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The immediate effects of Tai Chi on the postural stability, muscle activity and measures of inferred ankle proprioception of healthy young adults

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The Immediate Effects of Tai Chi on the Postural Stability, Muscle Activity and Measures of Inferred Ankle Proprioception of Healthy Young Adults

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List of Abbreviations

- COM – Center of Mass
- BOS – Base of Support
- COP – Center of Pressure
- AP – Anteroposterior
- ML – Mediolateral
- CNS – Central Nervous System
- EO – Eyes Open
- EC – Eyes Closed
- EA – 95% Elliptical Area
- MSV – Mean Sway Velocity
- RP – Relative Mean Power
- cm – Centimeters
- s – Seconds
- min – Minutes
- ICC – Intra-Class Correlation
- GTO – Golgi Tendon Organs
- SENIAM – Surface Electromyography for the Non-Invasive Assessment of Muscles
- EMG – Electromyography
- TA – Tibialis Anterior
- GM – Gastrocnemius Medialis
- TTDPM – Threshold to Detection of Passive Motion
- JPR – Joint Position Reproduction

- RMS – Root Mean Square
- Hz – Hertz
- PSI – Pounds Per Square Inch
- COVID-19 – coronavirus disease

Abstract

Tai Chi has often been applied in research among older adults to affect postural stability and proprioception in the lower limbs; however, little is known about the effects Tai Chi may have in these domains among healthy young adults. Therefore, the aim of the present study was to investigate these potential effects. A total of 30 (17 females and 13 males) healthy young adults were randomized to either an experimental group or control group. To assess postural stability, both groups performed a pre-intervention postural stability task under eyes open/closed and firm/foam surface conditions, while center of pressure-based measures of mean sway velocity (MSV) and 95% elliptical area (EA) were collected. Ankle proprioception was inferred using electromyography data from the tibialis anterior and gastrocnemius medialis bilaterally, in addition to, the spectral power within the 0.4 – 0.7 Hz band derived from all data points of COP sway in the anteroposterior direction, which is believed to be sensitive to change in ankle proprioception. For the intervention, the experimental group was engaged in a 15-minute Tai Chi task, while the control group sat comfortably in a chair. Post-intervention measures were then collected using the same protocol as the pre-intervention measures. Four-way ANOVAs were used to determine if the Tai Chi intervention had a significant effect on postural stability, muscle activity, or measures of inferred ankle proprioception. No significant differences were observed between the experimental or control group across pre-/post test measures. These findings suggest that a single 15-minute Tai Chi intervention is not sufficient to produce effects on the postural stability, muscle activity, or ankle proprioception of healthy young adults.

Chapter I: Literature Review

What is Tai Chi?

Tai Chi, also known as Taiji, T'ai Chi, Tai Chi Chuan, or Taijiquan, is a mind body exercise which originated in 17th century China (Wayne & Kaptchuk, 2008a). The full name, Tai Chi Chuan, has generally been translated to mean *Supreme Ultimate Boxing* (Wayne & Kaptchuk, 2008a). With such a name, it is not surprising that the roots of Tai Chi were based in combat-oriented applications (Jiménez-Martín, Liu, & Meléndez Ortega, 2017). Tai Chi first emerged as a new form of Kung Fu; however, it differentiated itself from the quicker, more agile martial arts with its slower, more methodical movements (Wayne & Kaptchuk, 2008a).

A single Tai Chi movement is referred to as a *posture*, however, when chained together in a series they create a *form* (Field, 2011). These *forms* can be quite diverse in nature. Some may contain a series of 18 *postures*, while others may be made up of more than 100 (Field, 2011). Further adding to the complexity, the order of the *postures* is not necessarily fixed. They may be shuffled around and modified in the face of constraints or to include objects such as swords or fans (Jiménez-Martín et al., 2017).

Despite the many variations possible within a Tai Chi form, Xu, Li, and Hong (2003) identified three primary characteristics which remain constant across all iterations; 1) all Tai Chi movements are continuous, even, and smooth. Tai Chi is performed with a slow tempo which facilitates a sensory awareness of the speed, force, trajectory, and execution of the movement throughout the exercise; 2) movements involve a continuous interchange of roles between stabilizer and primary movers, and between weight-bearing and non-weight-bearing positions; and 3) Tai Chi is performed in a semi-squatting posture, with various degrees of concentric and eccentric contraction, which demands moderate work of the musculature in the lower extremities (Liu et al., 2012; Xu et al., 2003).

These unique traits of Tai Chi were born out of Taoist philosophy. As outlined in the Tao Te Ching, *The Tao*, literally translating to *The Way* (Lao Tzu, 1963), described philosophical propositions which provided a set of principles to be used as a guide for achieving moral excellence. Its purpose was to aid the individual in the lifelong pursuit to stay on *The Way*, a place of optimal safety and challenge, between yin and yang, dark and bright, and order and chaos. This has been represented in Tai Chi with its many circular postures and its flow of movement and stillness; as one *posture* seamlessly becomes another (Ch'ing, 1985). These ideas were designed to promote principles of health and longevity (Field, 2011). As expressed by Ch'ing (1985) "[Tai Chi] helps the weak become strong, the sick to recover, and the timid to become brave (p. 23)." It is from an understanding of the philosophy behind the martial art, that the multi-faceted nature of Tai Chi has become apparent.

Tai Chi has been described as a mind-body exercise. An 8-factor whole-systems model (Figure 1) developed by Wayne and Kaptchuk (2008a) expanded on the multiple physiological, psychological, and cognitive components present in Tai Chi exercise. Consequently, Wayne et al. (2014) stated that Tai Chi may produce benefits above and beyond those observed in more conventional single-modality exercises. As such, Tai Chi has garnered increased interest among researchers, particularly regarding investigations on how Tai Chi affects balance (Chen, Hunt, Campbell, Peill, & Reid, 2016; Guan & Koceja, 2011; Li et al., 2012; Wayne et al., 2014).

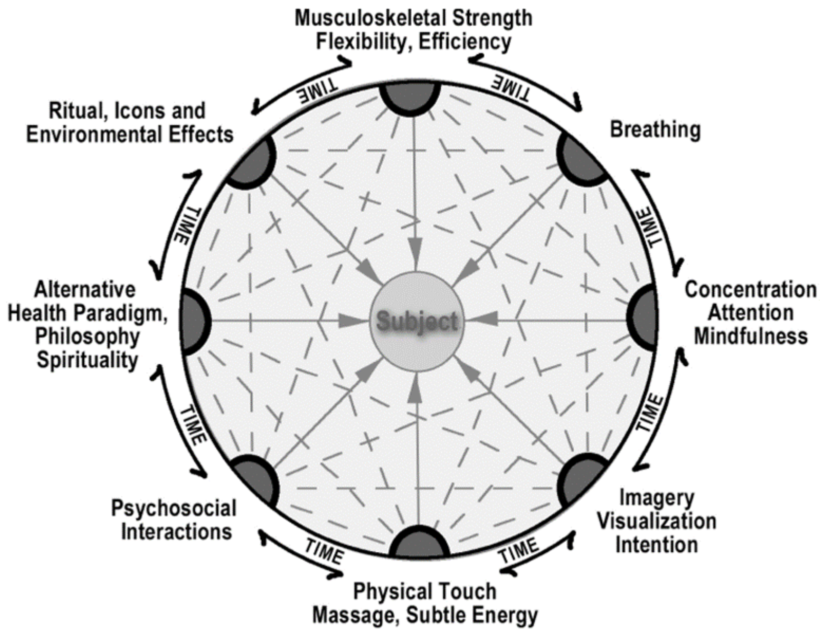

Figure 1. The whole-systems model depicting the complexity of a Tai Chi intervention and its therapeutic components. Adapted from "Challenges inherent to T'ai Chi research: Part I— T'ai Chi as a complex multicomponent intervention," by Wayne and Kaptchuk, 2008, *Journal of Alternative and Complementary Medicine, 14*(1), 95–102.

Fundamentals of Balance

Balance has been defined as the ability to maintain the body's center of mass (COM) within the limits of stability created by the base of support (BOS; Yim-Chiplis & Talbot, 2000). The COM is an abstract point on the body. It is the area at which the summed gravitational force acting on the body projects downward. It is also the point at which there is equal weight distribution of a body in three-dimensions (Winter, Prince, Frank, Powell, & Zabjek, 1996). The COM, however, is not a static point. The dynamic nature of the COM presents a particular problem for stability, as it must be contained within the BOS, which is defined by the points of contact beneath the feet and the area between them. Consequently, the BOS varies in shape and size with change in stance and locomotion (Cavanaugh et al., 2005).

The BOS has been broken into to three component thresholds (Blaszczyk, Bacik, & Juras, 2003). The first, termed the margin of stability, is defined by the area surrounding the COM, in in which the COM of most individuals oscillates dynamically while standing quietly (Blaszczyk et al., 2003). When the COM is confined to this area, the authors reported that postural correction required little effort, and often went unnoticed by conscious awareness. The second threshold was called the border of safety. If the COM exceeded this point, to maintain equilibrium, corrective postural responses occurred which disrupted the current motor activity (e.g., a brief loss of balance when stepping on unseen ice). Lastly, there was the limit of safety, which when crossed inevitably leads to a fall and possible injury (Blaszczyk et al., 2003). To express the unstable nature of human posture, a simplified model of an inverted pendulum has commonly been used.

The model depicts a mass attached to a moment arm which rotates about a single axis (Figure 2). Lakie, Caplan, and Loram (2003) described the parallels between the model and human posture such that the mass is representative of the COM present within the human body, located at about 2/3 of the total height of an individual; the single rotational axis is an analogue for the ankle joint, and a single moment arm, akin to a rigid trunk and lower limbs, allows the mass to rotate about the axis. To ensure the COM does not exceed the limits of stability its movement is constrained by a second force vector, the center of pressure (COP).

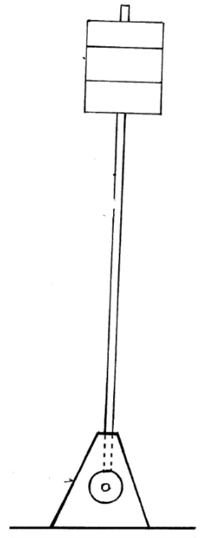

Figure 2. Inverted pendulum model of human upright posture. Adapted from “Human balancing of an inverted pendulum with a compliant linkage: Neural control by anticipatory intermittent bias,” by Lakie, Caplan, and Loram, 2003, *Journal of Physiology, 551*(1), 357–370.

Fundamentals of Postural Stability

The COP is the equal and opposite force generated by the COM. Just as the COM is the sum of all downward force vectors, its counter-part the COP, is the sum of all the upward ground reaction forces and the torques generated in the lower limbs (Cavanaugh et al., 2005). Torque generated at the ankle joint primarily stabilizes the COM in the AP plane. The knee joint has been suggested to play a role in lowering the COM in the AP plane during challenging postural conditions (Jeon, Hwang, & Woo, 2013). Additionally, torque generated at the hip joint primarily stabilizes the COM in the ML plane (Carpenter, Murnaghan, & Inglis, 2010; Gage, Winter, Frank, & Adkin, 2004; Gauchard, Vançon, Meyer, Mainard, & Perrin, 2010; Winter et al., 1996). It should be noted that the hip can also help maintain postural stability in the AP direction in response to unexpected or difficult perturbation, which cannot be compensated for at the ankle (Versteeg, Ting, & Allen, 2016).

The COP functions to oscillate about the COM, which guides the COM in a controlled sway cycle within the BOS (Morasso, Spada, & Capra, 1999; Shepard & Jacobson, 2016). The term postural stability has been commonly used to describe this relationship between the COP and COM. Perhaps more formally, postural stability has been defined as: 1) the ability to achieve an upright posture, and 2) the ability to maintain this posture in the face of destabilizing forces (Caron, 2003; Derave, De Clercq, Bouckaert, & Pannier, 1998; Szafraniec, Baranska, & Kuczynski, 2018). Even while standing quietly (i.e., positioned with the arms relaxed at the sides of the body, straight back, and feet positioned shoulder width apart), the simple act of breathing, the heart beating, and cognitive processes act as destabilizing forces which the central nervous system (CNS) must account for to maintain stability (Carpenter et al., 2010).

Direct observation of how these destabilizing factors impact COM movement requires the measurement of the COM of each body segment and the calculation of COM position in three-dimensional space, which can be cumbersome due to the precise nature of the measurements. As such, a more efficient method of examining the effect of various perturbations on postural stability has been too observe COP movements with a force platform and infer COM behaviour (Morasso et al., 1999).

Measuring postural stability. Considered to be one of the safest tools for postural assessment, the force platform has become a valuable tool for researchers and clinicians in providing unique insights into neuromechanical functioning particularly related to balance (Błaszczyk, 2016). It has allowed for the quantification of the external forces present during both human locomotion and quiet standing (Blaszczyk et al., 2003). Typical design of a force platform has been a rectangular metal plate placed on top of one or more force transducers (Payton & Bartlett, 2007). Several different types of force transducers have been used in force platform construction, which include strain gauges, piezoelectric, piezo resistive, and capacitive (Nigg & Herzog, 1994). Regardless of the type of the force transducer, each has been designed to deform in the face of applied force.

Within an electrical circuit, these force transducers produce an output voltage in proportion to the force applied to the transducer (He & Fu, 2001). The voltage is then run through an analogue to digital converter, which in turn converts the analogue voltage into a digital number that has been calibrated to be proportional to the analogue voltage (Iovine, 2012). The digital value is then collected by recording software and visually represented to the observer. In this manner, the change in voltage can be used as an indicator of the force applied (Nigg & Herzog, 1994). A single force transducer can quantify force application along a single axis; however, when several force transducers are paired together, multiple axes may be observed simultaneously. This principle has been applied in the construction of force platforms with tri-axial force transducers placed in the four corners of the platform, which measure forces in three directions (z, x, and y; Figure 3). The resultant directional forces (Fz, Fx, and Fy) can then be combined with the moments of the forces (My and Mx), such that the coordinates (X and Y) of the COP can be calculated (Equation 1; Nigg & Herzog, 1994). Consequently, the resultant force calculation provides insights into the way individuals sway during balancing activities which provides information about postural stability.

Equation 1:

$$COPx = \frac{-(My)}{Fz}$$

$$COPy = \frac{Mx}{Fz}$$

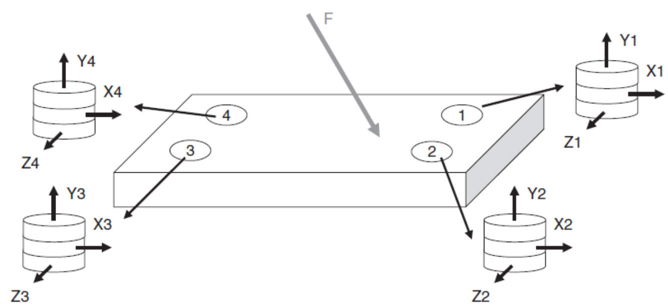

Figure 3. Diagram of a force platform. Adapted from "*Biomechanical Evaluation of Movement in Sport and Exercise*," by Payton & Bartlett, 2007, Routledge, Milton Park: AB

Mechanics of postural sway. Winter, Patla, Rietdyk, and Ishac (2001) initially postulated that the oscillation of the COM about the COP was maintained via intrinsic stiffness within the ankle. The elastic properties of the triceps surae, Achilles tendon, and foot were believed to maintain the passive stability during upright standing. Such that, as the body adopted a forward sway, the elastic stiffness of the muscle would store energy, which would eventually be released, and overcome the forward sway of the COM. In this manner, the inverted pendulum was returned to an equilibrated state and neutral position.

It was believed that the CNS set the tonic activity of the ankle muscles to produce the intrinsic ankle stiffness (Winter et al., 2001). Conversely, Lakie et al. (2003) observed that while intrinsic ankle stiffness was present during an upright standing posture, its was simply not enough to overcome the torque produced at the ankle as a consequence of gravity. Furthermore, the authors concluded that to control the pendulum effectively, the position must have the capacity to change as needed. This suggested a biphasic pattern of torque, which could not be attributed to a spring-like controller; as that would produce stability at only a single angle (Lakie et al., 2003). Loram and Lakie (2002) coined this biphasic pattern as *drop and catch*, if the pendulum was lowered, or *throw and catch*, if the pendulum was raised. This meant that constant sensory input was required to inform the CNS as to the approximate location of the COM, which ensured that the correct amount of torque was produced and at the correct time.

Function of sensory input. As such, the upright posture maintained by the CNS is mediated by sensory information provided by: i.) the visual, ii.) vestibular, and iii.) somatosensory systems (Speers, Kuo, & Horak, 2002). All three systems function in tandem, as no single system can provide a complete picture of the COM position. Instead, sensory information from all three are integrated by the CNS to interpret the COM position within a complex sensory environment (Chiba, Takakusaki, Ota, Yozu, & Haga, 2016; Horak, 2006).

i.) ***The visual system.*** Most individuals will attest to the fact that an upright posture can be maintained more effortlessly with vision, rather than, in the absence of it. This is because vision provides the postural control system information regarding visual motion (Kapoula & Le, 2006). There are two modes of visual motion perception, afferent and efferent. The afferent motion is related to the perception of movement of objects within the environment; whereas, efferent motion perception is related to movement of the eyes, head, or body (Kapoula & Le, 2006; Peterka, 2002). Within afferent motion, object information is processed differently based on its location within an individual's gaze. Interestingly, it is not the central area of focus, or focal vision, which functions to perceive motion. Focal vision is specialized to perceive and recognize objects. Instead, it is ambient, or peripheral vision, which primarily senses movement within the environment (National Research Council, 1985). In terms of perception of self movement, the visual system can produce the sensation of movement (vection); however, this role is primarily filled by the vestibular system (Shepard & Jacobson, 2016).

ii.) ***The vestibular system.*** Considered to be the sixth sense, the vestibular system detects head orientation and motion in relation to the vertical reference created by the downward force of gravity (Migliaccio, 2013; Peterka, 2002). This is achieved with two types of unique sensory organs. The semicircular canals, which are sensitive to three-dimensional angular acceleration, and the otolith organs, which sense linear acceleration in three-dimensions. The importance of the vestibular system to postural control is best demonstrated among individuals in which it is impaired. Those who suffer from vertigo (15–20% of adults affected annually) will attest to the importance of vestibular function to provide a sense of balance while standing still, moving dynamically, or when in a moving vehicle (Neuhauser, 2016). Failure of the vestibular system can produce disabling unsteadiness and oscillopsia (perception of environmental objects oscillating; Sprenger, Wojak, Jandl, & Helmchen, 2017). The vestibular system is, however, only able to adequately track head COM movement. Tracking of the total body COM displacement is accomplished via the somatosensory system (Jeka, Kiemel, Creath, Horak, & Peterka, 2004).

iii.) ***The somatosensory system.*** The somatosensory system is not a singular sensory system like the vision and vestibular systems, rather it represents an umbrella under which numerous senses fall under (Shepard & Jacobson, 2016). The sensory functions which make up the somatosensory system are pain, temperature, touch, and proprioception (Purves et al., 2004). These sensory modalities contribute to postural control by providing feedback regarding joint position, muscle tension, velocity of limb movement, and how the body is in contact with external surfaces. Together, these senses confer a feeling of wholeness (Blakeslee & Blakeslee, 2009). It is in this manner that an individual possesses an *in body feel*, allowing for a mental model of body schema; a sensorimotor representation of the body used to guide movement and action (Hoffmann, Marques, Arieta, Sumioka, & Lungarella, 2010; Proske & Gandevia, 2009; Walsh, Moseley, Taylor, & Gandevia, 2011)

Integration of sensory input. While each system performs a specific role, some overlap is present. The CNS can also dynamically weight the value of sensory information obtained from each system (Horak, 2006). This has two important applications: 1. Erroneous information from one system can be compensated for by the others (e.g., a brief sensation of motion when a vehicle in the peripheral vision begins to move); and 2. Functional impairment of a single system (e.g., blindness) can be compensated for by the remaining healthy systems (Horak, 2006).When working in unison, the visual, vestibular, and somatosensory feedback ensures the postural control system can maintain stability across changing environmental conditions (Guskiewicz, 2001; Horak, 2006; Shepard & Jacobson, 2016).

Referred to as fast dynamics, this immediate postural compensation in response to environmental demand works so well that it often goes unnoticed in healthy individuals (Chiba et al., 2016; Horak, 2006). For example, turning out the lights in a bedroom, and walking over to the bed to lie down is a daily experience for most individuals. The darkness of the room barely causes a healthy individual to break his/her stride moving to the bed, as the sensory input from the bottom of the feet grounds the individual's orientation in the absence of vision. Alternatively, an individual with sensory loss in the feet due to peripheral neuropathy would have greater difficulty compensating for the loss of vision (Horak, 2006). Knowing this, researchers and clinicians can challenge postural stability through imposed sensory constraints.

Challenging postural stability. Tests used to challenge postural stability have typically employed a restriction of vision and altered standing surface conditions (Bryanton & Bilodeau, 2019; Geurts, Knoop, & Van Limbeek, 1999; Thompson, Sebastianelli, & Slobounov, 2005; Thompson, Badache, Cale, Behera, & Zhang, 2017). Visual conditions have included eyes open (EO), eyes closed (EC) or blindfolded, and head mounted devices which distorted vision (Guskiewicz, 2001). Whereas, somatosensory accuracy has been impaired with the use of foam standing surfaces (Guskiewicz, 2001). The vestibular system has been less commonly restricted, as to do so required fixation of the head (Fitzpatrick, Rogers, & McCloskey, 1994). These sensory challenged conditions have been used in conjunction with COP-based measures via data collection from a force platform to identify individuals with injury, pathology, as well as, differences between age groups (Borah et al., 2007; Cavanaugh et al., 2006; Li et al., 2012).

Center of pressure based measures of postural stability. Two common variables used to measure postural stability among healthy young adults have been 95% elliptical area (EA) and mean sway velocity (MSV; Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996; Thompson et al., 2017). One such study by Kaji, Sasagawa, Kubo, and Kanehisa (2010), examined the immediate effects of core exercises on COP-based measures within a sample of healthy young adults. The authors found that two core exercises, each 30 seconds (s) in duration, produced an immediate significant decrease in both the sway velocity and area of sway (Kaji, Sasagawa, Kubo, & Kanehisa, 2010). These findings suggest that measures of sway velocity and sway area are sensitive to the immediate effects of exercise on postural stability. Therefore, the measures of MSV and EA may provide insight into the immediate effects of Tai Chi on healthy young adults.

Within the present study, EA has been defined as the sway area (cm^2) of the COP. It has previously been determined by creating an ellipse around the data points, which includes 95% of all the points collected during the trial (Doyle, Hsiao-Wecksler, Ragan, & Rosengren, 2007). The second measure, MSV, has been previously calculated as the average change of the COP x and y coordinate position on a Cartesian plane over time (cm/s).

Furthermore, both measures have been demonstrated to be reliable. Rafał, Janusz, Wiesław, and Robert (2011) assessed the intrasession reliability of MSV and EA among 27 healthy older adult males (mean age 71.4 years). The authors asked participants to stand quietly for 30 s, EO, and barefoot on a force platform. There were 4 trials, separated by 2-minute (min) breaks, during which the participant sat comfortably in a chair. It was found that MSV demonstrated excellent reliability as a measure of postural stability with an intra-class correlation (ICC) of .84, while EA had good reliability as a measure of postural stability with an ICC of .61.

In another study, Ghofrani, Olyaei, Talebian, Bagheri, and Malmir (2017) examined the intrasession reliability of COP-based measures in 15 healthy young adults (7 males, mean age 22.2 years; 8 females, mean age 24 years). Participants were asked to stand quietly while barefoot, under both EO and EC conditions. The authors used a protocol of three 30 s trials, each separated by a 1 min rest period. Similar to the findings of Rafał et al. (2011), under EO conditions, MSV demonstrated high reliability (ICC=.88); however, EA was much lower (ICC=.37). Under EC conditions, the reliability of MSV decreased (ICC=.68) while the reliability of EA increased (ICC=.73); however, the cause for this difference in reliability between EO and EC conditions was not explained by the authors. With respect to Tai Chi research, both EA and MSV have been used to demonstrate improvements to the postural control system as measured by increased postural stability.

The effects of Tai Chi on measures of postural stability. Long-term Tai Chi engagement has been well established to improve postural stability. Guan and Koceja (2011) compared the postural stability of eight healthy adults (mean age 44 years) with more than 3 years of Tai Chi experience, to that of eight healthy age-matched controls. Participants performed three trials of EC and EO conditions, 15 s in duration each. The Tai Chi group demonstrated significantly better postural stability than the control group, as measured by EA, under both EO and EC conditions.

A second study by Wu, Zhao, Zhou, and Wei (2002) found that Tai Chi could reduce fall risk among older adults. The authors compared 20 older adults (mean age greater than 55 years) with an average of 21 years of Tai Chi experience to 19 age-matched controls. The authors found that the older adults with a history of Tai Chi practice had less COP displacement than the controls. This was believed to be an indicator of reduced fall risk, as well as greater ability of the older adults to engage in activities of daily living. There has been some indication that short-term Tai Chi interventions can also reduce fall risk.

Hosseini et al. (2018) examined the effect of an eight-week Tai Chi intervention on the fall risk of 30 older adults. Balance was assessed with the Tinetti test, while fear of falling was assessed with the Falls Efficacy Scale International. The authors noted that fear of falling was an important predictor of subsequent falls. Baseline measured were collected prior to the intervention and participants were assessed again following the eight-weeks. The results of the Tai Chi group were also compared to results of a control group (*n*=30). It was found that the Tai Chi group participants had a significant improvement in balance and a significant reduction in fear of falling, as compared to both the baseline measures and control group. These findings are in line with a systematic review by Hu et al. (2016), which also indicated that Tai Chi may have a significant effect on reducing fall risk among older adults.

Similarly, Yu and Yang (2012) examined the effect of a 24-week Tai Chi intervention on the postural stability of 38 sedentary older adult males (ages ranged from 55–65 years). The participants attended 60 min Tai Chi exercise sessions 3 times/week. Data from only a single trial were collected before and after the 24-week intervention. The authors recorded COP-based measures while participants stood quietly, under both EO and EC conditions. Under both EO and EC conditions, EA significantly decreased; however, MSV was not significantly different under EO conditions but decreased significantly under EC conditions.

A shorter study by Ghandali et al. (2017) examined the effects of a short-term (8-weeks) Tai Chi intervention in older adults with knee osteoarthritis. Sessions were held twice a week and lasted 60 min and COP-based measures were collected under EO conditions, on both firm surface and foam surfaces. Data were collected for each condition over three 30 s trials. The Tai Chi intervention resulted in a significant reduction of the area of COP sway under firm surface conditions, in addition to a significant reduction of MSV under both firm and foam surface conditions. Although promise for improved postural stability has been demonstrated for Tai Chi interventions, not all studies have observed equal success.

Chen, Zhou, and Cartwright (2011) engaged 34 older adults (mean age 72.9 years) in a 12-week Tai Chi intervention and compared postural stability measures before and after the intervention. Postural data were collected while participants stood quietly both under EO and EC conditions and foam and firm surface conditions. Statistical analysis of COP displacement resulted in no significant change in postural stability following the intervention. When taken together, these studies demonstrated a common trend.

Gaps in Tai Chi research on postural stability. In general, Tai Chi interventions are reported to improve postural stability, reflected in the multiple reviews on Tai Chi (Field, 2011; Hong & Li, 2007; Jahnke, Larkey, Rogers, Etnier, & Lin, 2010). It can be argued, however, that firm conclusions cannot be drawn, as the methodological characteristics of much Tai Chi research are often disparate and of variable quality (Verhagen, Immink, van der Meulen, & Bierma-Zeinstra, 2004; Wayne & Kaptchuk, 2008a). For example, it is not uncommon for a Tai Chi study to cite that a Tai Chi *form* of a certain length was used, but not disclose the *postures* within the *form* (Wayne & Kaptchuk, 2008a). These methodological differences across studies may also explain, for example, why Chen, Zhou, and Cartwright (2011) observed no significant change in the postural stability of older adults following a 12-week intervention, whereas, the 8-week intervention by Ghandali et al. (2017) did. This inconsistency has made replication of many studies impossible. Furthermore, the duration of the Tai Chi interventions has appeared to be somewhat arbitrary.

A systematic review by Yang et al. (2015) examined 507 Tai Chi studies published between 1958–2003. Interestingly, the studies included demonstrated a wide array of Tai Chi intervention applications outside of postural stability; such as, the benefits of Tai Chi in cancer treatment, the impact of Tai Chi on mental health, and even how it can affect skin diseases, to name a few. The interventions reviewed ranged from 5 days to 3 years. The duration of each session has also varied greatly, some have used 30 min sessions, while others have used 2 hours. Additionally, the frequency of sessions per week has been as few as two, to as many as 14. On average, however, studies engaged participants in 1-hour Tai Chi sessions, 2–3 times/-week, for 12 consecutive weeks. This myriad of differences among Tai Chi interventions has left information regarding the exact duration of a Tai Chi intervention required to produce positive change unclear (Wayne & Kaptchuk, 2008a, 2008b). Conversely, unlike the variability in the duration of interventions, the target demographic of Tai Chi research has been largely singular in nature, primarily aimed at older adults (Sandlund & Norlander, 2000).

While many Tai Chi practitioners are older adults, a recent survey of 33,392 people in the United States of America has found that, of those who practiced Tai Chi, 12.6% were younger adults (aged less than 30 years) with 36.8% older adults (aged greater than 60 years; Jiang, Kong, & Jiang, 2015). In a similar study, Birdee, Wayne, Davis, Phillips, and Yeh (2009) surveyed 429 Tai Chi practitioners, of which 23.2 % were under the age of 30 years while only 15% were 65 years or older. These demographics suggested that the engagement of younger adults in Tai Chi may be variable, but still constituted a portion of the Tai Chi population, which apparently, has been largely ignored by postural research (Sandlund & Norlander, 2000). To the best knowledge of this author, only two prior studies have examined the effects of Tai Chi on the postural stability of healthy young adults.

The first study by Zheng et al. (2015) engaged 103 healthy young adults (16-25 years) in a 12-week Tai Chi intervention. An age matched control group which received no intervention was also included. Tai Chi sessions were held five days each week and lasted 60 min per session. Measures of COP perimeter and EA were taken before, after, and 12-weeks post intervention. Trial length and sample frequency of the postural stability tests were not indicated. The authors found that COP perimeter decreased significantly under EO and EC conditions following the 12 weeks; however, only the decrease in EC COP perimeter remained significant at the 12-week follow-up. This may suggest separate mechanisms which influence sway under EO and EC conditions.

The second study was performed by Harada et al. (2018) which had 24 healthy young adults perform a 40 min instructor led Tai Chi intervention, with postural stability measured before and after the intervention. The authors reported postural stability in unknown measures which were not defined and have not been previously reported on in reviews of COP-based measures, which left the reliability of this study questionable. (Lin, Seol, Nussbaum, & Madigan, 2008; Prieto et al., 1996; Ruhe, Fejer, & Walker, 2010). The measures used were, *locus length, locus environs area*, and *locus length per locus environs area.* The authors observed a decrease in *locus environs area* and *locus length per locus environs area* under EC conditions following the Tai Chi intervention. These results suggested that a short Tai Chi intervention can improve measures of postural stability. Although the sample used in this study was healthy young adults, the authors stated that the Tai Chi reduced dyskinesia, and reduce falls in older adult and Parkinsonian populations. This again brought into question the validity of the study.

In an effort to address the problem of limited Tai Chi research focused on younger adults, and the lack of knowledge surrounding the duration of Tai Chi required to produce positive effects on postural stability, this student researcher conducted a pilot study (unpublished findings). The pilot study aimed to observe the immediate acute effects of a single Tai Chi intervention on the postural stability of healthy young adults. Postural stability was measured with a force platform. Both MSV and EA data were collected from 15 healthy young adults (5 males; 10 females) under different vision conditions (EO and EC) and under different surface conditions (firm and foam). These measures were taken before and after a 15 min Tai Chi intervention.

Results indicated that immediately following the intervention, MSV significantly decreased following the intervention under EC firm surface conditions. Additionally, EA was not found to be significantly different under eye or surface conditions. These acute effects of Tai Chi were in line with both Harada et al. (2018) and Zheng et al. (2015); however, also similar to Harada et al. (2018) and Zheng et al. (2015), the data did not indicate by what mechanism postural stability had been improved.

Considering these results, it was unlikely that the vestibular system was affected as significance was not found under EC and foam conditions. The EC and foam conditions are intentional perturbations of the vestibular system consequently, study results suggest that the vestibular system was not impacted during this intervention(Kiers, Brumagne, van Dieen, van der Wees, & Vanhees, 2012). Furthermore, as vision was removed, within the results which found significance, it was likely that Tai Chi impacted the somatosensory system, specifically the proprioceptive system. Proprioception is a sensory system classified under the umbrella of the somatosensory system, which has been suggested to be a primary source of sensory information on firm surfaces in the absence of vision (Kiers et al., 2012; Nagy, Posa, Finta, Szilagyi, & Sziver, 2018). As such, an investigation into the possible capacity for a short Tai Chi intervention to influence proprioception may be beneficial.

If proprioceptive improvement can be observed among healthy young adults, this may open up avenues for Tai Chi exercises which improve proprioception to be used for injury prevention among athletes, as well as to rehabilitate proprioceptive function following an injury (Munn, Sullivan, & Schneiders, 2010; Witchalls, Blanch, Waddington, & Adams, 2012). Furthermore, with a perceived lack of time having been suggested as a barrier for patient compliance to home-based rehabilitative programs, the short 15 min duration of the Tai Chi intervention may be appealing for clinicians with low compliance patients (Essery, Geraghty, Kirby, & Yardley, 2016; Jack, Mclean, Moffett, & Gardiner, 2010).

An investigation into the potential benefit of a 15 min Tai Chi intervention on proprioception may have rehabilitative implications as the feeling that one does not have enough time to complete therapeutic exercises at home has been suggested as a potential barrier (Essery, Geraghty, Kirby, & Yardley, 2016; Jack, Mclean, Moffett, & Gardiner, 2010). If potential for proprioceptive improvement is shown among healthy young adults, this may open up avenues for Tai Chi exercises which improve proprioception to be used for injury prevention, as well as to rehabilitate proprioceptive function following an injury (Munn, Sullivan, & Schneiders, 2010; Witchalls, Blanch, Waddington, & Adams, 2012).

An Introduction to Proprioception

The idea that some form of communication was present between skeletal muscle and the CNS was first put forward in 1826 by the Scottish physiologist, Charles Bell (Han, Waddington, Adams, Anson, & Liu, 2016). This early work laid the foundation for future research with its descriptions of the afferent pathways which carried information from the muscle to the CNS and the efferent pathways which sent information from the brain to the muscles (Han et al., 2016). In 1887, Charlton Bastion detailed the concept of kinesthesia, which further advanced the knowledge surrounding body sense. Dr. Bastian described kinesthesia as not only the conscious and unconscious body position sense which informed movement, but also the memory of a movement sensation (Compston, 2015).

In 1906, English neurophysiologist, Charles Sherrington, built off the work of his predecessors to describe proprioception as how the CNS monitored body segment position (Han et al., 2016). Proprioception was defined as an innate awareness of movement derived from muscular, tendinous, and articular sources (Han et al., 2016). The term proprioception itself was formed from the Latin word *proprius*, meaning one's own, and the concept of perception; therefore, the literal translation was *perceiving one's own self* (Hillier, Immink, & Thewlis, 2015).

Current research has defined proprioception as one's ability to integrate the sensory signals from various mechanical receptors to thereby determine body position and movement in space and time (Han, Anson, Waddington, Adams, & Liu, 2015). Similar definitions have also been used to describe kinesthesia (Proske & Gandevia, 2009). Consequently, some have used kinesthesia and proprioception as interchangeable terms, while others have asserted that kinesthesia (along with joint position sense and sensation of force) is a sub-set of proprioception (Hillier et al., 2015). To avoid the confusion in the application of these terms present in the surrounding literature, this paper treated the terms as synonymous, and use proprioception as the preferred term to describe the sense of position and movement.

This sensation of position and movement arises from specialized sensory organs referred to as mechanoreceptors (Purves et al., 2004). These mechanoreceptors function to continuously provide the CNS with up-to-date information on the location of the body, and its parts, in space and time (Purves et al., 2004). The variety of mechanoreceptors present in cutaneous tissue, tendons, joints, and most skeletal muscle work in unison to provide the proprioceptive sense (Purves et al., 2004). These receptors can be summarized by grouping them into primary (muscle spindles and Golgi tendon organs) and secondary sources (cutaneous receptors and joint receptors) of proprioception.

***Primary sources of proprioception*.** Muscle spindles are comprised of four to eight muscle fibres, housed in a fusiform collagen sheath. These sheaths separate the muscle spindles from ordinary skeletal muscle. As such, they are often distinguished from each other with the names intrafusal (muscle spindle) and extrafusal (skeletal muscle; Purves et al., 2004). The intrafusal fibers are laid in a parallel arrangement to the extrafusal fibers, such that, when extrafusal fibers contract concentrically or eccentrically, the intrafusal fibres lengthen or shorten in the same manner (Purves et al., 2004).

The nuclei of the muscle spindles are centrally located. The majority of nuclei are located in the largest of the fibers; these larger fibers are referred to as nuclear bag fibers. The remaining nuclei are divided amongst smaller intrafusal fibers (Purves et al., 2004). Named nuclear chain fibers, these intrafusal fibers run alongside the nuclear bag fibers. Both types of fibers are innervated by Ia sensory axons. These axons wrap around the middle part of the intrafusal fibers. Whereas, IIa sensory axons primarily innervate the nuclear chain fibers, with minor connections to the nuclear bag fibers (Purves et al., 2004).

McCloskey (1978) identified that the Ia and IIa axons possessed separate neural pathways for movement and position. When vibrations were applied to skeletal muscle, two different illusionary sensations manifested depending on the frequency of the vibration. At higher vibration frequencies, the Ia axons were stimulated which produced an illusion of limb movement (Proske & Gandevia, 2009). Whereas, at lower vibration frequencies, the illusion of movement subsided; however, an illusion of false limb position occurred (Proske & Gandevia, 2009). For this reason, it has been suggested that the Ia axons are primarily responsible for the sense of velocity, while IIa are responsible for the sense of position. The sensation of force, however, was supplied by a separate organ.

Golgi tendon organs (GTO) are sensory receptors, located in the junction between muscle and tendon (Purves et al., 2004). They consist of an encapsulated Ib afferent neuron with its axon terminal intertwined with collagen fibers. Two traits significantly differentiate its function from that of the muscle spindle. Firstly, unlike the muscle spindle which lies in parallel with the muscle fibers, GTOs are in series. Secondly, the tendon is less elastic than the muscle (Purves et al., 2004). As a consequence of these two factors, during passive motion, the muscle fibers will deform, while little change will occur at the tendon. As such, the GTO is relatively insensitive to passive stretch.

Where the GTO excels, is detecting increases of muscle tension which arises from contraction (Jami, 1992). As such, GTOs monitor force production within a muscle throughout the range of motion. Another function of the GTO is to interface with inhibitor neurons connected to the alpha motor neurons of the related muscle (Purves et al., 2004). Such that, if muscle tension increases to a point at which damage may occur, the GTO inhibits the muscle reducing the torque applied by the muscle. As such, GTOs monitor force production within a muscle throughout the range of motion (Purves et al., 2004).

Secondary sources of proprioception. Out of all the receptors, those within the cutaneous tissue play the most minor role in proprioception. This is, however, not unexpected as the majority of receptors within cutaneous tissue respond to touch rather than movement (Purves et al., 2004). The primary cutaneous receptor which responds to movement are Ruffini's corpuscles. Oriented along the lines of stretch, these receptors provide sensory information regarding a push or pull of the cutaneous tissue. These Ruffini corpuscles are slow to adapt to stimulus, as such, they function better as measurements of static rather than dynamic stimuli (Purves et al., 2004).

Along with cutaneous receptors, joint receptors also play a more minor role in proprioception. Ironically, classical thought identified joint receptors as the primary source of proprioceptive information (Macefield, 2009). A more current understanding of their function has demonstrated that these receptors play little role in both the position sense of limbs and the magnitude of the movement (Purves et al., 2004). Instead, recent investigation has defined joint receptors as a form of Ruffini corpuscle, similar to those seen in cutaneous tissue; however, unlike the Ruffini corpuscle found in cutaneous tissue, those found in the joint capsule possess a high threshold for activation (Macefield, 2009). Consequently, the joint receptors respond primarily at only the extreme ranges of motion afforded by a joint (Macefield, 2009; Matthews, 1988).

Proprioceptive impairment. In a healthy individual, these mechanoreceptors function so well in tandem with the CNS that most movements required in everyday life are completed effortlessly (Proske & Gandevia, 2009). As such, the importance of proprioception has been best demonstrated among individuals in which proprioception has become impaired (Blakeslee & Blakeslee, 2009).

Perhaps the most common example of proprioceptive loss is that which occurs with age (Sohn & Kim, 2015). Loss of proprioceptive sensitivity has been observed to impair the ability of older adults to perceive changes in COM position, as well as, correct for postural disturbances, which increases fall risk (Ahmed & Ashton-Miller, 2005; Sohn & Kim, 2015). Both Colledge et al. (1994) and Benjuya, Melzer, and Kaplanski (2004) identified proprioception as the most heavily relied upon sense for postural control. Impairments, particularly at the ankle has been considered to be a significant contributing factor in falls (Sohn & Kim, 2015). Han et al. (2015) stated that as the ankle-foot complex is typically the only part of the body in contact with the ground, it provides much of the COM sway information required for the maintenance of upright posture.

***Importance of ankle proprioception*.** In a classic experiment, Fitzpatrick, Rogers, and McCloskey (1994) demonstrated that proprioceptive signals from the ankle musculature were sufficient to maintain an upright stance. The authors invited participants to balance an equivalent body (an inverted pendulum which had the same height and mass of its COM as the body of the participant) by using ankle plantarflexion and dorsiflexion. The caveat was that the participant was strapped to a rigid upright support (which prevented use of vestibular information), blindfolded (removed vision), and had pneumatic cuffs inflated to 350 mm Hg for an hour (to anesthetize the joint receptors in the ankles and cutaneous foot receptors).

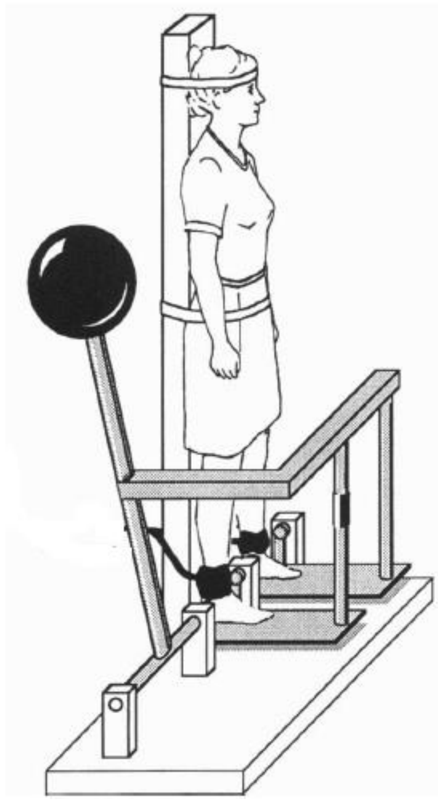

Figure 4. Balance of inverted pendulum. Adapted from "Stable human standing with lower-limb muscle afferents providing the only sensory input," by Fitzpatrick, Rogers, and McCloskey, 1998, *Journal of Physiology, 480*(2), 395-403

As such, only proprioceptive sensory information from the musculature surrounding the ankle affected sway. Surprisingly, the participants were able to balance the equivalent body without training, while distracted, and while engaged in conversation. This suggested that little cognitive effort was required to maintain balance, even under reduced sensory conditions (Fitzpatrick et al., 1994). A second study by Fitzpatrick and McCloskey (1994) found that not only was ankle proprioception alone sufficient to maintain an upright posture, but also had a lower threshold for sway detection than both vision and vestibular inputs.

Particularly at lower sway velocities, ankle proprioception was more sensitive than vision to postural sway; however, at sway velocities greater than 0.12^{o}/s, the sensitivity of vision began to approach that of ankle proprioception (Fitzpatrick & McCloskey, 1994). The authors noted that the velocity of sway during relaxed quiet standing was often above the ankle proprioceptive and visual thresholds, so that either input was likely sufficient under normal circumstances. Vestibular sensitivity was by far the least sensitive to sway and was described as possessing a threshold many times greater than vision and ankle proprioception. This was likely because vestibular input has been shown to be more sensitive to head COM displacement than that of total body COM displacement (Jeka et al., 2004). If ankle proprioception can be shown to improve as a consequence of Tai Chi, it could be applied in both a sporting, injury prevention, and rehabilitative context.

Han, Anson, Waddington, and Adams (2014) demonstrated the importance of ankle proprioception in sport in a study which compared right ankle proprioception of 100 right footed healthy young adult athletes from various sports, aged between 18–25 years, to 20 right footed age-matched non-athlete controls. It was believed that common actions in sport, such as jumping, landing and running, required a high degree of balance control largely informed by a sensation of ankle position and movement. Therefore, the athletes would possess greater ankle proprioception than the controls without specialized training.

The authors used a purpose-built ankle Active Movement Extent Discrimination Apparatus (AMEDA) to test ankle proprioception. Participants placed his/her barefoot flat on a platform which would rotate to five possible angles (10º, 11º, 12º, 13º, and 14º) and each angle was assigned a number from 1 to 5 (1 being the smallest angle and 5 the largest). All five conditions were presented to the participant three times. This allowed the participant to become familiar with the proprioceptive feel of each angle. The researchers then presented the conditions in a randomized order totalling 50 trials, 10 trials per condition. For each presented condition, the participant was asked to inform the researcher as to the condition number (1 to 5) which had just been presented. No feedback was given as to the correctness of the answer. In this manner, the proprioceptive memory of each participant was assessed (Compston, 2015).

It was found that the athletes had significantly better ankle proprioception than the controls. Furthermore, ankle proprioception was also significantly different across athletes who were competing at the regional, national, and international levels; with better proprioception found in individuals participating at higher levels of competition. This was true across all sport backgrounds examined. The authors believed that greater proprioceptive sensitivity directly improved balance control among athletes at higher levels of competition. As such, these athletes were able to devote more cognitive resources to tasks such as localising teammates and opponents, as well as opportune moments to pass or shoot, instead of more focus devoted to balance control. Beyond improved performance, proprioceptive deficits of the ankle has been implicated with increased injury risk (Munn, Sullivan, & Schneiders, 2010; Witchalls, Blanch, Waddington, & Adams, 2012).

Payne, Berg, and Latin (1997) measured the ankle proprioception, flexibility, and strength of 42 (11 males; 31 females) collegiate basketball players before and after a 9-week season to determine if these measures could predict ankle injury. Ankle proprioception was recorded by having the participant sit upright with both the hip and knee flexed to 100^{o}, while the ankle remained in a neutral position on a movable platform. Participants were asked to close his/her eyes and the foot was moved to predetermined positions. Once the foot was in position, the researcher asked the participant to remember that position. The position was held for 3-5 s, then the foot was returned to the neutral position. The participant was then asked to return the foot to the position just experienced. The error between the guess of the participant and the true position was used to score ankle proprioception (Payne, Berg, & Latin, 1997).

The first ankle injury was recorded, and preseason data were examined to determine if the measures predicted future injury. Following the 9-weeks, 8 participants (1 male; 7 females) experienced an ankle injury. The authors found that measures of proprioception predicted ankle injury among all participants. Measures of strength and flexibility, however, failed to account for additional variance. Similar results were found by Fu and Hui-Chan (2007) who examined the relationship between proprioception and muscle activation during landing from a height in 15 male collegiate basketball players.

Proprioception was measured while the participant lay prone with the ankle fixed in 90^o of dorsiflexion on a footplate. The footplate was rotated at a constant angular velocity of 1^o/s from the neutral starting position by 5^o of plantarflexion. This target plantarflexed position was held for 2 s. The foot was then returned to the starting position at the angular velocity. Once returned, the footplate then moved back to the target position, and the participant was instructed to press a button when he/she believed that the target position had been reached. The error between the guess of the participant and the true target position was used to score proprioception (Fu & Hui-Chan, 2007).

Fu and Hui-Chan (2007) reported that ankle proprioception was significantly correlated with co-contraction of the tibialis anterior (TA) and gastrocnemius medialis (GM) in both left and right legs. The degree of co-contraction between the TA and GM muscles in the left and right legs were further related to the magnitude of force produced upon landing (r=.54 and .53, respectively. It was suggested that this placed greater stress upon the ankle joint, which may partly explain the relationship between poorer ankle proprioception and greater ankle injury risk.

Ankle injuries have accounted for between 3–5% of all hospital visits in the United Kingdom, and between 10–30% of all sport related injuries (Doherty et al., 2014; Fong, Hong, Chan, Yung, & Chan, 2007). As a means of both prevention and rehabilitation, ankle proprioception exercises have captured the attention of researchers (Eils & Rosenbaum, 2001). Commonly used exercises have involved balance tasks on an unstable surface, such as a wobble board, foam surface, or ankle disk (Kiers et al., 2012). While demonstrated to improve balance, these modalities have, however, been observed to shift postural control from an ankle strategy to a hip strategy (Brumagne, Janssens, Knapen, Claeys, & Suuden-Johanson, 2008; Kiers et al., 2012). As such, they have come under criticism for not truly targeting ankle proprioception; instead they engaged other balance mechanisms (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001; Kiers et al., 2012; Nagy et al., 2018). These improved balance mechanisms may be helpful in their own right; however, they did not address the possibility of improved performance in sport, or the reduced injury risk associated with better ankle proprioception (Fu & Hui-Chan, 2007; Han et al., 2014; Payne et al., 1997; Witchalls, Waddington, Blanch, & Adams, 2012). Recently, researchers have turned to Tai Chi as a potential means of proprioceptive improvement (Jain, Taylor, Sanzo, & Zerpa, 2017).

The effect of Tai Chi on proprioception. Xu, Hong, Li, and Chan (2004) recruited 21 older adults who practiced Tai Chi for approximately 1.5 hours/day for the past 4 years, 20 older adults who engaged in swimming or running for at least 1 hour/day for the past 4 years, and 27 older adults who did not engage in regular physical activity for more than 4 years. To compare the groups, joint proprioception in the ankle and knee were measured. Joint proprioception of the ankle was measured with a threshold to detection of passive motion (TTDPM) technique. Participants were asked to sit with the dominant foot placed on top of a movable platform which rotated at a rate of 0.4^{o}/s.

The hip, knee, and ankle were all simultaneously set to a standardized angle of 90^{o} for all participants. The platform rotated the participant's ankle into either dorsiflexion or plantar-flexion six times in a randomized order. Participants were asked to press a switch the moment that movement of the ankle was detected. After which, the researcher recorded the angle of the platform and the direction of its movement as a TTDPM score. To ensure that the effects of visual and auditory stimuli were removed from testing, the trials were performed under closed eye conditions, and participants were given headphones with music playing (Xu et al., 2004)

Knee TTDPM data were collected in a similar manner. Participants were seated with the dominant knee placed at an angle of 45^{o}, and the apparatus extended or flexed the knee (0.4^{o}/s) six times in a randomized order. The authors found that those in the Tai Chi group detected significantly smaller motions of the ankle than both the control and the swimming or running groups. This suggests that although other exercises may stimulate proprioceptors within the ankle, Tai Chi may be a more suitable exercise for greater improvements. Tai Chi may improve ankle proprioception more effectively than other exercises perhaps due to the emphasis on body awareness and the feeling of the movement during Tai Chi (Zhang, Sun, Yu, Song, & Mao, 2015). With respect to knee motion, however, the Tai Chi group significantly outperformed the control group but not the swimming and running groups.

More recently, Zhang, Sun, Yu, Song, and Mao (2015) examined ankle plantarflexion, dorsiflexion, inversion, and eversion of the ankle in 60 older adult women (age ranged from 60–

65 years) following either 16 weeks of Tai Chi (*n*=20), brisk walking (*n*=20), or no intervention (*n*=20). Both the Tai Chi and brisk walking groups exercised for at least five 60 min sessions/week. The Tai Chi group was taught a 24-*form* routine from an instructor for the first 3-weeks, then were required to practice as a group, without instruction, for the following 13-weeks. Ankle proprioception data were collected during the intervention at baseline, week 4, 8, 12, and 16 (Zhang et al., 2015).

Ankle joint proprioception was measured with TTDPM, much in the same manner as Xu et al. (2004). Participants were seated on an adjustable chair, with the dominant foot placed on a movable platform. The hip and knee joints were flexed to 90^{o} such that the shank was perpendicular with the platform. The platform rotated at an angular velocity of 0.4^{o}/s in randomly presented directions of plantarflexion, dorsiflexion, inversion, and eversion (Zhang et al., 2015). Participants were tested under closed eye conditions and with headphones to eliminate the visual and auditory stimuli. Participants were asked to press a switch to stop the platform when movement was perceived. The direction of ankle movement and threshold angle of detection were then recorded. Five trials were completed in each direction, with the minimally detected angles sensed in each direction used for data analysis (Zhang et al., 2015).

Results indicated that the Tai Chi group significantly improved ankle proprioception of plantarflexion and dorsiflexion after 8-weeks (Zhang et al., 2015). Similarly, the brisk walking group improved ankle proprioception of plantarflexion and dorsiflexion, but only after 12-weeks. There was, however, no significant difference found in inversion and eversion across all groups throughout the entire study (Zhang et al., 2015). The authors believed that Tai Chi improved plantarflexion and dorsiflexion because the ankle was required to move through a large range of motion, which may have activated more proprioceptors, as well as, the emphasis placed on the awareness of joint position during Tai Chi (Zhang et al., 2015).

Tai Chi interventions have also been demonstrated to perform admirably even when compared against traditional training designed to improve proprioception in the lower limb. Liu et al. (2012) recruited 60 participants, who were spread evenly across a Tai Chi group (mean age of 70.5 years), a proprioceptive exercise group (mean age of 72.8 years), and a control group (mean age of 68.6 years). The Tai Chi and proprioceptive exercise groups attended the respective exercise sessions twice a week, for 45 min sessions, for 16-weeks. The control group was not engaged in regular physical exercise.

Proprioception was assessed with joint position reproduction (JPR) methods at baseline and after the 16-weeks. For the assessment, the participant was seated, such that the knee and hip were positioned at 45^{o} of flexion, and the ankle was in a neutral position. Participants were tested under EC conditions and wore headphones with music playing to eliminate visual and auditory stimuli (Liu et al., 2012). The ankle of the participant was passively moved by the researcher to maximal inversion or eversion, then was moved to two reference positions (10^{o} inversion and 20^{o} inversion). Each reference position was held for 10 s, and the participant was instructed to concentrate on the feeling of ankle position. The ankle was then brought back into either maximal inversion or eversion, and moved passively back towards eversion or inversion at an angular velocity of 1^{o}/s. The participant was instructed to push a stop button when he/she perceived that the reference position was reached. This protocol was repeated three times (Liu et al., 2012) .

Statistical analysis revealed a significantly better joint position sense in the Tai Chi group compared to the control group, as well as the proprioceptive exercise group compared to the control group. Interestingly, there was no significant difference between the Tai Chi and proprioceptive exercise groups for joint position sense between side for the left and right ankles (Liu et al., 2012). The authors concluded that the Tai Chi and proprioceptive exercises had similar effects on ankle joint proprioception in older adults. The participants, however, indicated greater satisfaction and engagement with the Tai Chi rather than the proprioceptive exercises. The authors concluded that this may have long term effects on exercise participation, compliance, and the maintenance of joint proprioception (Liu et al., 2012).

It has been suggested that these positive effects on ankle proprioception may be due to how Tai Chi engaged participants in three key actions required for proprioceptive improvement: a need for proprioceptive perception of joint movement, engagement of balance mechanisms, and neuromuscular control (Gatts & Woollacott, 2006; Hong & Li, 2007). If these components of Tai Chi were what produced significant findings in this author’s pilot study, Tai Chi should be explored as a low time requirement means of improving ankle proprioception for sport and rehabilitative purposes.

While the aforementioned studies have presented evidence for the positive effects of Tai Chi on proprioception, the design of the studies had two significant limitations. Firstly, similar to the studies regarding the effects of Tai Chi on postural stability, those which have examined its effects on proprioception have focused primarily on older adults (Zou et al., 2018). Furthermore, the results of these studies on older adults cannot be applied to a younger population as proprioception changes with age (Benjuya, Melzer, & Kaplanski, 2004a; Okada, Hirakawa, Takada, & Kinoshita, 2001). Secondly, the methods used to measure proprioception may have only captured one component of proprioception. As the TTDPM and JPR methods aim to achieve a large degree of control though isolation of a joint, these methods may not be representative of proprioceptive function under normal conditions. Proprioception used in every day tasks are unlikely to involve the slow movement velocities, non-weight bearing conditions, and joint isolation which have characterised these methods of analysis used (Capaday, Darling, Stanek, & van Vreeswijk, 2013; Han et al., 2016). In addition, the change observed with these joint position assessments might be the result of improvements in focused attention with repeated trials, more so than proprioceptive improvement (Ashton-Miller et al., 2001). Some have, therefore, argued that both TTDPM and JPR lack ecological validity (Capaday et al., 2013; Han et al., 2016).

The alternative AMEDA method was closer in line with more normal conditions of proprioception, as it tested the participant in a weight bearing stance; however, this method would not be suitable for all study designs due to the time constraints. Additionally, the AMEDA method did not allow for the concurrent assessment of changes in postural stability, and would likely miss the acute effects of the Tai Chi, due to the time requirement of 50 trials per ankle (Han et al., 2014).

Based on the previous literature examined, it would appear that an ideal test of proprioception would be one in which the participant is engaged in a functional task, and attention is not unnaturally focused on the feel of a joint when the proprioception of the joint is tested. Given these constraints, short of measurements of nerve conduction within muscle spindles a direct examination of proprioceptive function may be elusive (Weis, Schröder, & Dimpfel, 1995). Therefore, perhaps proprioceptive function of the ankle may be inferred via observation of muscle activity, as it is known to influence the function of muscle spindles (Day, Bent, Birznieks, Macefield, & Cresswell, 2017; Day, Lichtwark, & Cresswell, 2013; Di Giulio, Maganaris, Baltzopoulos, & Loram, 2009).

Inferring ankle proprioception: Electromyography. Classical thought believed that the muscle spindles responsible for ankle proprioception were located within the muscles of the triceps surae (Fitzpatrick & McCloskey, 1994). Recent evidence from Di Giulio et al. (2009) demonstrated the tibialis anterior (TA), rather than muscles of the calf, were the primary source of ankle proprioception. The authors used a force platform to measure the relative COP displacement in the sagittal plane, the root-mean-square (RMS) of the EMG to monitor muscle activity in the TA and GM, a 10-camera VICON© motion capture system to measure body kinematics, and ultrasound probes fixed to the gastrocnemius medialis (GM) and TA to measure change in muscle length of the TA, GM, and soleus muscles. Di Giulio et al. (2009) found the proprioceptive sense within the ankle primarily arose from the muscle spindles within the ankle musculature which crossed the joint. This has been suggested to be due to the degree of ankle joint rotation corresponding well with displacement of the COM (Gatev, Thomas, Kepple, & Hallett, 1999).

Nine healthy adults (mean age of 35 years) were recruited (7 males; 2 females) and performed four trials of quiet standing. Two trials were performed under EO conditions, and two trials were performed under EC conditions; however, no significant differences were found between the conditions, as such, the values of the two conditions were averaged. Five participants performed 40 s trials, while the remaining four performed 30 s trials. The authors found that the TA behaved primarily in an orthodox (change in muscle length due to ankle rotation) manner for 84±9% of total trial duration across all nine participants. While the GM and soleus muscles behaved primarily paradoxically (change in muscle length opposite to orthodox) for 71±23% and 81±16%, respectively, of the total trial duration for the nine participants.

As the change in muscle length within the TA was primarily a consequence of ankle joint rotation, it was concluded that the TA was more representative of body sway compared to the GM and soleus muscles. This suggested that the TA was the primary source of proprioceptive information within the ankle (Di Giulio et al., 2009). This was further emphasized by the modulation of the GM and soleus muscles throughout the majority of the balance task, while the TA remained largely inactive. Although increased gamma bias within the muscle spindles may compensate for some dynamic shortening of the muscle during contractions, it has not been found whether a rigid link exists between activation of the intrafusal and extrafusal activity; as this would allow for synchronous activity between alpha and gamma motor neurons (Day et al., 2013; Di Giulio et al., 2009; Hutton & Atwater, 1992; Loram, Lakie, Di Giulio, & Maganaris, 2009)

Hypothetically synchronous activity between alpha and gamma motor neuron would allow the muscle spindle to accurately represent the lengthening and shortening of a modulated muscle. Di Giulio et al. (2009), however, stated that even if this link existed to allow for dynamic subtraction of extrafusal activity from the signal of joint rotation within the muscle spindle, it would not be exact; thus, a certain degree of noise within the signal would inevitably be introduced. Simply put, even if gamma bias compensated for extrafusal activity, there has been no evidence to suggest that noise within the signal could be completely removed. Therefore, it was unlikely that the GM and soleus muscles contributed more accurate proprioceptive information than the TA (Di Giulio et al., 2009). As such, greater EMG activity within a muscle may provide an indication of proprioceptive signal quality.

Day, Lichtwark, and Cresswell (2013) aimed to confirm and progress the findings of Di Giulio et al. (2009) in a study which examined TA behaviour under both quiet standing and conditions which challenged postural stability. The authors used similar methods to Di Giulio et al. (2009), with the primary difference of varied postural conditions. Ten participants (8 males; 2 females) were engaged in four balance conditions, which lasted 60 s each. The first two conditions were EO and EC. During which, the participant was asked to perform simple arithmetic tasks aloud to shift attention away from postural control. The participant was then asked to stand on a narrow beam (8.5 cm wide by 1.7 cm high) which was placed under the ball of the foot and aligned in the frontal plane. Lastly, participants engaged in an active sway condition. In which, a metronome was set to 0.2 Hz and the participant was asked to sway in time at a self-selected amplitude as close to his/her limits of stability as comfortable.

Results indicated that the TA fascicle length changes were significantly less under EO and EC conditions, compared to the beam and active sway conditions. Muscle activity, however, was not found to be significantly different across the EO (4.58% of MVC), EC (4.42% of MVC), and the beam conditions (7.62% of MVC). Conversely, the active sway condition was found to produce significantly greater muscle activity than all three of the previous conditions (18.98% of MVC). Therefore, the authors concluded that the TA was a primary source of proprioceptive information due to its low, unmodulated activity during quiet standing; however, during increased postural demand, greater activation of the TA was required, which may have reduced the effectiveness of the TA muscle spindles (Day et al., 2013).

When taken together, these finding suggest that measures of muscle activity during quiet standing may be a means to infer the proprioceptive capability of a muscle (Day et al., 2013; Giulio et al., 2009). An EMG variable commonly used to quantify muscle activity has been RMS

(Day et al., 2013; Giulio et al., 2009). The RMS is a measure of the average power of a signal over a given period of time (Goen & Tiwari, 2013). Raw RMS data has been found to be a reliable measure in both the TA (ICC=.88) and GM (ICC=.86), as well as when normalized with MVC (ICC=.65; ICC=.84, respectively; Murley, Menz, Landorf, & Bird, 2010).

Inferring ankle proprioception: Spectral analysis. The EMG activity, however, is not the only way proprioception has been indirectly measured. Spectral analysis of COP-based measures was also reported as a means to infer change in proprioception (Cherng, Lee, & Su, 2003; Nagy et al., 2007, 2018; Peterka & Loughlin, 2004). The concept of spectral analysis could be defined as, examining the frequency content of a signal or the examination of signal power distribution over a specified frequency range (Dressler, Schneider, Stockmanns, & Kochs, 2004). As indicated by Speers et al. (2002), postural stability is driven by sensory subsystems, each of which have its own characteristic frequency band. Therefore, when function of a subsystem changes, so too does the frequency band (Cherng et al., 2003). The frequency ranges of low (0–0.1 Hz), low-medium (0.1–0.5 Hz), medium-high (0.5–1 Hz), and high (1–3 Hz), have been suggested to correspond with visual, vestibular, proprioceptive, and CNS functioning, respectively (Nagy et al., 2018).

Nagy et al. (2018) used these measures to evaluate the specific effect of a proprioceptive training program in a group of healthy female young adults. Training sessions were held twice a week and lasted 60 min/session. The program focused on standing balance exercises on an unstable Airex© balance pad under EC conditions. Postural stability was measured from a single force platform at baseline, and at the end of the 8-week proprioceptive training program. Postural stability tests involved participants in EO and EC conditions standing under both firm and foam surface conditions. Each trial lasted 10 s and each trial condition was repeated 3 times.

Participants were asked to stand quietly and barefoot during each trial. The displacement of the COP in the AP and ML directions were used in the frequency analysis.

Following the intervention, it was found that sway path in both AP and ML directions had decreased under the foam surface and EC conditions. This was accompanied by a significant decrease in post-intervention mean power in the low-medium frequency band (vestibular) under EC conditions on the foam surface, but not the medium-high (proprioceptive) frequency band. These findings reasserted that common proprioceptive training does not in fact target proprioception but rather other balance mechanisms (Ashton-Miller et al., 2001; Kiers et al., 2012; Nagy et al., 2018). Furthermore, these findings were in line with the assumption made following this author’s pilot study; had vestibular function been affected by the Tai Chi intervention, significance would have been found with the foam surface condition. While encouraging, these measures have been met with some criticism.

Firstly, the direct comparison of postural spectral analysis results across studies may be inappropriate as both sample duration and sample frequency have been suggested to impact results (Jancová, 2008). Secondly, there has been a lack of definitive consensus surrounding which frequency bands define the function of each sensory system (Nagy et al., 2007; Oppenheim, Kohen-Raz, Alex, Kohen-Raz, & Azarya, 1999; Singh, Taylor, Madigan, & Nussbaum, 2012). In light of this, Singh et al. (2012) performed a detailed analysis of the spectral content within postural sway, and how age, gender, vision, and somatosensory inputs affected the frequency distribution.

The authors recruited 16 young adults (aged 18–24 years) and 16 older adults (aged 55–65 years) and collected postural data (75 s) from each participant while quiet standing. Participants were tested under EO and EC conditions, as well as, standing on firm and foam surfaces. The sway path data in both AP and ML directions were transformed into the frequency domain with a fast Fourier transformation. Unlike Nagy et al. (2007) and Oppenheim et al. (1999) who examined the data under a few specific frequency bands, Singh et al. (2012) divided the entire power spectrum into 100 bands (width=0.1 Hz). The aim was to gain a high-resolution picture of where within the power spectrum each independent variable would manifest change.

There was no difference found in relative power (RP; the power of a band divided by the power of the entire spectrum) between the young males and females. Interestingly, the influence of vision was found to be represented throughout the power spectrum, rather than only at the low band, as suggested by Nagy et al. (2007). Somatosensory function, however, was found to be in line with what had been previously suggested. Singh et al. (2012) concluded that spectral content within the frequency range of 0.4-0.7 Hz was reflective of somatosensory function. This fit nicely within the boundaries set by Nagy et al. (2007, 2018) of 0.5–1.0 Hz believed to reflect proprioceptive function. Therefore, while the effects of vision on the spectral analysis of postural sway may be unclear, these findings indicate that examination of the RP within the 0.4–0.7 Hz frequency band may provide insight into proprioceptive change.

As the EMG activity of muscles and spectral analysis of sway have been shown as potential means of inferring proprioception, their application to the replicated methodology in this author’s pilot study may provide valuable insight into the mechanism which produced the observed increase in postural stability. Furthermore, these measures adhere to the guidelines for testing proprioception. Such that data can be collected concurrently with postural data while the participant is engaged in a functional task, and attention is not unnaturally focused on the feel of the joint which is currently being examined (Han et al., 2016).

Research Problem

Based on the prior review of literature, Tai Chi has been proposed to improve both the postural stability and ankle proprioception among older adults. Furthermore, previous pilot work observed an increase in postural stability under parameters which implied ankle proprioception may have been influenced. As this may open avenues to include a short Tai Chi intervention as part of a rehabilitation program, it may be useful to not only attempt to confirm the findings of the pilot study, but to also assess the potential means by which the results occurred. Additionally, this will add to the limited knowledge regarding the effect of Tai Chi in healthy young adults, which may point to new directions for the application of this ancient art.

Purpose

The purpose of this research was to examine the immediate effects of a single Tai Chi session on postural stability, muscle activity, and inferred potential change in the ankle proprioception of a healthy young adult sample using measures of balance and muscle activation. Based on the previously examined research, the following hypotheses were used to guide this investigation.

Hypotheses

1. Based on previous pilot work, a statistically significant interaction would be observed between independent variables of time (pre and post tests), eyes condition (eyes open and closed), and surface condition (firm and foam) for the Tai Chi experimental group, but not the control group, on the dependent variables mean sway velocity (MSV) and 95% elliptical area (EA) used to examine postural stability.

2. Based on previous pilot work, a statistically significant interaction would be observed between independent variables of time (pre and post tests), eyes condition (eyes open and closed), and surface condition (firm and foam) for the Tai Chi experimental group, but not the control group, on the dependent variable root mean square (RMS) used to examine muscular activity.

3. Based on previous pilot work, a statistically significant interaction would be observed between independent variables of time (pre and post tests), eyes condition (eyes open and closed), and surface condition (firm and foam) for the Tai Chi experimental group, but not the control group, on the dependent variable relative power (RP) used to infer proprioception.

Chapter II: Methods

Participants

Recruitment. After ethical consent was obtained from the Lakehead University Research Ethics Board, 30 healthy participants (17 females and 13 males) between the ages of 18 to 30 years were recruited. To garner interest, the student researcher canvassed various health and wellness businesses across Thunder Bay and spoke with patrons and business owners about the study. Additionally, posters (Appendix A) were handed out which advertised the study. The posters contained a short description regarding the purpose of the research, an outline of what was involved in the testing session, and an indication of time required to complete participation. Testing sessions were scheduled via email and times were chosen which were mutually convenient for both the prospective participant and the student researcher. Potential participants who contacted the student researcher were emailed a copy of the cover letter (Appendix A) and informed consent (Appendix B).

Inclusion/exclusion criteria. Volunteers were considered as potential participants if he/she had no previous history of formal Tai Chi training and did not have any contraindications as outlined in the Get Active Questionnaire (Appendix D). Potential participants were excluded if he/she had any health conditions which may have influenced postural stability and/or ankle proprioception. Such conditions included: a history of concussion within the last 6 months, peripheral neuropathy, vertigo, vestibular impairment, sensory loss in the feet, presence of cardiopulmonary disease, neurological disorder, reconstructive surgery to the ankle, or impaired vision (Ghofrani et al., 2017; Nagy et al., 2007; Payne, Berg, & Latin, 1997; Wayne et al., 2014). Potential participants were also excluded if he/she had an injury to the ankle, knee, hip, or low back within the past 6 months (Palmieri, Ingersoll, Stone, & Krause, 2002).

Procedure

Instrumentation

Advanced Mechanics Technologies Incorporated© (AMTI) force platform. The AMTI© force platform measured the ground reaction forces during quiet standing. These ground reaction forces were produced by the downward force of the COM and torque in the lower limbs (Cavanaugh et al., 2005). Tri-axial force transducers were present in each of the four corners of the force platform, which enabled both the measurement forces (Fz, Fx, and Fy) and moments (Mz, Mx, and My; Nigg & Herzog, 1994). The transducers produced an output voltage in proportion to the force applied to the force platform (He & Fu, 2001). This signal was sampled at 200 Hz, then amplified and converted from an analogue voltage to a digital signal by an AMTI© mini amplifier (MSA-6). The program used to capture and analyze the digital signal was AMTI NetForce Software©. The reliability of the ground reaction forces captured by AMTI© force platforms has been examined by Alenezi, Herrington, Jones, and Jones, (2014), who found a within-day ICC of .92 and .99, for single leg squats and single leg landings respectively.

Delsys® Trigno wireless electromyography system. The Delsys® Trigno wireless EMG system was used to capture the degree of activity present within the left and right TA and GM muscles. The EMG sensors contained four silver electrode contacts, which were placed over the belly of each muscle, and secured to the surface of the skin with a double-sided adhesive (Delsys, 2018). The signal collected by the EMG electrodes were uploaded to, and analyzed on, LabChart Software©. The Delsys® Trigno EMG system has been found to possess good reliability across a variety of muscles, with an ICC ranging from .813 to .916 for muscles within the upper extremities, and a similar ICC range of .81 to .92 for muscles within the lower extremities (Fauth et al., 2010; Varghese, Hui-Chan, Wang, & Bhatt, 2014).

Set-up. On the testing day, the student researcher met the participant in the Sanders Building at Lakehead University in room SB-1028. Each session took approximately 1.5 hours/person. Those who met the inclusion criteria were provided a cover letter which outlined the study purpose, the Get Active Questionnaire, and informed consent when he/she arrived at his/her scheduled time. Once all forms were signed, the student researcher reviewed the purpose, protocol, the participant's right to withdraw at any time, and answered any questions that he/she had. At this point in time, the student researcher used block randomization to assign the participant to either the control or experimental group. This removed student researcher bias in assigning a participant to a particular group and ensured a balanced number of participants assigned to each group (Suresh, 2011) The student researcher then collected demographic information including: height, age, mass, and sex.

Electrodes were attached to the TA and GM bilaterally. To standardize the procedure, the student researcher applied the electrodes according to the surface EMG for a non-invasive assessment of muscles (SENIAM) guidelines for each muscle. When the TA electrodes were placed, the participant was asked to lie supine on a table with his/her leg propped up with a pillow under the knee (Figure 4).

Figure 4. SENIAM placement of EMG electrodes for the tibialis anterior. Adapted from "SENIAM determination of sensor location," n.d. http://www.seniam.org/

The participant's leg was palpated, and both the tip of the fibula and the medial malleolus were marked with a washable water-based marker. The distance between the two marks was measured. A third mark was placed at the point of 1/3 proximal to the total distance. To improve signal fidelity, the area was shaved and cleaned with rubbing alcohol by the student researcher (Payton & Bartlett, 2008). Once the alcohol vaporized, the electrode was placed in the cleaned location, laying parallel to the direction of the muscle fibers. To palpate the muscle more easily, the participant was asked to dorsiflex his/her foot, which increased visibility and consequently, palpability of the muscle. For placement of the GM electrodes, the participant was then asked to lie prone on the table, with a pillow placed under his/her ankle such that the foot projected slightly off the table (Figure 5).

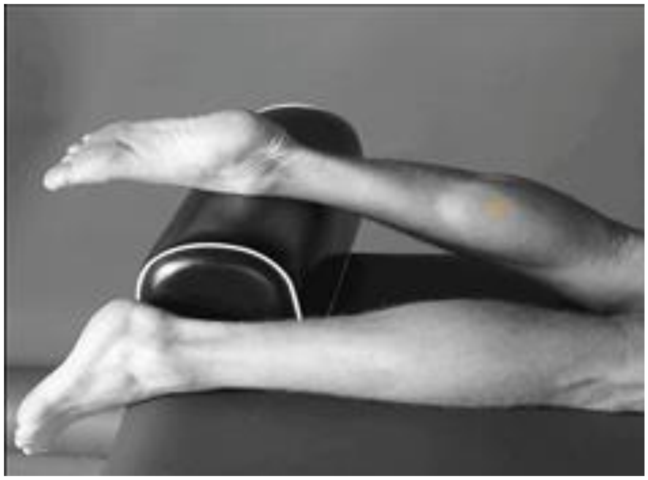

Figure 5. SENIAM placement of EMG electrodes for the gastrocnemius medialis. Adapted from "SENIAM determination of sensor location," n.d. http://www.seniam.org/

The participant was asked to plantarflex his/her ankle to allow the student researcher to more easily identify the muscle. The SENIAM guidelines suggested that the electrode should be placed on the most prominent bulge of the GM; however, it was believed that this may lead to inconsistency between participants. Alternatively, Sacco, Gomes, Otuzi, Pripas, and Onodera (2009) suggested that optimal signal acquisition can be achieved with an electrode placed at 38% of the distance from the medial side of the popliteal cavity to the medial side of the Achilles tendon insertion. This suggested protocol was used instead of the SENIAM protocol for the GM to improve consistency. After locating the area for the electrode placement, the area of skin was cleaned in the same manner as was used for the TA electrode site. The electrode was then attached such that it was parallel with the muscle fibers.

Warm-up. The participant was then led through a 2 min traditional Tai Chi warm-up. This technique involved asking the participant to rub the palms of his/her hands in a circular motion over his/her elbows, shoulders, hips, knees, and ankle joints. After warming up the joints, participants rubbed the palms of his/her hands up and down his/her calf, quadriceps, hamstring, gluteal, upper arm, forearm, and neck muscles. The purpose of which was to stimulate blood flow and prepare the body for Tai Chi. Following the warm-up, the EMG was normalized.

Normalizing electromyography. To normalize the EMG, maximal voluntary isometric contraction (MVIC) was taken from the TA and GM bilaterally. For the TA, the participant was asked to dorsiflex and invert his/her ankle maximally while supine to produce the MVIC. Whereas, to elicit the MVIC for the GM, the participant was asked to maximally plantarflex his/her ankle while prone. Three trials of 5 s per muscle was completed, and the average peak amplitude of the three trials was used as the MVIC (Warnica et al., 2014). To reduce the effects of fatigue, the participant had a 1 min rest period between each MVIC trial.

Data collection. The participant was brought over to the force platform and the electrodes were checked for proper connection. Once the electrodes were checked, the force platform was zeroed, and the participant was asked to stand on the force platform. A 35.37-centimeter (cm) screen was placed 2 m in front of the participant (Yamamoto et al., 2015). The height of the screen was adjusted to be at the participant’s eye level. On the screen, an “X” was displayed, which the student researcher asked the participant to stare at during EO open conditions. This was to prevent the participant’s gaze from wandering, as changes in the distance between the eyes and the object of focus can affect postural performance (Schubert, Kirchner, Schmidtbleicher, & Haas, 2012).

Before each trial, the force platform was zeroed. One of four conditions was then set-up (EO on firm or foam, EC on firm or foam). These conditions were presented in a randomized order.

To randomize the conditions, a random number generator was activated which produced values 1 to 4. The trial corresponding to the randomly generated number was then used.

The student researcher asked the participant to remove his/her shoes and socks, then stand quietly on the force platform. Readiness of the participant was confirmed verbally. The student researcher then silently counted down from five, and postural data collection began at the end of the final second. This was to aid in removing the adaptation period, which may skew results (Nagy et al., 2007). Postural data was collected at 200 Hz, with each trial lasting 90 s to improve the reliability of the measure (Ruhe et al., 2010). During postural data collection, EMG data was collected concurrently at 1000 Hz. Both postural and EMG data were collected simultaneously with AMTI Netforce Software© and LabChart Software©, respectively. After the four pre-intervention test conditions were completed, the participants assigned to the experimental group were engaged in a 15 min Tai Chi intervention, while those assigned to the control group were asked to just sit comfortably for 15 min. Immediately after either the intervention or sitting period, the electrodes were checked for proper contact, and post-intervention measures were taken. The same protocol was used for the post-intervention measures as was used for the pre-intervention measures.

Tai Chi intervention. Following the pre-intervention measures, the participants in the experimental group were seated, and the student researcher displayed a silent 2 min and 57 s video of Master Peng You performing a Tai Chi form (Appendix E). The form consisted of the following positions (in order of occurrence): commencing, wave single hand (right and left), lazily tying coat, six sealings four closings (right and left), and single whip (right and left). This Tai Chi form was generated by Master Peng with the consideration that it needed to challenge balance, but not be too complicated that is could not be learned in the short 15 min time frame.

The participant was asked to visualize him/herself performing the Tai Chi form as he/she watched. The purpose of which was to help the participant familiarize themselves with the movements prior to performing them. The participant viewed the video twice and then followed along with it three times.

As no previous research has utilised a Tai Chi intervention in this manner, the number of viewings and number of times the participant will follow along with the video was based on the student researcher's personal communications with Master Peng You (P. You, personal communication, November 24, 2017). These recommendations were in line with previous motor learning research which suggested that several viewings of a motor skill prior to engaging in the activity was beneficial to for optimal acquisition of form (Weeks & Anderson, 2000).

Concluding the session. Following the post intervention measures, the student researcher removed the electrodes from the participant. The student researcher then answered any questions that the participant had. Once the student researcher answered any questions the participant may have had, he/she was thanked for his/her participation and this concluded the session.

***Data processing*.** Data were extracted and analysed using LabChart Software©, AMTI NetForce Software©, and JupyterLab©. The scalar COP-based dependent variables included were mean sway velocity (MSV) and 95% elliptical area (EA). The variable acquired by the spectral analysis was the relative power (RP) within the 0.4–0.7 Hz frequency band derived from all data points of COP sway collected in the AP direction. The AP direction was chosen as the ankle is dominant in this direction while the hips dominate ML (Winter et al., 1996). As the signal acquired from postural data is not periodic in nature, Welch's method was used to transform the time series data into the frequency domain (Carroll & Freedman, 1993; Mehra, 2013; Oba, Sasagawa, Yamamoto, & Nakazawa, 2015).

In addition to the COP-based dependent variables, the root mean square (RMS) of bilateral TA and GM EMG activity were also included. To process the EMG signal, the raw data was converted to absolute values and a lowpass filter at 10 Hz was applied to remove noise. All of the dependent variables were operationally defined as such:

Mean sway velocity. The MSV was measured as the average change in COP position over time (cm/s) within each trial (Thompson et al., 2017).

95% elliptical area. Measured with an ellipse around the data, which included 95% of all points collected during the trial (Doyle et al., 2007).

Electromyography root-mean-square. The RMS was measured as the root square of the average of the filtered EMG signal raised to the power of 2 over the duration of each trial (Goen & Tiwari, 2013).

Relative power. The RP was measured as the mean power within the 0.4–0.7 Hz range divided by the total power within the entire spectrum, derived from the data points of sway collected within the AP direction (Singh et al., 2012).

Statistical analysis. Statistical Package for the Social Sciences© (SPSS) was used to perform the statistical analysis of the data. Descriptive statistics were calculated for the mean and standard deviation values for the age, gender, anthropometric measures, and dependent variables of interest. The independent variables included were eyes condition (EO and EC), surface condition (firm and foam), group (control and experimental), and time (pre-/post-intervention). The dependent variables examined were MSV, EA, RMS, and RP for each trial. A 2 (eyes condition) x 2 (surface condition) x 2 (group) x 2 (time) factorial ANOVA with repeated measures on time was run to determine if an interaction existed between independent variables of EO/EC conditions, firm/foam conditions, group, or time. Statistically significant interactions were explored with simple main effects. If no statistically significant interaction was observed, the main effects of each factor was examined.

Chapter III: Results

Demographics

Thirty healthy young adults (17 females and 13 males) were recruited for this study. The demographic characteristics of the sample are presented in Table 1.

Table 1.

Participant demographics

	Mean	Standard Deviation	Minimum	Maximum
Age (years)	24.1	2.38	18	30
Height (cm)	168.1	20.8	73	189
Mass (kg)	82.8	28.5	54	185

Scalar Center of Pressure Based Measures

Mean Sway Velocity. On MSV, there was no statistically significant interaction between the factors of eyes, surface, time, and group conditions (F(1,28)=0.052, p=.822). No significant main effects were observed for the factors of time (F(1,28)=0.561, p=.460) or group (F(1,28)=2.157, p=.153). There were statistically significant main effects with large effect sizes observed for both the eyes (F(1,28)=264.415, p=.005, η^2=.904) and surface (F(1,28)=174.613, p=.005, η^2=.862) factors. A statistically significant interaction with a large effect size was observed between the eyes and surface conditions for both the control (F(1,14)=77.880, p=.005, η^2=.848; Figure 7) and experimental group (F(1,14)=75.532, p=.005, η^2=.844; Figure 8). The two-way interaction was explored by examining the simple main effects of both factors.

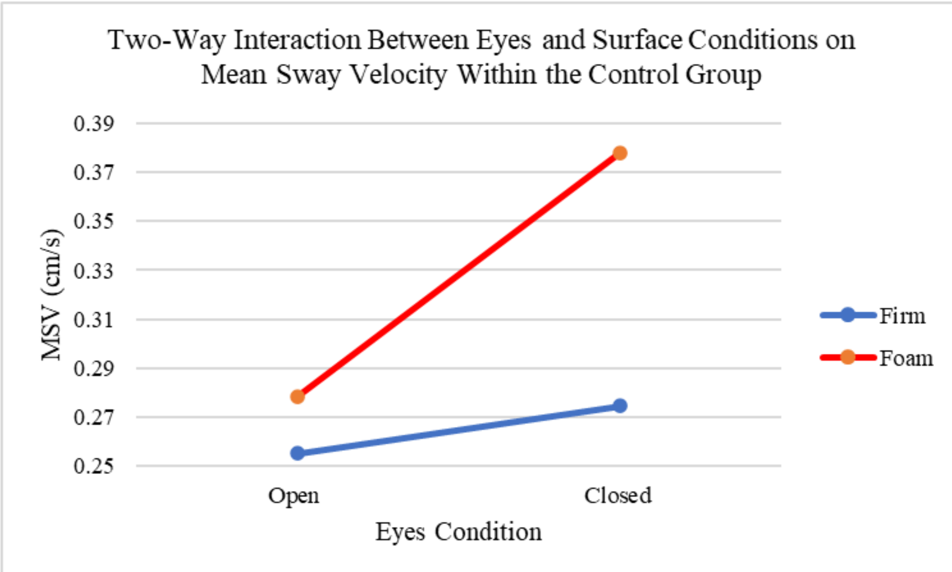

Figure 7. The two-way interaction observed between the eyes and surface conditions on MSV within the control group.

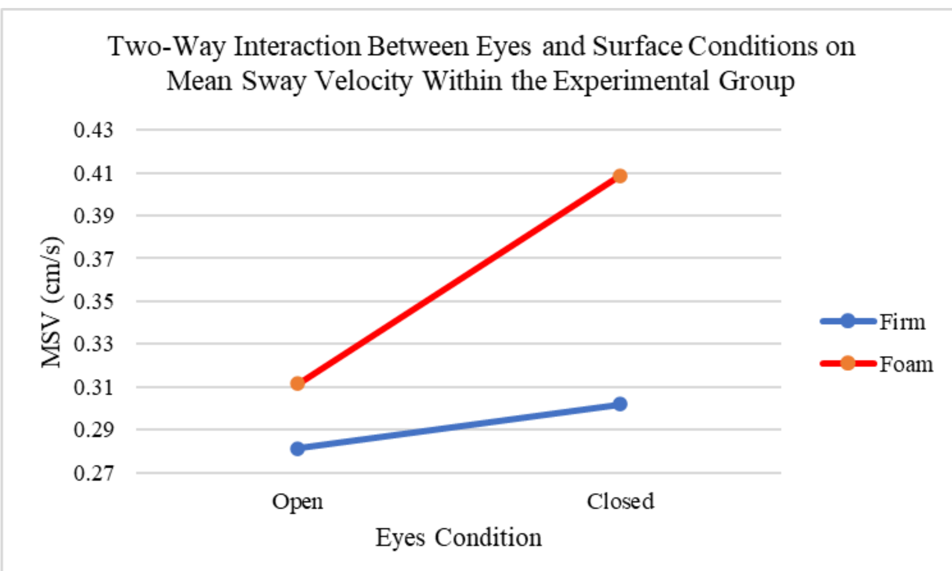

Figure 8. The two-way interaction observed between the eyes and surface conditions on MSV within the experimental group

The MSV from the EO firm to EC firm condition increased significantly with a large effect size in both the control group ($F(1,14)=10.966$, $p=.005$, $\eta^2=.439$; Figure 9) and experimental group ($F(1,14)=14.899$, $p=.002$, $\eta^2=516$; Figure 10). The control group had an increase of 0.18 cm/s (95% CI[.006, .030]) from the EO firm ($x=0.255$ cm/s, $SD=0.011$) to the EC firm ($x=0.273$ cm/s, $SD=0.013$). The experimental group had a slightly larger increase of 0.20 cm/s (95% CI[.009, .031]) from the EO firm ($x=0.282$ cm/s, $SD=0.018$) to the EC firm ($x=0.302$ cm/s, $SD=0.015$) condition.

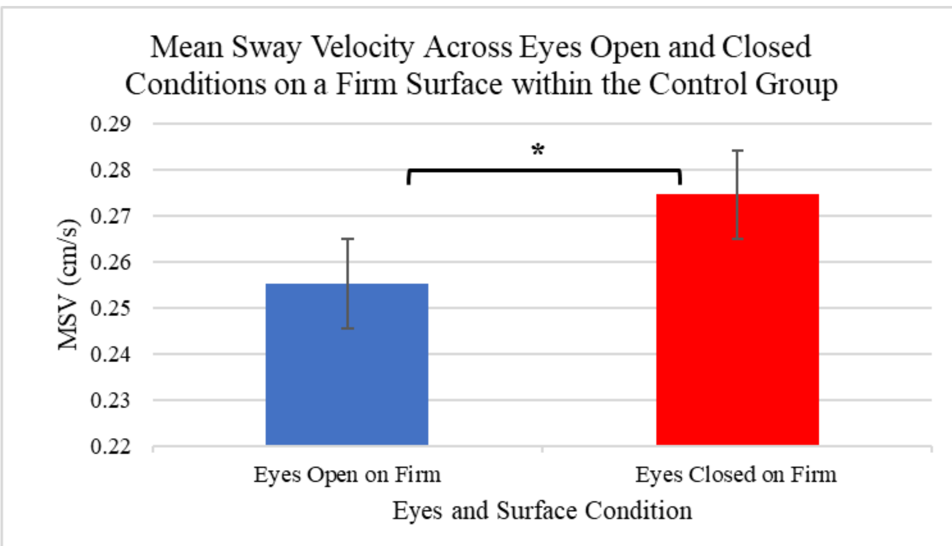

Figure 9. The difference in MSV within the control group between the eyes open and closed conditions while on a firm surface. Note. * indicates statistical significance at $p<.05$.

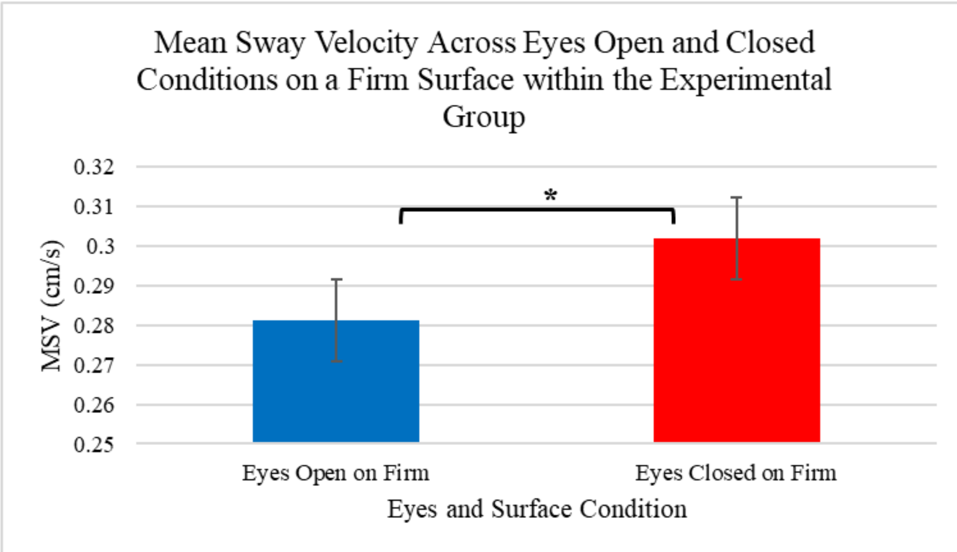

Figure 10. The difference in MSV within the experimental group between the eyes open and closed conditions while on a firm surface. Note. * indicates statistical significance at *p*<.05.

There was a significant difference with a large effect size in the MSV between the EO foam and EC foam condition for both the control group ($F(1,14)=167.663$, $p=.005$, $\eta^2=.923$; Figure 11) and the experimental group ($F(1,14)=141.312$, $p=.005$, $\eta^2=.910$; Figure 12). From the EO foam condition ($x=0.279$ cm/s, $SD=0.013$) to the EC foam condition ($x=0.376$ cm/s, $SD=0.013$), the MSV of the control group increased by 0.097 cm/s (95% CI[.081, .113]). Similarly, the MSV of the experimental group increased by 0.96 cm/s (95% CI[.079, .114]) from the EO foam condition ($x=0.312$ cm/s, $SD=0.017$) to the EC foam condition ($x=0.408$ cm/s, $SD=0.019$).

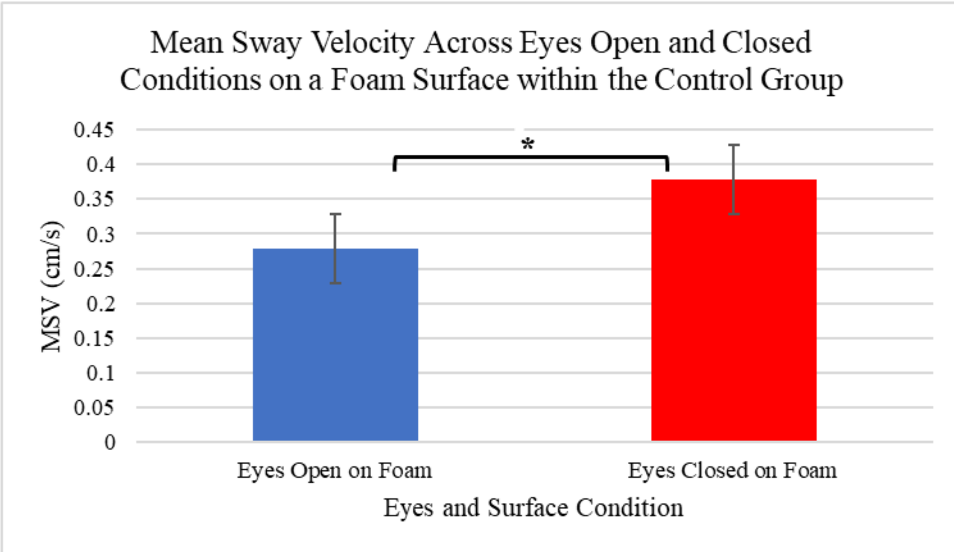

Figure 11. The difference in MSV within the control group between the eyes open and eyes closed conditions while on a foam surface. Note. * indicates statistical significance at $p<.05$.

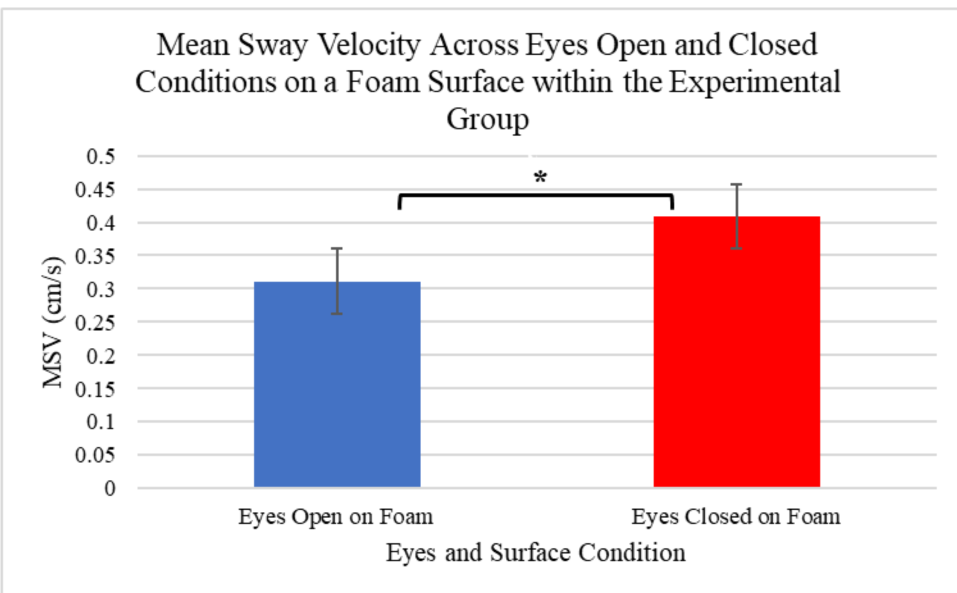

Figure 12. The difference in MSV within the experimental group between the eyes open and eyes closed conditions while on a foam surface. Note. * indicates statistical significance at $p<.05$.

A significant difference in the MSV with a large effect size was observed in the control group ($F(1,14)=26.264$, $p=.005$, $\eta^2=.652$; Figure 13) and experimental group ($F(1,14)=19.711$, *p*=.001, η^2=.585; Figure 14) between the EO firm and EO foam conditions. The MSV of the control group was found to increase from the EO firm condition (*x*=0.255 cm/s, *SD*=0.011) to the EO foam condition (*x*=0.279 cm/s, *SD*=0.013), an increase of 0.024 cm/s (95% CI[.014, .035]). The MSV of the experimental group was also found to increase from the EO firm condition (*x*=0.282 cm/s, *SD*=0.018) to the EO foam condition (*x*=0.312 cm/s, *SD*=0.017), an increase of 0.030 cm/s (95% CI[.016, .045]).

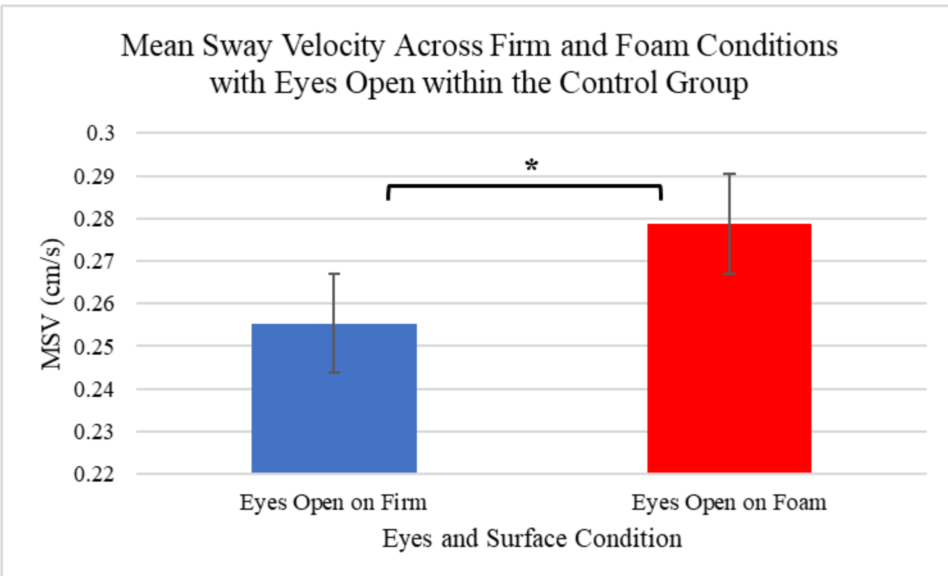

Figure 13. The difference in MSV within the control group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at $p<.05$.

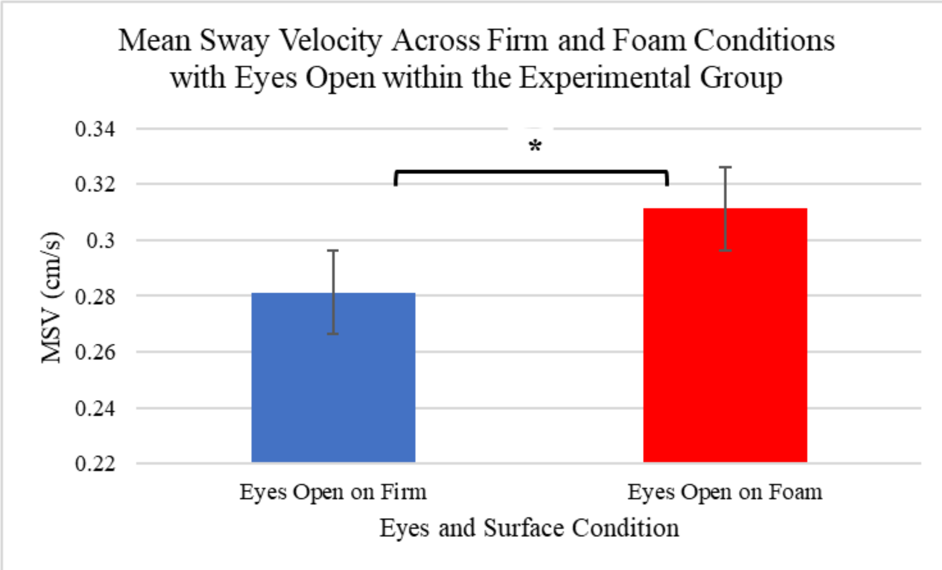

Figure 14. The difference in MSV within the experimental group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at $p<.05$.

For both the control group ($F(1,14)=103.584$, $p=.005$, $\eta^2=.881$; Figure 15) and experimental group ($F(1,14)=106.312$, $p=.005$, $\eta^2=884$; Figure 16), a significant increase in the MSV with a large effect size was observed between the EC firm and EC foam conditions. The MSV of the control group increased from the EC firm condition ($x=0.273$ cm/s, $SD=0.013$) to the EC foam condition ($x=0.376$ cm/s, $SD=0.013$) by 0.103 cm/s (95% CI[.081, .125]). The MSV of the experimental group also increased from the EC firm condition ($x=0.302$ cm/s, $SD=0.015$) to the EC foam condition ($x=0.408$ cm/s, $SD=0.019$), a difference of 0.106 cm/s (95% CI[.084, .128]).

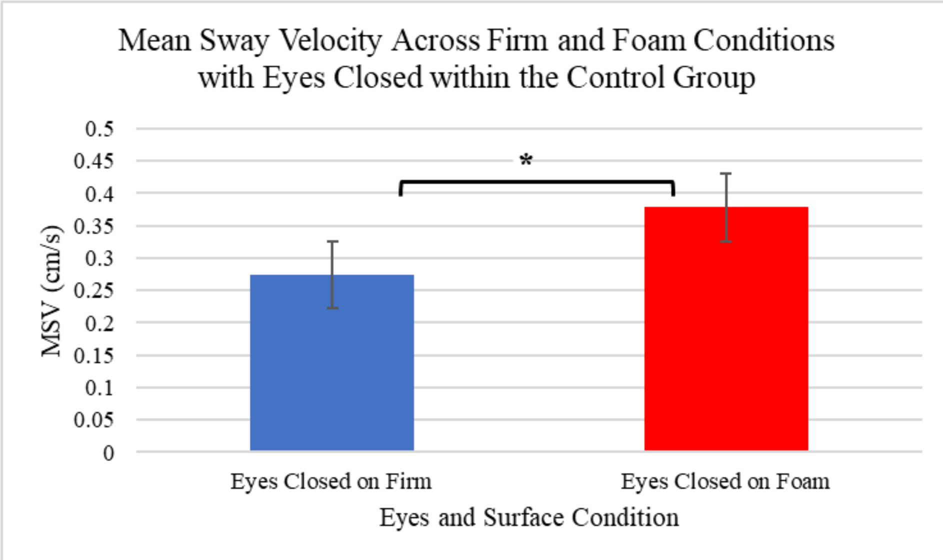

Figure 15. The difference in MSV within the control group between the firm and foam surface conditions while eyes were closed. Note. * indicates statistical significance at $p<.05$.

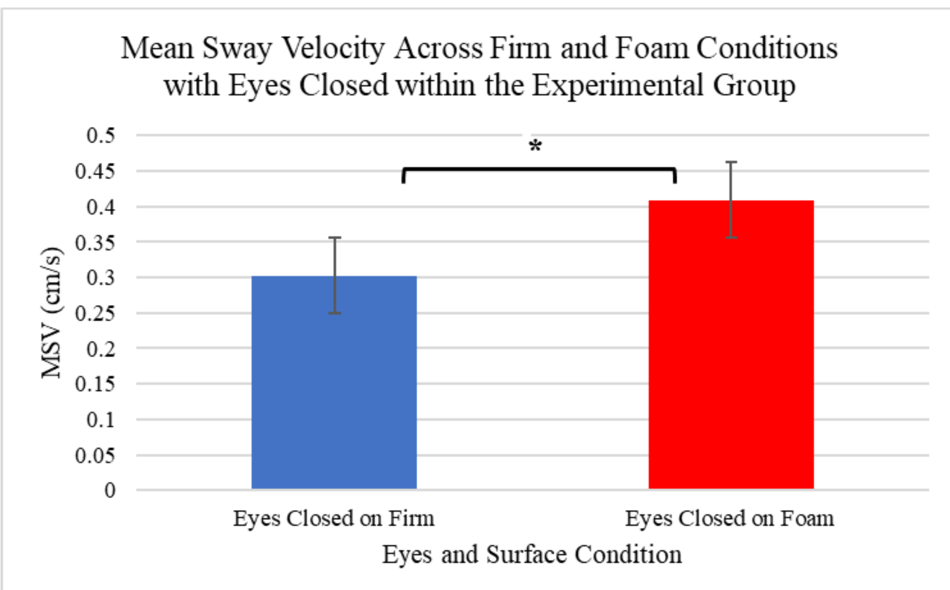

Figure 16. The difference in MSV within the experimental group between the firm and foam surface conditions while eyes were closed. Note. * indicates statistical significance at $p<.05$.

95% Elliptical Area. No significant interaction was observed between the factors of time, eyes, surface, and group ($F(1,28)=1.855$, $p=.184$). No significant main effects were observed for either the time (F(1,28)=0.899, p=.351) or group (F(1,28)=1.668, p=0.207) factors. There were statistically significant main effects with large effect sizes observed for both the eyes (F(1,28)=90.397, p=.005, η^2=.764) and surface (F(1,28)=137.727, p=.005, η^2=.831) factors. A significant two-way interaction with a large effect size was observed between the eyes and surface condition for both the control group (F(1,14)=29.245, p=.005, η^2=.679; Figure 17) and the experimental group (F(1,14)=21.828, p=.005, η^2=.609; Figure 18). To explore the two-way interaction, simple main effects were examined for both factors.

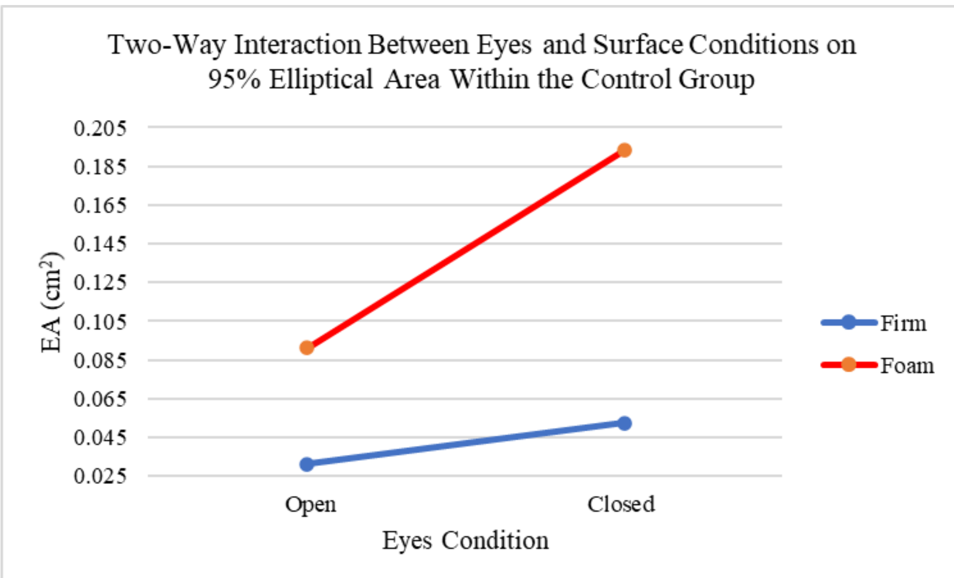

Figure 17. The two-way interaction observed between the eyes and surface conditions on EA within the control group.

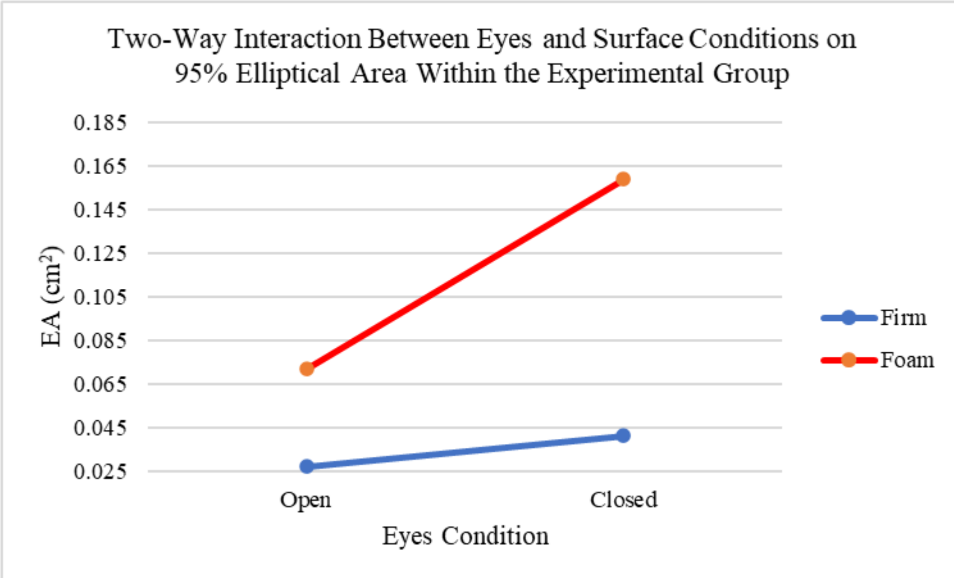

Figure 18. The two-way interaction observed between the eyes and surface conditions on MSV within the experimental group.

There was a significant difference in the EA with a large effect size between the EO firm condition and EC firm condition for both the control group (F(1,14)=7.351, p=.017, η^2=.344; Figure 19) and the experimental group (F(1,14)=11.922, p=.004, η^2=.460; Figure 20). The EA of the control group was found to increase from the EO firm condition (x=0.032 cm^2, SD=0.007) to the EC firm (x=0.051 cm^2, SD=0.012) by 0.019 cm^2 (95% CI[.004, .035]). The EA of the experimental group was also observed to increase from the EO firm condition (x=0.027 cm^2, SD=0.004) to the EC firm condition (x=0.041 cm^2, SD=0.004) by 0.014 cm^2 (95% CI[.005, .022]).

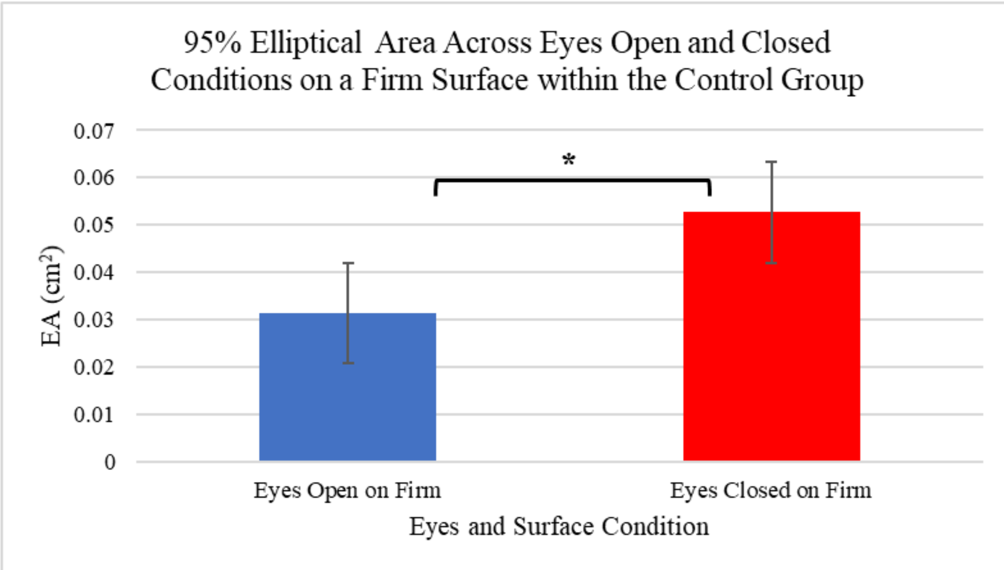

Figure 19. The difference in EA within the control group between the eyes open and closed conditions while on a firm surface. Note. * indicates statistical significance at $p<.05$.

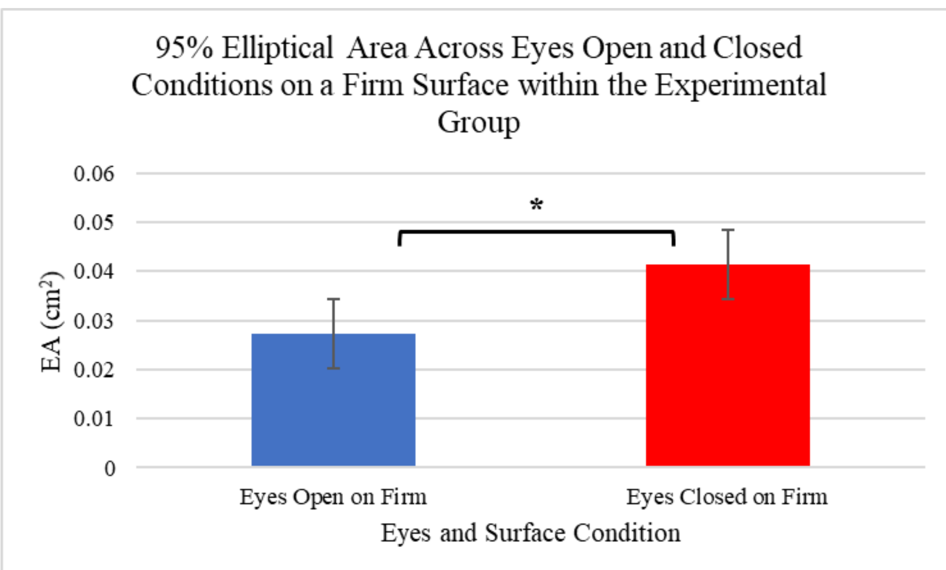

Figure 20. The difference in EA within the experimental group between the eyes open and closed conditions while on a firm surface. Note. * indicates statistical significance at $p<.05$.

A significant difference with a large effect size was observed on EA between the EO foam and EC foam conditions for both the control (F(1,14)=52.048, p=.005, η^2=.788; Figure 21) and experimental group (F(1,14)=30.721, p=.005, η^2=.687; Figure 22). The EA of the control group was found to increase by 0.103 cm^2 (95% CI[.072, .133]) from the EO foam condition (x=0.091 cm^2, SD=0.014) to the EC foam condition (x=0.193 cm^2, SD=0.024). The EA of the experimental group was also found to increase by 0.086 cm^2 (95% CI[.053, .120]) from the EO foam condition (x=0.072 cm^2, SD=0.005) to the EC foam condition (x=0.158 cm^2, SD=0.015).

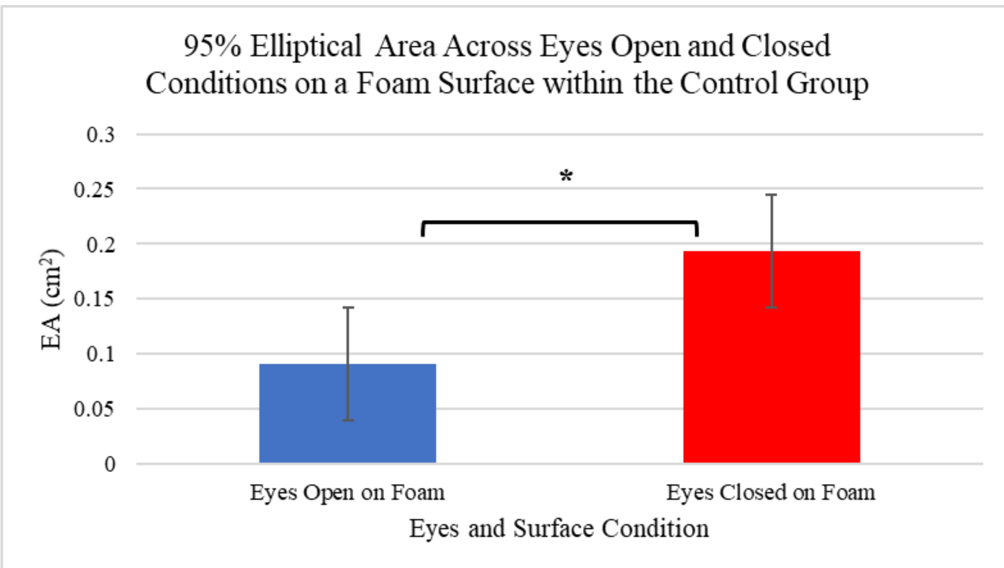

Figure 21. The difference in EA within the control group between the eyes open and closed conditions while on a foam surface. Note. * indicates statistical significance at p<.05.

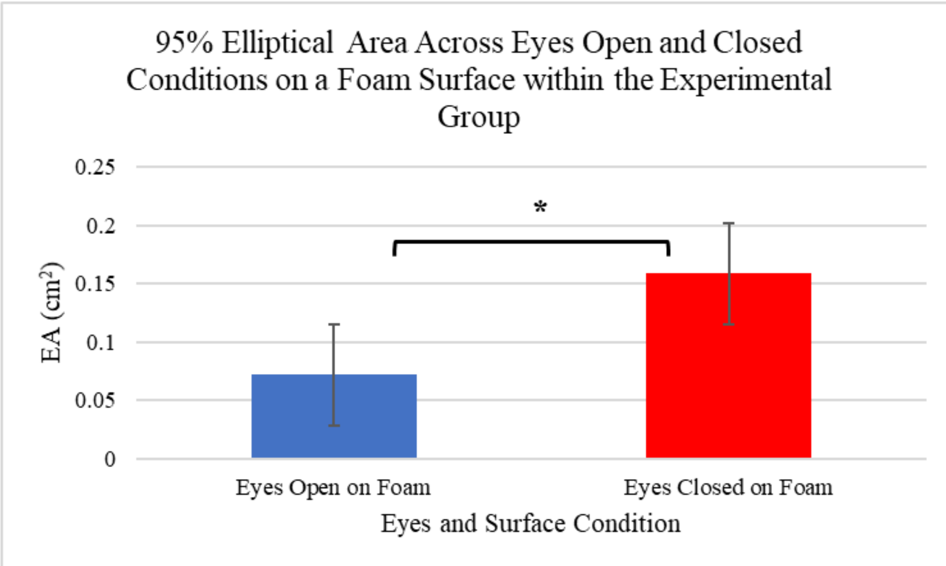

Figure 22. The difference in EA within the experimental group between the eyes open and closed conditions while on a foam surface. Note. * indicates statistical significance at *p*<.05.

A significant difference with a large effect size was found between the EO firm and EO foam conditions for both the control group ($F(1,14)=23.446$, $p=.005$, $\eta^2=.626$; Figure 23) and the experimental group ($F(1,14)=82.327$, $p=.005$, $\eta^2=.855$; Figure 24). The EA of the control group was found to increase from the EO firm condition ($x=0.032$ cm^2, $SD=0.007$) to the EO foam condition ($x=0.091$ cm^2, $SD=0.014$), a difference of 0.059 cm^2 (95% CI[.033, .085]). Similarly, the EA of the experimental group was found to increase by 0.045 cm^2 (95% CI[.034, .055]) from the EO firm ($x=0.027$ cm^2, $SD=0.004$) to the EO foam condition ($x=0.072$ cm^2, $SD=0.005$).

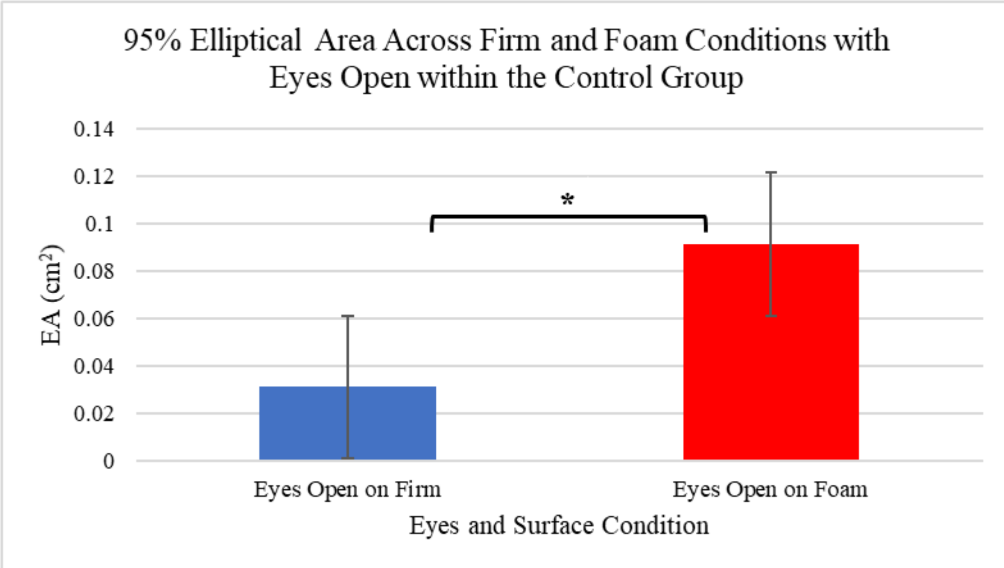

Figure 23. The difference in EA within the control group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at $p<.05$.

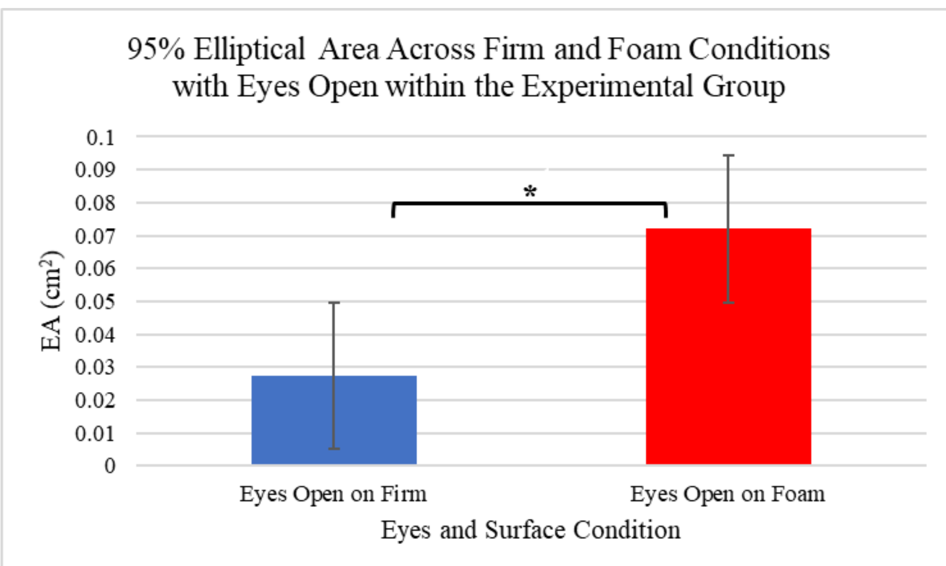

Figure 24. The difference in EA within the experimental group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at $p<.05$.

A significant difference in EA with a large effect size was observed between the EC firm condition and EC foam condition in both the control group ($F(1,14)=51.374$, $p=.005$, $\eta^2=.786$;

Figure 25) and experimental group ($F(1,14)=90.531$, $p=.005$, $\eta^2=.866$; Figure 26). Within the control group, the EA increased from the EC firm condition ($x=0.051$ cm^2, $SD=0.012$) to the EC foam condition ($x=0.193$ cm^2, $SD=0.024$) by 0.142 cm^2 (95% CI[.100, .185]). Within the experimental group, EA was also observed to increase between the EC firm condition ($x=0.041$ cm^2, $SD=0.004$) and the EC foam condition ($x=0.158$ cm^2, $SD=0.015$) by 0.117 cm^2 (95% CI[.091, .144]).

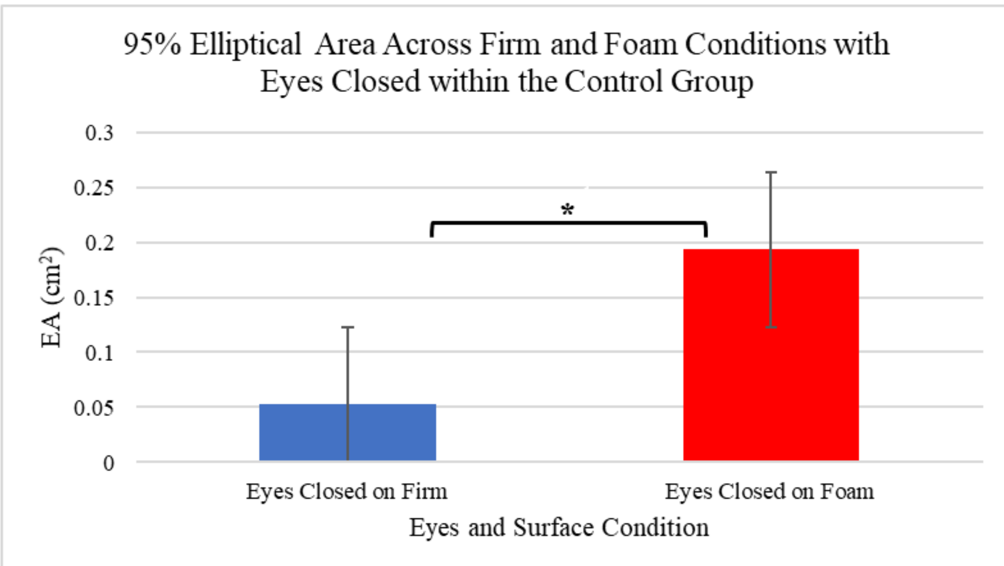

Figure 25. The difference in EA within the control group between the firm and foam surface conditions while eyes were closed. Note. * indicates statistical significance at $p<.05$.

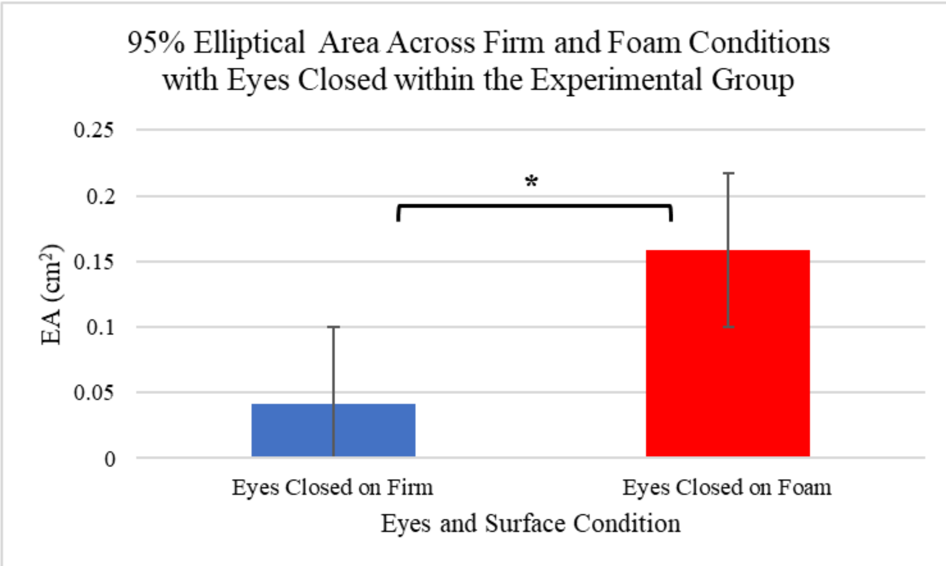

Figure 26. The difference in EA within the experimental group between the firm and foam surface condition while eyes were closed. Note. * indicates statistical significance at *p*<.05.

Electromyography Based Measures

R-TA. No significant interaction between the factors of time, eyes, surface, and group was found (F(1,28)=2.907, p=.099). Additionally, no significant three-way interactions, two-way interactions, or main effects of the time (F(1,28)=0.668, p=.421), eyes (F(1,28)=0.225, p=.639), surface (F(1,28)=1.640, p=.211), or group (F(1,28)=2.582, p=.119) factors were observed.

L-TA. No significant interaction was observed between the factors of time, eyes, surface, and group (F(1,28)=2.978, p=.095). Additionally, no significant three-way interactions, two-way interactions, or main effects of the time (F(1,28)=2.119, p=.157), eyes (F(1,28)=0.578, p=.454), surface (F(1,28)=1.934, p=.175), or group (F(1,28)=0.155, p=.697) factors were observed.

R-GM. No significant interaction between the factors of time, eyes, surface, and group was observed (F(1,14)=1.456, p=.238). No significant main effects were observed for the factors of time (F(1,28)=0.538, p=.469), eyes (F(1,28)=0.107, p=.746) or group (F(1,28)=0.088, p=.769).

A significant main effect of surface with a large effect size was observed for both the control group (F(1,14)=15.614, p=.001, η^2=.527) and the experimental group (F(1,14)=6.015, p=.028, η^2=.301).

A significant difference with a large effect size was observed on the RMS of the right GM between the EO firm condition and the EO foam condition for both the control group (F(1,14)=22.018, p=.005, η^2=.611; Figure 27) and the experimental group (F(1,14)=13.720, p=.002, η^2=.495; Figure 28). The RMS of the right GM of the control group was observed to increase by 0.037 mV (95% CI[.020, .054]) from the EO firm condition (x=0.258 mV, SD=0.023) to the EO foam condition (x=0.295 mV, SD=0.024). Similarly, the RMS of the right GM of the experimental group was observed to increase from the EO firm condition (x=0.255 mV, SD=0.029) to the EO foam condition (x=0.278 mV, SD=0.033) by 0.023 mV (95% CI[.010, .037]).

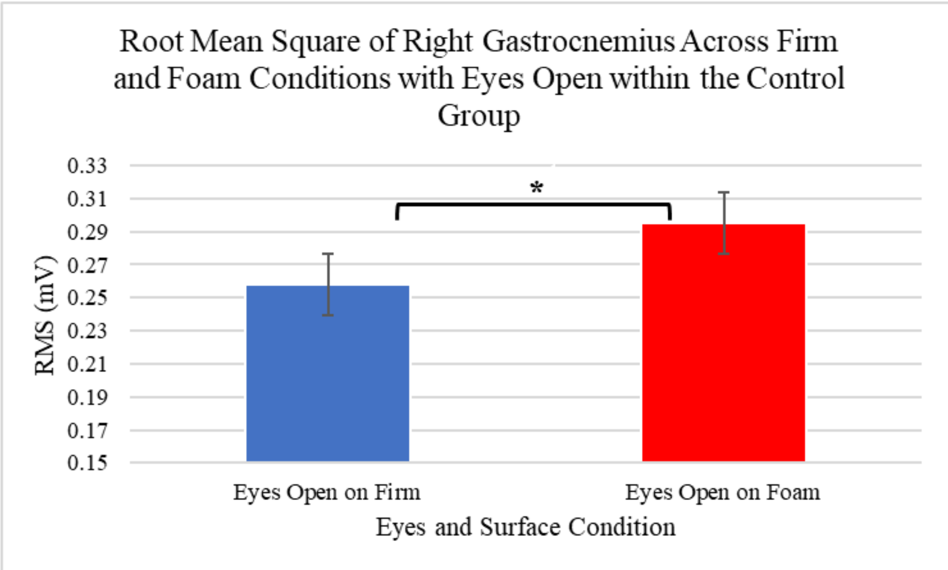

Figure 27. The difference in RMS of the right GM within the control group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at *p*<.05.

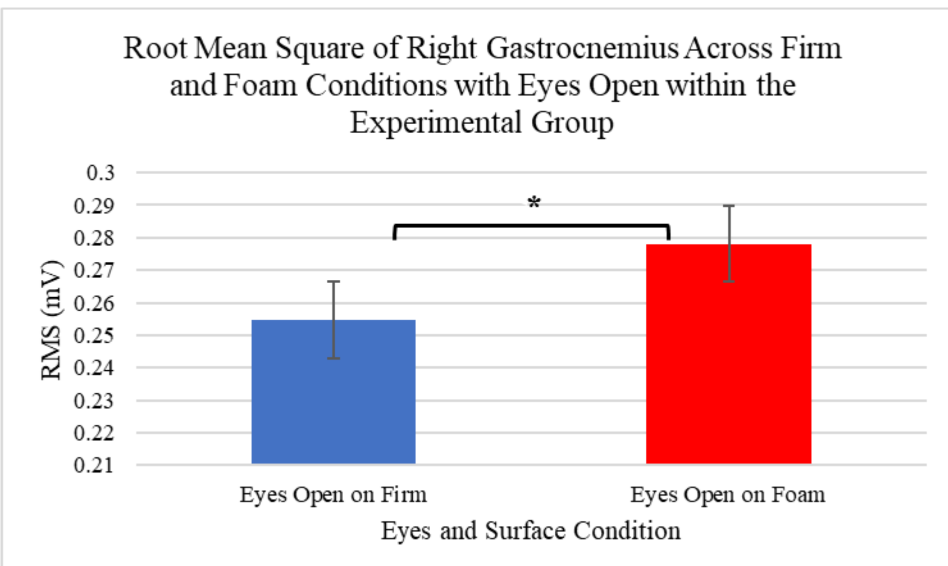

Figure 28. The difference in RMS of the right GM within the experimental group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at *p*<.05.

A significant difference with a large effect size was found on the RMS of the right GM between the EC firm and EC foam conditions was observed in both the control group ($F(1,14)=7.848$, $p=.014$, $\eta^2=.359$; Figure 29) and the experimental group ($F(1,14)=22.178$, $p=.005$, $\eta^2=.613$; Figure 30). The RMS of the right GM within the control group was found to increase by 0.033 mV (95% CI[.008, .059]) from the EC firm condition (x=0.263 mV, SD=0.023) to the EC foam condition (x=0.296 mV, SD=0.026). Similarly, the RMS of the right GM within the experimental group increased by 0.027 mV (95%CI[.015, .039]) from the EC firm condition (x=0.258 mV, SD=0.031) to the EC foam condition (x=0.285 mV, SD=0.033).

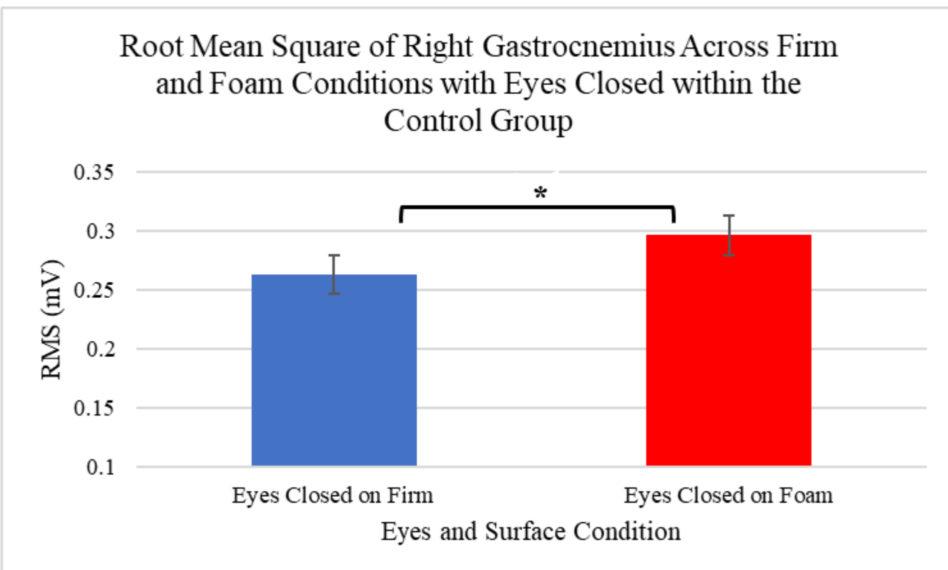

Figure 29. The difference in RMS of the right GM within the control group between the firm and foam surface conditions while eyes were closed. Note. * indicates statistical significance at $p<.05$.

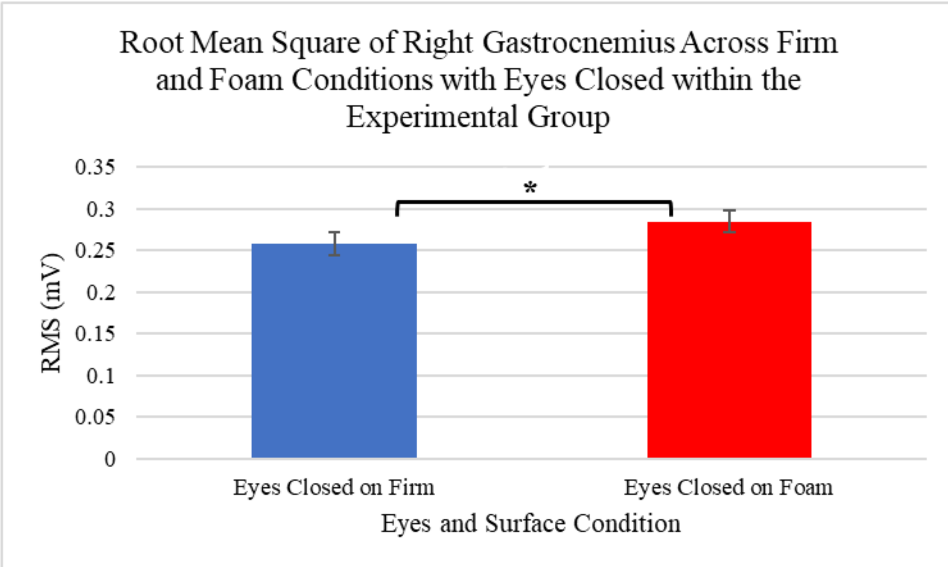

Figure 30. The difference in the RMS of the right GM within the experimental group between the firm and foam surface conditions while eyes were closed. Note. * indicates statistical significance at $p<.05$.

L-GM. No significant interaction between the factors of time, eyes, surface, and group conditions was observed ($F(1,28)=1.847$, $p=.185$). No significant main effects were observed for the factors of time ($F(1,28)=1.602$, $p=.216$), eyes ($F(1,28)=1.515$, $p=.229$) or group ($F(1,28)=1.455$, $p=.238$). A significant main effect of surface with a large effect size was observed for both the control group ($F(1,14)=11.819$, $p=.004$, $\eta^2=.458$) and the experimental group ($F(1,14)=8.976$, $p=.010$, $\eta^2=.391$).

A significant difference in the RMS of the left GM with a large effect size was observed in both the control group ($F(1,14)=9.262$, $p=.009$, $\eta^2=.398$; Figure 31) and the experimental group ($F(1,14)=8.710$, $p=.011$, $\eta^2=.384$; Figure 32). The RMS of the left GM in the control group was found to increase significantly by 0.044 mV (95% CI[.013, .075]) from the EO firm ($x=0.143$ mV, $SD=0.017$) to the EO foam condition ($x=0.187$ mV, $SD=0.023$). Similarly the RMS of the left GM in the experimental group increased significantly from the EO firm condition ($x=0.160$

mV, *SD*=0.017) to the EO foam condition (*x*=0.197 mV, *SD*=0.018) by 0.038 mV (95% CI[.010, .065]).

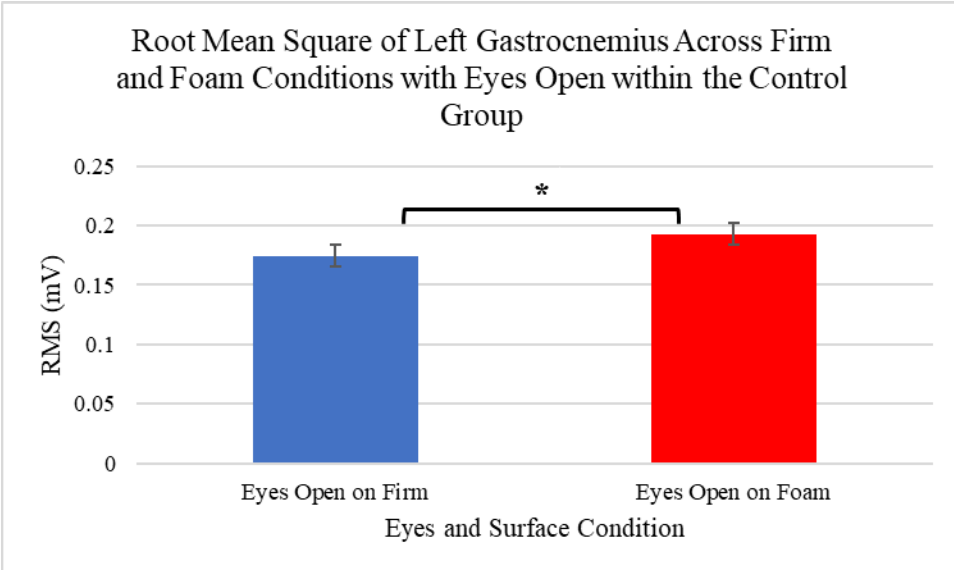

Figure 31. The difference in RMS of the left GM within the control group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at $p<.05$.

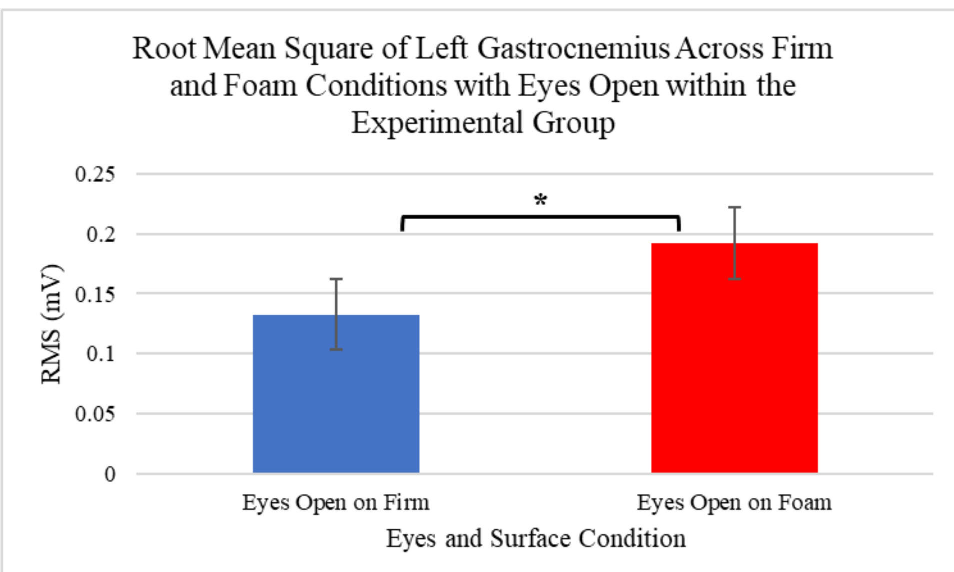

Figure 32. The difference in RMS of the left GM within the experimental group between the firm and foam surface conditions while eyes were open. Note. * indicates statistical significance at $p<.05$.

A significant difference in RMS of the left GM with a large effect size was observed between the EC firm and EC foam conditions for both the control group (F(1,14)=15.040, p=.002, η^2=.518; Figure 33) and the experimental group (F(1,14)=4.785, p=0.46 η^2=.255; Figure 34). The RMS of the control group was found to increase by 0.041 mV (95% CI[.018, .063]) from the EC firm condition (x=0.149 mV, SD=0.018) to the EC foam condition (x=0.190 mV, SD=0.021). Similarly, the RMS of the experimental group increased from the EC firm (x=0.192 mV, SD=0.026) to the EC foam condition (x=0.258 mV, SD=0.050) by 0.066 (95% CI[.020, .060]).

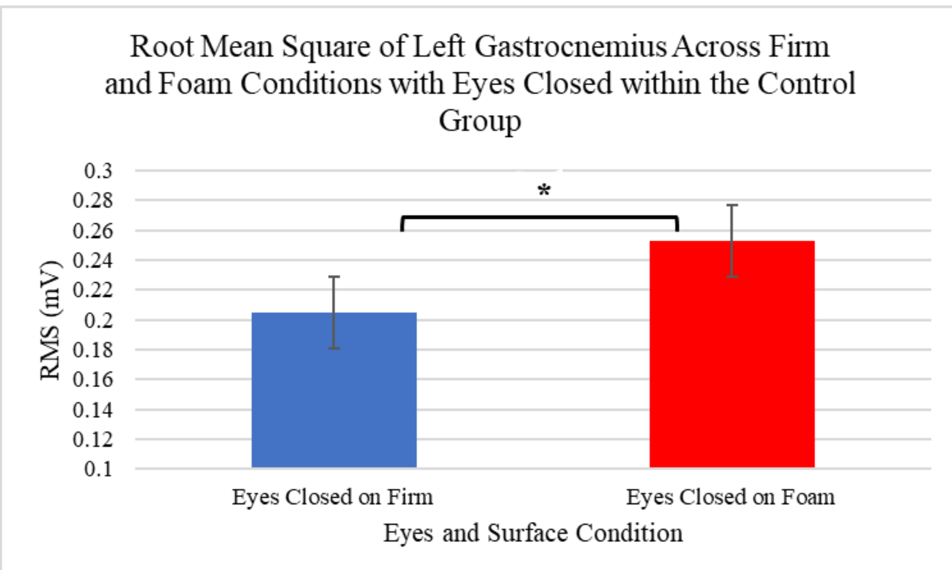

Figure 33. The difference in RMS of the left GM within the control group between the firm and foam surface conditions while eyes were closed. Note. * indicates statistical significance at p<.05.

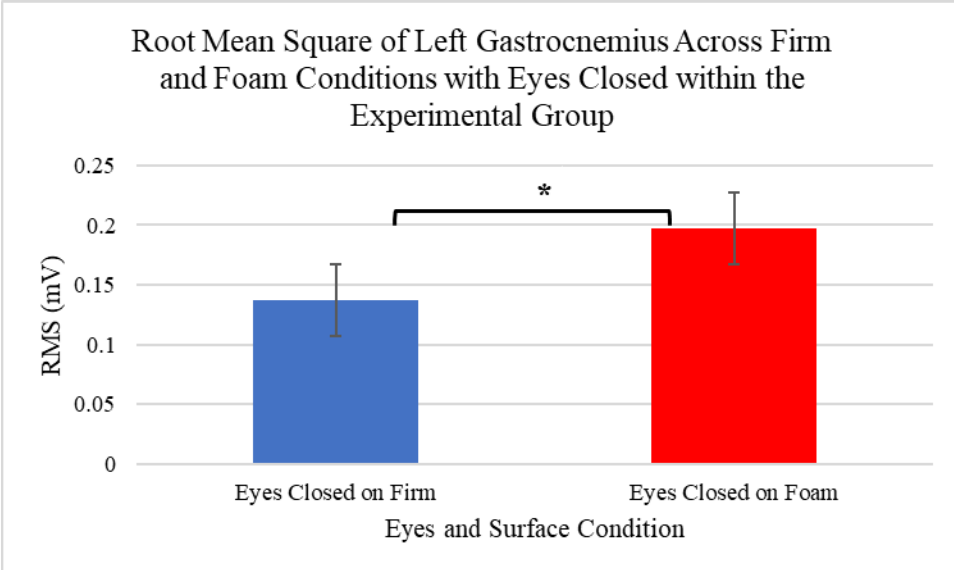

Figure 34. The difference in RMS of the left GM within the experimental group between the firm and foam surface conditions while eyes were closed. Note. * indicates statistical significance at $p<.05$.

Spectral Analysis Based Measure

Relative Power. No significant interaction was observed between the factors of time, eyes, surface, and group ($F(1,28)=0.036$, $p=.851$).There were also no significant three-way interactions, two-way interactions, or main effects of the time ($F(1,28)=0.631$, $p=.434$), eyes ($F(1,28)=0.314$, $p=.579$), surface ($F(1,28)=0.055$, $p=.816$), or group ($F(1,28)=0.001$, $p=.970$) factors were observed.

Chapter IV: Discussion

The purpose of this study was to examine the immediate effects of Tai Chi on the postural stability, muscle activity, and inferred change in ankle proprioception of healthy young adults. Across the COP-based measures, EMG activity, and spectral analysis of postural sway in the AP plane, no significant effect of the Tai Chi intervention was observed within the experimental group. Although this work did not demonstrate a statistically significant effect of Tai Chi on MSV, EA, RMS, and RP, an interaction between the eyes and surface conditions was observed on both MSV and EA; in addition to, an observed main effect on the surface condition of the left and right GM RMS.

Scalar COP-Based Measures

A significant interaction effect between the factors of time, eyes, surface, and group was not observed on MSV or EA. Although, previous research with older adults has observed that a Tai Chi intervention can improve postural stability under EO/EC conditions on both firm and foam surfaces, the interventions employed were several weeks in length, with multiple sessions each week (Ghandali et al., 2017; Yu & Yang, 2012). Conversely, the present study only had a single Tai Chi session, and the participants examined were all healthy young adults without neurological or balance impairment. As such, a greater duration or intensity of exercise may have been required to produce significant change among a sample of individuals who were young and physically healthy (Lesinski, Hortobágyi, Muehlbauer, Gollhofer, & Granacher, 2015). Although the statistical analysis did not reveal an interaction between the factors of time, eyes, surface, and group, other significant two-way interactions were observed.

On both MSV and EA, a significant interaction between the eyes and surface condition within both the experimental and control groups was observed. The MSV of both groups increased significantly across all condition combinations (i.e., EO firm to EC firm condition, EO firm to EC foam condition, EO firm to EO foam condition, and EC firm to EC foam condition). A similar trend was also observed on EA.

It has been previously suggested that multiple COP-based measures should be used when assessing postural stability, as these different indices quantify different aspects of postural control (Karlsson & Frykberg, 2000; Paillard et al., 2006). This was demonstrated by Prieto et al. (1996) who found that MSV identified age-related differences in postural control among young and older adults across EO and EC conditions, which was not reflected in differences of EA. In the present study, it is possible that MSV and EA were observed to behave similarly across conditions due to the homogeneity of the sample. This notion is in agreement with previous work which also found that MSV and EA fluctuate concurrently among healthy young adults (Prieto et al., 1996). As such the current findings should not discount the need for multiple COP-based measures when postural stability is examined.

Furthermore, there was no significant interaction observed between the eye conditions and time (i.e., the intervention) on either EA or MSV. This was contrary to the finding of the pilot study. A possible explanation for this incongruence with previous findings may have been due to some of the methodological changes between the pilot study and the present study.

The first change was that the trial times for each trial were increased from 70 s to 90 s. This change was made to increase the frequency resolution and to aid in the spectral analysis. As a result, participants may have experienced increased fatigue in the muscles of the lower extremities, which could have impacted the MSV and the EA (Bisson, Remaud, Boyas, Lajoie, & Bilodeau, 2012). The current study did not have any rest periods between postural conditions;

however, previous postural research typically has involved breaks between trials to reduce the effects of fatigue experienced by the participant. Some protocols have used 1 min, while others have employed up to 5 min of rest between conditions (Karlsson & Frykberg, 2000; Vieira, Oliveira, & Nadal, 2009). The decision to not have rest periods between trials was made to account for the potentially transient effects the Tai Chi intervention had on the variables of interest (Kaji et al., 2010).

The second change in methodology was to randomize the postural conditions. In the pilot study, the conditions before and after the Tai Chi intervention were standardized and fixed for each participant, such that the conditions progressed from least to most challenging (i.e., EO firm → EC firm → EO foam → EC foam). Whereas, in the present study the conditions were randomized before and after the Tai Chi intervention for each participant. This randomization could have impacted the results in two ways.

The transient effects Tai Chi could have had on postural stability may have been captured in the pilot study as the EC firm condition consistently occurred around 2.5 min after the Tai Chi intervention. Whereas, the EC firm condition in the present study may have occurred up to 5 min after the intervention, at which time the transient effects on postural stability may have diminished and returned to baseline. Within a sample of healthy young adults, Kaji et al. (2010) were able to produce transient improvement of postural stability (i.e., decreased MSV) which returned to baseline over the course of 10 min. These effects were observed under EC firm conditions following two core exercises, each 30 s in duration. The authors suggested that the increased engagement of the core following the exercises may have decreased movement at the hip, thereby encouraging sway to be resolved more at the ankle, which could decrease MSV (Kaji et al., 2010; Torres-Oviedo & Ting, 2007). This may suggest that improvement in postural stability following a Tai Chi intervention could be due to engagement of the core and trunk muscles, rather than changes in ankle proprioception.

Another consequence of the randomized postural conditions may have been increased fatigue in the lower limbs. Bisson, Mcewen, Lajoie, and Bilodeau (2011) demonstrated that fatigue of the musculature within the hip and ankle can increase the MSV of participants. Therefore, as the foam conditions may require more energy consumption and torque generated by the lower limbs, it may have had a fatiguing effect which possibly negated potential changes in postural stability following the Tai Chi intervention (Patel, Fransson, Lush, & Gomez, 2008).

Root Mean Square of the Electromyography Measures

The inclusion of the EMG measures was to potentially provide a means to infer proprioceptive function which could be collected concurrently with postural data from the force platform. The rationale was that the Tai Chi intervention may have improved proprioceptive capacity within the TA via reduction of the muscular activity required to maintain an upright posture. In other words, it was believed that the Tai Chi intervention may have reduced skeletal muscle activity within the TA, thereby enabling the muscle spindles of the TA to provide more accurate proprioceptive feedback regarding postural sway at the ankle.

As previously discussed, skeletal muscle and muscle spindles are innervated by separate neurons (i.e., alpha and gamma respectively). When skeletal muscle shortens during a concentric contraction, the muscle spindles must also contract so that they may continue to provide proprioceptive feedback regarding the change in position and movement (Purves et al., 2004). Previous work by Day, Lichtwark, and Cresswell (2013) and Di Giulio, Maganaris, Baltzopoulos, and Loram (2009) suggested that because the muscle spindles providing proprioceptive feedback and the skeletal muscle, in which the muscle spindles are imbedded, are not controlled by the same motor neurons, the skeletal muscle and muscle spindles may not contract synchronously. Therefore, a certain degree of error may occur in the proprioceptive estimations made by the muscle spindles in response to the COM movement because of skeletal muscle contraction within the ankle. As such, the muscle spindles within a muscle with less activity may better represent the COM movement (Day et al., 2013; Di Giulio et al., 2009).

When the RMS of the left and right TA were examined, no statistically significant interaction effect was observed between the factors of time, eyes, surface, and group conditions. Also, there were no statistically significant main effects observed for the left and right TA within the control group or the experimental group. There was, however, a significant main effect with the surface condition for both the left and right GM within both the control group and experimental group. The right and left GM RMS was observed to increase from the EC firm to EC foam condition and the EO firm to EO foam condition.

Although unexpected, the lack of a statistically significant difference in TA activity across the eyes and surface conditions may add support to the idea that the TA is a primary proprioceptor of the ankle. As a primary proprioceptor, the postural control system may adapt to keep it largely unmodulated even under challenging postural conditions, so as to provide more accurate feedback regarding ankle rotation (Day, Lichtwark, & Cresswell, 2013). Similar to the present study, Fransson, Gomez, Patel, and Johansson, (2007) examined the influence of EO and EC conditions, as well as firm and foam surface conditions, on the muscle activity in the TA and GM. The authors also found that vision had no effect on the muscle activity within the TA or GM; however, on foam surface conditions compensatory increases in knee, hip, and shoulder movements were observed. This may indicate movements at the knee, hip, and shoulder are possible mechanisms used by the postural control system to compensate for increased postural demand without increased TA activity. Additionally, the increased GM activity on the foam surface may be due to the increased torque required to move the COM in a controlled sway, as the foam absorbs some of the torque produced at the ankle (Patel et al., 2008).

The effect of the surface conditions on the RMS of the TA and GM was also observed by Blaszczyszyn, Konieczny, and Pakosz (2019). The authors examined the EMG activity within the lower limbs of healthy young adult women across both firm and foam conditions. The TA muscle activity was not found to increase between the firm and foam surface conditions. Whereas the GM activity was observed to increase between firm and foam conditions, but only under EC conditions. This again demonstrated the TA may remain purposefully inactive on foam surfaces to maintain some proprioceptive feedback, while the GM may need to exert more torque to plantarflex the ankle due to the compliance of the foam; however, not all research has found similar results.

Divergent observations were made by Braun et al. (2011) who examined the muscle activity of the ankle under EO and EC conditions on stable and unstable surfaces (i.e., trampoline, balance platform, proprioceptive disk, and proprioceptive board) in a sample of healthy young adults. The authors found that the TA activity increased from the stable to the unstable surface conditions, as well as from the EO to EC conditions on all surfaces except the trampoline, which was not found to be different from the firm surface. A separate study by Kang and Hyong (2012) used three rubber inflatable discs to examine the effects of different surface compliance on muscle activity within the TA and GM in healthy young adults. Each disc was inflated to a different pounds per square inch (psi), to create low (1.0 psi), medium (1.5 psi), and high (2.0 psi) conditions. The authors explained that the lower the pressure within the disc, the greater the instability when the participants stood upon it. Each trial lasted 15 s and was performed under EO conditions. It was found that across the high and medium pressure conditions, there was no significant difference in GM activity but significance was found on the low-pressure condition. The TA activity, however, was observed to be statistically different across all pressure conditions.

Although the work by Braun et al. (2011) and Kang and Hyong (2012) reported observations which conflicted with the results of the current study and Blaszczyszyn, Konieczny, and Pakosz (2019), these discrepancies may be in part due to the differences in type of unstable surface used to perturb postural stability. As noted by Lee et al. (2018) and Patel et al. (2008), the density and elasticity of the surface used can influence postural sway and the strategies used to maintain an upright posture. This has been echoed by Strang, Haworth, Hieronymus, Walsh, and Smart (2011), who suggested that increased postural sway on unstable surfaces may in part reflect the adoption of a control strategy specific to the characteristics of the surface used.

In the case of the current study, the properties of the foam may have encouraged the use of the muscles of the knee, hip, and shoulders to maintain posture, which were not included in the EMG analysis. Going forward, it may be prudent for researchers to have an understanding of the postural control strategy particular to a chosen unstable surface used in postural assessment. This may be useful for informing researchers on which muscle groups should be assessed based on the surface used. For rehabilitative purposes, it could also inform clinicians on which unstable surface may best be used to bias certain muscle groups for strengthening purposes. Lastly, this may call into question the ability of researchers to compare results across studies which have challenged postural stability with unstable surfaces of different density and elasticity.

Spectral Analysis of Center or Pressure Sway

There was no statistically significant interaction effect observed between the eyes, surface, time, and group conditions on RP. Also, there was no statistically significant interaction effect between the eyes and time conditions on RP, neither were there any main effects. Unfortunately, because no other regions aside from the 0.4–0.7 Hz region was examined, it cannot be definitively explained as to why this result was produced. A non-significant difference in RP across all conditions may suggest that the entire spectrum increased in power in proportion to the 0.4–0.7 Hz frequency band, or that one or more regions of the frequency spectrum increased in power along side the 0.4–0.7 Hz frequency band which were not observed. These findings may suggest that if a specific frequency band is designated for analysis, two or more specific frequency bands should be used for comparison, as opposed to using the entire spectrum as a reference (Bucci et al., 2017, Moon, Choi, Dong-Sik, Kim, 2019).

There is, however, in recent research more contention regarding if it is possible to specify the exact component of the postural control system represented by each frequency band (Daniels et al., 2019). In light of the lack of consensus, it is perhaps prudent that when spectral analysis of postural sway is used, each individual frequency is examined. This higher resolution approach may allow researchers to identify smaller changes in the power spectrum, as well as observe potential trends over a set of frequencies, rather than constraining observation to specific frequency bands (Daniels et al., 2019). Additionally, until research has definitively identified the role of specific frequency bands, the use of spectral analysis may be better suited in a descriptive role to indicate change, rather than an explanatory role to state what caused the change.

Chapter VI: Limitations and Future Directions

Limitations

Tai Chi is a complex mind-body exercise which places great emphasis on the integration of breathing, conscious awareness, spiritual and mental wellbeing, and social interactions (Wayne & Kaptchuk, 2008a). In the present study, only a single 15 min Tai Chi intervention was used, which was unable to capture the depth of this exercise. It is possible that the entirety of the Tai Chi experience may be germane to lasting improvements in health and wellness. Furthermore, the Tai Chi intervention used in the present study was virtually delivered via video rather than an in-person instructor.

While the video delivery format for the Tai Chi intervention benefited from remaining consistent across all trials and participants, the in-person Tai Chi may have allowed for an experience tailored to the individual needs of each participant. The instructor could have modified the performance by slowing it down or exaggerating a movement to allow the participant to better follow it. Verbal directions from the instructor may have also aided the participant by expressing the flow of the form and proper breathing techniques.

Considering the methodological limitations, no rest periods were used between postural stability trials. As previously discussed, the lack of rest periods between trials may have increased the fatigue of the participants, thereby masking changes in postural stability as a consequence of the Tai Chi intervention. Furthermore, only two muscles related to ankle motion were examined by the EMG and only a single frequency band was measured in the spectral analysis. This limited the ability to capture a broader system perspective of postural control.

The present study also lacked a more standardized measurement technique to assess ankle proprioception. While an attempt to infer ankle proprioception was made by examining muscle activity of the ankle and spectral analysis of postural sway, the lack of agreement regarding these measures would have limited the ability to draw conclusions regarding the influence of Tai Chi on ankle proprioception had an interaction with the intervention been observed.

Lastly, the sample size presented a limitation. Only 30 participants were recruited for this study, and with such a complex statistical design, there was need for more data collection to accommodate the greater risk of type 1 error. Unfortunately, in the wake of the COVID-19 outbreak, the physical palpations required to place EMG electrodes and the close proximity of the student researcher to the participant, a larger sample size could not be achieved.

Future Directions

In consideration of the limitations posed by the pre-recorded 15 min Tai Chi intervention, it would be valuable for future research to examine the effectiveness of pre-recorded Tai Chi sessions compared to an in-class setting. If differences can be identified, perhaps the pre-recorded sessions could be modified to better simulate an in-class setting. New frontiers in virtual reality technology may be aptly used in this regard. As such, individuals who are unable to attend in-class sessions, may be able to receive the same health and wellness benefits of Tai Chi at home.

This is perhaps more pertinent with COVID-19 where there is a need for social distancing, particularly among the older adult populations and individuals with health comorbidities. An investigation into the virtual delivery of Tai Chi interventions which is able to approximate in-class sessions may provide the therapeutic physical benefits of Tai Chi, as well as a social component to aid those in social isolation. Lastly, a greater understanding of how to improve virtual delivery of Tai Chi interventions would allow for research teams with less funding to engage in Tai Chi research. As the virtual delivery system would make Tai Chi research more cost-effective, as there would be less of a need to keep Tai Chi instructors on retainer for the duration of the study.

Previous Tai Chi research among older adults has demonstrated 20-weeks of Tai Chi to be just as effective as a general exercise program of the same duration for improving postural stability; however, it is still unknown as to the required duration of intervention to produce improvement among young adults (Taylor et al., 2012). Therefore, if research into short 15 min duration Tai Chi interventions is to be continued, as this study identified a single session is insufficient to produce significant change, future work may benefit from following the balance training guidelines suggested by Lesinski et al. (2015). These guidelines recommended balance training sessions to be held at least 3 times per week, with 11-15 min sessions, for 11-12 weeks.

As these guidelines allow for the shorter Tai Chi sessions, the general methodology of the present study could be repeated. Such that, participants would be engaged in a 15 min Tai Chi session with balance testing before and after at varying frequencies over the course of 12 weeks. This protocol could enable researchers to investigate the exact frequency and dosage of Tai Chi interventions required to produce improvements of postural stability among young adults. These findings could help clinicians in a rehabilitative context to estimate timelines for patients, as well as serve as a more standardized set of guidelines for future Tai Chi research.

Lastly, future Tai Chi research which includes EMG or spectral analysis-based measures should consider the inclusion of more observed muscles and a higher resolution power spectrum analysis, in addition to a traditional measure of proprioception to provide a comparison. As Tai Chi is a whole-body exercise, it may be worthwhile to examine the effects Tai Chi has on muscle activity beyond the ankle. Additionally, the whole frequency spectrum related to postural control should be examined. As this would allow for a greater understanding of the reorganization of power density across all frequencies and how these shifts in power relate to the changes in postural conditions.

Chapter VII: Conclusion

The purpose of this study was to examine the immediate effects of Tai Chi on the postural stability, muscle activity, and to infer potential change in the ankle proprioception of healthy young adults. The results of the study demonstrated that a single 15 min Tai Chi intervention is insufficient to significantly produce changes in the postural stability, muscle activity measures of inferred ankle proprioception among healthy young adults. Future work should consider applying Tai Chi interventions based on traditional balance exercise dose-response relationship guidelines and compare the delivery methods using a virtual delivery platform to a face to face model.

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Appendix-A: Cover Letter

Dear Potential Participant,

Thank you for your interest in participating in the study titled “The Immediate Effects of Tai Chi on the Postural Stability and Ankle Proprioception of Healthy Young Adults.” Zachary Cordingley, a second-year Masters of Kinesiology student at Lakehead University, working under the supervision of Dr. Paolo Sanzo, Associate Professor, will be conducting this study. You have been invited to participate as you are between the ages of 18 to 30 years. The purpose of this study is to examine the immediate effects of Tai Chi performance on measures of postural stability and ankle proprioception.

As a participant, you will not have to make any significant changes to your schedule. There will be one laboratory session carried out in the Sanders building at Lakehead University, in room SB-1028. The session will be scheduled based on your availability and will last approximately 1.5 hours. A maximum of 30 individuals will be invited to participate. You will be asked to not ingest any stimulants (caffeine), depressants (alcohol), or smoke for at least 8 hours before your testing session. Additionally, you will be asked to wear athletic shorts to your scheduled lab session. In the lab session, you will be asked to remove your shoes, at which point your height will be measured. You will then be asked to perform a stationary bike warm-up, as directed by the student researcher. This is to reduce the risk of musculoskeletal injury during the completion of the physical tasks and testing procedures. After which, the student researcher will attach electromyography electrodes to your tibialis anterior and gastrocnemius medialis on both legs. This will involve palpation of the muscles, shaving of hair at the point of electrode application, and cleaning of the area with rubbing alcohol. You will then be asked stand on the AMTI force platform for 70 seconds, with your eyes open and eyes closed. You will then be asked to repeat this a second time while standing on a foam surface. These will constitute your baseline measures. Once the baseline measures have been completed, if you are part of the experimental group, you will watch a short video of a Tai Chi performance. Following the video, you will be asked to perform the Tai Chi form to the best of your ability. Alternatively, if you are part of the control group, you will be asked to sit quietly for 15 minutes. After the intervention, or lack there of, the measures taken for your baseline will be repeated. After which, the research will address any questions you may have, and the testing session will be concluded. Please come to your lab session in lightweight, fitted clothing and socks.

It is also the responsibility of the student researcher to inform you of your rights as a participant. Your participation in this study is entirely voluntary and, as such, you may refuse to participate, not answer questions you are uncomfortable with, or withdraw from the study at any time, without penalty. Data gathered from this study will only be accessible to the student researcher conducting the study and the supervisor of the study, Dr. Paolo Sanzo. All digital data will be stored on a password-protected computer, with up to date virus software, until completion of the study. Hard copy data will be stored in a locked filing cabinet owned by the student researcher, until completion of the study. Following completion of the study, all data will be turned over to the supervisor, Dr. Paolo Sanzo, who will store it at Lakehead University for five years, in accordance with Lakehead University policy. The results and data of the study will be presented verbally and in a written document. To protect your identity, you will be assigned a unique identification number, which will be used as a substitute for your name in all digital or hard copy documents. Additionally, you will not be identified in published or presented results without your explicit consent.

There will be no direct physical or mental harm by participating in this study. There is a small risk that you may fall during the testing, as you will be unfamiliar with the Tai Chi form. As such, the student researcher will act as a spotter to prevent any potential falls. You will also be instructed to stop and refrain from continuing to perform the Tai Chi form at any time if you begin to feel unstable; however, this is unlikely as you will have both feet firmly planted for the majority of the task. Lastly, there is no direct benefit to participating in this study, but you will be introduced to Tai Chi as a moderate intensity aerobic exercise option. Tai Chi has been performed all over the world as a form of moving meditation. It has been shown to provide both physical and mental health benefits with regular practice.

If you would like to receive a copy of your personal results, and/or the results of the study upon completion, please indicate on the informed consent letter. The student researcher will then contact you upon the completion of the study to provide you with the requested results. If you wish to participate in the study, please sign the informed consent form, and complete the PARQ+ form. These forms can be submitted to the researcher in person at the time of baseline testing. If you do not meet the requirements of the PARQ+, you will be asked to contact your family physician who can clear you for participation and review some of the findings reported. If you have any questions or concerns, do not hesitate to contact the student researcher or his supervisor. This study has been approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research project and would like to speak to someone outside of the research team, please contact Sue Wright from the Research Ethics Board at 807-343-8283 or research@lakeaheadu.ca.

Thank you for your consideration,

Zachary Cordingley zacordin@lakeheadu.ca

Student Researcher

Dr. Paolo Sanzo psanzo@lakeheadu.ca

Associate Professor

Faculty Supervisor

Appendix-B: Informed Consent

Lakehead UNIVERSITY | School of Kinesiology

Consent to Participate in Research

I,___________________________ have read and understand the terms and conditions outlined in the cover letter for the study "The Immediate Effects of Tai Chi on the Postural Stability and Ankle Proprioception of Healthy Young Adults". I am willingly volunteering to participate. In signing this form, I understand all the potential risks and benefits of the study. I have also been informed of and understand my rights as a participant. I understand that I may refuse to participate, not answer questions that I am uncomfortable with, or withdraw from the study at any time, without penalty. I am aware that the results of this study will be stored either in a locked cabinet or password-protected computer at Lakehead University for five years following completion of the study. I have been informed that I may request to receive my personal results from this study, as well as the results of the study after it has been completed. I understand that any personal information I provide will remain anonymous in any presentations or publications of research findings, and the student researcher will only disclose my identity if I explicitly state my consent. I give consent for my anonymous data to be presented and published.

I wish to receive my results via email. ________ Yes ________No

I wish to receive results of the study via email. _______ Yes ________No

Email:___________________________________

Signature of Participant:__________________________ Date:____________

Signature of Witness:__________________________________ Date:______

Appendix-C: Recruitment Poster

Lakehead UNIVERSITY | School of Kinesiology

RESEARCH PARTICIPANTS WANTED

You are invited to participate in a study entitled "The Immediate Effects of Tai Chi on the Postural Stability and Ankle Proprioception of Healthy Young Adults".

Why are We Doing This Research?

The purpose of this study is to examine changes in the postural control system after an individual performs a Tai Chi form.

Who is Eligible?

We are looking for a maximum of 30 healthy young adults between the ages of 18 and 35 years, who have never practiced Tai Chi. Participants must also not have any health conditions which may impact balance, or have experienced injury to the ankle, knee, hip, or low back within the past 6-months

What Will You Be Asked to Do?

You will be asked to volunteer approximately 1.5 hours of your time. Electrodes will be attached to lower leg muscles, and you will be asked to stand on a force platform. If part of the experimental group, you will also engage in a short Tai Chi form.

Where Will the Testing Take Place?

All testing sessions will be completed on the Lakehead University campus, in the Sanders Building, room SB-1028.

When Will Testing Take Place?

At a convenient time, which aligns with your schedule and lab hours of availability.

Interested?

For more information on the study or to sign up as a participant, please contact Zachary Cordingley by email zacordin@lakeheadu.ca.

Appendix-D: Get Active Questionnaire

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ I am completing this questionnaire for myself.

☐ I am completing this questionnaire for my child/dependent as parent/guardian.

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer **YES** or **NO** to each question before you become more physically active. If you are unsure about any question, answer **YES**.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	**2** Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	**3** Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	**4** Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

CSEP | SCPE THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now.

1 During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)? ☐ DAYS/ WEEK

2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity? ☐ MINUTES/ DAY

For adults, please multiply your average number of days/week by the average number of minutes/day: ☐ MINUTES/ WEEK

Canadian Physical Activity Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct. If my health changes, I will complete this questionnaire again.

I answered NO to all questions on Page 1

Sign and date the Declaration below

I answered YES to any question on Page 1

Check the box below that applies to you:

- ☐ I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.
- ☐ I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

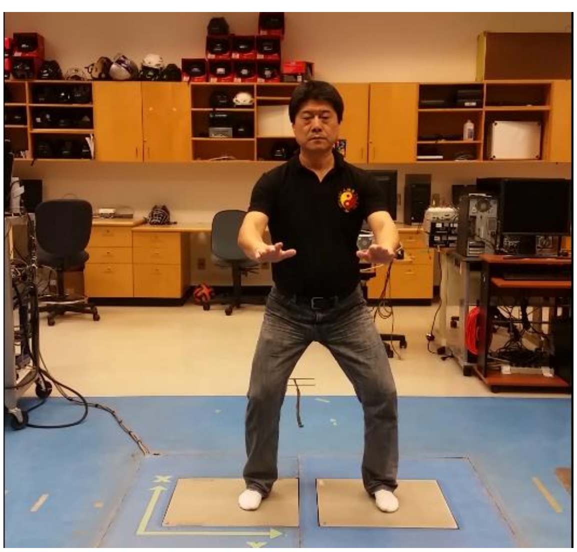
Name (+ Name of Parent/Guardian if applicable) [Please print] | Signature (or Signature of Parent/Guardian if applicable) | Date of Birth

Date | Email (optional) | Telephone (optional)

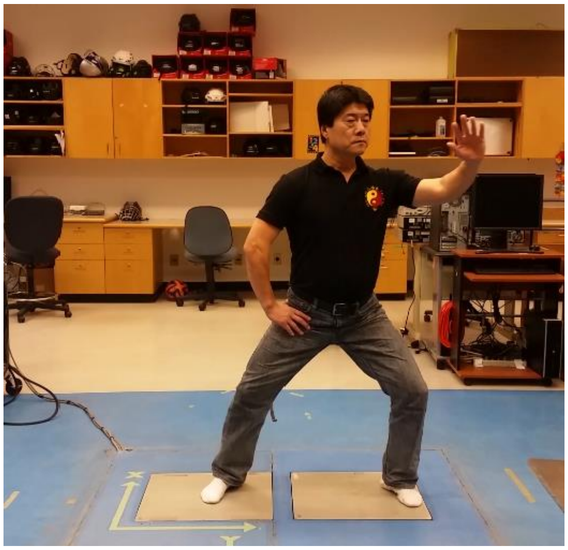
With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ Check this box if you would like to consult a QEP about becoming more physically active. (This completed questionnaire will help the QEP get to know you and understand your needs.)

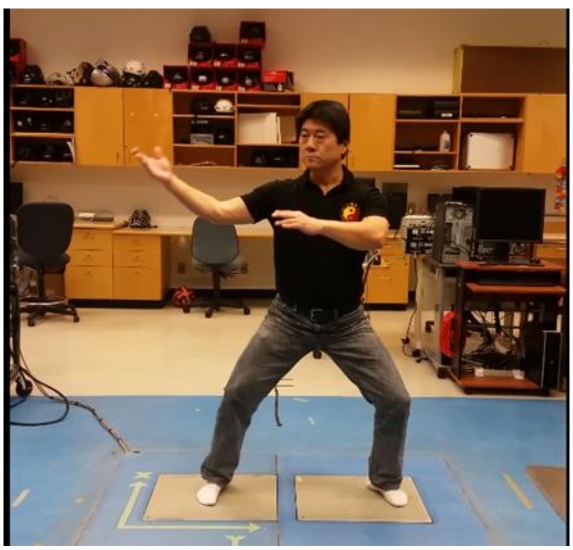
Appendix-E: Tai Chi Stances



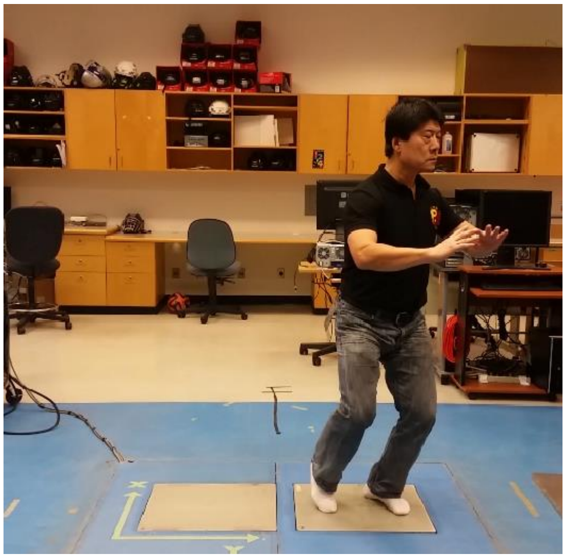
Performance of Commencing (Starting)



Performance of Wave Single Hand



Performance of Lazily Tying Coat



Performance of Six Sealings, Four Closings

Performance of Single Whip