC), Standard Deviation (StDev), Confidence Interval (CI).*

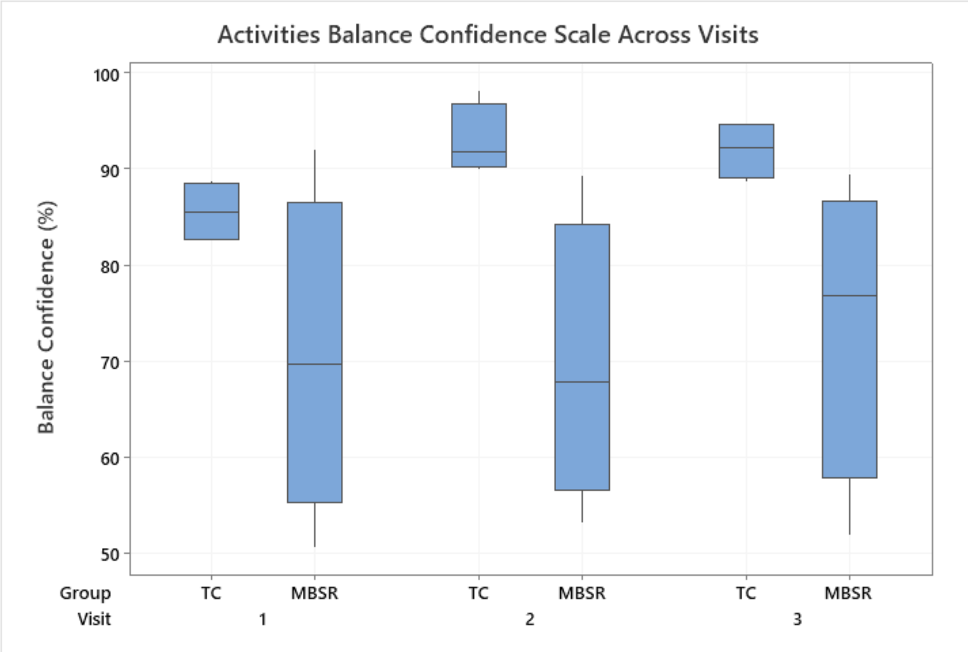
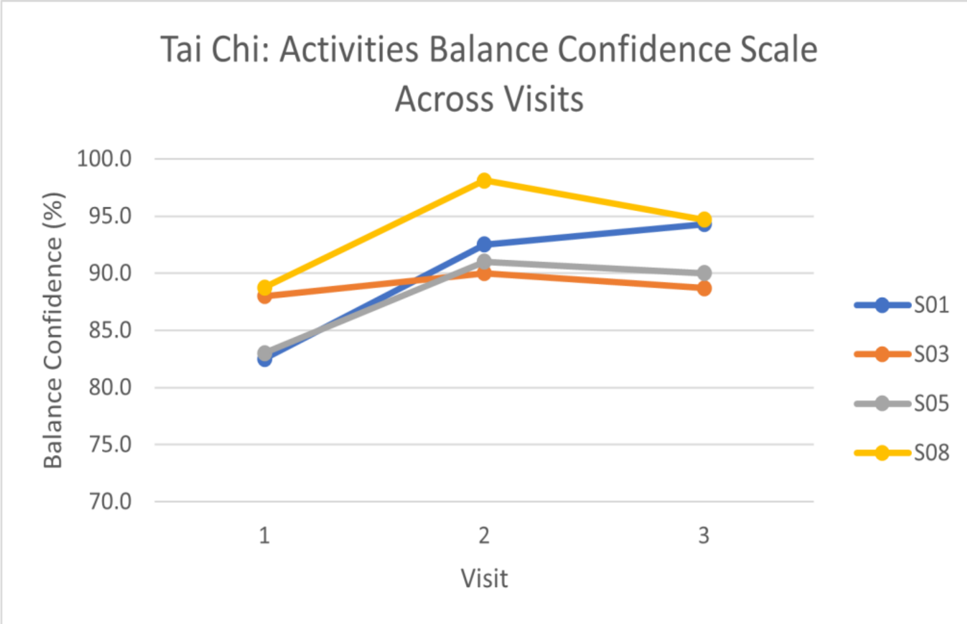



*Figure 35: ABC Score Group Averages. Balance confidence as a percent is plotted by group and visit above. The maximum balance confidence would be 100% where participants feel they would not fall, a balance confidence level of 0% would indicate a fall. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Of the 8 individuals evaluated, 5 participants (4 TC, 1 MBSR) had increased balance confidence after the intervention, while the other 3 (MBSR) participants had reduced balance confidence. After the washout period 4 participants (1 TC, 3 MBSR) had increased their balance confidence, while the other 4 participants (3 TC, 1 MBSR) had reductions in confidence. It appears that the intervention was effective at improving balance confidence in the Tai Chi group, but not the MBSR group.



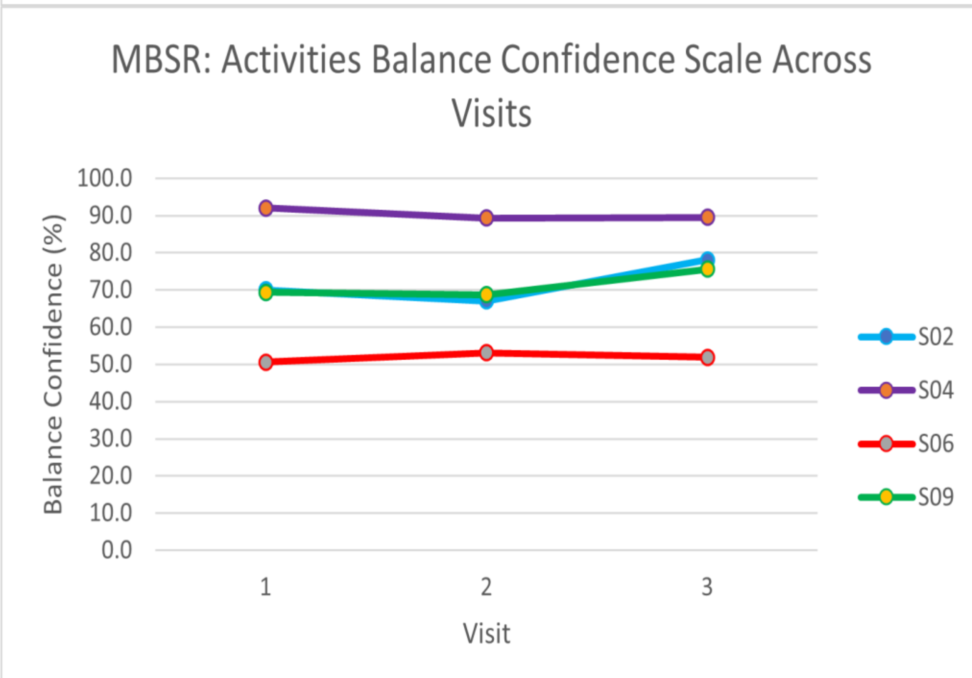




*Figure 36: ABC Score Individual Trends Across Visits. Balance confidence individual trends are plotted as a line graph. The maximum balance confidence would be 100% where participants feel they would not fall, a balance confidence level of 0% would indicate a fall. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Abbreviated Profile of Mood States (POMS):

The abbreviated POMS is used to get an overall 'total mood disturbance score' based on how the 7 subscales correspond to each other. Higher scores are indicative of higher mood disturbance with negative emotions (maximum score of 160), while lower scores have less mood disturbance and more positive affect. For the Tai Chi group there was no effect to mood states after the intervention or the washout period. The MBSR group had a small increase in negative mood states after the intervention, with no effect after the washout period. The MBSR group had lower POMS scores at baseline (indicating greater mood disturbance), and both groups scores stayed about the same throughout the intervention and washout periods. POMS specific descriptive statistics ae shown in Table 20, Cohen's d effect sizes and group percent change in Table 17, boxplots of average POMS score by group across the visits in Figure 37, and line graphs showing individual POMS score trends over time in Figure 38.

*Table 20: POMS Scale Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence Interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Abbreviated POMS | 1 | 4 | 90.50 | 13.63 | 88.50 | 68.81 to 112.18 |
| | 2 | 4 | 92.3 | 24.3 | 84.0 | 53.54 to 130.95 |
| | 3 | 4 | 95.50 | 12.07 | 100.00 | 76.29 to 114.70 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| Abbreviated POMS | 1 | 4 | 80.50 | 15.37 | 77.50 | 56.03 to 104.96 |
| | 2 | 4 | 83.25 | 10.50 | 80.50 | 66.54 to 99.95 |
| | 3 | 4 | 85.00 | 14.02 | 88.50 | 62.68 to 107.31 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Abbreviated Period of Mood States (POMS), Standard Deviation (StDev), Confidence Interval (CI).*

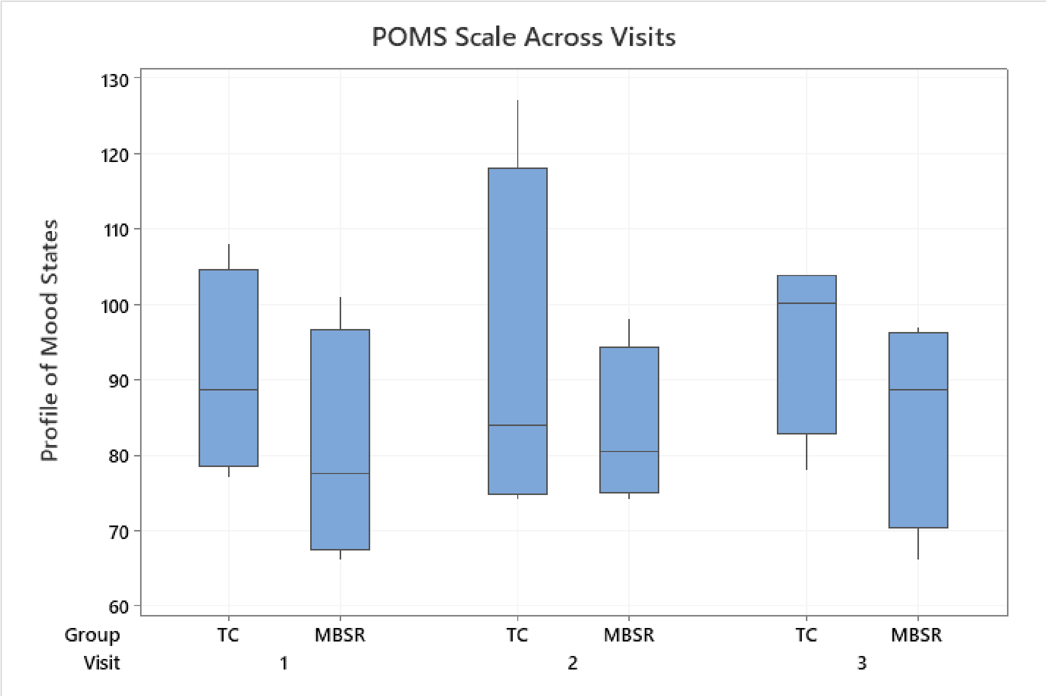



*Figure 37: POMS Score Group Averages. Profile of Mood states is plotted by group and visit above. Higher scores indicate greater mood disturbance (maximum score is 160), while lower scores indicate less mood disturbance and more positive affect. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3$^{rd}$ Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Of the 8 individuals evaluated, 3 participants (2 TC, 1 MBSR) had a reduction in POMS score indicating greater positive affect, 2 participants (1 TC, 1 MBSR) maintained exactly the same score from V1 to V2, and the other 3 participants (1 TC, 2 MBSR) scores worsened after the intervention. After the washout period 3 participants (1 TC, 2 MBSR) had a reduction in their POMS score, while the other 5 participants (3TC, 2 MBSR) had an increase in their POMS score. Based the effect size and individual data it does not appear that the POMS were impacted by the intervention or washout periods.

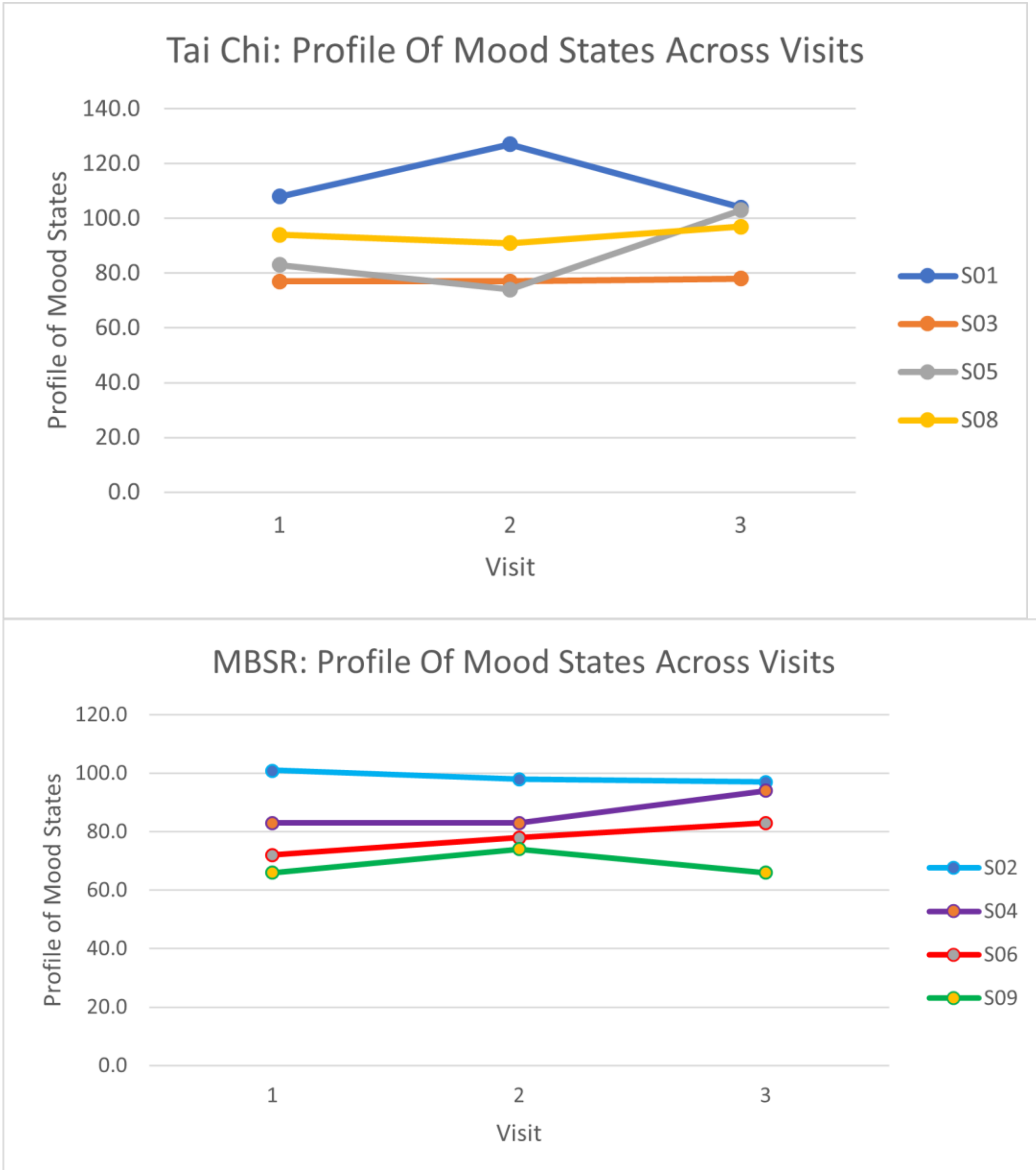



*Figure 38: POMS Score Individual Trends Across Visits. Profile of Mood states individual trends are plotted in the line graphs below. Higher scores indicate greater mood disturbance (maximum score is 160), while lower scores indicate less mood disturbance and more positive affect. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Coping Adaptation Processing Scale (CAPS):

The CAPS scale is a 15-item questionnaire used to evaluate individual ability to cope with crisis. Higher scores indicate greater ability to cope (maximum score is 65), and lower scores indicate less ability to cope with crises (minimum score 15). For the Tai Chi group there was a large effect on coping ability after the intervention (d=-1.63), with the benefits retained after the washout period. The MBSR group had only negligible to small changes in coping ability after the intervention and washout periods. Refer to Table 21 for descriptive stats, Table 17 for Cohen's d effect sizes and group percent change, Table 18 for a visual overview of individual trends, Figure 39 for boxplots of average CAPS score by group across the visits, and Figure 40 for line graphs showing individual CAPS score trends over time.

*Table 21: CAPS Scale Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence Interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| CAPS Scale | 1 | 4 | 33.5 | 9.71 | 35.0 | 18.04 to 48.95 |
| | 2 | 4 | 46.00 | 4.69 | 48.00 | 38.53 to 53.46 |
| | 3 | 4 | 48.00 | 4.24 | 48 | 41.24 to 54.75 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| CAPS Scale | 1 | 4 | 45.5 | 13.18 | 46.00 | 19.53 to 61.47 |
| | 2 | 4 | 44.75 | 8.26 | 46.00 | 31.60 to 57.89 |
| | 3 | 4 | 47.25 | 5.68 | 49.50 | 38.21 to 56.28 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Coping Adaptation Processing Scale (CAPS), Standard Deviation (StDev), Confidence Interval (CI).*

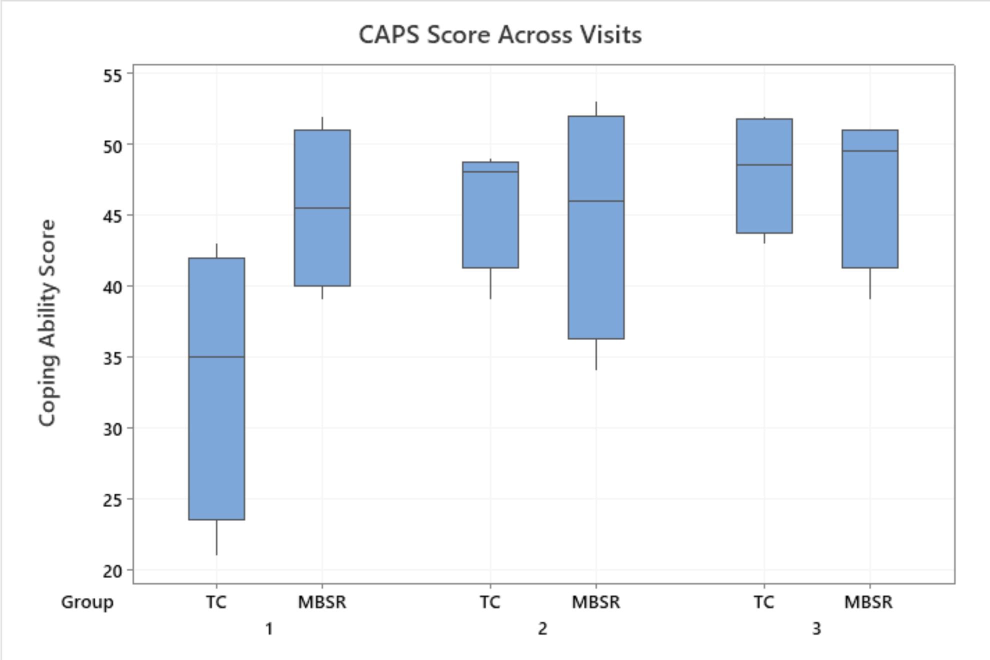
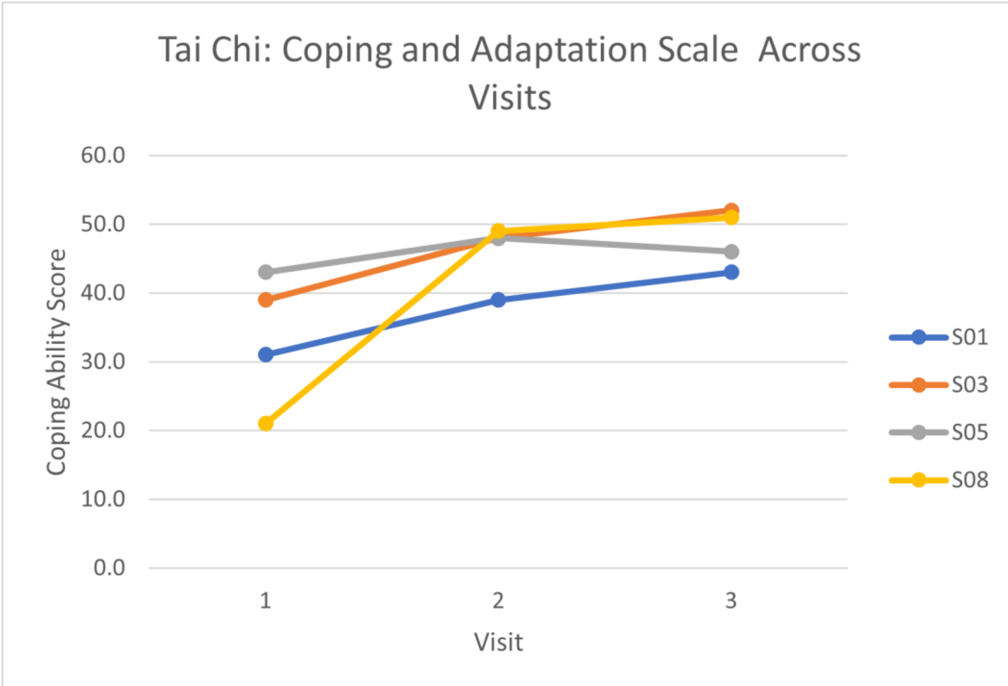



*Figure 39: CAPS Score Group Averages. Coping Adaptation Processing score is plotted by group and visit above. Higher scores indicate greater coping ability (maximum score is 65), while lower scores indicate less ability to cope with crises (minimum 15). Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Of the 8 individuals evaluated, the 4 Tai Chi participants increased their CAPS scores indicating greater coping ability, 3 MBSR participants maintained the same score from V1 to V2, and the other MBSR participant had decreased coping ability after the intervention. After the washout period 3 participants (3 TC, 1 MBSR) had an increase in coping ability, 2 MBSR participants maintained the same score from V2 to V3, and the other 2 participants (1 TC, 1 MBSR) had a decrease in coping ability. It appears that the Tai Chi intervention had a beneficial impact on coping ability after the intervention and benefits were retained through the washout period, the MBSR group coping ability did not appear to be impacted by the intervention with a small improvement in coping found after the washout period.



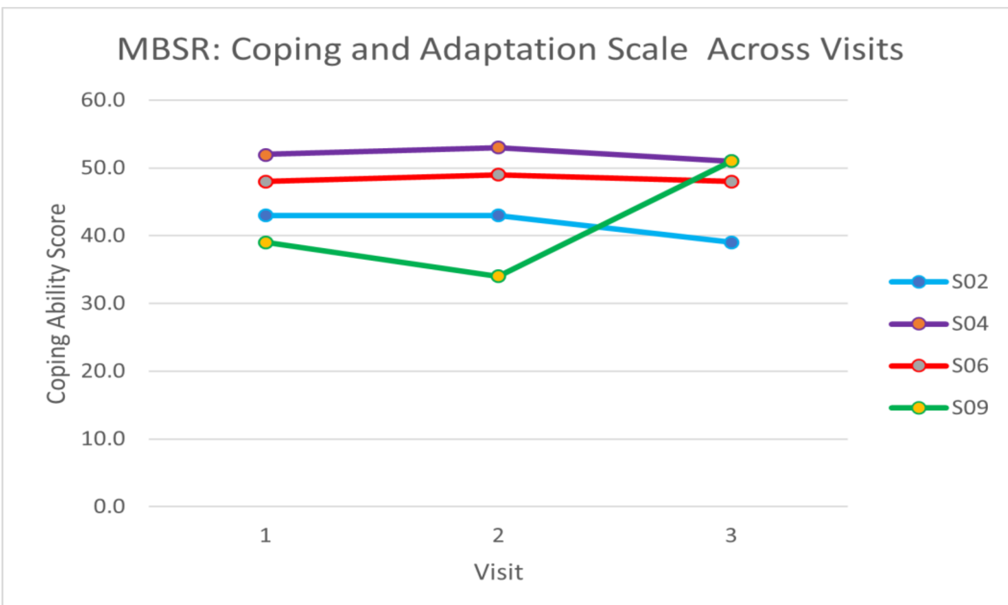




*Figure 40: CAPS Score Individual Trends Across Visits. Coping Adaptation Processing individual trends are plotted via line graph. Higher scores indicate greater coping ability (maximum score is 65), while lower scores indicate less ability to cope with crises (minimum 15). Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Fatigue Severity Scale (FSS):

The FSS evaluates an individuals' average level of fatigue over the past 2 weeks. It is a 9-question likert scale, with higher scores indicative of greater fatigue (maximum score is 126), and lower scores less fatigue on average over the last 2 weeks (minimum score is 9). For the Tai Chi group there was a moderate reduction in fatigue severity (d=0.763) after the intervention, and a small increase in fatigue after the washout period. For the MBSR group there was a large reduction in fatigue severity (d=0.867), with no change after the washout period (benefits retained). The MBSR group at baseline had a greater level of fatigue severity than the Tai Chi group, however both groups had reductions in fatigue during the intervention period. For FSS specific descriptive statistics refer to Table 22, Table 17 for Cohen's d effect sizes and group percent change, Table 18 for a visual overview of individual trends. Figure 41 is a boxplot of average FSS score by group across the visits, and Figure 42 has line graphs showing individual FSS score trends over time.

*Table 22: FSS Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence Interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| FSS | 1 | 4 | 38.75 | 7.80 | 36.50 | 26.33 to 51.16 |
| | 2 | 4 | 29.50 | 15.26 | 27 | 5.21 to 53.78 |
| | 3 | 4 | 33.50 | 11.09 | 30.0 | 15.82 to 51.14 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| FSS | 1 | 4 | 70.50 | 17.48 | 70.00 | 42.68 to 98.32 |
| | 2 | 4 | 52.75 | 23.05 | 46.00 | 16.06 to 89.43 |
| | 3 | 4 | 57.00 | 13.88 | 56.5 | 34.91 to 79.08 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Fatigue Severity Scale (FSS), Standard Deviation (StDev), Confidence Interval (CI).*

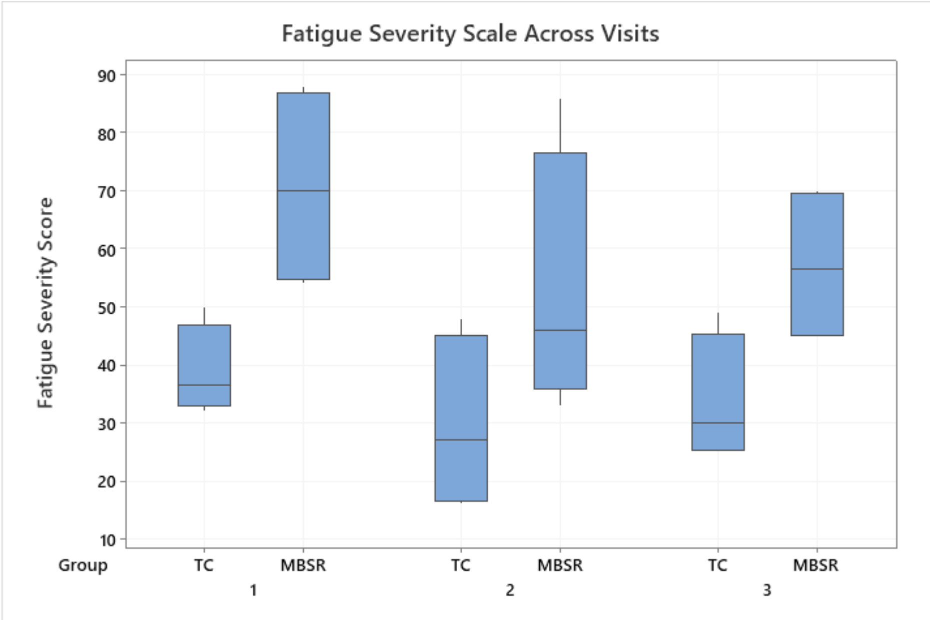
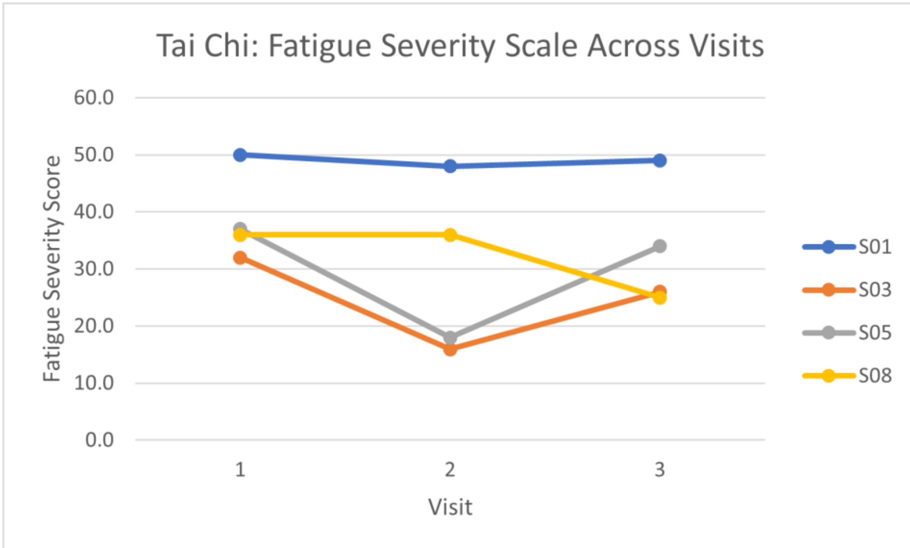



*Figure 41: FSS Score Group Averages. Higher scores indicate greater fatigue severity (maximum of 126) and lower scores indicate less fatigue (minimum score is 9). Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Of the 8 individuals evaluated, 6 participants (3 TC, 3 MBSR) reduced their fatigue severity after the intervention, while 2 participants (1 TC, 1 MBSR) had an increase in fatigue severity after the intervention. After the washout period all 8 participants had lower fatigue severity at V3 then at V1, with 3 participants (1 TC, 2 MBSR) had reduced fatigue severity, and the other 5 participants (3 TC, 2 MBSR) had increased fatigue severity from V2 to V3. It appears that both interventions were effective at reducing fatigue symptoms, and that some of the benefits were retained throughout the washout period.



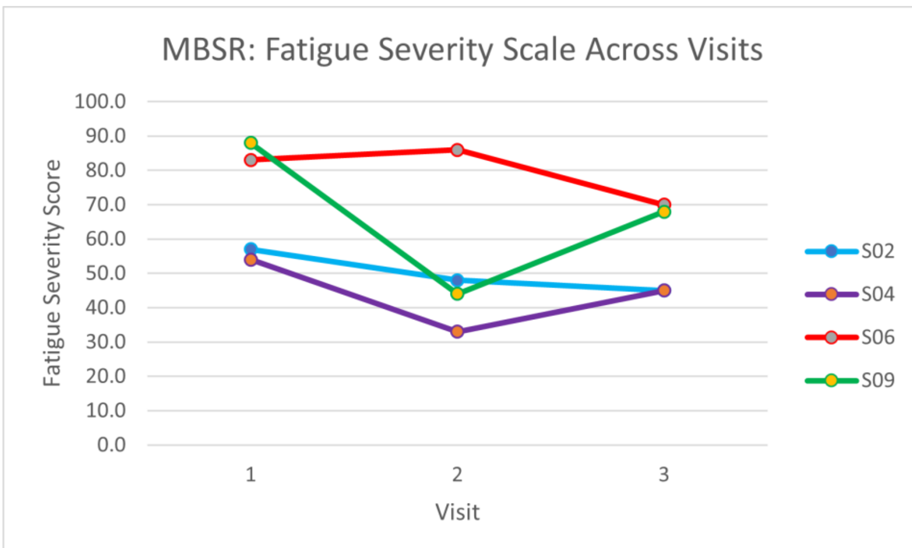




*Figure 42: FSS Score Individual Trends Across Visits. Fatigue severity individual trends are plotted as a percentage in line graphs. Higher scores indicate greater fatigue severity (maximum of 126) and lower scores indicate less fatigue (minimum score is 9). Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

Multiple Sclerosis Impact Scale-29 (MSIS-29):

The MSIS-29 is based on a 29 question, 5-point likert scale. Higher scores are indicative of greater MS disease impact on daily function and wellbeing (maximum score being 145), lower scores indicate less of an impact to wellbeing. The MSIS-29 total score combines both the psychological and physical scores. For the Tai Chi group there was a moderate reduction in MS disease daily impact for MSIS-29 total (d=0.531) with improvements in both the psychological score (d=0.540) and physical scores (d=0.497). No changes were found for MS disease impact after the washout period, so it appears that some benefits to wellbeing were retained. For the MBSR group there was a large reduction in MS disease impact for MSIS-29 total (d=0.845) with improvements in both psychological score (d=0.677) and physical scores (d=0.479). No changes were found after the washout period for total, physical or psychological MSIS-29 scores; therefore it appears that some benefits to wellbeing were retained in the MBSR group as well. Refer to Figures 43-46 for boxplots of average MSIS score by group across the visits, and Figures 47 and 48 for line graphs showing the individual MSIS score trends over time, Table 23 for the descriptive statistics, Table 17 for Cohen’s d effect sizes and group percent change, and Table 18 for a visual overview of individual trends.

*Table 23: MSIS-29 Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence Interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| MSIS-29 Total Score | 1 | 4 | 28.0 | 21.3 | 23.7 | 0 to 61.954 |
| | 2 | 4 | 17.68 | 17.34 | 11.21 | 0 to 45.268 |
| | 3 | 4 | 17.08 | 10.43 | 14.31 | 0.478 to 33.677 |
| MSIS-29 Physical Score | 1 | 4 | 24.71 | 19.08 | 23.15 | 0 to 55.08 |
| | 2 | 4 | 16.26 | 14.56 | 12.50 | 0 to 39.438 |
| | 3 | 4 | 15.90 | 11.09 | 14.90 | 0 to 33.551 |
| MSIS-29 Psychological Score | 1 | 4 | 35.4 | 28.8 | 25.0 | 0 to 81.262 |
| | 2 | 4 | 20.8 | 25.1 | 9.7 | 0 to 58.333 |
| | 3 | 4 | 19.70 | 11.10 | 15.29 | 2.039 to 37.352 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| MSIS-29 Total Score | 1 | 4 | 42.2 | 22.2 | 43.5 | 6.838 to 77.636 |
| | 2 | 4 | 25.24 | 17.68 | 24.19 | 0 to 53.382 |
| | 3 | 4 | 26.75 | 19.29 | 23.30 | 0 to 57.447 |
| MSIS-29 Physical Score | 1 | 4 | 46.6 | 24.0 | 50.6 | 8.359 to 84.766 |
| | 2 | 4 | 35.5 | 22.3 | 42.1 | 0 to 70.982 |
| | 3 | 4 | 29.1 | 20.6 | 25.0 | 0 to 61.893 |
| MSIS-29 Psychological Score | 1 | 4 | 32.6 | 20.6 | 27.8 | 0 to 65.386 |
| | 2 | 4 | 22.21 | 6.81 | 23.59 | 11.374 to 33.049 |
| | 3 | 4 | 21.54 | 16.40 | 19.45 | 0 to 47.647 |

*Note: Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Multiple Sclerosis Impact Scale- 29 (MSIS-29), Standard Deviation (StDev), Confidence Interval (CI).*

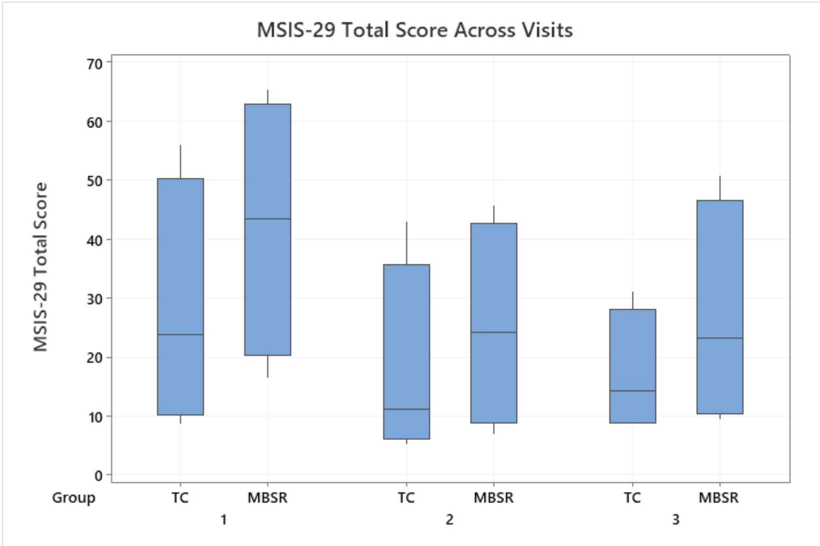



*Figure 43: MSIS-29 Total Score Group Averages. MS symptom impact is plotted by group and visit above. Greater scores indicate larger impact of MS symptom on daily wellbeing, lower scores indicate less impact on daily wellbeing. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

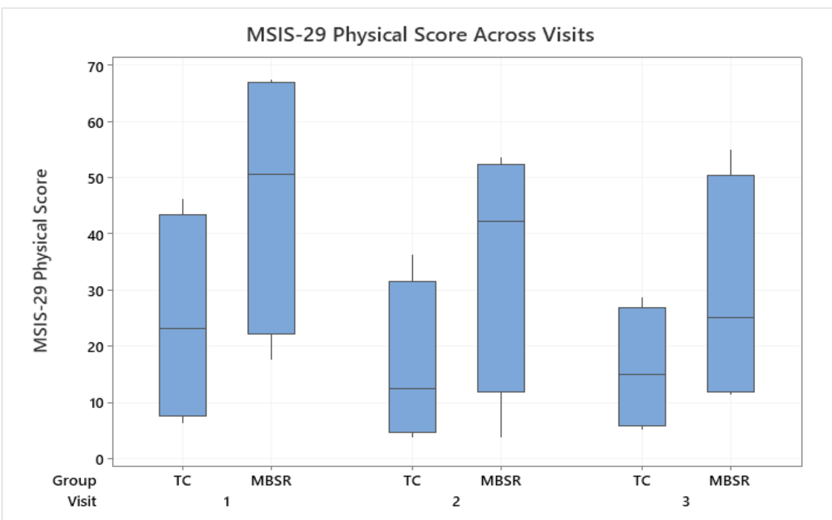



*Figure 44: MSIS-29 Physical Score Group Averages. MS symptom impact is plotted by group and visit above. Greater scores indicate larger impact of MS physical symptoms on daily wellbeing, lower scores indicate less impact on daily wellbeing. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

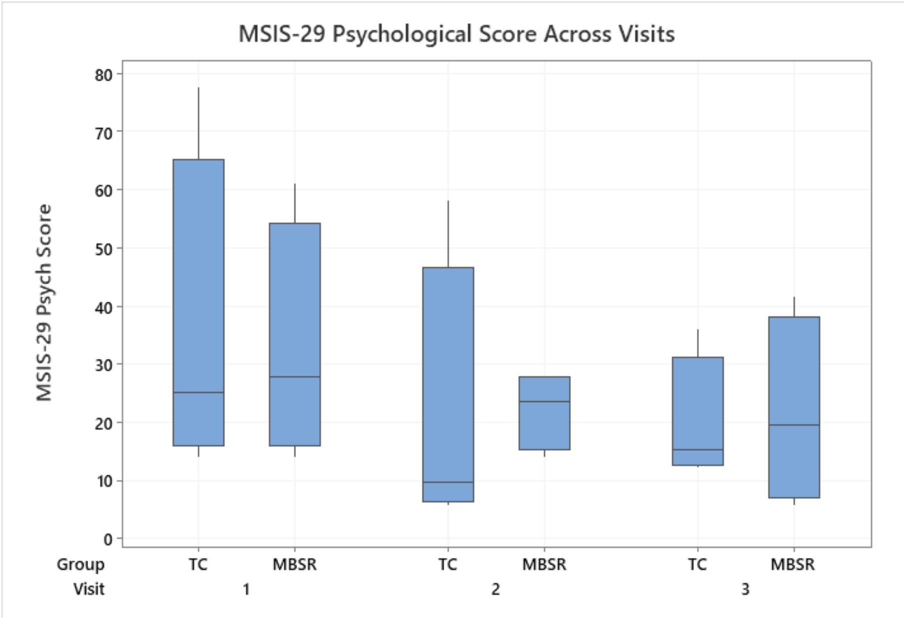
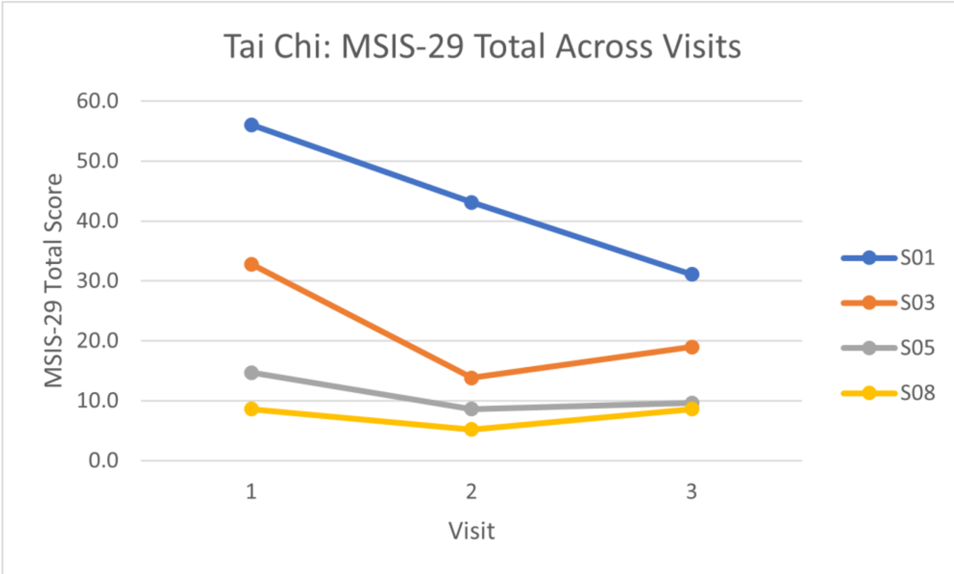



*Figure 135: MSIS-29 Psychological Score Group Averages. MS symptom impact is plotted by group and visit above. Greater scores indicate larger impact of MS psychological symptoms on daily wellbeing, lower scores indicate less impact on daily wellbeing. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3$^{rd}$ Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

All eight individuals evaluated reduced MS symptom impact on daily wellbeing, with 7 (4 TC, 3 MBSR) also having improvements in both physical and psychological symptom scores. Two different MBSR individuals had declines in the physical or psychological symptom scores after the intervention. These improvements in the MSIS-29 scores (Total, Physical and psychological) may be associated with the reductions in fatigue that were seen in both groups after the intervention period, and some of the beneficial postural changes. After the washout period 2 participants had reductions in total MS symptom impact on daily life (1 TC, 1 MBSR), 2 individuals stayed the same (1TC, 1 MBSR) and the remaining 4 declined (2 TC, 2 MBSR), however all values at V3 were still better than those at V1 so

benefits were overall retained.  Similar findings were found for the psychological and physical scores after the washout period where even though the individual trends were scattered all eight participants had MSIS-29 psychological and physical scores that were lower at V3 then were found at the V1 visit. (Refer to figure 47)



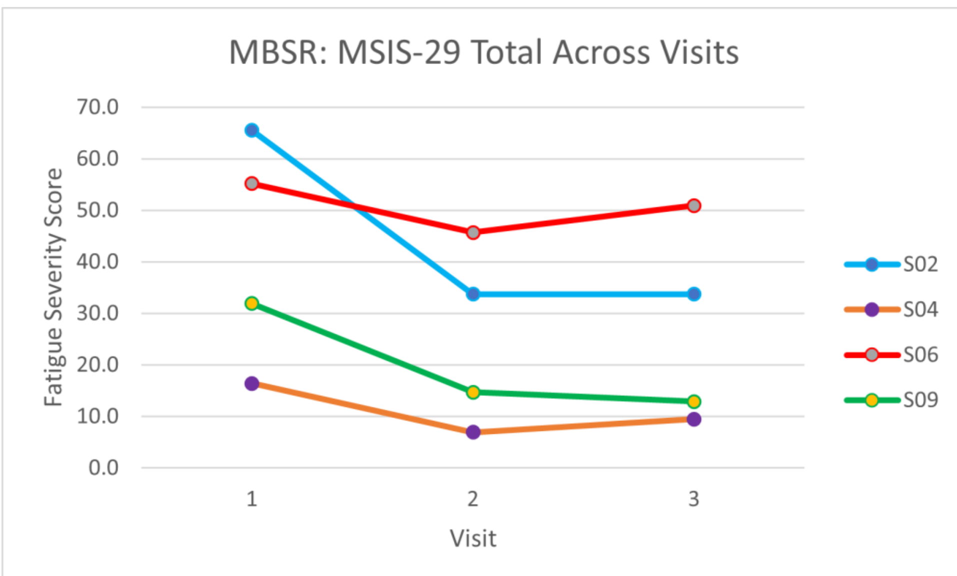
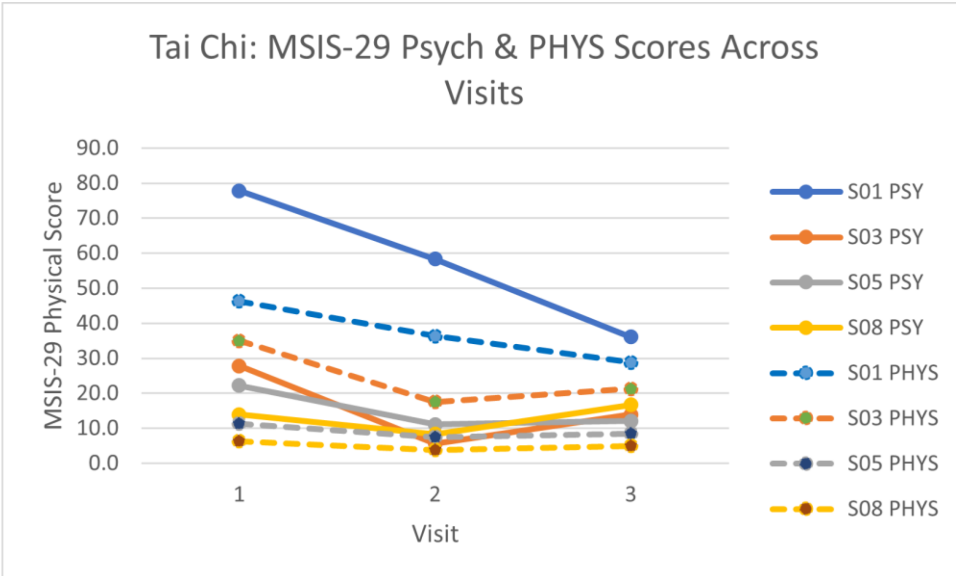




*Figure 46: MSIS-29 Total Individual Trends Across Visits. MS symptom impact individual trends are plotted below. Greater scores indicate larger impact of MS symptom on daily wellbeing, lower scores indicate less impact on daily wellbeing. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*



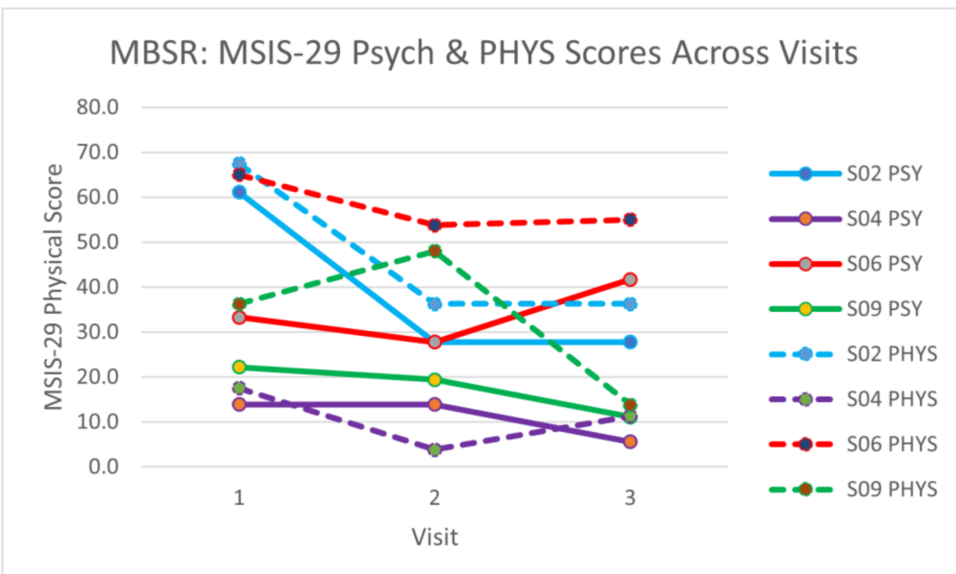




*Figure 47: MSIS-29 Physical and Psychological Individual Trends Across Visits. MS physical symptom individual trends are plotted below.  Greater scores indicate larger impact of MS physical symptoms on daily wellbeing, lower scores indicate less impact on daily wellbeing. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

4.5 Specific Aim 3 Results:

Specific Aim #3: Evaluate (3.1) which intervention (Tai Chi or MBSR) will yield the greatest improvements in sensorimotor function; and (3.2) whether improvements are retained after a washout period. We hypothesize (3.1) that Tai Chi will lead to the greatest improvements in sensorimotor function, and that (3.2) these benefits will be retained after the washout period. The sensorimotor variables of interest will include plantar cutaneous vibration sensitivity assessed with a Biothesiometer, and motor drive assessed via a foot tapping test.

4.5.1 Sensorimotor Function

For sensorimotor function the variables of interest will include plantar vibration sensitivity and foot tapping ability. Vibration sensitivity will be measured across the Hallux, fifth Metatarsal, and Heel of both feet; with feet classified into 'Greater or Lesser Sensitivity' for statistical analyses based on baseline vibration sensitivity. Foot tapping ability will be measured via the parameters of: tap quantity, inter-tap interval, and tap coefficient of variance; with legs classified into 'Greater or Less Function' for statistical analyses based on baseline tap quantities. To evaluate these variables descriptive stats, Cohen's d effect sizes, and both individual and group percent change analyses will be used. Positive effect sizes for plantar sensitivity, inter-tap interval and the tap coefficient of variance indicate an improvement in sensitivity and function, while negative effect sizes indicate a worsening of plantar sensitivity and these parameters of function. In contrast, a negative effect size for tap quantity is indicative of increased tap quantity with an improvement in function, with

positive effect size a decline. The group percent change values are interpreted in the opposite direction as the Cohen's d effect size.

Plantar Cutaneous Vibration Sensitivity Results:

To evaluate plantar vibration sensitivity a Biothesiometer was used to measure the smallest amount of perceived vibration in volts, with a minimum value of 0 and a maximum of 50 volts recorded. The foot with 'greater sensitivity' (GS) is the one that could perceive smaller vibration quantities at baseline, while the 'less sensitive foot' (LS) was the foot with higher vibration thresholds. Plantar sensitivity descriptive statistics can be found in Table 24, and the Cohen's d effect sizes and group percent change in Table 25. Refer to Figures 48-50 for boxplots of average plantar sensitivity by group across visits, and Figure 52 showing a line graph with the individual trends of plantar sensitivity changes. For the Cohen's d measures the positive effect sizes indicate an improvement in sensitivity while negative effect sizes indicate a worsening of plantar sensitivity. The group percent change values are interpreted in the opposite direction as the Cohen's d effect size, so for these values a negative % change indicate an improvement in the plantar vibration. One participant's data (S06) was excluded from all plantar vibration analyses (Cohen's d, group % change) due to edema from an MS medication leading to vibration insensitivity. By visit 3 this participant was taken off the medication and had some plantar sensitivity values. Their data was included in the line graphs in Figure 52 so that the outlier could be visualized.

*Table 24: Plantar Sensitivity Descriptive Statistics. Mean, Standard Deviation, Median, and 95% Confidence Interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Hallux GS | 1 | 4 | 9.25 | 3.86 | 10.00 | 3.104 to 15.395 |
| | 2 | 4 | 9.00 | 3.56 | 8.00 | 3.336 to 14.663 |
| | 3 | 4 | 10.25 | 5.32 | 10.00 | 1.793 to 18.707 |
| M5 GS | 1 | 4 | 9.00 | 4.97 | 9.00 | 1.097 to 16.902 |
| | 2 | 4 | 10.00 | 5.10 | 9.00 | 1.886 to 18.114 |
| | 3 | 4 | 8.00 | 3.27 | 8.00 | 2.803 to 13.196 |
| Heel GS | 1 | 4 | 10.25 | 6.95 | 8.50 | 0 to 21.303 |
| | 2 | 4 | 10.00 | 6.88 | 7.50 | 0 to 20.947 |
| | 3 | 4 | 11.00 | 6.68 | 10.00 | 0.365 to 21.635 |
| Hallux LS | 1 | 4 | 13.75 | 8.85 | 15.50 | 0 to 27.826 |
| | 2 | 4 | 12.00 | 5.35 | 11.50 | 3.480 to 20.520 |
| | 3 | 4 | 11.50 | 7.33 | 9.50 | 0 to 23.157 |
| M5 LS | 1 | 4 | 16.50 | 13.82 | 14.00 | 0 to 38.491 |
| | 2 | 4 | 13.75 | 8.54 | 13.00 | 0.162 to 27.338 |
| | 3 | 4 | 11.50 | 7.33 | 11.00 | 0 to 23.157 |
| Heel LS | 1 | 4 | 11.75 | 7.04 | 11.00 | 0.545 to 22.955 |
| | 2 | 4 | 9.50 | 4.36 | 10.50 | 2.564 to 16.436 |
| | 3 | 4 | 11.75 | 5.56 | 13.00 | 2.902 to 20.598 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| Hallux GS | 1 | 3 | 22.33 | 23.11 | 10.00 | 0 to 79.75 |
| | 2 | 3 | 16.66 | 14.22 | 10.00 | 0 to 52.002 |
| | 3 | 3 | 24.00 | 22.71 | 14.00 | 0 to 80.429 |
| M5 GS | 1 | 3 | 10.33 | 2.88 | 12.00 | 3.16 to 17.50 |
| | 2 | 3 | 7.67 | 2.89 | 6.00 | 0.495 to 14.837 |
| | 3 | 3 | 18.3 | 16.28 | 11.00 | 0 to 58.79 |
| Heel GS | 1 | 3 | 7.66 | 2.51 | 8.00 | 1.41 to 13.91 |
| | 2 | 3 | 19.25 | 20.51 | 9.5 | 0 to 51.89 |
| | 3 | 3 | 29.7 | 23.38 | 30.00 | 0 to 66.96 |
| Hallux LS | 1 | 3 | 16.33 | 8.38 | 12.00 | 0 to 37.167 |
| | 2 | 3 | 16.00 | 12.12 | 9.00 | 0 to 46.119 |
| | 3 | 3 | 15.66 | 9.81 | 10.00 | 0 to 40.04 |
| M5 LS | 1 | 3 | 11.33 | 5.13 | 10.00 | 0 to 24.081 |
| | 2 | 3 | 10.33 | 4.93 | 8.0 | 0 to 22.58 |
| | 3 | 3 | 22.66 | 22.81 | 10.00 | 0 to 79.33 |
| Heel LS | 1 | 3 | 16.00 | 9.64 | 12.00 | 0 to 39.956 |
| | 2 | 3 | 23.33 | 23.1 | 10.00 | 0 to 80.702 |
| | 3 | 3 | 24.66 | 22.03 | 14.00 | 0 to 79.39 |

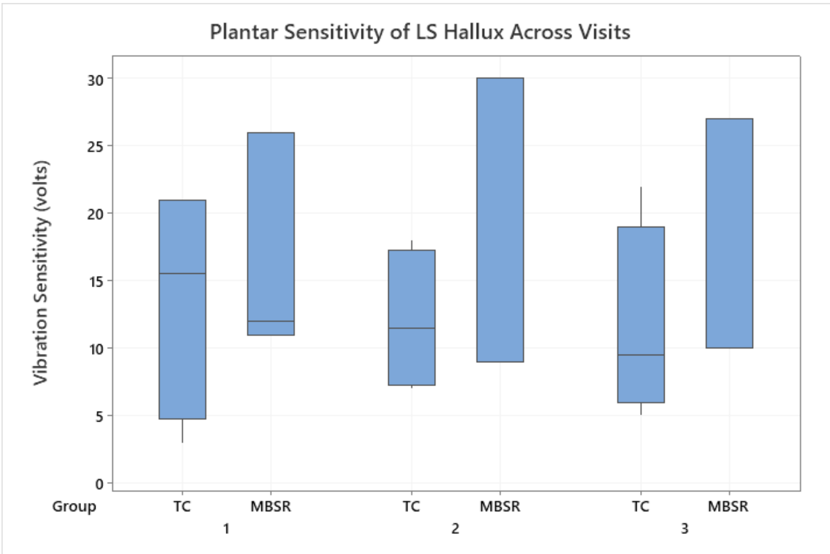
*Note: The foot with 'greater sensitivity' (GS) is the foot which could perceive the smallest amount of vibration at the baseline visit, the 'Less Sensitive foot' (LS) is the foot which needed a larger amount of vibration to be perceived at baseline. Groups: Tai Chi (TC) and Mindfulness Based Stress*

*Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Metatarsal 5 (M5), Standard Deviation (StDev), Confidence Interval (CI). Participant S06 visit 2 data was excluded because of unreliable measures due to edema. Even though the maximum voltage gauged by a Biothesiometer is 50, it is possible to have a 95% CI with a number over 50 as participants may be able to feel vibration at 51 but not at 50.*

Based on the Cohen's d results for the Tai Chi group there were small improvements in hallux, M5, and heel sensitivity for the LS foot after the intervention (able to perceive smaller amounts of vibration). With no change observed for the hallux, M5 or heel of the GS foot after the intervention. After the washout period there was no change for the LS hallux sensitivity, however there were small improvements in LS M5 and heel sensitivity at V3. No change in GS heel sensitivity was observed after the washout period, however there were small improvements in GS hallux and M5 thresholds.

For the MBSR group the Cohen's d results showed a moderate reduction in sensitivity for LS Heel (a higher level of vibration needed to perceive) (d=-0.414), with no changes found for the LS M5 or the LS Hallux after the intervention. A large improvement in GS M5 sensitivity (d=0.922) was found after the intervention, with small to moderate reductions in GS hallux and Heel sensitivity (d=-0.793). After the washout period small to moderate reductions in LS hallux and LS M5 sensitivity (d=-0.747) were observed, with no change to LS heel sensitivity. After the washout period moderate to large reductions in GS M5 sensitivity (d=-0.909) and GS heel sensitivity (d=-0.475) were observed, as well as a small reduction in GS Hallux sensitivity. Based on these data it appears that while the MBSR group did see an improvement in GS M5 plantar vibration sensitivity, this improvement did not carry over to other sites and did not last through the washout period. For the Tai Chi

group there were only negligible to small changes in plantar sensitivity after the intervention and washout periods.



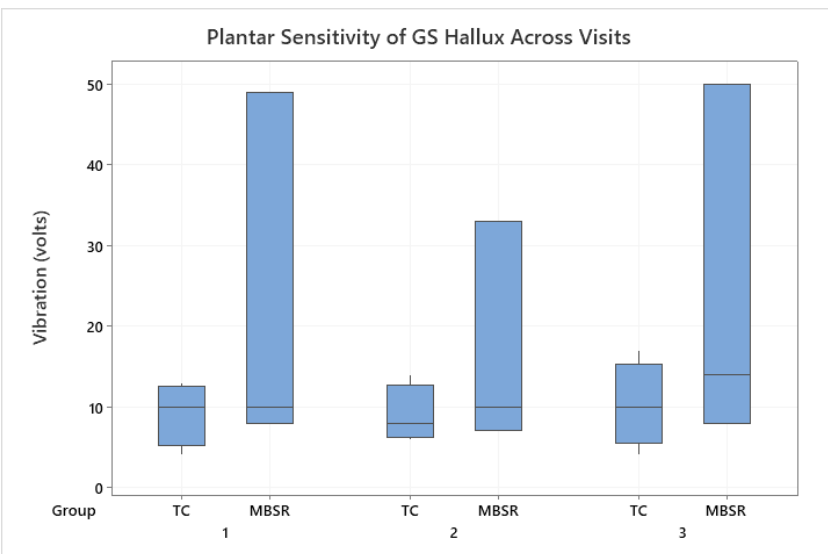
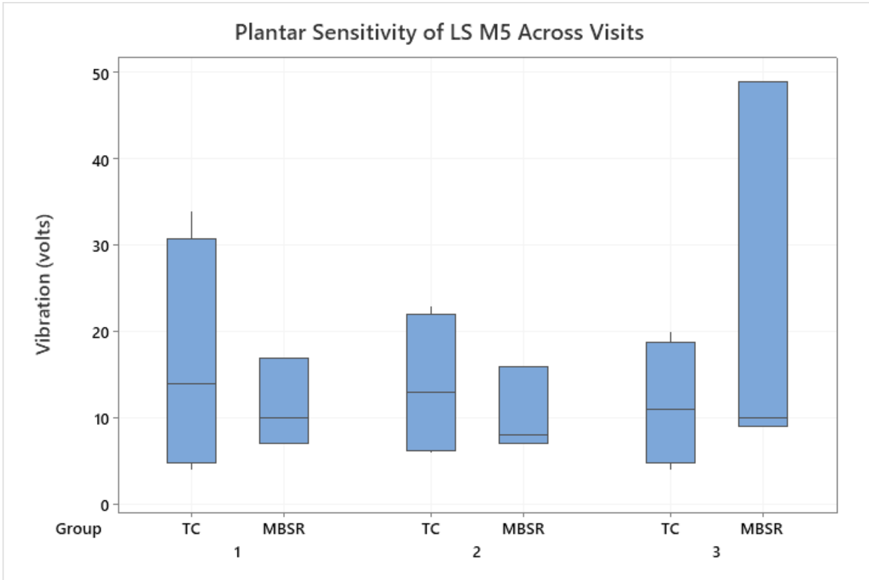




*Figure 48: Hallux Plantar Sensitivity Averages. Smallest perceivable vibration threshold is plotted by group and visit above. Higher scores indicate less sensation (larger vibration needed to feel), lower scores indicate greater sensitivity. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3$^{rd}$ Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*



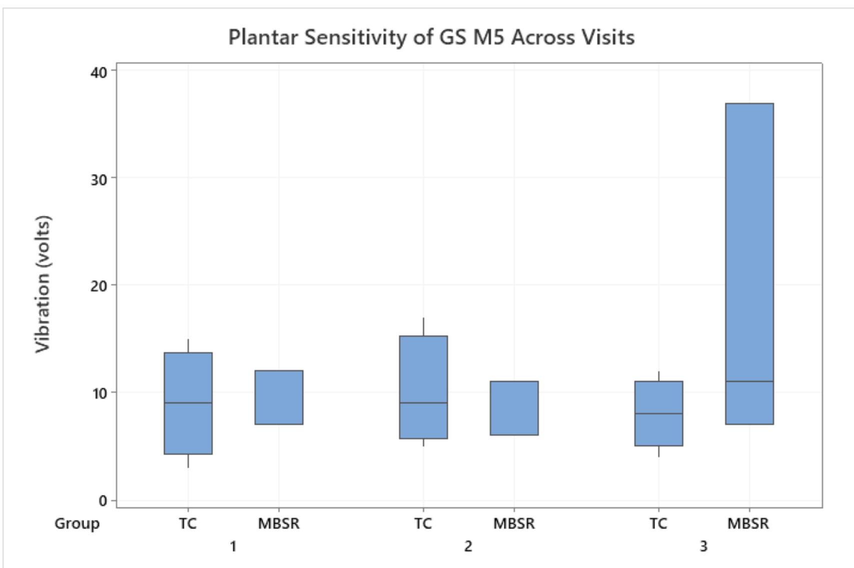
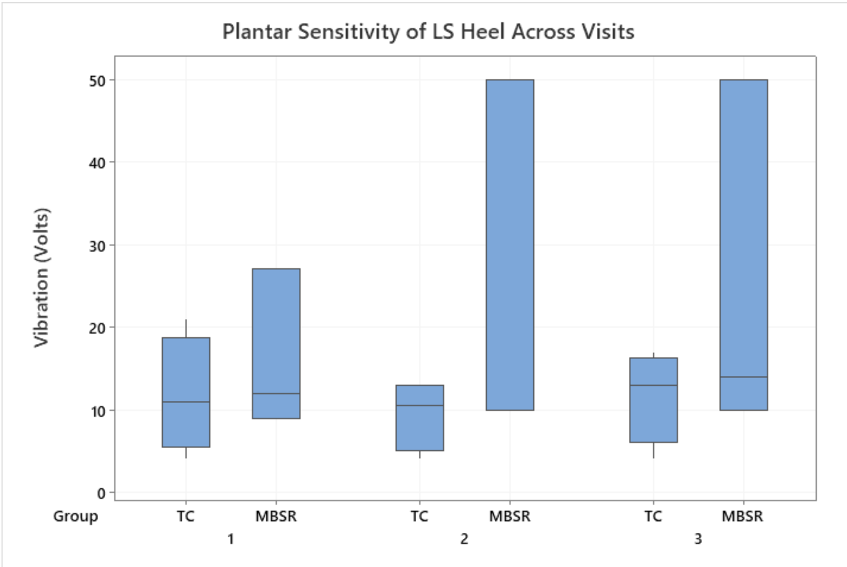




*Figure 49: Fifth Metatarsal Plantar Sensitivity Averages. Smallest perceivable vibration threshold is plotted by group and visit above. Higher scores indicate less sensation (larger vibration needed to feel), lower scores indicate greater sensitivity. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*



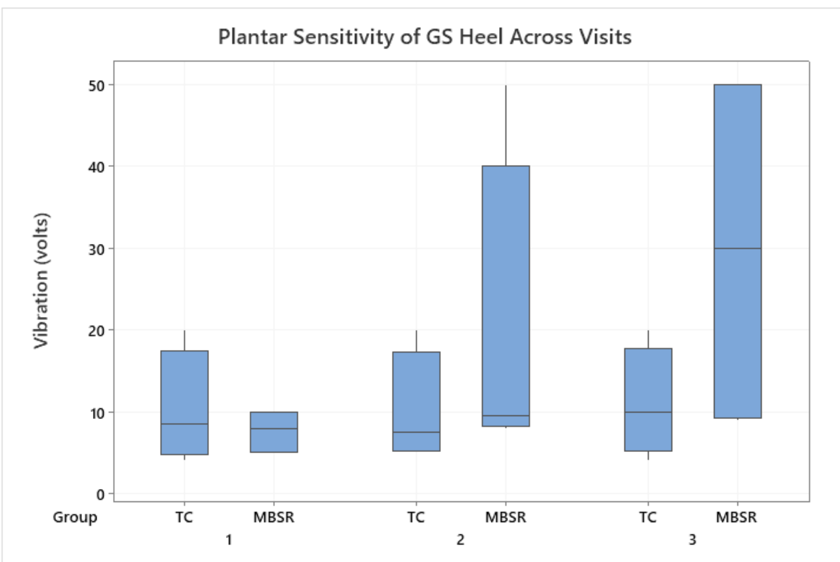




*Figure 50: Heel Plantar Sensitivity Averages*. *Smallest perceivable vibration threshold is lotted by group and visit above. Higher scores indicate less sensation (larger vibration needed to feel), lower scores indicate greater sensitivity. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3$^{rd}$ Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

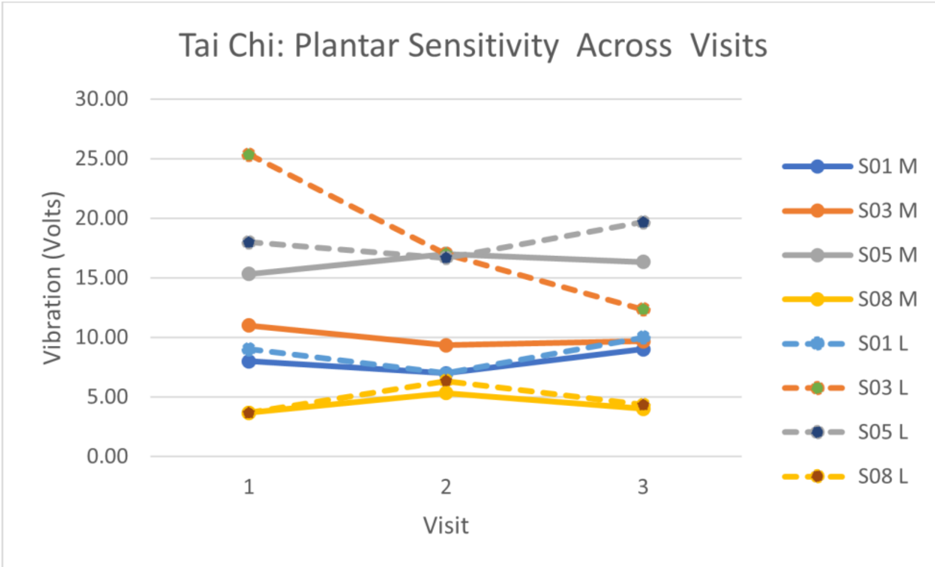
*Table 25: Plantar Sensitivity Effect Sizes Across Visits*

| | Tai Chi | | | | MBSR | | | |
|---|---|---|---|---|---|---|---|---|
| | **Intervention V1 to V2** | | **Washout V2 to V3** | | **Intervention V1 to V2** | | **Washout V2 to V3** | |
| | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** | **Cohen's d** | **Group % Change** |
| **Hallux GS (volts)** | 0.067 | -2.70 | -0.276 | 13.88 | 0.295 | -25.39 | -0.312 | 44.05 |
| **Hallux LS (volts)** | 0.239 | -12.72 | 0.077 | -4.16 | 0.031 | -2.02 | -0.030 | -2.12 |
| **Metatarsal Five GS (volts)** | -0.198 | 11.11 | 0.466 | -20.0 | 0.922 | -25.75 | -0.909 | 138.59 |
| **Metatarsal Five LS (volts)** | 0.239 | -16.66 | 0.282 | -16.36 | 0.198 | -8.82 | -0.747 | 119.36 |
| **Heel GS (volts)** | 0.036 | -2.43 | -0.147 | 10 | -0.793 | 151.30 | -0.475 | 54.28 |
| **Heel LS (volts)** | 0.384 | -19.14 | -0.450 | 23.68 | -0.414 | 45.81 | -0.058 | 5.70 |

*Note: Cohen's d effect sizes are interpreted as: 0-0.2 as no effect; 0.2-0.49 as small, 0.5 to 0.8 as moderate, and 0.8 and above as a large effect. Positive effect sizes are indicative of improved sensitivity perception, whereas negative effect sizes show a loss of sensitivity. Negative group % change is indicative of an improvement in plantar sensitivity, while positive group % change is indicative of a decline. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Foot with greater sensitivity (GS), Less Sensitive foot (LS), Metatarsal five (M5).*

When evaluating individual participant trends using percent change it became clear that the intervention seemed to improve some participants' plantar sensitivity but not others. Interestingly it appears that four of the participants (S01, S02, S03, S04), who were split evenly between the two groups, had improvements in plantar sensitivity compared to the final three participants (S06, S08, S09). Participant S08 had a decrease in the sensitivity of both feet after the intervention (which may be as they already had very sensitive values at baseline and were potentially moving around their normal value range), while participants

S06 (outlier) and S09 both had improved sensitivity on the less sensitive foot at baseline and declined on the foot with greater sensation. No real benefits were retained after the washout period with the individual trends being scattered by group and foot. With S03 and S08 having improved sensitivity, S09 and S06 having split sensitivity (one foot improves one declines), S02 and S04 maintained about the same values from V2 to V3, and S01 had worsened sensitivity. Refer to Table 26 below to view this pattern.



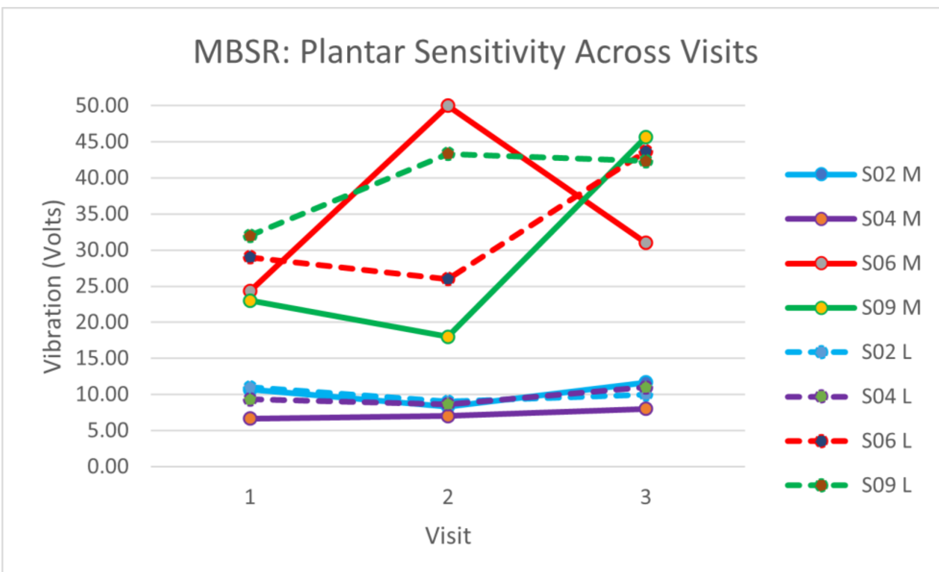




*Figure 51: Plantar Sensitivity Individual Trends Across Visits. Individual trends are plotted with all three foot sites averaged for each visit. Higher scores indicate less sensation (larger vibration needed to feel), lower scores indicate greater sensitivity. The maximum vibration voltage is 50 volts. The solid lines indicate the 'more sensitive' foot at baseline, while the dashed lines indicate the 'less sensitive' foot at baseline. While S06 was removed from the above data as an outlier, here they are included in the graph to see the change in sensitivity across visits. Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

*Table 26: Plantar Sensitivity Percent Change Visual Summary*

| | **Percent Change V1 to V2: Intervention** | | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Hallux** | | **M5** | | **Heel** | |
| **PT** | **Group** | **GS** | **LS** | **GS** | **LS** | **GS** | **LS** |
| **S01** | **Tai Chi** | | | | | | |
| **S02** | **MBSR** | | | | | | |
| **S03** | **Tai Chi** | | | | | | |
| **S04** | **MBSR** | | | | | | |
| **S05** | **Tai Chi** | | | | | | |
| **S06** | **MBSR** | | | | | | |
| **S08** | **Tai Chi** | | | | | | |
| **S09** | **MBSR** | | | | | | |
| | **Percent Change V2 to V3: Washout** | | | | | | |
| | | **Hallux** | | **M5** | | **Heel** | |
| **PT** | **Group** | **GS** | **LS** | **GS** | **LS** | **GS** | **LS** |
| **S01** | **Tai Chi** | | | | | | |
| **S02** | **MBSR** | | | | | | |
| **S03** | **Tai Chi** | | | | | | |
| **S04** | **MBSR** | | | | | | |
| **S05** | **Tai Chi** | | | | | | |
| **S06** | **MBSR** | | | | | | |
| **S08** | **Tai Chi** | | | | | | |
| **S09** | **MBSR** | | | | | | |

*Note: Plantar Sensitivity Individual Percent Change data is shown above. Green boxes indicate improved plantar sensitivity (able to feel lower values), yellow boxes indicate no change in sensation, and red boxes indicate worsened plantar sensitivity values (higher vibration needed to perceive). Abbreviations: Greater Sensitivity at baseline (GS), and Lesser sensitivity at baseline (LS), Metatarsal Five (M5).*

The individual percent change trends show an interesting effect where possibly some participants had a greater improvement in sensitivity then others, regardless of the intervention group. It is unknown whether these differences in participants sensitivity improvements were based on lesion location, or other factors. Based on the above data it appears that while the MBSR group did have an improvement in Hallux and M5 sensitivity

of the foot with greater sensitivity after the intervention, these plantar sensitivity benefits were not retained through the washout period.

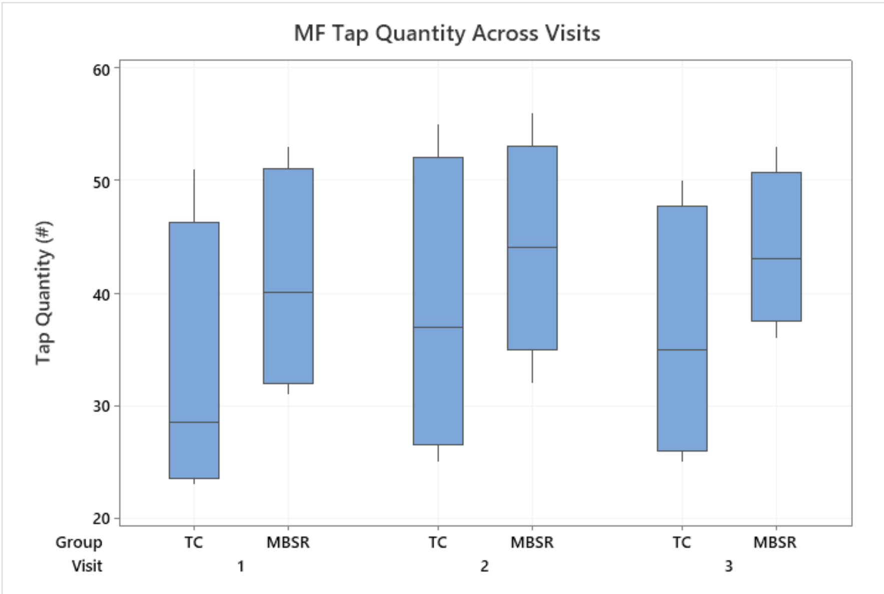
Foot Tapping Results:

Motor function was assessed with the following foot tapping measures: tap quantity, the inter-tap interval time in milliseconds, and the tap coefficient of variance which is a measure of relative variability (which is the ratio of the tap standard deviation to the mean). For these analyses the foot tapping data has been organized into ‘more’ versus ‘less’ function legs based on foot tapping quantity at the baseline visit. The leg with ‘more function’ (MF) is the one that could produce the most foot taps at baseline, and the leg with ‘less function’ (LF) was the leg with fewer taps. By arranging the data in this manner it clarifies leg asymmetry, common to MS, which is not as clear when sorted ‘right versus left’ alone. For foot tapping descriptive statistics refer to Table 27, while Cohen’s d effect sizes and group percent change are presented in Table 28. Refer to Figures 52-54 for boxplots of average foot tapping characteristics by group across visits, and Figures 55 and 56 for line graphs showing individual trends of foot tapping changes. Cohen’s d effects sizes are interpreted as: positive effect sizes for inter-tap interval and the tap coefficient of variance indicate an improvement in function, while negative effect sizes indicate a worsening of function. In contrast, a negative effect size for tap quantity is indicative of increased tap quantity with an improvement in function, with positive effect size a decline. The group percent change values are interpreted in the opposite direction as the Cohen’s d effect size.

*Table 27: Foot Tapping Descriptive Statistics. Mean, Coefficient of Variance, Median, and 95% Confidence Interval for mean data are presented.*

| **Tai Chi Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
|---|---|---|---|---|---|---|
| Tap Quantity MF | 1 | 4 | 32.75 | 12.76 | 28.50 | 12.44 to 53.06 |
| | 2 | 4 | 38.50 | 13.30 | 37.00 | 17.33 to 59.67 |
| | 3 | 4 | 36.25 | 11.41 | 35.00 | 18.09 to 54.41 |
| Tap Quantity LF | 1 | 4 | 32.50 | 11.21 | 28.50 | 14.66 to 50.33 |
| | 2 | 4 | 37.50 | 12.48 | 37.00 | 17.64 to 57.35 |
| | 3 | 4 | 37.25 | 11.56 | 36.50 | 18.85 to 55.64 |
| Inter Tap Interval MF (ms) | 1 | 4 | 298.5 | 100.7 | 289.5 | 138.30 to 458.66 |
| | 2 | 4 | 239.6 | 59.2 | 228.5 | 145.32 to 333.81 |
| | 3 | 4 | 252.7 | 63.1 | 233.5 | 152.34 to 353.14 |
| Inter Tap Interval LF (ms) | 1 | 4 | 285.1 | 67.7 | 294.9 | 177.45 to 392.78 |
| | 2 | 4 | 251.7 | 64.9 | 238.5 | 148.35 to 355.02 |
| | 3 | 4 | 247.6 | 50.1 | 242.0 | 167.83 to 327.34 |
| Tap CoefV MF | 1 | 4 | 28.76 | 14.50 | 29.23 | 5.68 to 51.83 |
| | 2 | 4 | 17.62 | 3.79 | 18.84 | 11.58 to 23.66 |
| | 3 | 4 | 19.48 | 6.20 | 20.26 | 9.61 to 29.35 |
| Tap CoefV LF | 1 | 4 | 34.21 | 16.33 | 29.20 | 8.22 to 60.20 |
| | 2 | 4 | 22.75 | 5.78 | 25.03 | 13.54 to 31.95 |
| | 3 | 4 | 19.90 | 2.22 | 19.93 | 16.36 to 23.44 |
| **MBSR Group** | **Visit** | **N** | **Mean** | **StDev** | **Median** | **95% CI** |
| Tap Quantity MF | 1 | 4 | 41.00 | 9.93 | 40.00 | 25.19 to 56.80 |
| | 2 | 4 | 44.00 | 9.80 | 44.00 | 28.40 to 59.59 |
| | 3 | 4 | 43.75 | 7.04 | 43.00 | 32.54 to 54.95 |
| Tap Quantity LF | 1 | 4 | 35.75 | 11.21 | 32.00 | 17.91 to 53.58 |
| | 2 | 4 | 35.25 | 12.37 | 34.00 | 15.57 to 54.92 |
| | 3 | 4 | 38.00 | 10.65 | 38.00 | 21.06 to 54.94 |
| Inter Tap Interval MF (ms) | 1 | 4 | 275.6 | 87.7 | 271.9 | 135.95 to 415.20 |
| | 2 | 4 | 275.2 | 97.4 | 262.6 | 120.27 to 430.14 |
| | 3 | 4 | 272.5 | 88.6 | 255.4 | 131.51 to 413.57 |
| Inter Tap Interval LF (ms) | 1 | 4 | 318.8 | 91.8 | 338.6 | 172.71 to 464.83 |
| | 2 | 4 | 340.7 | 109.8 | 360.1 | 165.91 to 515.49 |
| | 3 | 4 | 313.0 | 97.5 | 332.6 | 157.88 to 468.10 |
| Tap CoefV MF (%) | 1 | 4 | 14.86 | 5.03 | 15.52 | 6.85 to 22.87 |
| | 2 | 4 | 15.36 | 10.91 | 13.64 | -2.00 to 32.73 |
| | 3 | 4 | 17.24 | 5.41 | 16.08 | 8.63 to 25.85 |
| Tap CoefV LF (%) | 1 | 4 | 18.02 | 18.80 | 11.25 | -11.88 to 47.92 |
| | 2 | 4 | 15.10 | 8.31 | 12.95 | 1.88 to 28.31 |
| | 3 | 4 | 15.30 | 8.27 | 17.64 | 2.13 to 28.45 |

*Note: Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and coefficient of variance. Data have been organized into 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Abbreviations: Coefficient of Variance (CoefV), Confidence Interval (CI).*



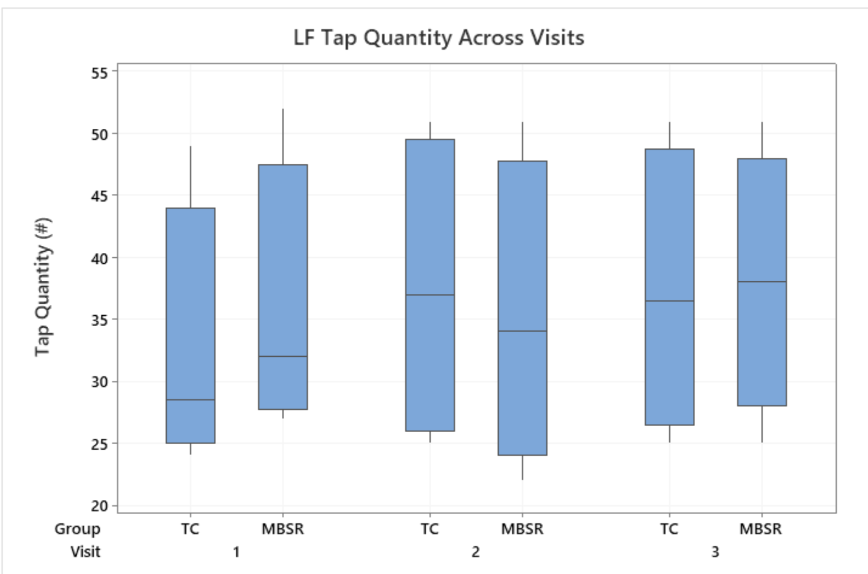
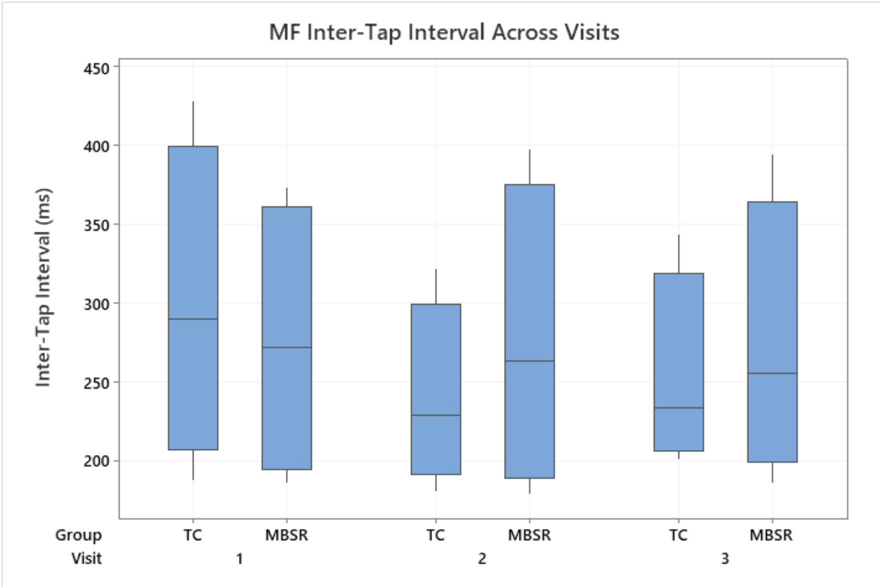




*Figure 52: Foot Tapping Quantity Across Visits. Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Data have been organized into 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*



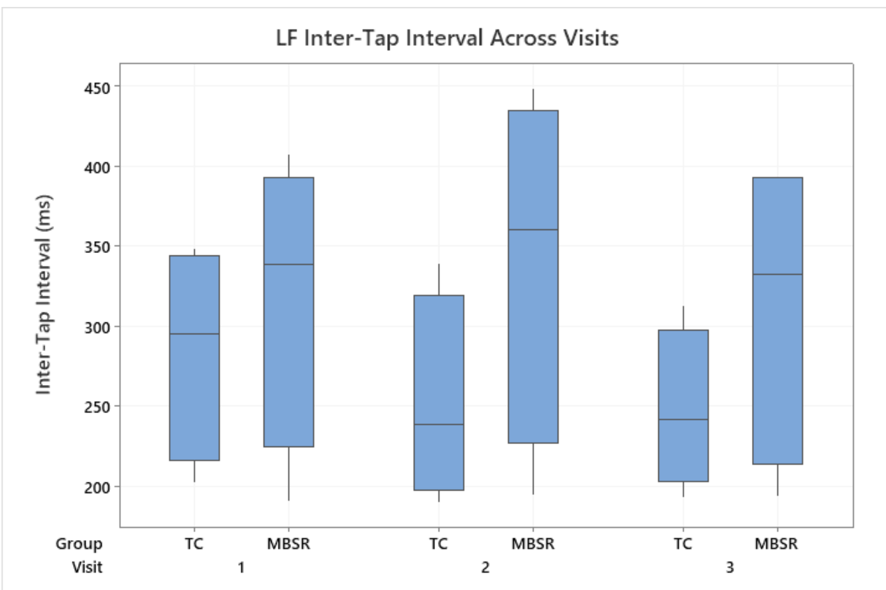
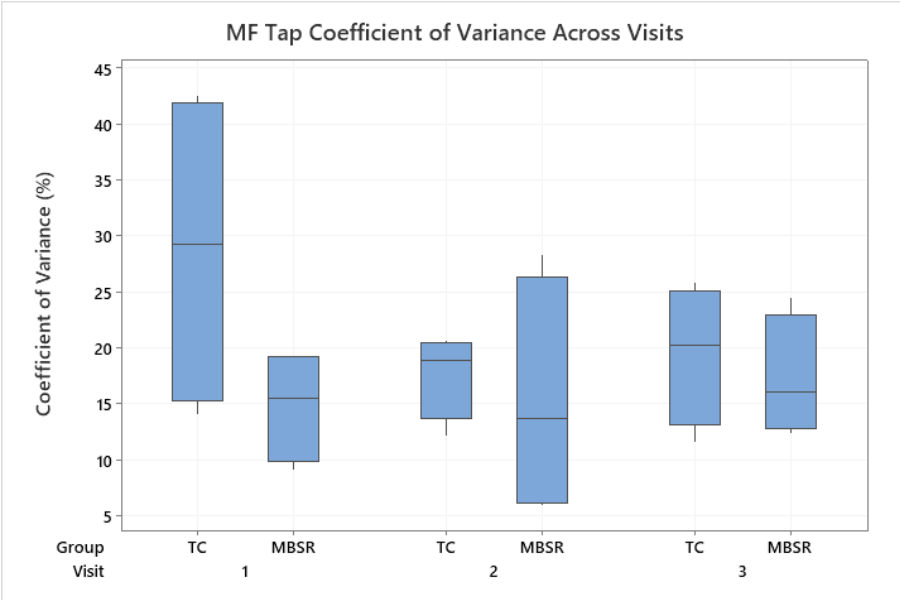




*Figure 53: Foot Tapping Inter-tap Interval Across Visits*. *Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Data have been organized into 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3$^{rd}$ Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*



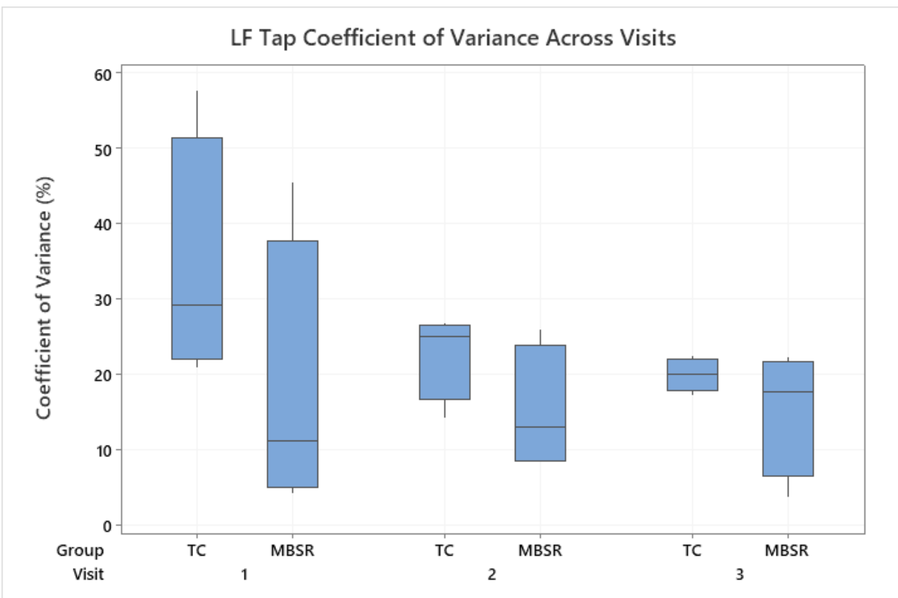




*Figure 54: Foot Tapping Coefficient of Variance Across Visits. Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Data have been organized into 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3$^{rd}$ interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

After the intervention the Tai Chi group had small increases in tap quantity for both feet, moderate to large reductions in inter-tap interval (MF, d=0.713; LF, d=0.503), and large reductions in the tap coefficient of variance for both feet (MF, d=1.05; LF, d=0.935). It appears that the intervention was beneficial for the Tai Chi group with the small improvements in tap quantity, shorter intervals between taps, and reduced coefficient of variance of tap production indicative of improved motor function. After the washout period there was no change for tap quantity, and negligible (LF) to small (MF) increases in inter-tap interval, with a small increase in MF tap coefficient of variance (d=-0.361) and moderate reduction in LF tap coefficient of variance (d=0.650). It appears the small benefits attained from the intervention were retained after the washout period.

After the intervention the MBSR group had negligible (LF) to small (MF) increases in tap quantity, negligible (MF) to small reductions (LF) in inter-tap interval, and negligible (MF) to small reductions (LF) in the tap coefficient of variance. After the washout period there was negligible (MF) to small (LF) increases in tap quantity, negligible (MF) to small (LF) reductions in inter-tap interval, and negligible (MF) to small (LF) reductions in the coefficient of variance. Based on this data it appears the MBSR group motor function was not impacted by the intervention or the washout periods.

*Table 28: Foot Tapping Effect Sizes Across Visits*

| | Tai Chi | | | | MBSR | | | |
|---|---|---|---|---|---|---|---|---|
| | Intervention V1 to V2 | | Washout V2 to V3 | | Intervention V1 to V2 | | Washout V2 to V3 | |
| | Cohen's d | Group % Change | Cohen's d | Group % Change | Cohen's d | Group % Change | Cohen's d | Group % Change |
| **Tap Quantity MF (#)*** | -0.441 | 17.55 | 0.181 | -5.84 | -0.304 | 7.31 | 0.029 | -0.56 |
| **Tap Quantity LF (#) *** | -0.421 | 15.38 | 0.020 | -0.666 | 0.042 | -1.39 | -0.238 | 7.80 |
| **Inter Tap Interval MF (ms) $^{\alpha}$** | 0.713 | -19.73 | -0.214 | 5.46 | 0.004 | -0.145 | 0.028 | -0.981 |
| **Inter Tap Interval LF (ms) $^{\alpha}$** | 0.503 | -11.71 | 0.070 | -1.62 | -0.216 | 6.86 | 0.266 | -8.13 |
| **Tap CoefV MF (%)$^{\alpha}$** | 1.05 | -38.73 | -0.361 | 10.55 | -0.058 | 3.36 | -0.218 | 12.23 |
| **Tap CoefV LF (%)$^{\alpha}$** | 0.935 | -33.49 | 0.650 | -12.52 | 0.200 | -16.20 | -0.024 | 1.32 |

*Notes: Cohen's d effect sizes are interpreted as: 0-0.2 as no effect; 0.2-0.49 as small, 0.5 to 0.8 as moderate, and 0.8 and above as a large effect. Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and coefficient of variance. Tapping measures with an asterisk (*) denote when a negative effect size is indicative of motor function improvements, and positive effect sizes indicate a decline in motor function. Tapping measures with an alpha ($\alpha$) denote when a positive effect size is indicative of motor function improvements, with negative effect sizes indicating a decline in motor function. Improvements in group % change are indicated if the sign is opposite the Cohen's d sign, this will depend on the specific tapping measures whether an improvement in tap characteristics are listed as a positive or negative Cohen's d. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period. Abbreviations: Coefficient of Variation (CoefV).*

After the intervention MF tap quantity had increased for 5 participants (2 TC, 3 MBSR), decreased for 2 participants (1 TC, 1 MBSR), and stayed the same for 1 TC. For the LF tap quantity 5 participants increased (4 TC, 1 MBSR), 2 decreased (2 MBSR), and 1 MBSR participant stayed the same. After the washout period MF tap quantity increased for 1 MBSR, decreased for 5 participants (3 TC, 2 MBSR), and stayed the same for 2 participants

(1 TC, 1 MBSR). This differed from LF tap quantity where 4 participants increased (1 TC, 3 MBSR), 1 TC decreased, and 2 participants (TC) stayed the same (Table 29).

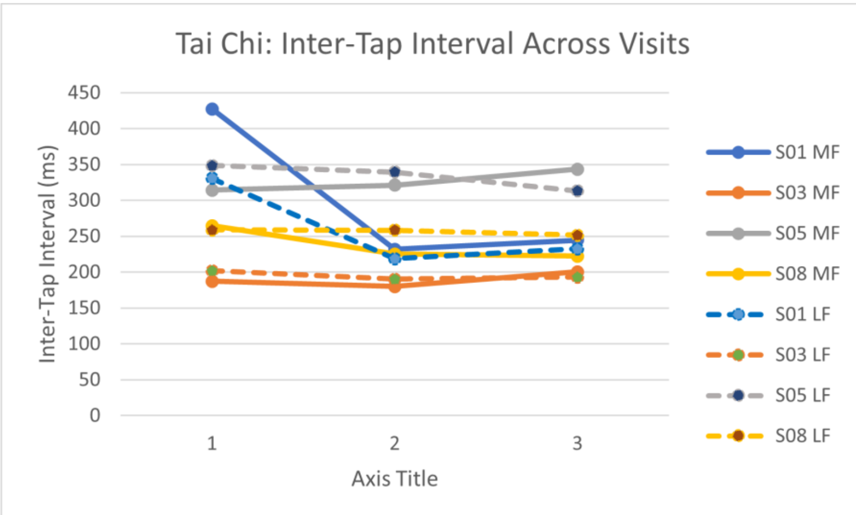
*Table 29: Foot Tapping Percent Change Visual Summary*

| | Foot Tapping Percent Change after the Intervention | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Tap Count | | Inter-Tap Interval | | Coefficient Variation | |
| PT | Group | MF | LF | MF | LF | MF | LF |
| S01 | TC | | | | | | |
| S02 | MBSR | | | | | | |
| S03 | TC | | | | | | |
| S04 | MBSR | | | | | | |
| S05 | TC | | | | | | |
| S06 | MBSR | | | | | | |
| S08 | TC | | | | | | |
| S09 | MBSR | | | | | | |
| | | | | | | | |
| | Foot Tapping Percent Change after the Washout | | | | | | |
| | | Tap Count | | Inter-Tap Interval | | Coefficient Variation | |
| PT | Group | MF | LF | MF | LF | MF | LF |
| S01 | TC | | | | | | |
| S02 | MBSR | | | | | | |
| S03 | TC | | | | | | |
| S04 | MBSR | | | | | | |
| S05 | TC | | | | | | |
| S06 | MBSR | | | | | | |
| S08 | TC | | | | | | |
| S09 | MBSR | | | | | | |

*Note-Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Percent change direction is indicated by the color coding. Green boxes indicate improvements (increased tap quantity, reduced inter-tap interval, and reduced coefficient of variation), yellow boxes show no change, and red boxes indicate (decreased tap quantity, increased inter-tap interval, and increased coefficient of variation).*

After the intervention MF inter-tap interval decreased for 5 participants (3 TC, 2 MBSR), increased for 2 participants (1 TC, 1 MBSR), and stayed the same for 1 MBSR. For LF inter-tap interval 4 participants decreased (3 TC, 1 MBSR), 2 MBSR increased, and 2 participants stayed the same (1TC, 1 MBSR). After the washout period MF inter-tap interval decreased for 3 participants (1 TC, 2 MBSR), and increased for 5 participants (3 TC, 2

MBSR). This differed from LF inter-tap interval where 4 participants decreased (2 TC, 2 MBSR), 2 TC increased, and 2 MBSR stayed the same.



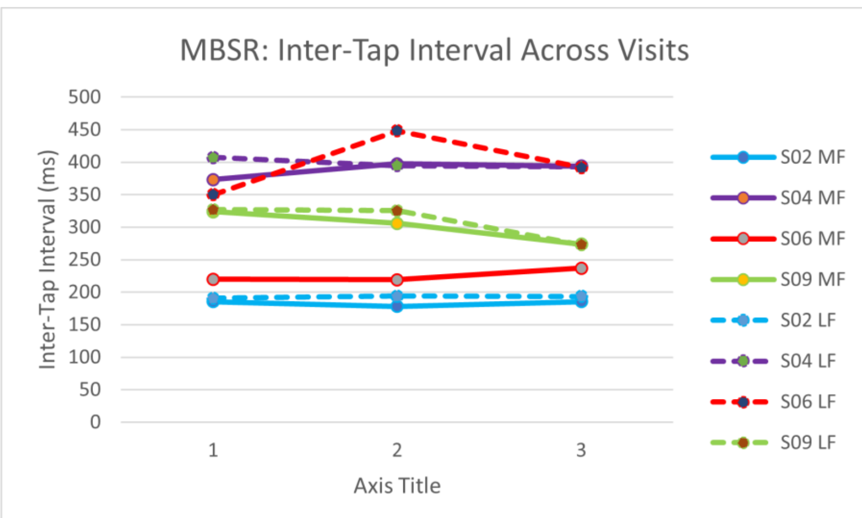
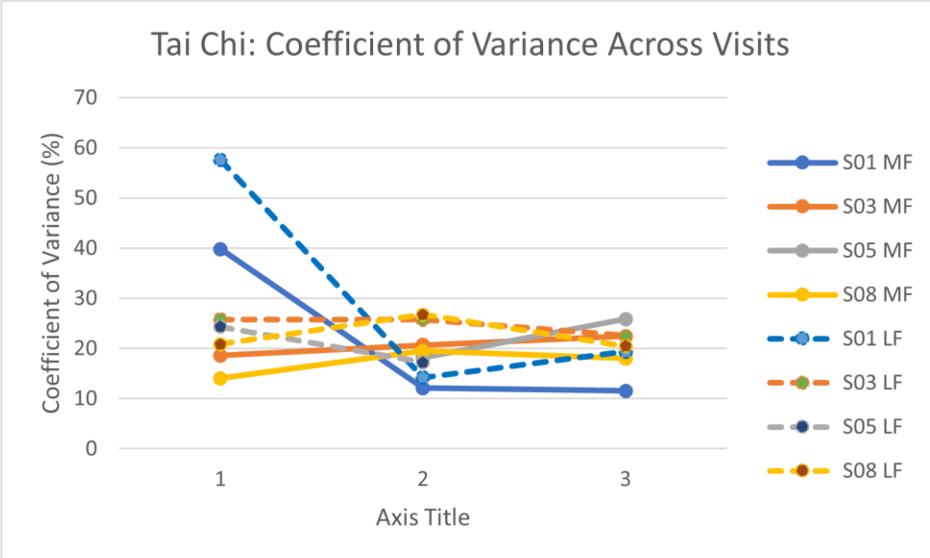




*Figure 55: Inter-tap Interval Individual Trends Across Visits. Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Data have been organized into 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3rd Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*



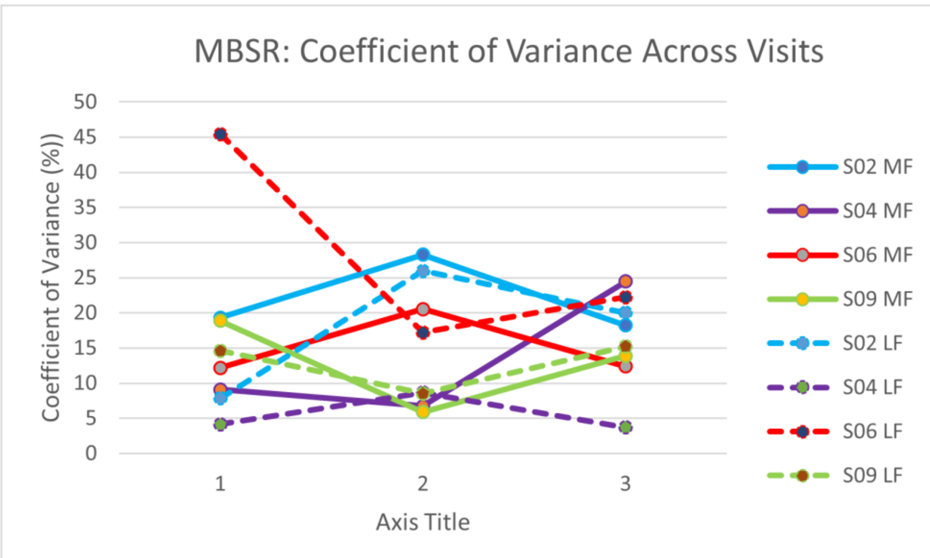




*Figure 56: Coefficient of Variance Individual Trends Across Visits. Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Data have been organized into 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Medians are designated by a horizontal line, with the top and bottom whiskers (vertical lines) designating the 1st and 3$^{rd}$ Interquartiles. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week washout period.*

After the intervention MF tap coefficient of variation decreased for 3 participants (1 TC, 2 MBSR), and increased for 4 participants (2 TC, 2 MBSR). For LF tap coefficient of variation 3 participants decreased (1 TC, 2 MBSR), and 3 participants increased (1 TC, 2 MBSR). After the washout period MF tap coefficient of variance decreased for 4 participants (2 TC, 2 MBSR), and increased for 4 participants (2 TC, 2 MBSR). This differed from LF coefficient of variation where 5 participants decreased (3 TC, 2 MBSR), and 3 participants increased (1 TC, 2 MBSR).

# CHAPTER 5- DISCUSSION

## 5.1 Summary

**The purpose of this study** was to determine which 8-week intervention (Tai Chi or Mindfulness Based Stress Reduction, MBSR) would have a greater effect on physical balance, psychosocial wellbeing and sensorimotor function in people with MS, and whether benefits were retained after a 2-week washout period. Due to the Covid-19 pandemic the data set will include a total of eight participants (7 female, 1 male) who completed the full 8-weeks of community-based Tai Chi or MBSR classes, and the washout period. Because of the small sample sizes we did not perform direct tests of group differences in response to the intervention, but compared the groups based on their individual effect sizes and percent change observed due to the intervention and washout compared to baseline.

## 5.2 Physical Balance Measures

**Specific aim #1, (1.1) predicted that the Tai Chi group would have greater improvements in physical balance than the MBSR group, and that (1.2) balance improvements in Tai Chi would be retained to a greater degree.** Hypothesis 1.1 and 1.2 were both not supported, because the MBSR group appeared to improve physical balance to a greater extent than the Tai Chi group and had greater retention or continued improvements after the washout period. Following the intervention period the MBSR group improved quiet stance, narrow stance, forwards reach with a moderate reduction in STS times, whereas the Tai Chi improved forwards reach and backwards lean parameters with a small reduction in STS times and a small increase in TUG times. Even though the two groups differed for

baseline 25ft walk trial time neither intervention impacted the walking parameters. After the washout period the MBSR group had continued reductions in their narrow stance ellipse sway, quiet stance and narrow stance mean sway velocity, a further small reduction in STS times, with no change in forwards reach ellipse sway or TUG times (benefits retained). While the Tai Chi group had an increased quiet stance ellipse sway and mean sway velocity, an increased mean sway velocity for both forwards reach and backwards lean trials (negligible to small changes in ellipse sway), a small increase in TUG times, with STS times unchanged after the washout.

### 5.2.1 Static Balance Measures V1 to V2

Both groups reported improvements due to the intervention in 95% ellipse sway and mean sway velocity characteristics, however the specific trials impacted differed. The MBSR group had improvements in quiet stance, narrow stance and the forward reach trials, whereas the Tai Chi group had improvements in forwards reach and backwards lean trials. Refer to Table 30 for a visual summary of the effect size results for the postural trials, including small to large directional effects. What could have caused this difference? The differences began in quiet stance and narrow stance where the MBSR group had reduced 95% ellipse sway and mean sway velocity following the intervention whereas the Tai Chi group were unchanged. The moderate improvement in quiet stance characteristics was primarily driven by two participants, S06 who had a great improvement in in sway characteristics from V1 to V2, and S04 who had a smaller improvement from V1 to V2. While the individual trends are split, this still may indicate that the mindfulness training was applicable enough to beneficially

impact the postural characteristics of an everyday posture such as quiet stance and narrow stance with its reduced area of support for some people with MS, and that the Tai Chi intervention was less applicable to these basic postural trials. An alternate explanation would be that the baseline quiet stance values of the Tai Chi group were 63% lower for ellipse sway and 66% lower for mean sway velocity than the MBSR group, suggesting that there was potentially less room for improvement for quiet stance and narrow stance trials.

How did the two groups compare to the known literature on quiet stance postural characteristics? For quiet stance the two groups had similar 95% ellipse sway to what has been reported within both MS and healthy control populations. The baseline 95% ellipse sway quiet stance values were 170±146mm$^2$ for the Tai Chi group and 465.9±376.4mm$^2$ for the MBSR group, which fit into the normal range of those reported during quiet standing in other MS populations, including 187.1±376.4mm$^2$ in Kalron and Achiron (2013); 309±116.3mm$^2$ in Kalron et al. (2017); and 1333±738.5mm$^2$ in Brincks et al. (2017). These values are also similar to those reported in healthy control populations with 95% ellipse sway values of (median) 438.8±236.7mm$^2$ in Baltich et al. (2015), and (mean) 735±518.3mm$^2$ in Brincks et al. (2017). Based on this information it appears that the Tai Chi group did have reduced sway at baseline which may indicate that the Tai Chi group may have already been more stable and had less room for postural improvements in quiet stance and narrow stance after the intervention.

Both groups improved forwards reach 95% ellipse sway and mean sway velocity, but for backwards reach group differences emerged again. The Tai Chi participants reported a large reduction in backwards lean mean sway velocity after the intervention with 95% ellipse

sway unchanged, suggesting that after the intervention they had greater stability in this challenging position. Whereas the MBSR group backwards lean postural characteristics were negligible to small, one interesting note is in the individual trends all 4 MBSR participants increased their measured forwards reach backwards lean distances whereas only 1 Tai Chi participant increased their measured reach and lean distances. That the Tai Chi group did not increase reach and lean distance is unexpected, but not unexplainable. Chan et al. (2003) reported that when evaluating the kinematics and electromyography of a Tai Chi master completing forward and backward body shifts, the Tai Chi master adjusted their CoM by increasing or decreasing the joint angles of the bilateral lower limbs rather than by adopting a forward or backward postural lean. Therefore the shorter reach and lean distances accompanied by the improvements in forwards reach and backwards lean postural characteristics in the Tai Chi group are likely due to the practice of staying grounded while reaching and leaning. When evaluating the bigger picture of the postural trials together, it appears that the MBSR program was effective at training participants to attend to quiet stance, narrow stance and were at the limits of improvement in the forwards reach trials, possibly due to having more baseline postural sway. The combination of the Tai Chi group having specialized training in transitioning between postures while staying grounded and starting out with less sway may explain the greater impact of training on forwards reach and the more challenging backwards lean postures.

*Table 30: Static Balance Effect Size Summary Table*

| | Static Postural Variables Effect Size by Time Period | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | QS | | NS | | FR | | BL | |
| Group | Interval | 95% CI | Mean Velocity | 95% CI | Mean Velocity | 95% CI | Mean Velocity | 95% CI | Mean Velocity |
| TC | Intervention | | | | | | | | |
| MBSR | Intervention | | | | | | | | |
| TC | Washout | | | | | | | | |
| MBSR | Washout | | | | | | | | |

*Note-These data are a visual interpretation of the Cohen's D effect sizes for the physical balance trials. Green boxes indicate moderate to large improvements (improved balance measures of reduced 95% ellipse sway and sway velocity), yellow boxes show negligible to small improvements, and red boxes indicate small, moderate, and large declines in postural measures (worsened balance measures with increased 95% ellipse sway and mean velocity).*

Having a reduced ellipse sway area and slower mean sway velocities would mean that the participants were better able to maintain their CoM within the area bounded by their feet and be at less risk of falling. A few MS intervention studies have reported that reductions in ellipse sway area and mean sway velocities or longer time to contact (the boundaries of support) values indicate greater postural stability in static tasks (Averill et al., 2013; Kalron et al., 2016; Prosperini et al., 2013), with the bulk of postural literature linking increased postural sway and mean sway velocity to greater fall risk (Daley et al., 1981; Finlayson et al., 2006). Similar to the MBSR narrow stance findings in this study, improvements in tandem stance (heel to toe) postural stability were found for Averill (2013) where the MS participants had longer time to contact with decreased mean sway velocity values after a 3-week Tai Chi intervention. Improvements in the postural characteristics of narrow stance and tandem stance are significant, because with narrower stances the amount of time and space for postural adjustments to be made decreases (Saunders et al., 1953).

The reductions in ellipse sway and mean sway velocity noted for the MBSR and Tai Chi groups after the intervention could have been due to participants moving through the stages of motor 'relearning' in the case of these standing trials. Bernstein (1967) lists three stages of motor learning; the first stage is a freezing of the number of degrees of freedom to a minimum; second is the gradual releasing of frozen degrees of freedom allowing more to be utilized in the movement; and third is when an individual can utilize and exploit all degrees of freedom that arise in movement control. After the intervention the groups were likely in the second stage of motor learning, where the gradual releasing of degrees of freedom led to a more coordinated system and the postural improvements occurring with the reduced 95% ellipse sway and mean sway velocities. For the MBSR group, exhibiting greater sway at baseline, there may have been more room for improvement, and the mindfulness practices such as attention to body orientation, breath, and relaxation may have led to improved stability and awareness for quiet stance, narrow stance, and forwards reach. For the Tai Chi group the intervention itself would have led to instruction on how to remain grounded while transitioning between different postures, and how to remain relaxed and breathe into the more complex tasks of forwards reach and backwards lean. Even though the postures of narrow stance, forwards reach and backwards lean were not practiced by participants during the intervention period, the second stage of motor learning and the unfreezing of degrees of freedom would explain the improvements that were observed.

5.2.2 Dynamic Balance Measures V1 to V2

STS Trials

The Cohen's D effect sizes showed that the MBSR group had a moderate reduction in STS times and the Tai Chi group a small reduction, with the individual trends showing that 7 of the 8 participants had faster STS after the intervention (3 TC, 4 MBSR; with 1 TC unchanged). There was no difference between the two groups at baseline for STS, with times for the Tai Chi group: 12.12±5.07s and the MBSR group 16.56±8.79s. After the intervention both groups had a reduction in STS times Tai Chi (10.21±2.4s; MBSR 11.85±6.4)s, but how do these results compare to other MS participants and controls? Scalzitti et al. (2018) reported a mean STS time for their MS participants of 16.1±5.9s, while Whitney et al. (2005) reported sit to stand times for younger controls of 8.2±1.7s, for younger subjects with balance dysfunction 15.3±7.6s, for older control subjects 22.2±1.7s, and for older subjects with balance dysfunction a timing of 15.8±5.1s. At baseline both groups had similar STS times as adults with balance dysfunction, however both groups improved after the intervention, with the Tai Chi group performing with STS times closer to those of healthy young adults. Refer to Table 31 for a visual summary of dynamic postural variables effect size by time period, including small to large directional effects. Faster STS times may be indicative of greater lower limb strength (Bowser et al., 2015) or increased coordination of movement and attentional focus (Clark et al., 2015); these improvements in STS times have been reported in other MS intervention studies as well including resistance training (Aidar et al., 2017) and a 'start to run' program (Feys et al., 2019). The moderate STS improvements

in the MBSR group may have resulted from the enhanced body awareness and increased ability to coordinate attention and movement practiced in the MBSR class. Clark et al. (2015) suggested that mindful movement practices may create conditions in which the coordination of goals, attention, and specific movements can occur by inhibiting unwanted actions and reducing mind wandering. While both groups improved their STS times, the larger improvements seen within the MBSR group were likely due to the greater range of improvement available. The interventions (Tai Chi and MBSR) then added the extra stimulus needed to improve balance and awareness.

*Table 31: Dynamic Postural Variables Effect Size Summary Table*

| Dynamic Postural Variables Effect Size by Time Period | | | | |
|---|---|---|---|---|
| | | TUG | STS | 25FT Walk |
| Group | Interval | Time | Time | Time |
| TC | Intervention | | | |
| MBSR | Intervention | | | |
| TC | Washout | | | |
| MBSR | Washout | | | |

*Note-These data are a visual interpretation of the Cohen's D effect sizes for the dynamic balance trials. Green boxes indicate moderate to large improvements (faster STS, TUG, and 25ft walk times), yellow boxes show negligible to small improvements, and red boxes indicate small, moderate, and large declines in dynamic balance (slower STS, TUG and 25ft walk times).*

## TUG Trials

Both groups were hypothesized to have a reduction in TUG trial time, which would traditionally indicate an improvement in balance and mobility. Even though the effect sizes were small, for the Tai Chi group there was a surprising increase in average TUG trial duration after the intervention, with extra time was spent in both the Sit to Stand and Stand to

Sit parts of the test. The Tai Chi group had a baseline of 7.34±1.41s compared to the MBSR group TUG time of 13.58±5.51s. These TUG times appear to be within the expected range of healthy control and MS times, as Miehm et al. (2020) reported average TUG times of 6.6±1.0s for healthy controls, 12.4±7.7s for relapsing-remitting MS, and 18.1±14.0s for progressive MS. That the Tai Chi group was more similar to healthy controls at baseline, makes the pattern of slower TUG times observed for all four Tai Chi participants after the intervention very interesting. Especially compared to the MBSR group where all four participants performed faster (small effect). In the literature increased TUG times are an indicator of worsening strength and mobility that is linked to increased fall risk (Jeong et al., 2019; Shumway-Cook et al., 2000); however based on the baseline TUG times and the mobility level of these participants the slower trial speed may be due to a conscious adjustment related to the speed versus accuracy tradeoff. As the speed of aimed movements increases there is typically a decrease in spatial accuracy, this relationship is known as the speed versus accuracy tradeoff (Meyer et al., 1990). In Tai Chi individuals are trained to move slowly and deliberately with their focus on moving from center; it is likely that the Tai Chi group were optimizing on movement accuracy (in this case postural stability) over speed. In contrast, the MBSR group had the opposite response--a small decrease in average TUG times, with all four MBSR participants performing the trials faster after the intervention. Reductions in TUG times have been reported within the MS literature after balance interventions, and may indicate improved strength and mobility (Eftekharsadat et al., 2015; Guclu-Gunduz et al., 2014; Yazgan et al., 2019). These balance interventions that led to improved TUG times included pilates, and exergaming balance training interventions. The

exergaming balance interventions had participants using Nintendo Wii fit boards to receive virtual biofeedback while accomplishing game objectives. The emphasis on moving slowly and deliberately for the Tai Chi curriculum is likely what caused the slower TUG times, whereas the MBSR training did not have any instructions on moving slowly and deliberately to maintain stability, but instead trained individuals on being attentive to body sensations and breathing while moving at any speed. This may explain why the MBSR group had a similar result to the other MS balance interventions listed above.

25ft Walk

Neither intervention impacted the 25ft walk characteristics which may mean that the information learned in these classes may not translate to changes in regular walking parameters. There was a small difference between the two groups at baseline for 25ft walk time, with the Tai Chi group at 8.93±1.29s and MBSR group 11.27±1.33s, which were within the normal range of walk times reported for healthy controls and an MS population. Healthy control 25ft walk times were 7.0±1.0s, 10.7±5.3s for relapsing-remitting MS, and 14.5±11.1s for progressive MS (Miehm et al., 2020). When the difference in the baseline walk times is compared to the data from Miehm et al. (2020) it becomes clear that, even though the PDDS times were only a half a point apart for mobility, the Tai Chi group had 25ft walk times that fit between those of healthy controls and those with relapsing-remitting MS, whereas the MBSR group had 25ft walk times similar to those with relapsing-remitting MS.

In summary while improvements in postural characteristics were found for both groups it appears that MBSR group improved to a greater extent than the Tai Chi group for

both static and dynamic physical balance measures, therefore hypothesis 1.1 was not supported.

### 5.2.3 Static and Dynamic Measures V2 to V3

For hypothesis 1.2 we predicted that the Tai Chi group would retain greater physical balance benefits after the washout period; this hypothesis was not supported as the MBSR group some continued improvements indicating greater retention. The Tai Chi group after the washout period had moderate increases in ellipse sway and mean sway velocity, and negligible to small changes in TUG and STS times. The MBSR group had continued moderate to large reductions in narrow stance ellipse sway and mean sway velocity, a large reduction in quiet stance mean sway velocity, and no change STS, TUG, or forwards reach 95% ellipse sway (all indicating improvements maintained). After the washout period five of the eight participants had reductions in their forwards reach (3 TC, 2 MBSR) and backwards lean (4 TC, 1 MBSR) distances washout, suggesting that any improvements from the intervention were likely short lived. Although both groups had some trials with ellipse sway area unchanged, the slowed TUG times, increased mean sway velocities and shortened reach and lean distances of the majority of participants indicate that benefits from the intervention were likely short lived.

After the washout period the Tai Chi group had a moderate reduction in 25ft walk speed (improvement), while the MBSR group maintained the same 25ft walk speed but had moderate to large reductions in stride length. This result might have occurred again due to the small differences in mobility noted between the two groups at baseline for the basic postural

and dynamic trials. The Tai Chi group were almost as fast as healthy controls for baseline walking, so it is unsurprising that they maintained their walking ability after the washout period--as it was not impacted by the intervention. The MBSR group on the other hand had greater room for improvement throughout the intervention period and appeared to maintain or retain most of their physical balance trials excluding the 25ft walk shorter stride lengths. Based on our findings it appears that while both groups improved their physical balance, the MBSR group had the greatest improvements after the intervention and better retention. Previous research has shown that general balance retention to perturbations occurs in MS up to 24 hours (Suhaimy et al., 2020), but there are no data across longer time intervals or within the MS literature about retention after a MBSR intervention.

5.3 Psychosocial Measures

**Specific aim #2, (2.1) predicted that both groups would improve psychosocial measures but the MBSR group have greater improvements than the Tai Chi group, and (2.2) that the MBSR group would have greater retention after the washout period.** Hypothesis 2.1 was not supported, because while both groups improved fatigue and MS symptom severity scores, the Tai Chi group alone improved balance confidence and coping ability. The MBSR group had only negligible to small changes in their balance confidence, coping adaptation scores, and period of mood states. Hypothesis 2.2 was not supported as the Tai Chi group retained more psychosocial benefits after the washout period. After the washout period, both groups had negligible to small changes in fatigue severity or for the total and physical MS symptom scores which indicates that benefits were retained. The Tai

Chi group had a small reduction in balance confidence which was still larger than the values reported at baseline, and a continued small improvement in coping ability. While the MBSR group had a small increase in balance confidence, a small increase in coping adaptation, and no change for the period of mood states after the washout period.

### 5.3.1 Psychosocial Measures V1 to V2

After the intervention both groups had moderate to large improvements in fatigue severity and MSIS-29 scores (Total, Physical, Psychological), with no changes found to the Period of Mood states. In addition, the Tai Chi group also had large improvements in balance confidence and coping ability, whereas the MBSR group balance confidence and coping measures were unchanged. Refer to Table 32 for a visual summary of effect size results by time period, including small to large directional effects.

*Table 32: Psychosocial Effect Size Summary Table*

| | Psychosocial Variables Effect Size by Time Period | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Group | Interval | ABC | FSS | CAPS | POMS | MSIS-29 Total | MSIS-29 Physical | MSIS-29 Psych |
| TC | Intervention | | | | | | | |
| MBSR | Intervention | | | | | | | |
| TC | Washout | | | | | | | |
| MBSR | Washout | | | | | | | |

*Note: These data are a visual interpretation of the Cohen's D effect sizes for the psychosocial questionnaires. Green boxes indicate moderate to large improvements (improved balance confidence, fatigue, coping, mood states, and reduced MS symptom severity), yellow boxes show negligible to small improvements, and red boxes indicate small, moderate, and large declines in psychosocial measures (worsened balance confidence, fatigue, coping, mood states and increased MS symptom severity).*

## Activities Balance Confidence Scale

The Tai Chi group reported a large increase in balance confidence after the intervention, with the MBSR group unchanged. Of the 8 individuals evaluated, 5 participants (4 TC, 1 MBSR) increased balance confidence after the intervention, while the other 3 (MBSR) participants had reduced balance confidence. Which is interesting because for the actual measured reach and lean differences only 1 Tai Chi participant increased their forwards reach distance, and only 1 Tai Chi participant increased their lean distance after the intervention, compared to all 4 MBSR participants increasing reach/lean distances after the intervention. This increase in balance confidence scores observed with the reductions in reach/lean ellipse sway and mean sway velocity, suggest that the shorter reach/lean distances

measured in the Tai Chi group may have been due to the participants being more centered and stable while performing these tasks. This is likely due to a combination of the Tai Chi curriculum which emphasizes not over-reaching and keeping ones' center within the stability boundaries, as well as the Tai Chi group being more stable at baseline as discussed above. The addition of Tai Chi training then was the catalyst needed to improve balance confidence in the more challenging forwards reach and backwards lean trials. Improvements in ABC scores have been found in people with MS after Tai Chi (Kaur et al., 2014) and other balance training interventions (Kasser et al., 2015; Gandolfi et al., 2015), with ABC scores significantly correlated to overall range of sway acceleration and amplitude (Solomon et al., 2015). That ABC scores are significantly correlated to postural parameters (especially backward lean) fits the large improvement in ABC score in the Tai Chi group, but why were similar balance confidence improvements not found in the MBSR group who had improved postural parameters for quiet stance, narrow stance, and forwards reach?

The difference in confidence improvement between the groups may have occurred because the Tai Chi group received personalized instruction on how to structurally improve balance while standing and transitioning between postures. This instruction which led to improvements in forwards reach and backwards lean could have been directly applicable to the questions asked on the ABC questionnaire which focused on perceived balance confidence during everyday activities and transitioning between postures. The MBSR group on the other hand were taught to train their attentional focus without the personalized balance training instruction, so the improvements in quiet stance, narrow stance, and forwards reach postural parameters may have occurred without a subjective perception of improved balance

confidence. Baseline balance confidence scores were higher for the Tai Chi group (85.5±3.2 which increased to 92.9±3.6 after the intervention), while the MBSR group baseline was at 70.5±16.9 and was relatively unchanged after the intervention 69.5±14.9. This trend is similar to what was seen for the TUG trials, quiet stance postural characteristics and 25ft walk times at baseline where the Tai Chi group seemed to be more mobile and begin with a higher level of balance confidence. As a comparison, Wood et al. (2019) reported ABC scores of 54.1±18.7 in MS fallers, 72.9±21.9 in MS non-fallers, and 92.4±8.1 in their healthy control population. Our study population were relatively confident for an MS population, as all participants fit into the MS non-faller up to healthy control level of balance confidence.

Fatigue Severity Scale

Both groups reported moderate to large improvements in fatigue severity as measured by the FSS, with the individual trends showing improved fatigue in 7 of the 8 participants (4 TC, 3 MBSR). At baseline the two groups had different fatigue levels, with the Tai Chi group having a baseline score of 38.76±7.8 which decreased to 29.5±15.2 after the intervention, while the MBSR group baseline was 70.5±17.4 and decreased to 49.5±25.5 after the intervention. These fatigue scores fit in to the normal range of scores within the MS population, where Averill et al. (2013) reported baseline fatigue scores of 73.58±18 (n=8), and Goodwin et al. (2019) an average fatigue severity score of 43.7±15 for their 1,056 MS participants. Even though the two groups differed for baseline fatigue levels, the improvements in both groups after the intervention period may be due to the increased awareness of body energy levels when performing everyday tasks. Fatigue may have been

reduced in the Tai Chi group due to the emphasis of conserving energy during stepping and moving, maintaining coordination of breath and body, and paying attention to the movement at hand and not dual tasking. Improvements in fatigue have been found for other MS intervention studies ranging from aquatic exercises to Tai Chi (Averill et al., 2013; Burschka et al., 2014; Kooshiar et al., 2014), MBSR interventions that have led to improvements in fatigue both in people with MS and those with traumatic brain injuries (Cavalera et al., 2018; Grossman et al., 2010; Nejati et al., 2016; Ulrichsen et al., 2016). The reduced fatigue in the MBSR group may have occurred due to the focus on breath and relaxation, and the greater awareness of stress in the body whether physical stress or letting go of stressful thoughts and emotions.

Multiple Sclerosis Impact Scale-29

Both groups had moderate to large improvements in their MSIS-29 disease impact scores for Total, Psychological and Physical symptom categories after the intervention. The Tai Chi group reported baseline scores of MSIS-29 Physical of 24.71±19 and Psychological of 35.4±28, while the MBSR group had baseline scores of MSIS-29 Physical of 46.6±24 and Psychological of 32.6±20. These baseline scores are similar to those reported in other studies, including Garrett et al. (2013B) who reported baseline scores of MSIS-29 Physical of 29.6±23 and Psychological of 22.2±12, and Feys et al. (2019) with group baselines of MSIS-29 Physical of 23.5±14.4 and Psychological of 30±24.3. The MBSR group at baseline had a higher Physical symptom score then was listed with the comparison studies, but the reduction in MS disease impact for physical symptoms aligned them with the other studies following

the intervention. Refer to Table 32 for MSIS-29 data. All eight individuals evaluated reduced MS symptom impact on daily wellbeing, with 7 (4 TC, 3 MBSR) also having improvements in both physical and psychological symptom scores. Our results are supported by similar improvements in physical MSIS-29 scores that were reported after both individual walking or fitness instructor led exercise interventions in people with MS (Feys et al., 2019; Garrett et al., 2013A). The previously discussed improvements in fatigue severity may be part of the reason that we see the improvements in MSIS-29 scores, as Kehoe et al. (2014) observed that fatigue and baseline walking distance in people with MS (n=242) were significant predictors of the MSIS-29 physical component after a 10-week walking intervention.

Coping Adaptation Scale

The Tai Chi group reported a large increase in coping ability after the intervention, with the MBSR group unchanged. Of the 8 individuals evaluated, 5 participants (4 TC, 1 MBSR) increased coping ability, while the MBSR participants either maintained the same coping score or worsened. This is an interesting finding as the Tai Chi training did not explicitly train new coping strategies or deal with emotional awareness, whereas the MBSR group who did receive that training had only negligible changes to coping after the intervention. Possibly the improved coping ability in the Tai Chi group occurred due to the 8 weeks of increased physical activity leading to a greater feeling of confidence (improved balance confidence) and mastery over this new form of exercise. The act of learning how to center and ground the body physically may have indirectly improved the feeling of being able to cope with stressful situations. In addition the MBSR group (who had more

progressive MS trajectories, PDDS: 2.5, and greater fatigue at baseline) also had higher initial CAPS scores, so it could be that these individuals already had strong coping abilities without much room to grow. At baseline the MBSR group had a mean coping score of 45.5±13.18 which increased to 47.25±5.68 after the intervention, while the Tai Chi group started at 33.5±9.71 and then increased to 48.0±4.24 after the intervention. If the MBSR group at baseline already had strong coping abilities, then why was a small improvement in coping ability found for the MBSR group after the washout period? People with MS use a number of different coping strategies, including problem-focused coping, support based coping, and coping based on stopping unpleasant thoughts/emotions from rising (Mikula et al., 2014); if participants' preferred coping style did not match the MBSR training (which emphasized awareness of emotions and thoughts) then it could explain why after the washout period the coping scores had a small improvement.

Abbreviated Period of Mood States Scale

Both groups had only negligible to small changes in the Abbreviated Period of Mood states after the intervention, with scattered individual trend data. The lack of improvement in period of mood states may have been due to the small sample size, or potentially the abbreviated POMS questionnaire was not the most sensitive tool for measuring mood in these two groups. With both groups having improvements in other psychosocial measures (fatigue scores, MSIS-29 disease impact scores, and balance confidence/coping for Tai Chi) we would have expected more then the negligible to small changes registered by the mood states questionnaire. However, this finding of no change for the abbreviated periods of mood

states questionnaire after a mindfulness intervention was similar to Oken et al. (2004) who reported unchanged mood scores after a 6-month yoga intervention. This differed from the MBSR group who had lower scores (indicative of greater mood disturbance) then the Tai Chi group throughout the study duration and washout period. The MBSR group had a small increase in POMS score (more negative mood states) after the intervention, but the individual trends were again scattered (1 improved, 1 unchanged, 2 declined). This small increase in negative mood states may have been due to the MBSR training, as participants are asked to acknowledge all emotions and thoughts that arise equally. Therefore individuals may have been more aware of their negative mood states leading to the small increase in negative mood states that was noted.

Psychosocial Measures Summary

We predicted that the MBSR group would have greater improvements for the psychosocial measures due to the curriculum training improved attentional focus, and ability to view emotions and thoughts in a nonjudgmental manner; however, the Tai Chi group did not have any formal training on these constructs but had similar improvements on measures of fatigue severity and MSIS-29. Why might this result have occurred? Both MBSR and Tai Chi are forms of mindfulness training which strengthen the ability to refocus attention on movement, emotions, and then refocus ones' attention when distracted. These improvements in attentional focus may have increased awareness of positive thoughts, emotions, and symptom improvement and increased individuals' ability to halt patterns of negative thoughts and emotions related to MS symptoms, resulting in the improved psychosocial measures.

Quality of life and fatigue reduction have been linked to training MS individuals for self-care and the ability to be more adaptable and accepting of MS physical and mental symptoms (Fernandez et al., 2011). Even though the training modes differed, this did appear to be the case for both groups. The MBSR group trained their attentional focus directly via meditation, whereas the Tai Chi group would have trained their attentional focus indirectly by continuously bringing the focus back to moving from center. While neuronal demyelination in MS may limit the quality of sensory information available, it could be that both groups improved their awareness of available sensory information allowing the participants to allot their available resources in ways to reduce fatigue and improve MS disease impact on daily life.

Another possibility could be that some of the psychosocial improvements stemmed from the increased social support, and not explicitly from the interventions themselves. Having supportive community groups have been shown to improve wellbeing and reduce depression in diverse populations (Jensen et al., 2014), including people with MS (Koelmel et al., 2017). Learmonth and Motl (2016) identified peer support as a perceived facilitator of physical activity in MS, and that the positive benefits of social participation greatly improve the likelihood of attrition. Therefore in addition to the intervention curriculum the improvements in fatigue and MS symptom severity may have occurred due to the increased social support of belonging to a community with a common practice goal (MBSR and Tai Chi). Based on our findings hypothesis 2.1 was rejected because, even though both groups improved their psychosocial variables at V2, based on the balance confidence and coping results, the Tai Chi group improved to a greater extent after intervention.

### 5.3.2 Psychosocial Measures V2 to V3

After the washout period the improvements in fatigue and MSIS-29 scores were retained for both groups, and the Tai Chi group also maintained the large effect improvements in balance confidence and coping ability with only a small decrease. After the washout period the MSIS-29 individual trends became more scattered, however all participants MSIS-29 scores (Total, Psychological and Physical) still were lower at V3 then were initially measured at V1. Garrett et al. (2013B) had similar findings related to MSIS-29 Psychological score retention after a 12-week intervention, and found that improvements in the MSIS-29 Psychological scores and fatigue were retained to a better extent at a 12-week post-intervention follow up then the MSIS-29 Physical scores. With our shorter washout period the Physical score improvements were still retained to a greater extent, but it is likely they would decline if measured after a longer washout period. No changes were found for the Period of Mood States scores for either group. Our hypothesis 2.2 was also not supported as the Tai Chi group retained more psychosocial benefits after the washout period.

## 5.4 Sensorimotor Function Measures

**Specific aim #3, (3.1) predicted that the Tai Chi intervention would lead to greater improvements in sensorimotor function (plantar vibration sensitivity & foot tapping ability), and that (3.2) these benefits would be retained to a greater extent in the Tai Chi group after the washout period.** For vibration sensitivity the MBSR group showed improvements in the hallux and M5 after the intervention, while the Tai Chi group had small to no changes in sensitivity across all sites of both feet. For motor function the Tai Chi group

had moderate to large reductions in their inter-tap interval and large reductions in the tap coefficient of variance of both feet, indicating a greater improvement in motor function. No effects on tapping parameters were found for the MBSR group. Therefore hypothesis (3.1) was partially supported, as the Tai Chi group had improvements in motor function but not vibration sensitivity, and Hypothesis (3.2) was supported as the Tai Chi group retained their improvements in tapping performance after the washout period. After the washout period the Tai Chi group had negligible to small changes in tap count and inter-tap interval from V2, a continued moderate reduction in the coefficient of variance in the foot with less function. The MBSR did not retain any of their vibration sensitivity improvements through the washout period.

### 5.4.1 Sensorimotor Function V1 to V2

#### Vibration Sensitivity

The MBSR group had improvements in their Hallux and M5 sensation on the foot with greater sensitivity after the intervention, with the Tai Chi group having only small improvements in sensitivity across all sites of the less sensitive foot (Hallux, M5, Heel). Refer to Table 33 for a visual summary of plantar vibration sensitivity percent change by group, including small to large directional effects. The Tai Chi group at baseline were able to perceive smaller amounts of vibration then the MBSR group; with an overall average value across all sites of 11.75±7.4 volts for the Tai Chi group and 18.25±9.9 volts for the MBSR group. Differences at baseline were observed for the GS hallux thresholds, which were 9.25±3.86 volts for the Tai Chi group versus 22.33± 23.11 for the MBSR group. This range

of hallux values is not unusual within an MS population, as Miehm et al. (2020) reported an average Hallux vibration threshold of 15.23±12.1 volts for the relapsing-remitting MS group, 26.38±13.52 volts for the progressive MS group, and 10.60±5.44 volts for controls. Even though the GS hallux sensitivity values differed between groups, the M5 and Heel values were closer between the two groups.

*Table 33: Plantar Sensitivity Effect Size Summary Table*

| | Vibration Sensitivity Effect Size by Time Period | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Hallux | | M5 | | Heel | |
| Group | Interval | GS | LS | GS | LS | GS | LS |
| TC | Intervention | | | | | | |
| MBSR | Intervention | | | | | | |
| TC | Washout | | | | | | |
| MBSR | Washout | | | | | | |

*Note-These data are a visual interpretation of the Cohen's D effect sizes for the vibration sensitivity trials. Green boxes indicate moderate to large improvements (improved vibration perception), yellow boxes show negligible to small improvements, and red boxes indicate small, moderate, and large declines in plantar sensitivity measures (worsened vibration sensitivity).*

The improvement in M5 sensitivity in the MBSR group may have occurred due to an enhanced ability to focus attention directly to the sites on the foot and register small sensations earlier. The first meditation practice taught in the MBSR class was the 'Body Scan' meditation where people were instructed to attend to their hallux and perceive any sensations of pressure, temperature, before moving through each of the limbs. Meditation has been shown to improve alertness, attention, and reaction times in diverse populations (Clark et al., 2015; Jedrczak et al., 1986; Williams et al., 1978), and the emphasis on focusing on

present sensory input without cognitive elaboration or emotional reactivity may have led to the improvements in GS Hallux and M5 sensitivity. Meditation training has been shown to improve pain levels in chronic migraineurs and people with MS (Day et al., 2014; Tavee et al., 2011; Zeidan & Vago et al., 2016) possibly due to increased inhibitory control of the cortico-thalamo-cortical activation (Zeidan & Vago et al., 2016). However these results should be approached with caution as no other sites had improvements in sensitivity in the MBSR group.

The Tai Chi group had only small improvements in plantar vibration across all sites on the less sensitive foot, with no change to the foot with greater sensitivity at baseline. These very small changes in vibration sensitivity after the Tai Chi intervention likely occurred to due to increased blood flow and mechanoreceptors being directly stimulated by people stepping (Alfuth & Rosenbaum., 2011); in addition to performing the Tai Chi movements barefoot. In Tai Chi there is an emphasis on foot placement and controlled weight shifts during the practice itself that may increase mechanoreceptor stimulation (Li & Manor, 2010; Manor et al., 2013; Richerson & Rosendale, 2007). What may have caused these small changes in sensitivity in the Tai Chi group to be unilateral? Based on the baseline descriptive data the Tai Chi groups' foot with greater sensitivity had similar vibration thresholds as those found in healthy controls, it is likely that the foot with greater sensation was already performing at an optimal level without much room for improvement. Similar vibration sensitivity improvements were found in Averill (2013), where the Tai Chi group also improved vibration sensation solely on their less sensitive foot after a 3-week Tai Chi intervention. Other studies have also reported improved plantar sensitivity after Tai Chi

interventions in a population of older adults with and without peripheral neuropathies, however these studies measured plantar pressure sensitivity using monofilaments (Li & Manor, 2010; Manor et al., 2013; Richerson & Rosendale, 2007). Even though the mechanoreceptors would differ for vibration sensitivity versus pressure sensitivity, it appears that Tai Chi as an intervention may lead to some beneficial improvements in plantar sensitivity.

Foot Tapping

After the intervention the Tai Chi group had moderate to large reductions in inter-tap interval, and large reductions in the tap coefficient of variance for both feet which may be indicative of improved motor function. At baseline the groups produced an MF average foot tap quantity of TC at 32.75±12.76 versus MBSR at 41.00±9.93, an MF average inter-tap interval of 298.5±100.7ms for TC and 275.6±87.7ms for MBSR, and an MF average coefficient of variance of for TC of 28.76±14.5 and 14.8±5 for MBSR. From baseline to after the 8-week intervention both groups had small improvements in tap count, for the more function foot, tap counts for the Tai Chi group went from 32.75±12.76 at baseline to 38.50±13.3, and for the MBSR 41.00±9.93 at baseline to 44.00±9.80 after the intervention. Increased foot tapping was observed after a 3-week Tai Chi intervention (Averill, 2013) where the average tap count increased from 27.86±8.38 at baseline to 39.25±4.25 after the Tai Chi training; while the tapping quantity changes were small for this study (based on the Cohen's d effect sizes), these improvements are is still worth noting.

Both groups were within the normal range of MS foot tapping ability, as Miehm et al. (2020) reported an average of 37.43±9.5 taps for the relapsing-remitting MS group, 29.63±7.67 taps for the progressive MS group, and 45.95±4.29 taps for healthy controls. Reduced inter-tap intervals and coefficients of variance have been noted during foot tapping in younger adults compared to healthy older adults, and are considered to be a measure of movement ‘steadiness’ (Takimoto et al., 2016). Faster Tibialis Anterior reaction times and increased neural drive after Tai Chi interventions in older adults have been noted (Gatts, 2008; Gatts & Woollacott, 2006), which may explain the mechanism that inter-tap interval and the coefficient of variance may be reduced with Tai Chi training. Refer to Table 34 for foot tapping characteristics effect size by time period, including small to large directional effects. The Tai Chi group practiced barefoot and each Tai Chi practice time was spent moving, stretching and stepping, all of which may have increased blood flow, stimulated the plantar mechanoreceptors, and led to faster tibialis anterior reaction times (Wang et al., 2017; Xu et al., 2005). The mechanism as proposed in Figure 6 would include directly training body orientation in space with less reliance on vision with greater awareness of foot and lower limb position and weighting during movement.

*Table 34: Foot Tapping Effect Size Summary Table*

| | Foot Tapping Variables Effect Size by Time Period | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Tap Quantity | | Inter-Tap Interval | | Tap Coefficient of Variance | |
| Group | Interval | MF | LF | MF | LF | MF | LF |
| TC | Intervention | | | | | | |
| MBSR | Intervention | | | | | | |
| TC | Washout | | | | | | |
| MBSR | Washout | | | | | | |

*Note-These data are a visual interpretation of the Cohen's D effect sizes for the foot tapping trials. Green boxes indicate moderate to large improvements (improved foot tap count, reduced inter-tap interval and coefficient of variance), yellow boxes show negligible to small improvements, and red boxes indicate small, moderate, and large declines in foot tapping measures (worsened foot tap count, increased inter-tap intervals and coefficients of variance).*

This differed from the MBSR group who had only negligible to small increases in tap quantity, inter-tap interval, and the tap coefficient of variance. Why do we not see improvements in the MBSR group for the foot tapping measures? The differences in the two groups behavior could also be due to training. The MBSR group trained awareness of body sensations in space primarily using static postures (sitting, standing, or lying down), only two MBSR practices included movement: yoga and the sensory walk meditation. Which may explain how vibration sensitivity improvements were found without a change in foot tapping ability.

Based on the foot tapping data above the hypothesis (3.1) that the Tai Chi group would improve on sensorimotor function to a greater extent was partially supported, as both improvements in motor function but not vibration sensitivity were observed.

### 5.4.3 Sensorimotor Function V2 to V3

After the washout period the Tai Chi group retained some of the tapping parameters, whereas the improvements in Hallux and M5 vibration sensitivity of the MBSR group were not retained. Retention of motor function in the Tai Chi group may have been caused by increased blood flow and faster Tibialis Anterior reaction times which still appear to have beneficial physiological changes after the washout period. Retention of speed and accuracy in finger tapping tasks have been noted up to 12 and even 24 hours post training in healthy controls (Bilodeau et al., 2015; Doyon et al, 2009). For the MBSR group after the washout no vibration sensitivity benefits were retained, with the V3 values being similar to those found at V1. Based on the data hypotheses 3.1 was partially supported, and hypothesis 3.2 was supported as the Tai Chi group had improvements in motor function after the intervention, and retained these benefits to a greater extent than the MBSR group after the washout period.

### 5.4.4 Conceptual Framework and Neurophysiological Mechanisms

After the intervention the Tai Chi group had improved static postural characteristics (narrow stance, forwards reach, backwards lean), STS times, bilateral inter-tap interval and tap coefficient of variance, balance confidence, coping ability, fatigue, and MSIS-29 disease impact scores. The MBSR group had improved static postural characteristics (quiet stance, narrow stance), STS and TUG times, hallux and M5 vibration sensitivity, fatigue and MSIS-29 disease impact scores. What neurophysiological mechanisms would explain the patterns of improvement observed in these specific trends? In Figures 3-6 a conceptual framework

was proposed addressing how the Tai Chi and MBSR training might lead to improvements in the different measures. Improvements in both groups likely stemmed from beneficial neural adaptations specific to the interventions, as well as increased mindfulness while performing the V2 measures. The Tai Chi group likely had improved corticospinal conduction times (de Ruiter et al., 2001), increased lower limb strength, improved motor unit recruitment/rate-coding, increased motor unit synchronization, and decreased muscular co-contraction after increasing their physical activity over the 8-week intervention period. These neural adaptations would explain the improvements in the forwards and backwards lean trials, the improved foot tapping parameters, and potentially have helped with the reduction in MSIS-29 scores and fatigue levels (as muscle weakness may be linked with fatigue in MS, Chung et al., 2008). This concept is supported by the literature where Tai Chi training has led to faster reaction times to perturbations with decreased muscular co-contraction, and increased joint proprioception in diverse populations (Gatts et al., 2008; Sattin et al., 2005; Fong et al., 2006). The improvements in psychosocial measures were likely due to wellbeing and increased strength from the increased physical activity during the intervention leading to improved balance confidence and reduced fatigue, and an improved feeling of mastery of the Tai Chi techniques may have led to the increased coping ability.

The MBSR group did not increase their activity to the level of the Tai Chi group, so any beneficial neural adaptations would likely be in the cortical and upper motor regions, with improved functional connectivity occurring due to the regular meditation practice. Improvements in functional connectivity at the cortex level might allow for downstream improvements including better motor unit synchronization and less muscular co-contraction

during activities, which may explain the improvements in STS and TUG times, postural characteristics, and vibration sensitivity. Beneficial changes in grey matter and increased cortical thickness have been found in both short- and long-term meditators (Holzel et al., 2011; Grant et al., 2010; Lazar et al., 2005), with cardiorespiratory synchronization leading to a decreased parasympathetic body response during meditation, leading to improvements in functional connectivity over time (Jerath et al., 2014). The improvements in fatigue and MSIS-29 disease impact scores could have occurred due to better awareness of the body, allowing for participants to make adjustments earlier to reduce overall fatigue or handle MS symptoms. Or the MBSR curriculum may have led to a better capacity to not hold onto negative thoughts and emotions, allowing for an improved feeling of wellbeing and lessened impact of MS symptoms on daily life (Aftanas & Golosheykin, 2005; Wielgosz et al., 2016).

# CHAPTER 6- CONCLUSION

## 6.1 Study Purpose and Significance

The purpose of this study was to determine whether a Tai Chi or Mindfulness Meditation intervention would have a greater effect on physical balance, psychosocial wellbeing and sensorimotor function in people with MS, and whether benefits were retained after a 2-week washout period. While the small sample size makes it difficult to directly compare the two interventions, the strength of this pilot study is that the small group allows for individual trend data to be presented across all measures. Which is important as people with MS have different symptoms and disease progression, therefore the individual responses may differ in how they react to the intervention and washout periods. Group trajectories of improvement are then beneficial to note, even if not reaching statistical significance, as it may be an indicator of positive impacts of the intervention and retention capacity on specific MS individuals. This pilot study supports the previous literature regarding the beneficial impacts of Tai Chi and MBSR as interventions for people with MS, and gives some information about the retention capacity of Tai Chi and MBSR interventions after a 2 week washout period.

## 6.2 Highlights: Group Differences

The two groups while only a half a PDDS value apart, did differ. For descriptive statistics the MBSR group was older 59.3 years ± 5.2 and had a higher PDDS mobility score indicating greater impairment PDDS: 2.5, whereas the Tai Chi group was 35.5 years ±10.8 with an average PDDS of 2.0. Baseline fatigue severity was higher for the MBSR group, with

slower 25ft walk times. Other trends in the data showed that the Tai Chi group for most trials was more similar to healthy control values for quiet stance, narrow stance, TUG, STS, and vibration sensitivity. The MBSR group tended to have values that ranged from healthy control levels like those observed in the foot tapping trials, up to values more similar to those seen in non-progressive MS. The MBSR group seemed to have a higher impact of MS symptoms on daily life (MSIS-29, Fatigue Severity Scale) and a higher coping ability at baseline then the Tai Chi group even though the PDDS scores were only half a point off. Why were such differences found when participants were matched for PDDS level? The PDDS is based on distance for mobility and not on the time to perform mobility tasks such as the 25ft walk. The sample size due to recruitment issues and the Covid-19 pandemic then lead to the groups not being balanced for comparison. Both groups were able to complete similar amounts of practice time (home and class combined) with the Tai Chi group average at 28 ± 7.1 hours and the MBSR group average at 30 ± 5.1 hours.

### 6.3 Highlights: Intervention Differences

The MBSR curriculum led to improvements in attentional focus which were generalizable across the basic balance trials (quiet stance, narrow stance, and at its limits for forwards lean), the STS, M5 vibration sensitivity, with mild effects for the TUG. These benefits in improved attentional focus were retained in most cases though the washout period. This is supported by the proposed mechanisms from Figure 6, namely that the MBSR training would lead to reduced attentional distractions during trials, improved body sensation/orientation in space, and improved relaxation during movement. The MBSR group

improvements in fatigue levels and MSIS-29 disease impact scores were likely due to the increased bodily relaxation during movement and greater awareness of body sensation/orientation in space leading to more awareness during movement and a greater ability to modify movements to reduce fatigue and MS symptoms. Based on this small set of pilot data it appears that an MBSR intervention for people with MS improved psychosocial benefits, as has been reported in the literature, and in addition led to improvements in vibration sensitivity and physical balance. This finding is significant as previous studies had not evaluated the effect of MBSR on physical balance and sensory function in people with MS.

The Tai Chi group had improvements as well, including the more challenging static balance trials (forwards reach and backwards lean), fatigue, balance confidence, coping ability, MSIS-29 disease impact scores, and the foot tapping parameters of inter-tap interval and coefficient of variance. The proposed mechanisms of improvement in the Tai Chi group included: improved perception of body orientation in space with less reliance on vision, improved responses to directional force, and improved relaxation during movement (Figure 6). The combination of these three mechanisms could result in the improvements in the challenging static balance trials, and the foot tapping parameters as the body would be more adaptable and relaxed during these trials. The improved relaxation during movement and better awareness of body orientation in space are the mechanisms that would lead to improved fatigue levels and MS symptom daily life impact scores, as the Tai Chi group would potentially be more effective when moving through postures (relaxed) and be able to modify movements to reduce fatigue and MS symptoms—similar as seen in the MBSR

group. The basic balance trials and STS were not impacted in the Tai Chi group, which could be due to the group having baseline values closer to those seen in healthy controls with less room for improvement in these trials. The slower TUG times observed in the Tai Chi group after the intervention indicate that the participants were applying what they learned from the curriculum to the mobility trials, but in an unexpected way. While it is possible that the Tai Chi group had less room for improvement on the basic postural trials, STS, and TUG, when the whole picture is put together with the improvements in fatigue, balance confidence and reduced MS disease impact, and motor function parameters, it seems that the Tai Chi group improved in the trials more aligned with the Tai Chi curriculum. This curriculum puts emphasis on maintaining centeredness while transitioning between postures in a slow controlled manner. Future studies with larger sample sizes are needed to confirm the impact of the intervention curriculum on key parameters (e.g. TUG time, STS, standing balance…) and to clarify if group differences were indeed due to the specific training regimens or if these results were due to the small sample size.

## 6.4 Recruitment Issues and Study Limitations

The main study limitation was the small sample size. More interventions for people with MS living in rural areas like western Massachusetts are needed, so why were difficulties in recruitment observed even prior to the Covid-19 pandemic? As of October 2019, approximately 15,273 individuals were registered with the National MS Society as living with MS in Massachusetts, and of those individuals about 1,785 live in western Massachusetts counties who would be within the acceptable driving distance of the study

locations (1 hour or less). The MS Center at UMass Memorial Medical Hospital (UMMS) in Worcester has 1,200 patients seen yearly. Flyers were posted for the study at the UMMS MS center during the study period, and multiple presentations were given at the 5 support groups closest to the intervention locations. Other outreach included an article about the study published in the UMass Amherst News and Media Relations publication (April 16th, 2019), a study Facebook page created with paid advertising through Facebook, print flyers posted around the towns local to the study, and lastly the National MS society had the study listed online under their ‘Ongoing research’ tab, and emailed the local support groups reminders/updates about the study.

Recruitment and attrition issues have been reported as obstacles in other complementary and alternative medicine (CAM) studies as well, for example when evaluating the use of CAM interventions in individuals with neurological issues the attrition rates were 9% to 21% in control groups, and 3% to 16% in intervention groups (Tavee et al., 2011). Which may indicate some barriers to recruitment and attrition in CAM or mindfulness interventions, that need to be explored. In addition, Motl et al. (2018) reported that even though the literature strongly supports that physical activity is beneficial in MS, there is still a lack of participation in exercise by individuals with MS. For this study we had difficulty recruiting mobile MS individuals in the western Massachusetts locale who were willing to do an 8-week CAM intervention; one barrier was in not recruiting MS individuals who had more progressive disease trajectories with greater mobility impairment. This decision was made originally as physical balance and mobility were a main aim of the study therefore individuals were excluded if they could not stand for greater then 15s without assistance and

with a PDDS of 4.0 or less. While this allowed us to evaluate more ‘mobile’ MS individuals and allow for easier transition into non-MS specific classes (for participants and class instructors alike), this did however exclude a number of people who were interested in the study. More participants could have been recruited if the original study parameters allowed for 1) a seated Tai Chi or MBSR routine, including separate seated classes for Tai Chi and videos to match on the homework website; for MBSR modifying the yoga/walking meditations, and breaking up the final full day meditation practice across multiple days to reduce fatigue; 2) greater handicap accessibility of intervention sites, which while technically handicap accessible generated issues based on the age and layout of the buildings, and from the distance from site to the available parking; 3) extra study personal on site to assist with class flow and accessibility in and out of the practice locations; and 4) exclusion of some of the balance and mobility parameters evaluated in the study aim 1. A recommendation for future studies would be to have multiple intervention sites statewide if evaluating a more ‘mobile’ MS group, otherwise if working with a more rural group with limited intervention site capacity making sure to have wider mobility inclusion criteria and to have the intervention sites inspected by some pilot MS participants with mobility impairments to evaluate any potential accessibility issues. If issues arise then renting a fully accessible space would be the best way to go (an aerobics studio for example with accessible parking), however that brings its own issues (as we found in this study) as the rented space has less of the ‘feel’ of the original mindfulness/Tai chi studios, and can generate more work for the instructors to bring supplies in and out of the rented location that would normally be onsite (e.g., MBSR yoga mats, yoga cushions, access to location wifi for MBSR class presentation

components, etc). And that the accessible space is only maintained while the study is ongoing, so if participants want to continue in the classes post study end, then they must navigate the original potentially less accessible class spaces.

Another study limitation was due to the classes being structured for non-MS individuals, this was originally thought to be an asset as participants could rejoin the classes after the official end to the study. However, some issues arose similar to what Simpson et al. (2019) found when they implemented MBSR in an MS population. Modifications to the MBSR program were needed specifically when it came to: handicap accessibility of class locations/parking, adaptations needed to the accommodate MBSR/Tai Chi curriculum to comorbidity and disability, and shortening of the length of classes (the MBSR class was 2.5 hours long per week). Simpson et al. (2019) listed helpful adaptations to future MS MBSR classes as including: shorter classes, more time with peers, more MS focused curriculum (e.g. instead of ‘mindful walking’ having ‘mindful locomotion’ to be more inclusive of greater disability), and an extra orientation to help prepare participant expectations. While some of these recommendations are MBSR specific, most could be applied to the Tai Chi group as well. Having the MBSR and Tai Chi interventions tailored to an MS population may also lead to a greater recruitment pool. Further research has shown that some people with MS when starting MBSR identify with the disease and struggle with being asked to sit with their thoughts and emotions as it is. Simpson et al. (2018; 2019) also stated that other instructors have listed not wanting to dwell on MS-identity if there were non-MS individuals in the class, which may make it difficult for some MS individuals to apply mindfulness to where they are in the moment. While not dwelling on disease-identity is an important part of

mindfulness training, if a participant is not ready to practice that aspect—then it may make them less likely to continue in the class.

While practice times did not differ by group, there was some variation in practice times across the 8 participants, which may have been related to adherence and overall interest. Barnard et al. (2020) noted that long term adherence to health behavior modification interventions in people with MS were related to person-centered support, motivation, and family support, and that adherence to “time-consuming” exercise and meditation recommendations were less common and episodic. To improve adherence to group sports or exercise five themes have been reported by people with MS as being important: level of personal engagement to exercise, influencing barriers/enablers of exercise, sustaining independence, integrating exercise into lifestyle, and getting the balance right on too much versus too little exercise (Smith et al., 2019). With this study design we tried to improve study participation and adherence as best as possible by setting up the homework times to be based on individual schedules, and even offering a ‘bring a friend’ discount if the participant had a non-MS friend who was interested in taking the class at the same time. Even though practice times differed, it appeared that most participants had good adherence to the practice goals. Of the 8 participants in this study, only 3 continued their practice after the official end of the study. All 3 were in the MBSR group and had continued their mindfulness home practices when contacted a month later.

## 6.5 Future Steps

The individual trends in this pilot study highlight the potential benefits of mindfulness interventions in people with MS, not just for psychosocial benefits but also for some physical balance and sensorimotor function improvements. To expand on this dissertation a larger study should be completed to see if the findings are maintained within a larger MS population, and specifically if there are benefits for individuals with more progressive forms of MS. The results from this small pilot further suggest that improvements in physical balance, psychosocial measures, and sensorimotor function can occur within the MBSR group even with minimal time spent walking or moving, which might be especially beneficial for those with more progressive forms of MS. Lastly, it would be interesting to design a study to delve deeper into the potential mechanisms that may have resulted in the improvements observed for the MBSR and Tai Chi groups. For example most of the improvements in Aims 1 and 3 are potentially explained by beneficial neural adaptations occurring due to the 8-week training period, benefits that potentially could be assessed through current MRI imaging techniques to evaluate grey matter changes pre/post the intervention, which would allow for these mechanisms to be investigated further.

## 6.6 Conclusion

With this study we confirmed the previous literature regarding the beneficial aspects of Tai Chi and MBSR as interventions for people with MS, specifically that both Tai Chi and MBSR interventions may lead to improvements in physical balance, fatigue and MS disease impact scores. Tai Chi additionally may improve balance confidence, coping ability, and

motor function parameters such as inter-tap interval and coefficient of variance. With MBSR having a potential impact on M5 vibration sensitivity. Neither intervention appeared to impact 25ft walk characteristics, or the period of mood states. We were able to evaluate the individual participant trends of two mindfulness pilot interventions, and report participant individual trends of improvement in physical balance, psychosocial and sensorimotor function, with some benefits retained after a 2-week washout period. These data should be regarded with caution due to the small sample size, however this dissertation when taken as pilot data adds and supports the current literature on mindfulness interventions in MS.

# Appendix A

Consent Form for Participation in a Research Study
University of Massachusetts Amherst

**Researcher(s):** Richard Van Emmerik, Anna Paskausky, Julianna Averill, Kelly Kalagher, Katie Ryder

**Study Title:** Tai Chi and Mindfulness Training to Improve Balance in People with Multiple Sclerosis: A Community Based Intervention

**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. It will also describe what you will need to do to participate and any known risks, inconveniences or discomforts that you may have while participating. We encourage you to take some time to think this over and ask questions now and at any other time. If you decide to participate, you will be asked to sign this form and you will be given a copy for your records.

**2. WHO IS ELIGIBLE TO PARTICIPATE?**

We are recruiting a total of n=36 men and women diagnosed with Multiple Sclerosis (MS). To be recruited participants must be otherwise healthy individuals between 21-70 years of age, who can stand and walk independently for 15 minutes at a time, with minimal to no gait impairment due to MS, and who have not experienced an MS relapse within the past three months. Participants will be excluded after the telephone screening if they are current smokers, are diagnosed with any neurological disorders (other than MS), diabetes mellitus, visual or inner ear related problems, circulatory issues, or any orthopaedic injuries. Participants will also be excluded if they have participated within a regular Tai Chi or Mindfulness Based Stress Reduction class within the past year, or are unable to get transportation to and from the data collection and intervention locations in Amherst MA and Florence MA. The time commitment for being a part of this study will also include your personal travel time.

**3. WHAT IS THE PURPOSE OF THIS STUDY?**

The purpose of this research study is 1) to learn whether an 8-week intervention of Tai Chi or Mindfulness Based Stress Reduction is effective at improving physical and psychological aspects of balance in people with MS, and 2) whether any physical or psychological aspects of balance remain after a 2-week washout period. The results from this study will allow clinicians to better understand how local community-based interventions impact physical and psychological aspects of balance in people with MS.

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

If you participate, you will attend a total of three (3) data collections at the Motor Control Lab (Totman Building, Department of Kinesiology at the University of Massachusetts Amherst) each lasting 1.5 hours, for a total study duration of 10 weeks. Data collections will

be scheduled at Week 0 (prior to training), Week 8, and Week 10. You will be asked to take part in one 8-week session of either Tai Chi or Mindfulness Based Stress Reduction training followed by a 2-week session where you will be asked to not practice Tai Chi or Mindfulness Based Stress Reduction. The Tai Chi intervention will occur at YMAA Western MA Tai Chi School in Florence MA, while the Mindfulness Based Stress Reduction intervention will occur at the Downtown Mindfulness Meditation Center in Amherst MA.

**5. WHAT WILL I BE ASKED TO DO?**

If you agree to be in this study, you will be asked to do the following:

Data Collection:

Part I:

After you read and sign the informed consent document, you will be asked to complete a couple of questionnaires asking about your balance confidence, fatigue level, overall wellbeing, general mood states, and MS disease progression. You may skip any questions you feel uncomfortable answering. The following tests will be performed on you if you are a participant.

Vibration sensitivity of your feet will be measured using an electrical device called a biothesiometer. A biothesiometer is a clinical vibrator, used to measure the smallest amount of vibration a person can perceive. The amount of vibration is slowly increased from zero until the participant indicates that they can feel the vibration. Next you will be fitted with inertial sensors (Opal, APDM) in the form of wristbands on your wrists and over your shoes, and in the form of a vest and a belt for your torso. These body worn sensors include an accelerometer and gyroscope in the form of a wristwatch, and allow for body sway and precise joint angle information to be measured. After being fitted with the inertial sensors, your foot tapping ability will be measured. For this task you will be asked to tap your foot as many times as possible within a 10 second time period, this test will be performed three times total per foot.

Part II

For the physical balance testing, you will be asked to perform a series of balance trials while wearing the inertial sensors. First, a Berg Balance Scale will be performed where you will be asked to: stand unsupported for 10 seconds with feet apart or together, stand unsupported with eyes closed for 10 seconds, perform one forward reach without losing balance, transfer from one chair to another, lean forward and pick up an object off the ground, stand on a single leg for 10 seconds, and alternate placing a foot on a step while standing, turn 360 degrees without falling, and stand with feet in a heel to toe position for 30 seconds maximum.

Second, for the standing balance trials you will be asked to stand with eyes open for regular standing, narrow standing (feet together, parallel), standing and holding a maximal reach forwards, and standing and leaning backwards. These trials will occur 3 times, for 20 seconds each condition.

Third, for the standing and moving balance trials, you will be timed while walking 25ft at both your preferred and brisk walking speeds (25ft Walk Test), will be timed for performing 5 trials going from seated to standing (Sit to Stand Test), and will be timed for going from seated to standing, walking 10ft around a cone and returning back to the initial seated position (Timed Up and Go test). The standing and walking trials will occur 2 times, with the times recorded until test completion. The physical balance trials will include the Berg Balance scale plus twelve trials of standing balance and six standing and walking trials.

Part III

The last part of the data collection will include open ended interviewing to gain your MS related fall history, and to understand how MS impacts your life physiologically and/or psychologically. These interviews will be audiotaped and then transcribed into written format.

Intervention:

Part I:

By participating in this study you are agreeing to become a regular student of either YMAA

Western MA Tai Chi or Mindfulness Based Stress Reduction for a total of 8-weeks. To be a ‘regular’ student you will be expected to practice for a total of 5 hours per week of your assigned intervention (Tai Chi or Mindfulness), with a minimum of 2.5 hours of that total being made up by in class time with your intervention group, and the remaining 2.5 hours or less to be achieved through online home practice. For Mindfulness Meditation one weekly class (2.5 hours) will be scheduled based on group availability, while the those in the Tai Chi group can pick whichever class days/times work best for their schedule from within the available YMAA Western MA class schedule (2.5 hours).

Part II:

For the homework component of this study each participant will be given a secure login to the study website. From this website you will be able to access a variety of either Mindfulness Meditation Podcasts or Tai Chi videos (depending on your intervention group) for home practice. You may pick whichever podcasts or videos to practice along with to attain the total weekly practice goal of 5 hours. By logging into this website you will be able to see your progress towards your 5 hour weekly practice goal, which will include both class and homework practice time.

Part III:

The Washout period will begin after your 2nd data collection, during this period you will be asked to not practice your intervention for 2 weeks until the 3rd data collection has been completed.

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

Although you may not receive any direct benefits as a result of your participation in this study, we hope that through the Tai Chi or Mindfulness Based Stress Reduction classes that you may learn more about your own abilities and limits. In the event that the Tai Chi or Mindfulness Based Stress Reduction practice is helping you, both practices can be continued individually or as part of the local community after the study has ended. This research will contribute towards understanding how community-based interventions may improve physical and psychological aspects of balance in MS.

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

Data Collection:

We believe that the risks involved in this project are no different than what you encounter as you move about your environment in your normal daily life for the data collection protocol. Although we allow sufficient rest throughout the protocol to prevent you from becoming tired, you may experience some physical or mental fatigue during or after the protocol because you will be asked to stand and perform balance tasks. A chair will be provided for you to take rest breaks should you need any. During the standing and walking trials, a research assistant will walk alongside you to assure good balance.

Intervention:

There is a minimal fall risk when practicing Tai Chi, but it is no greater then what would occur while taking part in a senior center balance class. The Tai Chi classes are structured to help you build balance slowly, and practitioners are able to take rest breaks and water breaks as needed during the regular class period. Research assistants will attend the Tai Chi classes to assure good balance during Tai Chi form and learning/practicing the various Tai Chi techniques.

There is a minimal risk to psychological well-being in taking part in the Mindfulness Based Stress Reduction class as you may temporarily become more aware of negative emotions when working through constraints to meditation. However, the Mindfulness Based Stress Reduction class curriculum is structured to help people deal with these emotions and be able to move past them compassionately and non-judgmentally.

## 8. HOW WILL MY PERSONAL INFORMATION BE PROTECTED?

The following procedures will be used to protect the confidentiality of your study records. The researchers will keep all study records, including any numeric codes to your

data, in a secure location within a locked cabinet, in a locked laboratory. Research records will be labeled with an unidentifiable code. A master key that links names and codes will be maintained in this secure location. No electronic records containing identifiable information will be generated. Electronic records of unidentified data will be stored and analyzed on password-protected computers. 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?**

No compensation will be given to participants for participating in this study.

**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 researchrelated problem, you may contact the researcher(s), Richard Van Emmerik (413-545-0325) or Julianna Averill (413-695-8590). 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.

**10. 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.

**11. 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. In the case of a medical emergency at either the data collection site or at the intervention site, an ambulance will be called for the participant to obtain rapid medical attention.

**12. SUBJECT STATEMENT OF VOLUNTARY CONSENT**

When signing this form I am agreeing to voluntarily enter this study. I have had a chance to read this consent form, and it was explained to me in a language which I use and understand. I have had the opportunity to ask questions and have received satisfactory answers. I understand that I can withdraw at any time. A copy of this signed Informed Consent Form has been given to me.

**By checking this box I give my consent to being interviewed, and have my responses audiorecorded** ☐

| ____________________ | ____________________ | |
|---|---|---|
| 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 Obtaining Consent | Print Name: | Date: |

# PDDS Patient-Determined Disease Steps

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.

## Patient Administered Expanded Disability Status Scale

*****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.)*****

**Strength**:

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 the limb in the air | Can move limb, not raise it in the air | Cannot move limb at all |
|---|---|---|---|---|---|
| Right arm | | | | | |
| Left arm | | | | | |
| Right leg | | | | | |
| Left leg | | | | | |

**Coordination**:

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 | | | | | |

**Sensation:**

*****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**:

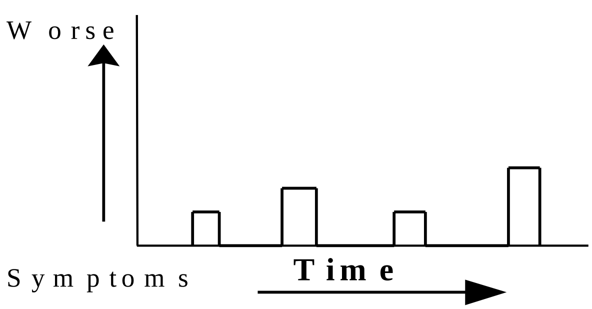
On an <u>average day,</u> my thinking and memory is:

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

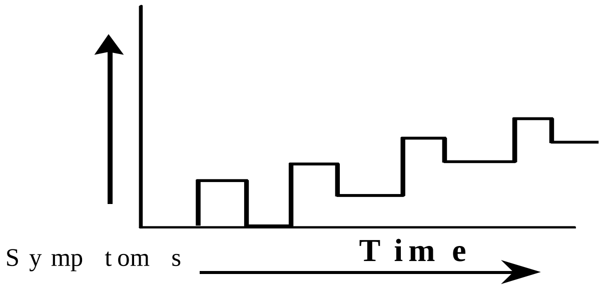
- ☐ Is the same as before I had MS
- ☐ Is almost the same as before I had MS
- ☐ Occasionally causes a problem in my daily life
- ☐ Frequently causes a problem in
- ☐ my daily life Others have to

help me manage my affairs

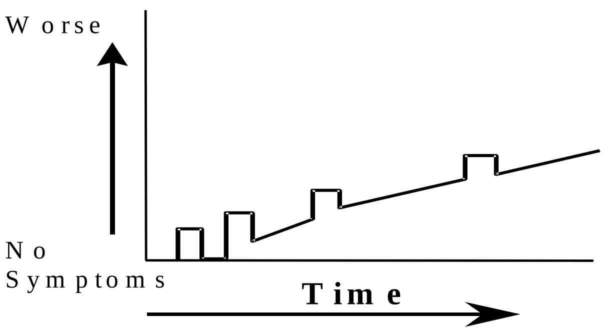
**Check *<u>only</u>* one box that best describes your *<u>MS disease activity over time</u>***



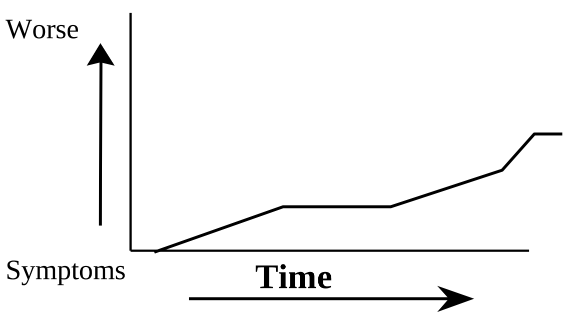

☐ Attacks (exacerbations, relapses) come on over a few hours or days, and last for a few hours or days, to several weeks but once they are over you feel the same as you always have.




☐ 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 then before. The symptoms that remain after the attack are stable until a new attack occurs.

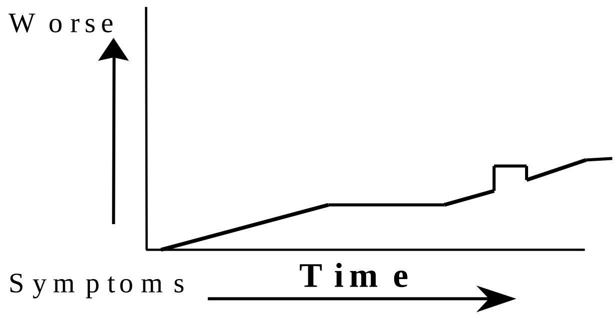



☐ At the start of the disease, attacks (exacerbations, relapses) occur. You may feel your symptoms get worse because of these attacks. Then even between the attacks, you feel you are getting worse. In some cases, attacks cease, yet your symptoms continued to worsen.




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

------------------------------------------------------------------------------------------------------------------------------------------------------------------




☐ 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.

# Appendix B

## The Activities-specific Balance Confidence (ABC) Scale*

**<u>Instructions to Participants:</u>** For each of the following activities, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale from 0% to 100% If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as if you were using these supports.

| 0% | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100% |
|---|---|---|---|---|---|---|---|---|---|---|
| No Confidence | | | | | | | | | Completely Confident | |

How confident are you that you will <u>not</u> lose your balance or become unsteady when you…

1. …walk around the house? _____%
2. …walk up or down stairs? _____%
3. …bend over and pick up a slipper from the front of a closet floor? _____%
4. …reach for a small can off a shelf at eye level? _____%
5. …stand on your tip toes and reach for something above your head? _____%
6. …stand on a chair and reach for something? _____%
7. …sweep the floor? _____%
8. …walk outside the house to a car parked in the driveway? _____%
9. …get into or out of a car? _____%
10. …walk across a parking lot to the mall? _____%
11. …walk up or down a ramp? _____%
12. …walk in a crowded mall where people rapidly walk past you? _____%
13. …are bumped into by people as you walk through the mall? _____%
14. …step onto or off of an escalator while you are holding onto a railing? _____%
15. …step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? _____%
16. …walk outside on icy sidewalks? _____%

*Powell LE & Myers AM. The Activities-specific Balance Confidence (ABC) Scale. Journal of Gerontology Med Sci 1995; 50(1):M28-34.

**Total ABC Score: __________**

# Coping Adaptation Processing Scale

**Directions**: Sometimes people experience very difficult events or crises in their lives. Below is a list of ways in which people respond to those events. For each item, please circle the number closest to how you personally respond: 1 = never; 2 = rarely; 3 = sometimes; or 4 = always.

"When I experience a crisis, or extremely difficult event, I…"

1 = NEVER 2 = RARELY 3 = SOMETIMES 4 = ALWAYS

| | **Never** | **Rarely** | **Sometimes** | **Always** |
|---|---|---|---|---|
| 1. Can follow a lot of directions at once, even in a crisis | 1 | 2 | 3 | 4 |
| 2. Call the problem what it is and try to see the whole picture | 1 | 2 | 3 | 4 |
| 3. Gather as much information as possible to increase my options | 1 | 2 | 3 | 4 |
| 4. Generally try to make everything work in my favor | 1 | 2 | 3 | 4 |

| | | | | |
|---|---|---|---|---|
| 5. Can think of nothing else, except what's bothering me | 1 | 2 | 3 | 4 |
| 6. Try to get more resources to deal with the situation | 1 | 2 | 3 | 4 |
| 7. Use humor in handling the situation | 1 | 2 | 3 | 4 |

Go to next page ⇨

1

# Coping Adaptation Processing Scale

"When I experience a crisis, or extremely difficult event, I…"

| | **Never** | **Rarely** | **Sometimes** | **Always** |
|---|---|---|---|---|
| 8. Am more effective under stress | 1 | 2 | 3 | 4 |
| 9. Take strength from spirituality or the successes of courageous people | 1 | 2 | 3 | 4 |

| | | | | |
|---|---|---|---|---|
| 10. Can benefit from my past experiences for what is happening now | 1 | 2 | 3 | 4 |
| 11. Try to be creative and come up with new solutions | 1 | 2 | 3 | 4 |
| 12. Brainstorm as many possible solutions as I can even if they seem far out | 1 | 2 | 3 | 4 |
| 13. Find I become ill | 1 | 2 | 3 | 4 |
| 14. Too often give up easily | 1 | 2 | 3 | 4 |
| 15. Develop a plan with a series of actions to deal with the event | 1 | 2 | 3 | 4 |

**Fatigue Severity Score – General**

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.

For each statement: Strongly Disagree is 1; Strongly Agree is 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 duties and responsibilities. | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| 8. Fatigue is among my most three disabling symptoms. | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| 9. Fatigue interferes with my work, family or social life. | **1** | **2** | **3** | **4** | **5** | **6** | **7** |

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

For each statement Completely Disagree is 1 Completely Agree is 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 both my legs limits my daily activity. | **1** | **2** | **3** | **4** | **5** | **6** | **7** |

**Abbreviated POMS (Revised Version)**

Below is a list of words that describe feelings people have. Please **CIRCLE THE NUMBER THAT BEST DESCRIBES HOW YOU FEEL RIGHT NOW**.

| | Not At All | A Little | Moderately | Quite a lot | Extremely |
|---|---|---|---|---|---|
| Tense | 0 | 1 | 2 | 3 | 4 |
| Angry | 0 | 1 | 2 | 3 | 4 |
| Worn Out | 0 | 1 | 2 | 3 | 4 |
| Unhappy | 0 | 1 | 2 | 3 | 4 |
| Proud | 0 | 1 | 2 | 3 | 4 |
| Lively | 0 | 1 | 2 | 3 | 4 |
| Confused | 0 | 1 | 2 | 3 | 4 |
| Sad | 0 | 1 | 2 | 3 | 4 |
| Active | 0 | 1 | 2 | 3 | 4 |
| On-edge | 0 | 1 | 2 | 3 | 4 |
| Grouchy | 0 | 1 | 2 | 3 | 4 |
| Ashamed | 0 | 1 | 2 | 3 | 4 |
| Energetic | 0 | 1 | 2 | 3 | 4 |
| Hopeless | 0 | 1 | 2 | 3 | 4 |
| Uneasy | 0 | 1 | 2 | 3 | 4 |
| Restless | 0 | 1 | 2 | 3 | 4 |
| Unable to concentrate | 0 | 1 | 2 | 3 | 4 |
| Fatigued | 0 | 1 | 2 | 3 | 4 |
| Competent | 0 | 1 | 2 | 3 | 4 |
| Annoyed | 0 | 1 | 2 | 3 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| Discouraged | 0 | 1 | 2 | 3 | 4 |
| Resentful | 0 | 1 | 2 | 3 | 4 |
| Nervous | 0 | 1 | 2 | 3 | 4 |
| Miserable | 0 | 1 | 2 | 3 | 4 |

**PLEASE CONTINUE WITH THE ITEMS ON THE NEXT PAGE**

| | **Not At All** | **A Little** | **Moderately** | **Quite a lot** | **Extremely** |
|---|---|---|---|---|---|
| Confident | 0 | 1 | 2 | 3 | 4 |
| Bitter | 0 | 1 | 2 | 3 | 4 |
| Exhausted | 0 | 1 | 2 | 3 | 4 |
| Anxious | 0 | 1 | 2 | 3 | 4 |
| Helpless | 0 | 1 | 2 | 3 | 4 |
| Weary | 0 | 1 | 2 | 3 | 4 |
| Satisfied | 0 | 1 | 2 | 3 | 4 |
| Bewildered | 0 | 1 | 2 | 3 | 4 |
| Furious | 0 | 1 | 2 | 3 | 4 |
| Full of Pep | 0 | 1 | 2 | 3 | 4 |
| Worthless | 0 | 1 | 2 | 3 | 4 |
| Forgetful | 0 | 1 | 2 | 3 | 4 |
| Vigorous | 0 | 1 | 2 | 3 | 4 |
| Uncertain about things | 0 | 1 | 2 | 3 | 4 |
| Bushed | 0 | 1 | 2 | 3 | 4 |
| Embarrassed | 0 | 1 | 2 | 3 | 4 |

Copyright © 1993 J.R. Grove, PhD for abbreviated POMS

# Multiple Sclerosis Impact Scale (MSIS-29)

- The following questions ask for your views about the impact of MS on your day-to-day life **during the past two weeks**
- For each statement, please **circle** the **one** number that **best** describes your situation
- Please answer **all** questions

| **In the <u>past two weeks</u>, 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 <u>past two weeks</u>, 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 |

**Please check that you have answered all the questions before going on to the next page**

**®2000 Neurological Outcome Measures Unit, 4th Floor Queen Mary Wing, NHNN, Queen Square, London WC1N 3BG, UK**

| 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.** | **Problems concentrating?** | 1 | 2 | 3 | 4 | 5 |
| **28** | **Lack of confidence?** | 1 | 2 | 3 | 4 | 5 |
| **29.** | **Feeling depressed?** | 1 | 2 | 3 | 4 | 5 |

**Please check that you have circled ONE number for EACH question**

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# APPENDIX C

*Table C1: Static Postural Data ANOVA Table*

| ANOVA Postural Variables | Factor | F-Value | P-Value |
|---|---|---|---|
| **QS 95% Ellipse Sway (m^2/s^4)** | Time | 1.81 | 0.192 |
| | Group | 6.66 | 0.019 |
| | Group*Time | 3.86 | 0.030 |
| | | | |
| **QS Mean Velocity (m/s)** | Time | 0.17 | 0.846 |
| | Group | 2.75 | 0.115 |
| | Group*Time | 1.32 | 0.304 |
| | | | |
| **NS 95% Ellipse Sway (m^2/s^4)** | Time | 1.50 | 0.249 |
| | Group | 5.38 | 0.032 |
| | Group*Time | 2.86 | 0.068 |
| | | | |
| **NS Mean Velocity (m/s)** | Time | 1.00 | 0.385 |
| | Group | 1.29 | 0.271 |
| | Group*Time | 1.02 | 0.409 |
| | | | |
| **FR 95% Ellipse Sway (m^2/s^4)** | Time | 2.33 | 0.125 |
| | Group | 0.76 | 0.393 |
| | Group*Time | 0.77 | 0.525 |
| | | | |
| **FR Mean Velocity (m/s)** | Time | 2.03 | 0.158 |
| | Group | 2.27 | 0.149 |
| | Group*Time | 3.00 | 0.059 |
| | | | |
| **BL 95% Ellipse Sway (m^2/s^4)** | Time | 0.13 | 0.883 |
| | Group | 1.28 | 0.273 |
| | Group*Time | 0.52 | 0.675 |
| | | | |
| **BL Mean Velocity (m/s)** | Time | 0.65 | 0.535 |
| | Group | 2.64 | 0.121 |
| | Group*Time | 0.88 | 0.473 |

*Note: Static Postural Data ANOVA Table. P-Values of 0.05 or less indicate a significant change. Abbreviations include: Quiet Stance (QS), Narrow Stance (NS), Forward Reach (FR), and Backwards Lean (BL). Time includes data over 3 visits: baseline, after the 8-week Intervention, after the 2 week wash out period.*

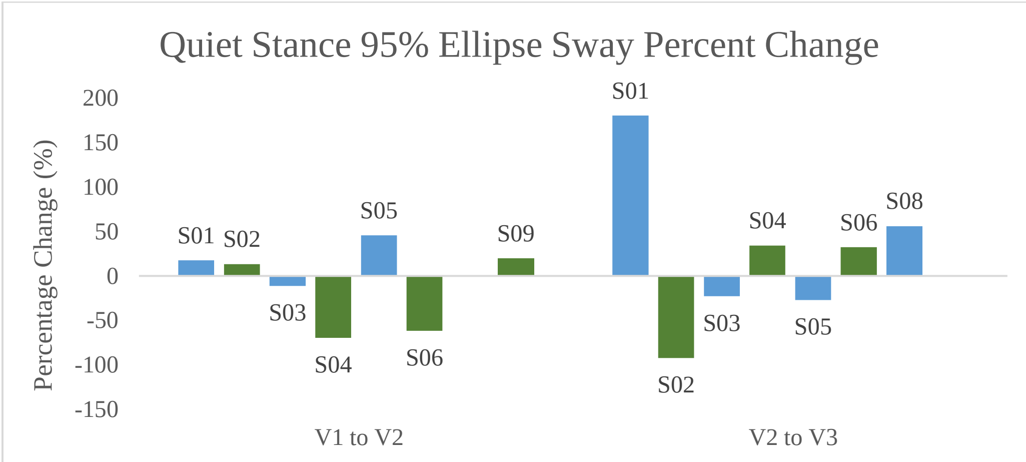


*Figure C1: Quiet Stance 95% Ellipse Sway Percent Change. Quiet Stance (QS) 95% Ellipse sway is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased sway area, and a negative change of reduced sway area.*

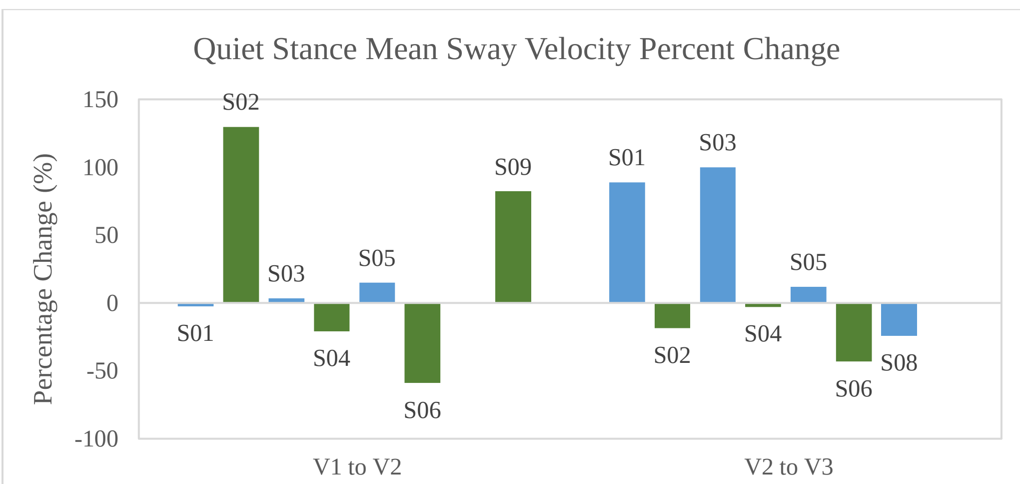


*Figure C2: Quiet Stance Mean Sway Velocity Percent Change. Quiet Stance mean sway velocity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased mean sway velocity, and a negative change of decreased mean sway velocity.*

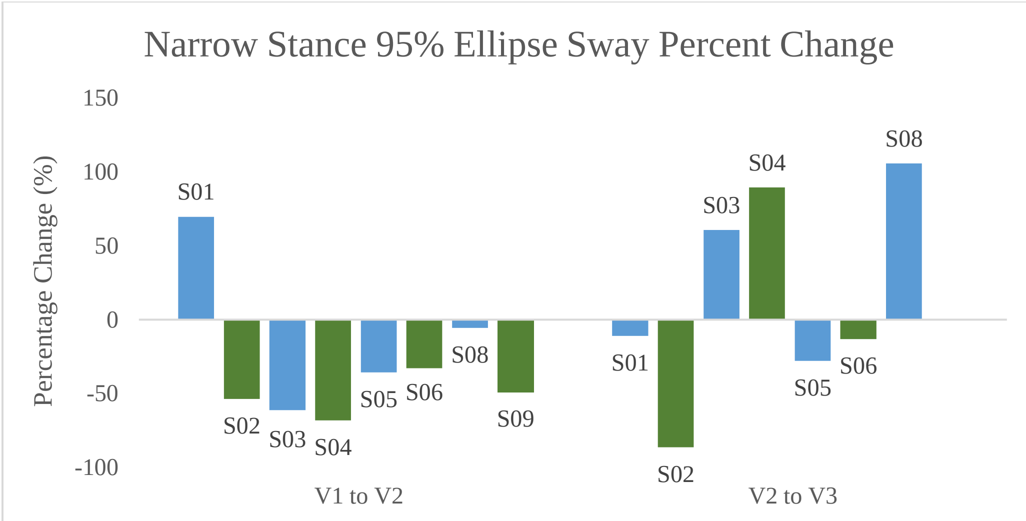


*Figure C3: Narrow Stance 95% Ellipse Sway Percent Change. Narrow 95% Ellipse sway is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased sway area, and a negative change of reduced sway area.*

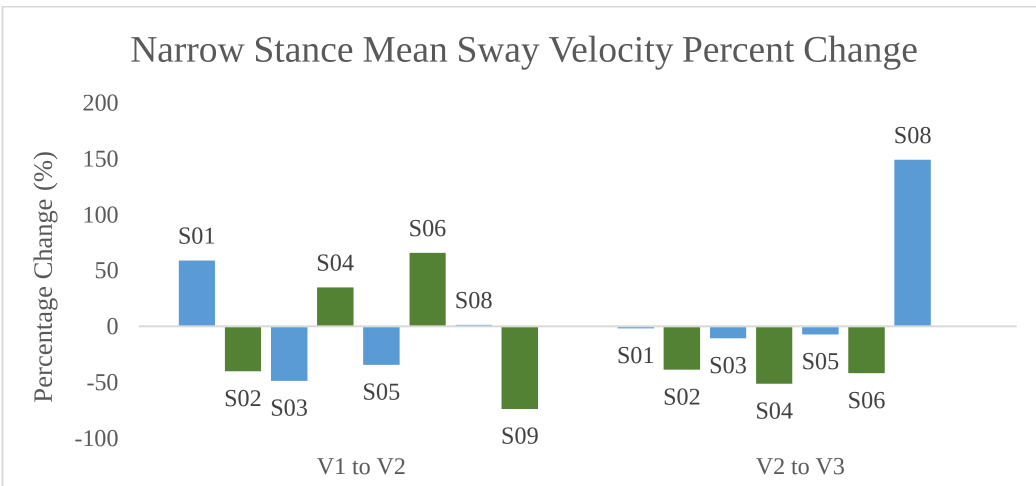


*Figure C4: Narrow Stance Mean Sway Velocity Percent Change. Narrow stance mean sway velocity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased mean sway velocity, and a negative change of decreased mean sway velocity. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*

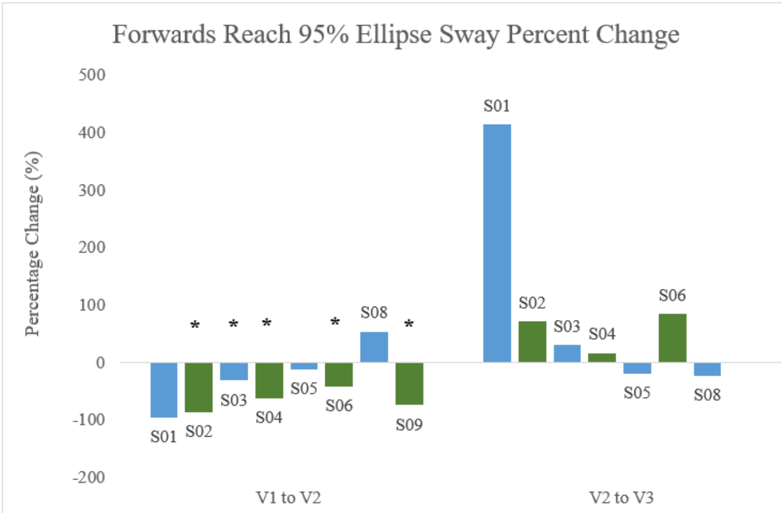


*Figure C5: Forwards Reach 95% Ellipse Sway Percent Change. Forwards Reach 95% Ellipse sway is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased sway area, and a negative change of reduced sway area. The Asterisk (*) indicates the participants who increased their FR distance from V1 to V2. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*

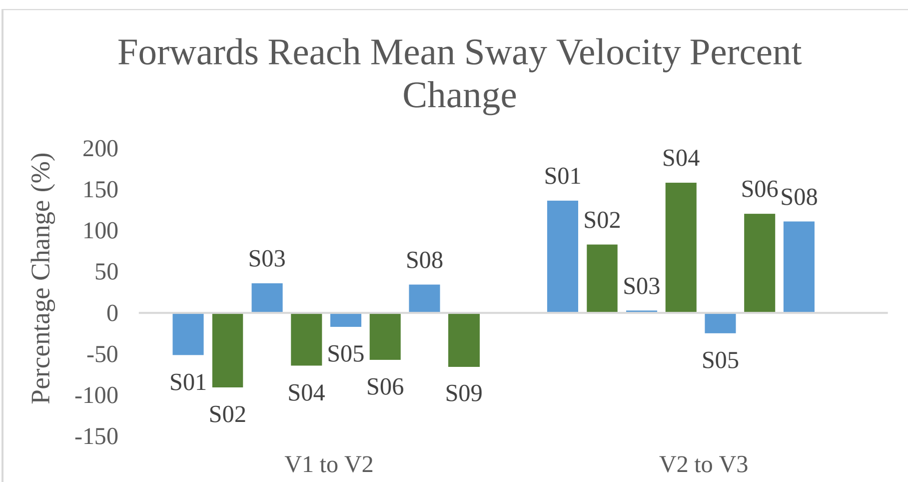


*Figure C6: Forwards Reach Mean Sway Velocity Percent Change. Forwards Reach mean sway velocity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased mean sway velocity, and a negative change of decreased mean sway velocity. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*

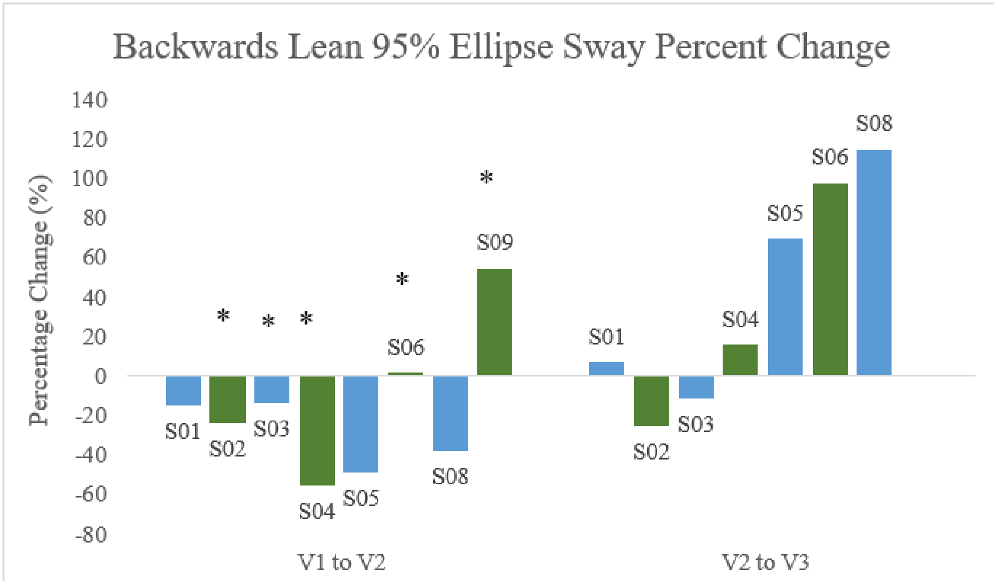


*Figure C7: Backwards Lean 95% Ellipse Sway Percent Change. Backwards Lean 95% Ellipse sway is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased sway area, and a negative change of reduced sway area. The Asterisk (*) indicates the participants who increased their BL distance from V1 to V2. Note- columns were not listed if participants maintained the same values (0% change).*

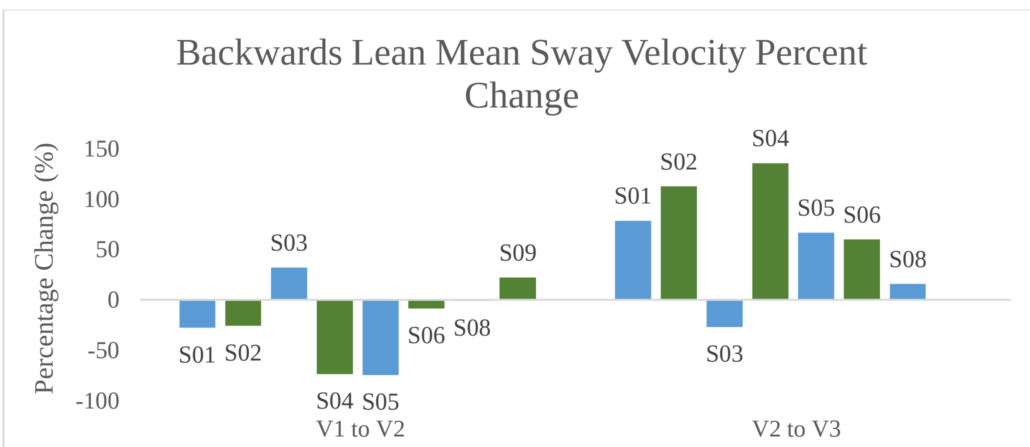


*Figure C8: Backwards Lean Mean Sway Velocity Percent Change. Backwards lean mean sway velocity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased mean sway velocity, and a negative change of decreased mean sway velocity. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*

*Table C2: TUG*

| **ANOVA TUG Variables** | **Factor** | **F-Value** | **P-Value** |
|---|---|---|---|
| Average TUG Trial Duration (s) | Time | 0.06 | 0.946 |
| | Group | 10.19 | 0.005 |
| | Group*Time | 3.29 | 0.045 |
| Average TUG Sit to Stand – Duration (s) | Time | 0.00 | 1.00 |
| | Group | 7.74 | 0.012 |
| | Group*Time | 4.72 | 0.014 |
| Average TUG Stand-Sit Duration (s) | Time | 0.20 | 0.818 |
| | Group | 5.43 | 0.031 |
| | Group*Time | 3.18 | 0.051 |
| Average TUG Turn Duration (s) | Time | 0.38 | 0.690 |
| | Group | 15.93 | 0.001 |
| | Group*Time | 5.37 | 0.009 |

*Note: P-Values of 0.05 or less indicate a significant change. Abbreviations include: Timed Up and Go (TUG). Groups: Tai Chi (TC), Mindfulness Based Stress Reduction (MBSR). Time includes data over 3 visits: baseline, after the 8-week Intervention, after the 2 week wash out period.*

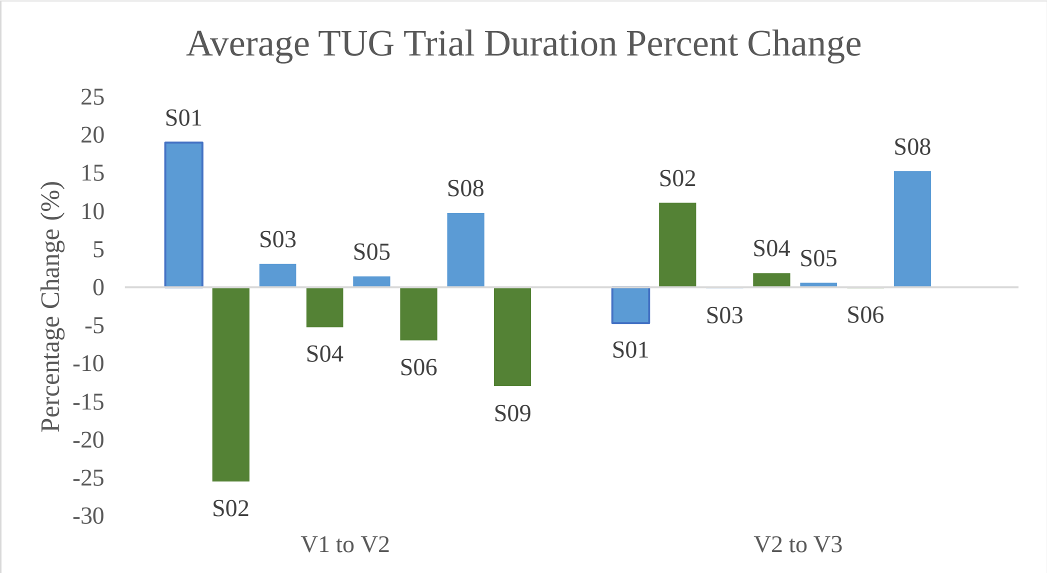


*Figure C10: Average TUG Trial Duration Percent Change. TUG duration is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased (slower) TUG times, and a negative change of decreased (faster) TUG*

*times. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*

*Table C3: STS*

| ANOVA STS Variables | Factor | F-Value | P-Value |
|---|---|---|---|
| Average STS Trial Duration (s) | Time | 1.47 | 0.256 |
| | Group | 0.84 | 0.371 |
| | Group*Time | 0.50 | 0.685 |
| Average Sit to Stand – Duration (s) | Time | 0.94 | 0.407 |
| | Group | 3.39 | 0.081 |
| | Group*Time | 1.72 | 0.201 |
| Average Stand-Sit Duration (s) | Time | 0.63 | 0.541 |
| | Group | 0.56 | 0.462 |
| | Group*Time | 0.33 | 0.802 |

*Note: P-Values of 0.05 or less indicate a significant change. Average STS trial duration is the overall time for participants to complete 5 sit to stand transitions, with individual components of Sit to Stand and Stand to Sit times as well. Abbreviations include: Sit to Stand (STS). Groups: Tai Chi (TC), Mindfulness Based Stress Reduction (MBSR). Time includes data over 3 visits: baseline, after the 8-week Intervention, after the 2 week wash out period.*

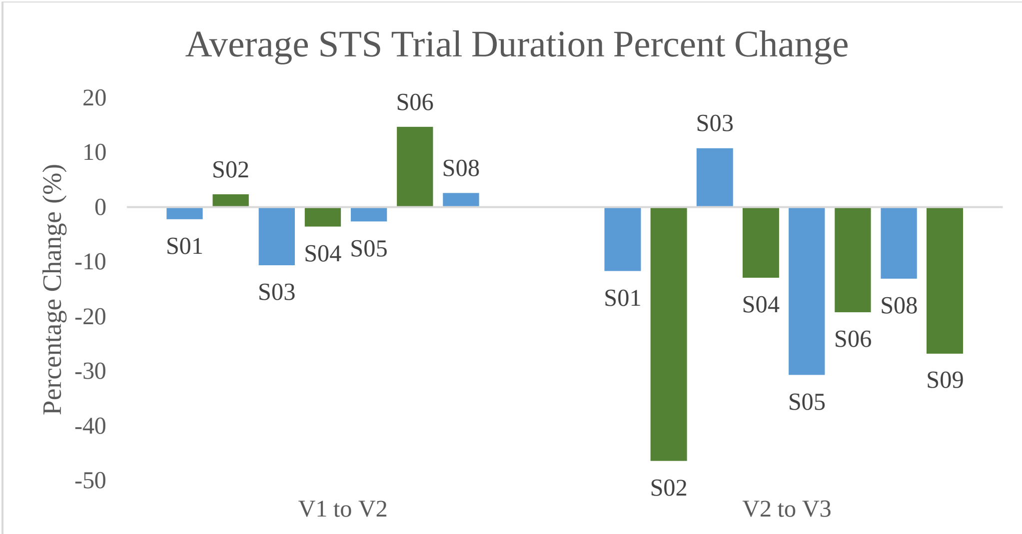


*Figure C11: Average STS Trial Duration Percent Change. STS trial duration is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased (slower) STS times, and a negative change of decreased (faster) STS times. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*

*Table C4: 25ft Walk*

| ANOVA Characteristics | Factor | F-Value | P-Value |
|---|---|---|---|
| Average 25ft Walk Duration (s) | Time | 0.24 | 0.788 |
| | Group | 8.96 | 0.007 |
| | Group*Time | 2.70 | 0.078 |
| Stride Length LF (m) | Time | 0.60 | 0.559 |
| | Group | 17.88 | 0.000 |
| | Group*Time | 5.86 | 0.006 |
| Stride Length MF (m) | Time | 0.75 | 0.485 |
| | Group | 21.66 | 0.000 |
| | Group*Time | 6.97 | 0.003 |
| Dual Support Time LF (GCT%) | Time | 0.24 | 0.785 |
| | Group | 0.13 | 0.721 |
| | Group*Time | 0.12 | 0.948 |
| Dual Support Time MF (GCT%) | Time | 0.30 | 0.744 |
| | Group | 0.08 | 0.778 |
| | Group*Time | 0.05 | 0.983 |

*Note: P-Values of 0.05 or less indicate a significant change. Average 25ft walk duration (s) is the main trial variable, also included are stride length and dual support times of the gait cycle. Both stride length and dual support measures have been organized so the data represents the participants 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Abbreviations include: Global Cycle Time (GCT) %. Groups: Tai Chi (TC), Mindfulness Based Stress Reduction (MBSR). Time includes data over 3 visits: baseline, after the 8-week Intervention, after the 2 week wash out period.*

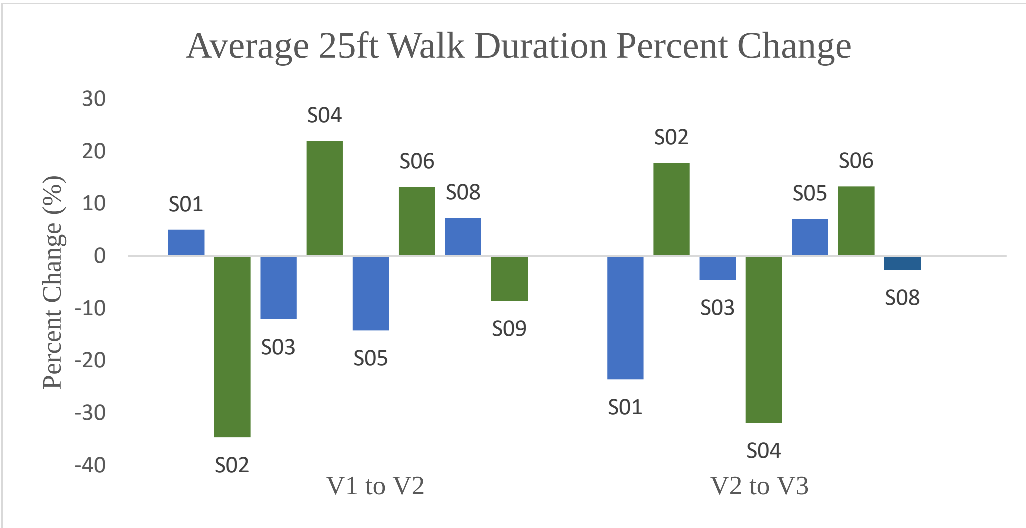


*Figure C12: Average 25ft Walk Duration Percent Change. 25ft walk trial duration is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased (slower) TUG times, and a negative change of decreased (faster) walk times. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same 25ft walk values, so it would be 0% change in their case.*

*Table C5: Psychosocial Data ANOVA Table*

| ANOVA Questionnaire Variables | Factor | F-Value | P-Value |
|---|---|---|---|
| **Activities Balance Confidence** | Time | 0.39 | 0.680 |
| | Group | 17.46 | 0.00 |
| | Group*Time | 5.57 | 0.007 |
| | | | |
| **Abbreviated Profile of Mood States** | Time | 0.21 | 0.816 |
| | Group | 2.64 | 0.120 |
| | Group*Time | 0.79 | 0.513 |
| | | | |
| **Coping Adaptation Processing Scale** | Time | 0.64 | 0.537 |
| | Group | 0.56 | 0.465 |
| | Group*Time | 0.29 | 0.833 |
| | | | |
| **Fatigue Severity Scale** | Time | 2.17 | 0.140 |
| | Group | 11.46 | 0.003 |
| | Group*Time | 4.03 | 0.023 |
| | | | |
| **MSIS-29 Total Score** | Time | 1.29 | 0.297 |
| | Group | 3.09 | 0.094 |
| | Group*Time | 0.95 | 0.435 |
| | | | |
| **MSIS-29 Psychological Score** | Time | 1.28 | 0.299 |
| | Group | 0.00 | 0.985 |
| | Group*Time | 0.02 | 0.995 |
| | | | |
| **MSIS-29 Physical Score** | Time | 1.12 | 0.347 |
| | Group | 5.88 | 0.025 |
| | Group*Time | 1.86 | 0.173 |

*Note-. P-Values of 0.05 or less indicate a significant change. Groups include Tai Chi and MBSR. Time includes data over 3 visits: baseline, after the 8-week Intervention, after the 2 week wash out period.*

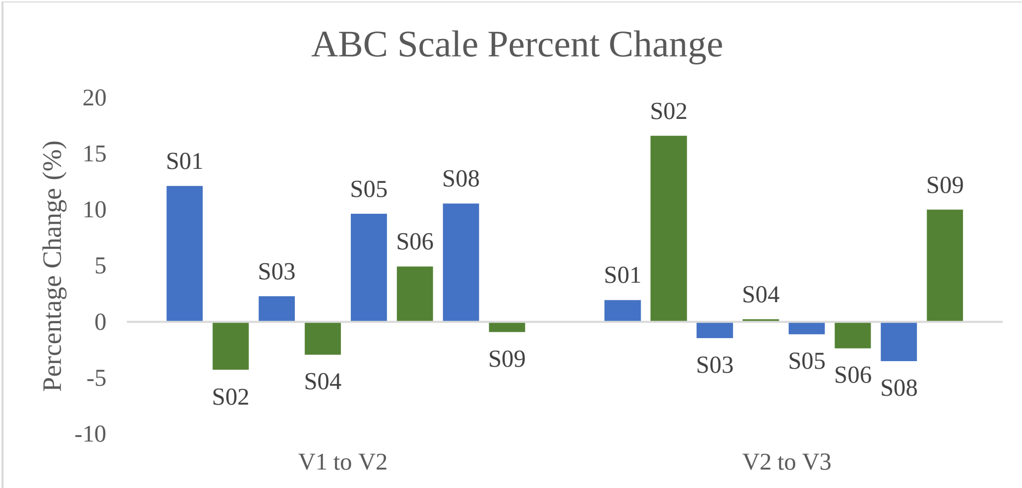


*Figure 14: Activities Balance Confidence Percent Change. Balance Confidence is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased balance confidence, and a negative change of reduced balance confidence. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same questionnaire values, so it would be 0% change in their case.*

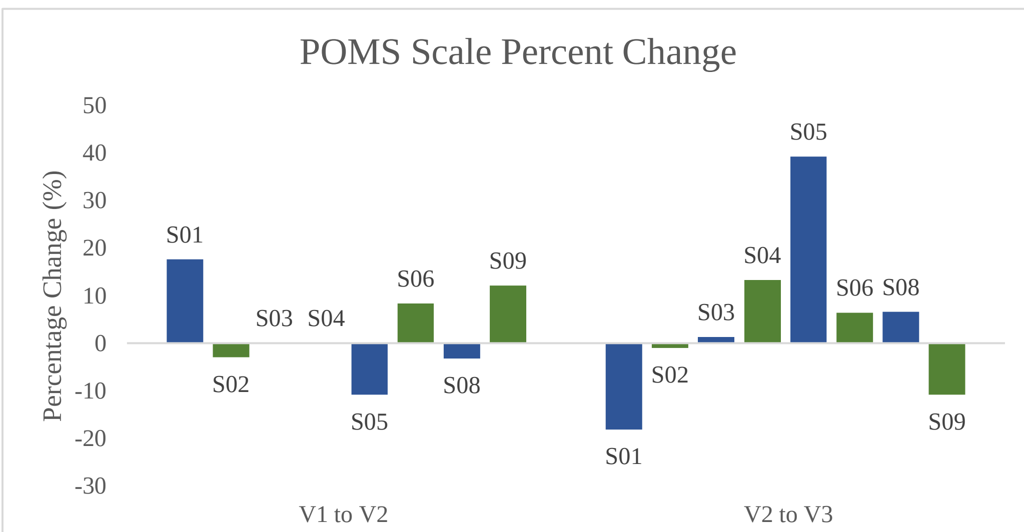


*Figure C14: POMS Scale Percent Change. Profile of mood states is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased mood disturbance, while a negative change indicates increased positive affect. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same questionnaire values, so it would be 0% change in their case.*

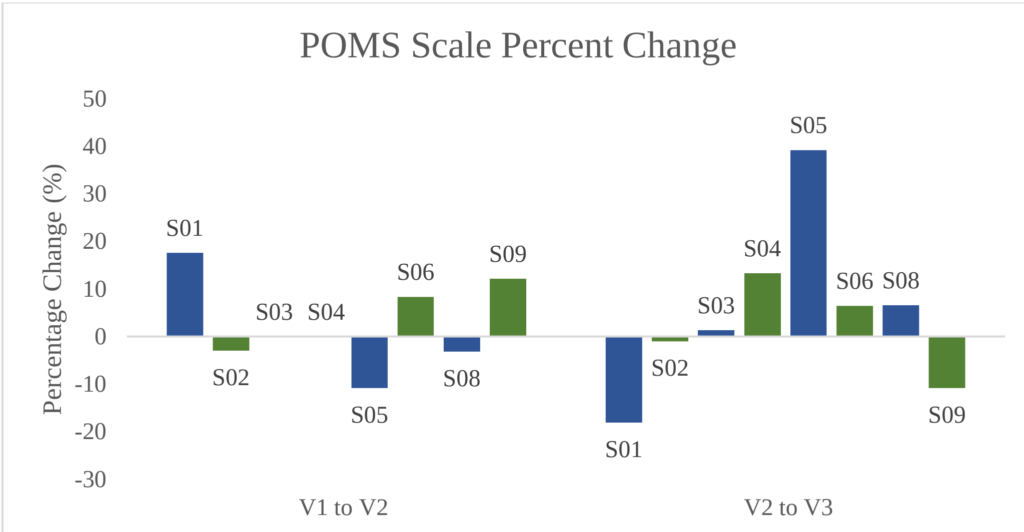


*Figure 15CAPS Scale Percent Change Coping ability and processing is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased coping ability, while a negative change indicates decreased coping ability. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same questionnaire values, so it would be 0% change in their case.*

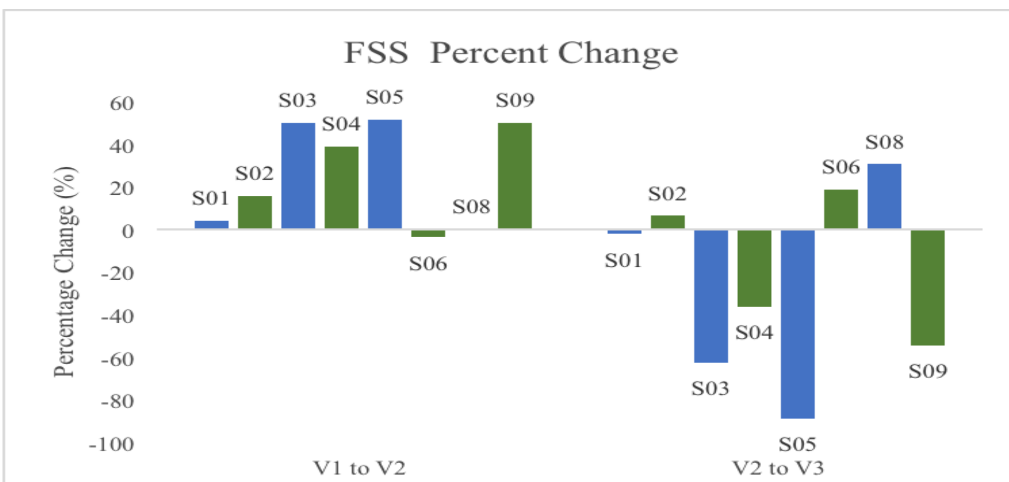


*Figure C16: Fatigue Severity Percent Change. FSS is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of reduced fatigue severity, and a negative change of increased fatigue severity. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same questionnaire values, so it would be 0% change in their case.*

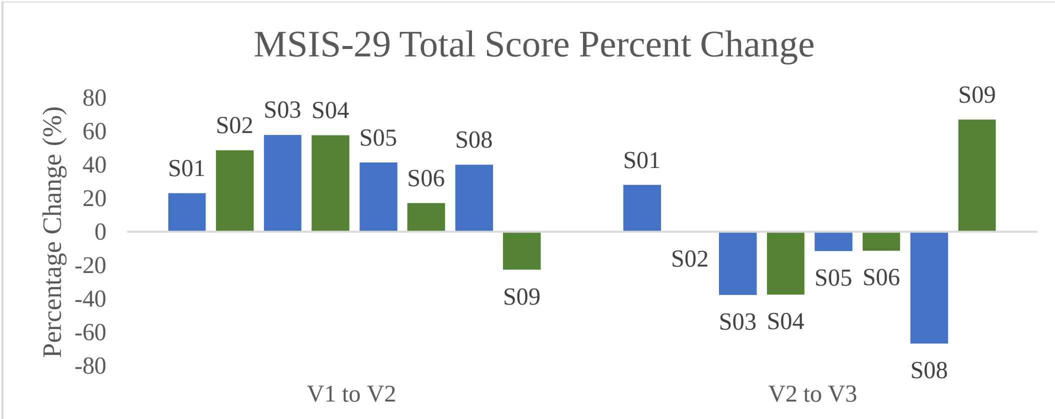


*Figure C1716: MSIS-29 Total Score Percent Change. MS symptom severity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of reduced MS symptom impact on daily wellbeing, and a negative change being increased MS symptom severity impacting daily wellbeing. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same questionnaire values, so it would be 0% change in their case.*

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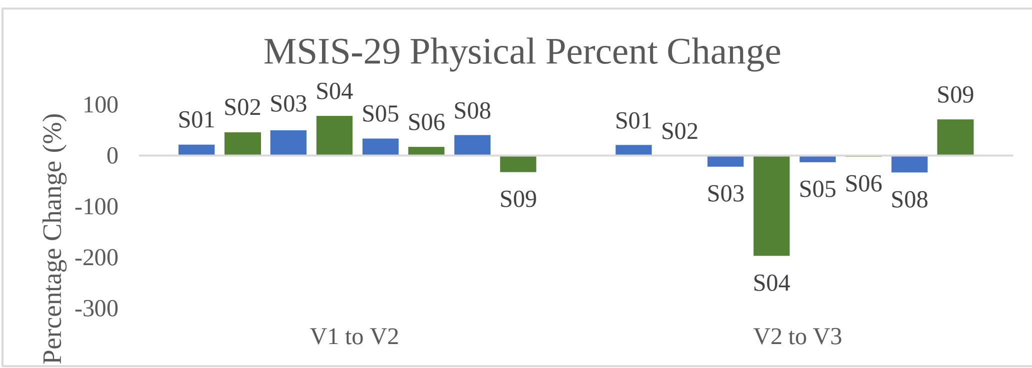



*Figure C18: MSIS-29 Physical Percent Change. MS symptom severity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of reduced MS physical symptom impact on daily wellbeing, and a negative change being increased MS physical symptom severity impacting daily wellbeing. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same questionnaire values, so it would be 0% change in their case.*

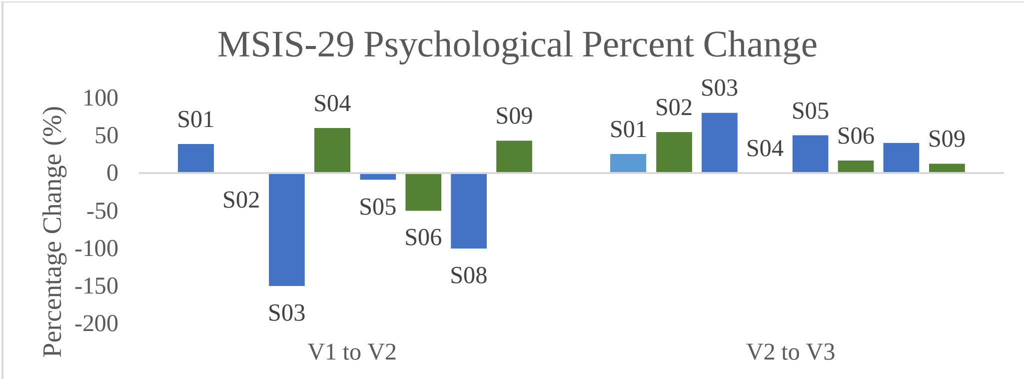



*Figure C19: MSIS-29 Psychological Percent Change. MS symptom severity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of reduced MS psychological symptom impact on daily wellbeing, and a negative change being increased MS psychological symptom severity impacting daily wellbeing. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same questionnaire values, so it would be 0% change in their case.*

Table C6: Plantar Sensitivity

| ANOVAs by Site | Factor | F-Value | P-Value |
|---|---|---|---|
| Hallux GS (volts) | Time | 0.39 | 0.681 |
| | Group | 4.46 | 0.048 |
| | Group*Time | 0.43 | 0.786 |
| Hallux LS (volts) | Time | 0.32 | 0.730 |
| | Group | 2.19 | 0.155 |
| | Group*Time | 0.21 | 0.930 |
| Metatarsal 5 GS (volts) | Time | 0.80 | 0.463 |
| | Group | 0.67 | 0.425 |
| | Group*Time | 0.95 | 0.459 |
| Metatarsal 5 LS (volts) | Time | 0.07 | 0.929 |
| | Group | 0.92 | 0.350 |
| | Group*Time | 0.07 | 0.991 |
| Heel GS (volts) | Time | 0.78 | 0.472 |
| | Group | 0.30 | 0.593 |
| | Group*Time | 0.65 | 0.638 |
| Heel LS (volts) | Time | 0.08 | 0.922 |
| | Group | 3.00 | 0.100 |
| | Group*Time | 0.26 | 0.900 |

*Notes: P-Values of 0.05 or less indicate a significant change. Vibration sensitivity at three sites on the foot was measured for the hallux, metatarsal five (M5), and the heel. The foot with 'Greater sensitivity' (GS) is the foot which could perceive the smallest amount of vibration at the baseline visit, the 'Less Sensitive foot' (LS) is the foot which needed a larger amount of vibration to be perceived at baseline. Groups: Tai Chi (TC), Mindfulness Based Stress Reduction (MBSR). Time includes data over 3 visits: baseline, after the 8-week Intervention, after the 2 week wash out period.*

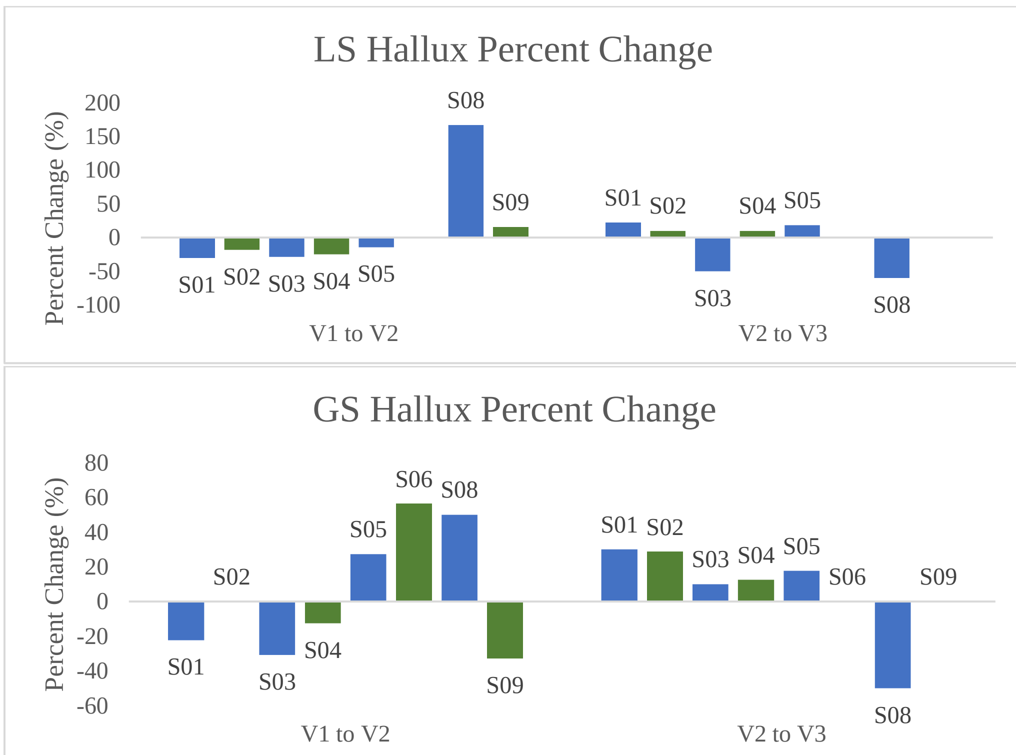
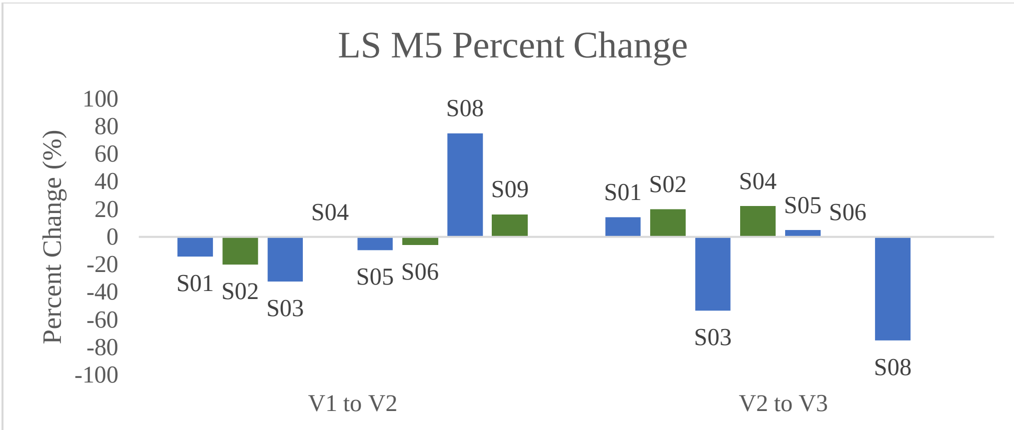



*Figure C20: Plantar Sensitivity of LS & GS Halluxes Percent Change. Percent change of smallest perceivable vibration thresholds are plotted by group and visit. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week wash out period.*



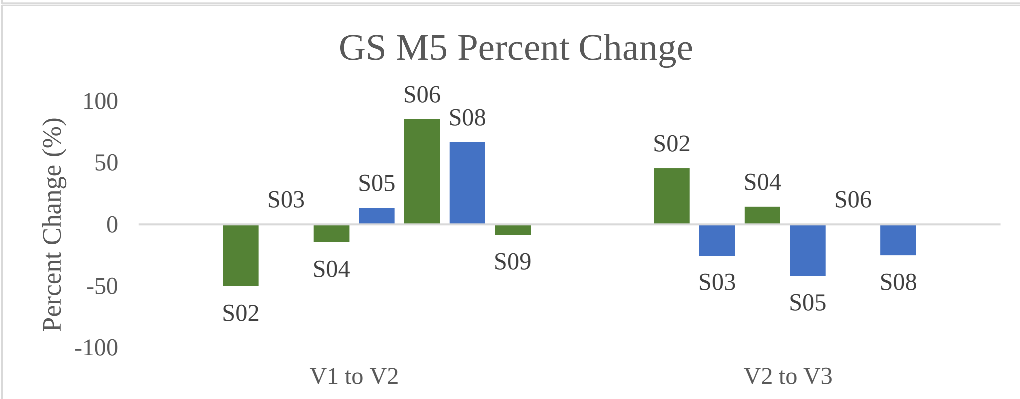




*Figure C21: Plantar Sensitivity of LS & GS M5 Percent Change. Percent change of smallest perceivable vibration thresholds are plotted by group and visit. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week wash out period.*

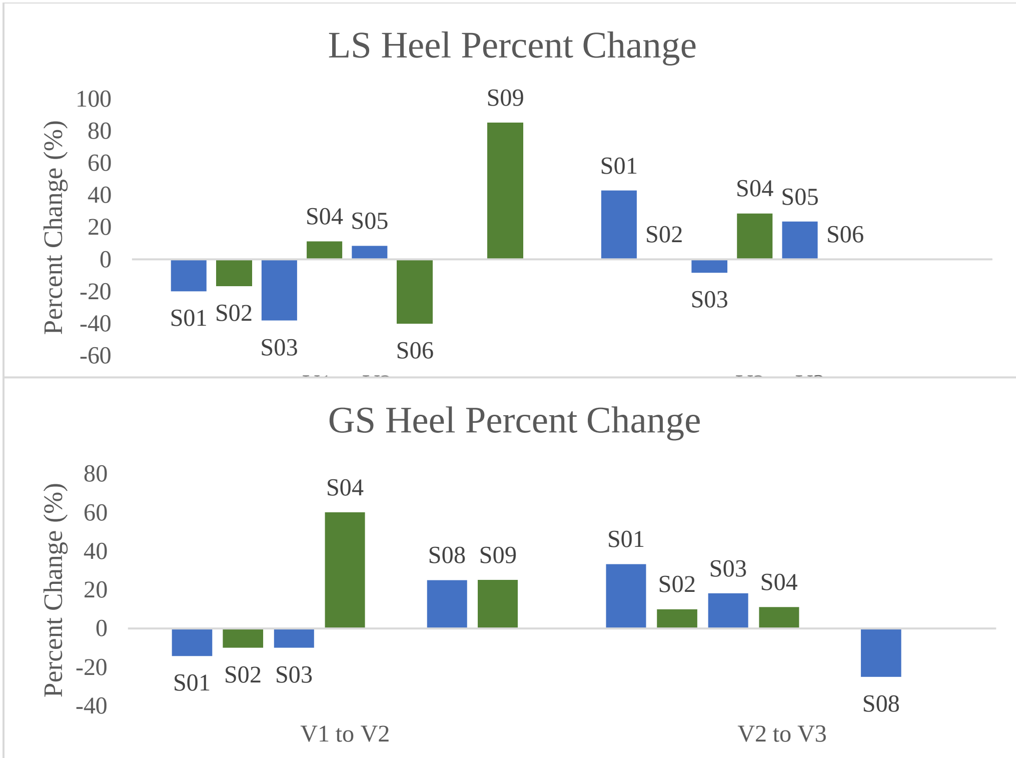
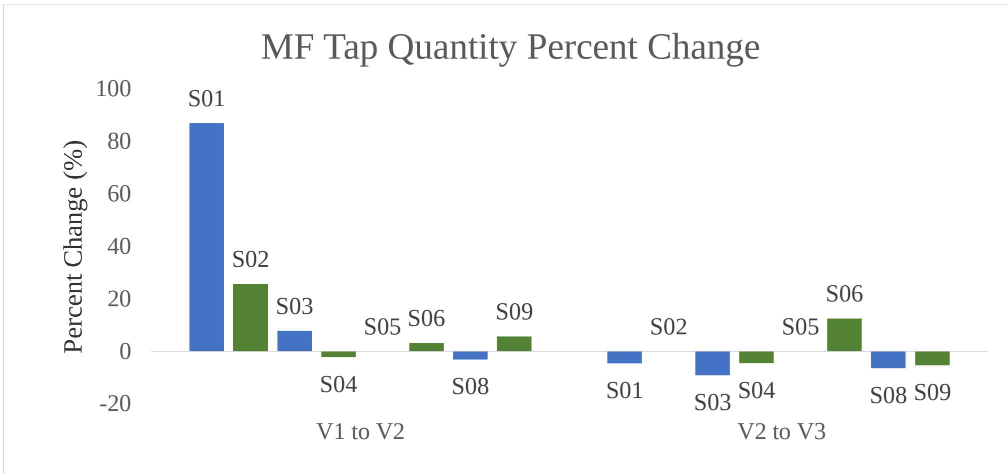



*Figure C2217:Plantar Sensitivity of LS & GS Heel Percent Change. Percent change of smallest perceivable vibration thresholds are plotted by group and visit. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week wash out period.*

*Table C7: Foot Tapping ANOVA Table*

| **ANOVA Foot Tapping Values** | **Factor** | **F-Value** | **P-Value** |
|---|---|---|---|
| Tap Quantity MF (#) | Time | 0.38 | 0.690 |
| | Group | 2.80 | 0.110 |
| | Group*Time | 0.19 | 0.942 |
| Tap Quantity LF (#) | Time | 0.21 | 0.816 |
| | Group | 0.02 | 0.899 |
| | Group*Time | 0.15 | 0.961 |
| Inter Tap Interval MF (ms) | Time | 0.30 | 0.741 |
| | Group | 0.11 | 0.747 |
| | Group*Time | 0.27 | 0.894 |
| Inter Tap Interval LF (ms) | Time | 0.16 | 0.854 |
| | Group | 3.71 | 0.068 |
| | Group*Time | 0.19 | 0.943 |
| Tap CoefV MF (%) | Time | 0.78 | 0.471 |
| | Group | 3.03 | 0.097 |
| | Group*Time | 1.02 | 0.423 |
| Tap CoefV LF (%) | Time | 1.33 | 0.288 |
| | Group | 4.26 | 0.052 |
| | Group*Time | 0.91 | 0.482 |

*Note: P-Values of 0.05 or less indicate a significant change. Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Data have been organized into 'More Functional Leg' (MF) versus their 'Less Functional leg' (LF) based on foot tap counts at baseline. Groups: Tai Chi (TC) and Mindfulness Based Stress Reduction (MBSR). Visits: Visit 1 is baseline, Visit 2 is after the 8-week Intervention, and Visit 3 is after the 2 week wash out period. Abbreviations: Coefficient of Variation (CoefV).*



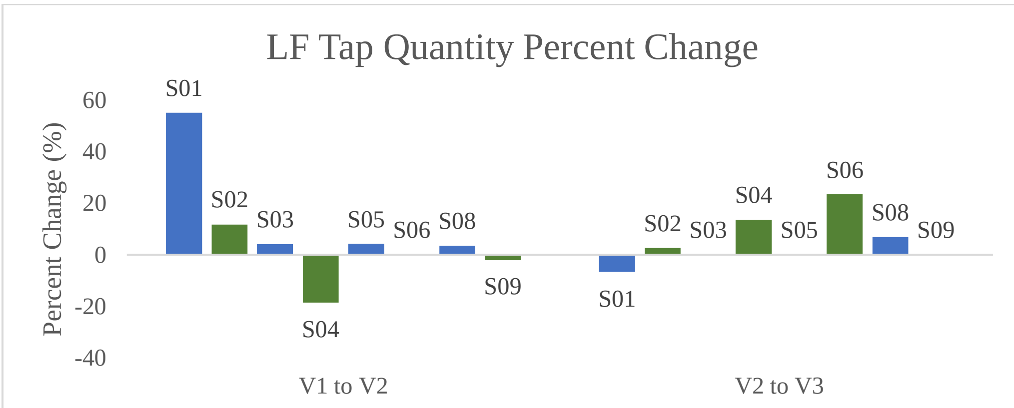
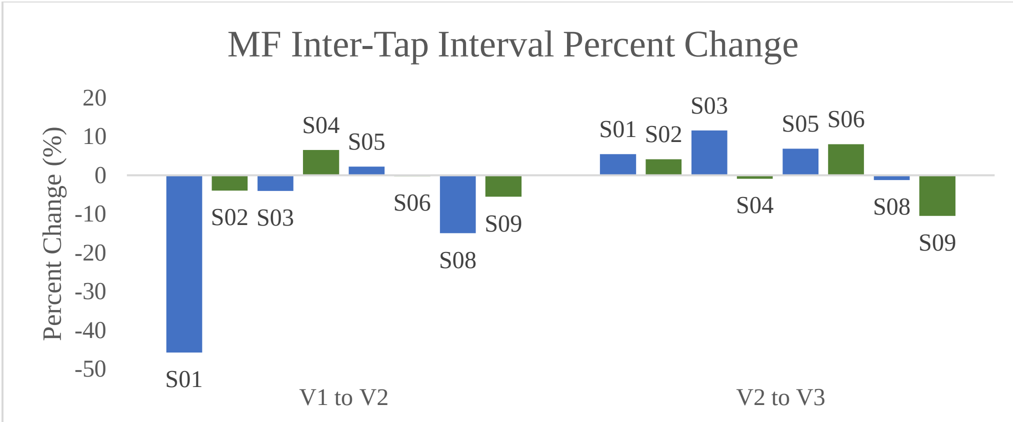




*Figure C23: Tap Quantity Percent Change Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Tap quantity is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A positive percent change is indicative of increased foot tapping quantity, whereas a negative percent change is indicative of reduced tap quantity. Note-Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*



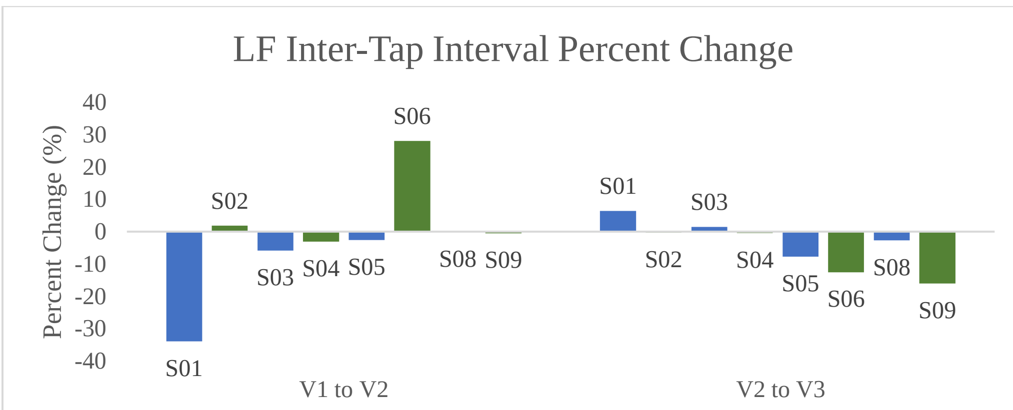
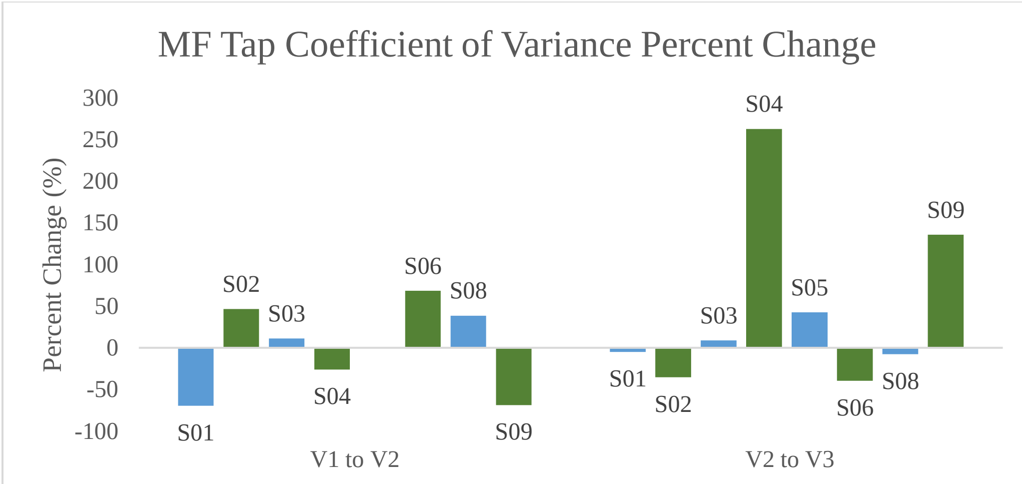




Figure C24: Inter-Tap Interval Percent Change. *Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Inter-tap interval is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A negative percent change is indicative of reduced inter-tap interval, whereas a positive change is an increase in inter-tap interval. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*



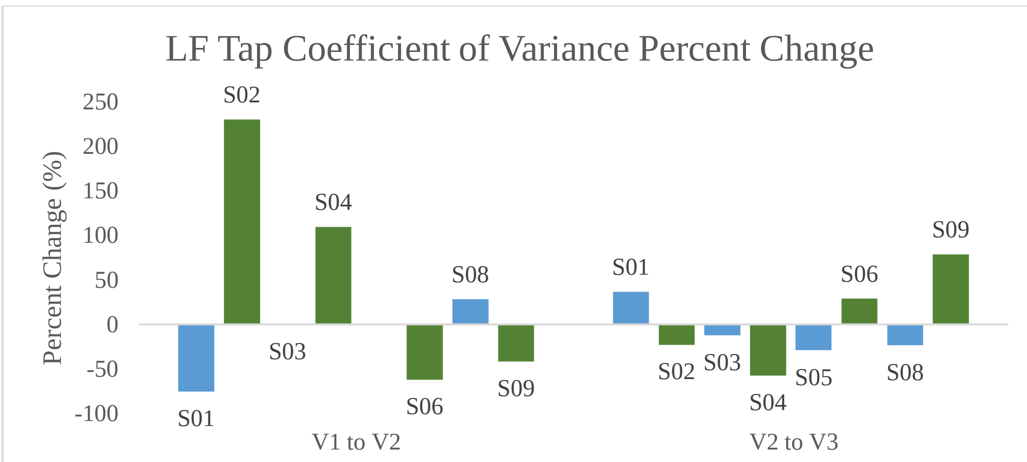




*Figure C25: Tap Coefficient of Variation Percent Change. Foot tapping data are based on angular velocity measured via a gyroscope in the opal foot sensors for the individual tap counts, timing, and standard deviation. Tap coefficient of variation is plotted by individual for percent change from V1 to V2 (intervention) and from V2 to V3 (wash out period). The groups are color coded with Tai Chi in blue and MBSR in green. A negative percent change is indicative of reduced coefficient of variation, whereas a positive change is an increase in the coefficient of variation. Note- Participants would not have a column listed for V1 to V2 or V2 to V3 if they maintained the exact same trial values, so it would be 0% change in their case.*

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