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Impact of Military Boots and Military Workload on Balance

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Impact of military boots and military workload on balance

By

John Hunter DeBusk

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Impact of military boots and military workload on balance

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The US Army Annual Injury Epidemiology Report in 2008 reported that 18.4% of all causes of injuries were attributed to falls/near falls (USAPHC, 2008). The purpose of this investigation was to determine the effect of two military type boots (minimalist and standard) on balance prior to and after a physiological workload. Twenty-four healthy male adults completed the study following a repeated measures design and a counter balanced footwear assignment. Participants underwent a balance analysis prior to and after completing a military workload. The dependent kinetic variables from balance tests were analyzed using a 2x2 RM-ANOVA independently, $p<0.05$. Results demonstrated minimalist boots showed superior balance in most conditions likely due to low mass, low heel-midfoot drop, and thin, hard midsoles; however, standard boots demonstrated greater balance on unstable surfaces likely due to a large sole surface area. Optimal balance would likely be a result of a combination of both boots' characteristics.

DEDICATION

I dedicate this work to my grandmother, Jeweline “Grams” Ann Burger Parton, a passionate and dedicated individual who gave her all in everything she did. A woman enamored by her Christian faith, her encompassing love and diligence demonstrated how to not only live, but to live fearlessly. Without Grams in my life, none of this would have been possible.

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OPERATIONAL DEFINITIONS

1. Posture- The orientation of a segment of the body with respect to the gravity vector (Winter 1995)

2. Balance- The dynamic control of the body against inertial forces to prevent falling (Winter 1995)

3. Centre of Mass (COM)- In relation to the global reference system, this is the point equal to the total body mass. This passive variable is manipulated by the balance control system. (Winter 1995)

4. Center of Gravity (COG)- The vertical projection of the COM onto the ground. (Winter 1995).

5. Center of Pressure (COP)- The weighted average of all the pressures on the surface which have contact with the body; point of ground reaction force vector. (Winter 1995)

6. Base of Support (BOS)- The area of contact of the body to the surface of the ground

CHAPTER I

INTRODUCTION

Human balance and postural control is crucial in maintaining an erect bipedal stance. Multiple factors affect the maintenance of balance and postural control both intrinsically (within the body) and extrinsically (within the environment) (Gauchard, Chau, Mur, & Perrin, 2001). Intrinsic factors are composed of the physiological changes that affect sensorimotor function, central integration, and specific motor responses. Such changes could be a result of aging, total body mass, speed of walking, fatigue, etc. Extrinsic factors are comprised of the physical characteristics of the ground surface and/or the surface in which the foot is in contact, as well as other environmental factors such as lighting, smoke, fog, etc. Variations in environmental factors, due to setting, are infinite but include surface type, surface friction, variations in surface level, compliance of surface, presence or absence of contaminants, and most importantly footwear characteristics (Redfern et al., 2001, Buczek et al., 1990 & Chander et al., 2014). The presence of intrinsic and extrinsic factors affects the preservation of balance and postural control by perturbing the sensorimotor function.

The sensorimotor systems within the human body sustain postural control and balance and are composed of the vestibular system (inner ear), visual system (eyes), and somatosensory system (nervous innervations) (Simeonov et al., 2009). The sensorimotor system must recognize changes in both intrinsic and extrinsic factors and use muscular contractions to maintain postural control. An environment conducive to the sensorimotor systems would suggest an increase in the ability to maintain postural control and balance; although, there appears to be a consistent lack of such environments because of the extensive volume of slips, trips, and falls in the United States.

In 2011, the Bureau of Labor Statistics found 15% of a total 4,693 workplace fatalities, as well as 299,090 non-fatal workplace injuries were accredited to slips, trips, and falls (BLS, 2011). The monetary value annually attributed to workplace injuries due to slips, trips, and falls was estimated to be in excess of 6 billion US dollars with an expected cost of $43.8 billion by 2020 (Courtney et al., 2001). This data does not include the occupational injuries due to slips, trips, and falls in association with the military.

“Military personnel” is an extraordinarily large umbrella term for all US service members regardless of the assigned duties. Military personnel jobs vary from infantry, medical personnel, mechanics, flight controllers, pilots, office administrators, etc. Many of the military occupations consist of environments much like those in the civilian life, but military environments are further inclusive in extrinsic and intrinsic factors such as diverse terrains (sand, rocks, steep ground level deviations, mud, etc.), lack of light, increased decibel range (gun shots, explosives, etc.), unstable ground surfaces (deck of boat, aircraft floor surface), fatiguing workloads, (running, carrying packs, etc.) etc. (Kaufman, Brodine, & Shaffer, 2000, Hollander & Bell, 2010 & Grenier et al., 2012) Expanded environmental deviations as well as augmented intrinsic and extrinsic factors suggest an increased inability to maintain balance and postural control (Kaufman et al., 2000). In fact, the US Army Annual Injury Epidemiology Report in 2008 found 18.4%

of all causes of injuries were attributed to falls/near falls (including slips, trips, and falls) (USAPHC, 2008).

The immense number of slips, trips, and falls contributing to occupational injuries suggest an improvement in the ability to maintain postural control and balance must be discovered. In an erect bipedal stance, the contact between the surface of the ground and the human body is at the foot or shoe. Shoe design has taken a wide range of directions in order to accommodate a variety of athletes and common people (Subotnick, King, Vartivarian, & Klaisri, 2010) It has been reported that the ability to maintain balance and postural control is best in the barefoot condition (Winter, 1995). Further research has shown a thinner, harder sole to increase balance, suggesting this condition is closer to the barefoot condition by increasing proprioceptive feedback (Perry et al. 2006 & Robbins et al., 1994). An increase in proprioceptive feedback was suggested with the inclusion of a boot shaft, and as the boot shaft decreased in stiffness, there appears to be an increase in force production (You et al. 2004 & Bohm et al. 2010). Therefore, current literature suggests a shoe that more closely associates with the barefoot condition with the inclusion of a moderately stiff boot shaft may increase postural control and balance through an increase in sensory feedback.

The current literature has explored workloads and the ability of workloads to fatigue participants. Workloads that result in fatigue can cause a detriment in balance, and differing workloads can cause a variable effect on balance (Lepers et al., 1997). In order to complete relevant balance and postural control research on military personnel, a workload must closely associate the conditions in which a military personnel would encounter. DeMaio and colleagues comprised a workload that fatigues the human body much like what would be found in military personnel actively serving (DeMaio et al., 2009). This simulated military workload included treadmill walking/running at increasing velocities and grades while wearing a 16kg military style rucksack.

Although scholarship is well developed on how shoe characteristics affect balance and how certain workloads cause fatigue and affect balance, there is a gap in literature in how a boot that has a moderately stiff boot shaft and a thin, hard sole will affect balance when a participant is exposed to a military workload.

Purpose

The purpose of the investigation was to determine the effect of two military type boots (minimalist boot and hot weather boot) on balance prior to and after a simulated military, physiological workload. The results of the study is available for use as footwear design suggestions to enhance balance performance and to understand the effect of a military workload on postural control and balance maintenance.

Hypotheses

Footwear Hypothesis:

Specific Aim 1:To investigate the effects of military footwear (hot weather military boot and minimalist military boot) on balance.

H_{01}: There will be no differences between footwear conditions in participants' balance when exposed to the two military footwear.

H_{A1}: There will be significant differences between footwear conditions in participants' balance when exposed to the two military footwear.

The sensorimotor systems of the human body utilize afferent sensory feedback to maintain postural control and balance. Theoretically, as the amount of sensory information increases to the visual, somatosensory, and vestibular systems, the ability to maintain postural control and balance increases. According to previous literature, harder, thinner soles and boot shafts increase balance because of an increase in sensory feedback (Perry et al. 2006, Robbins et al. 1994 & You et al. 2004). The minimalist boot consists of these shoe characteristics, however, research has not been completed investigating a comparison of the minimalist boot and the standard issue boot.

Workload Hypothesis:

Specific Aim 2:To investigate the effects of a simulated military workload on balance while donning military footwear

H_{02}: Participants' balance will not be affected when exposed to a simulated military workload in different military footwear.

H_{A2}: Participants' balance will be significantly impaired when exposed to a simulated military workload in different military footwear.

The sensorimotor systems of the human body maintain balance and postural control. Previous literature suggests differing workloads constitute varying effects on balance (Lepers et al. 1997). Occupational workloads have been implemented in previous literature in which balance has been assessed pre- and post-workload (Garner et al. 2013 & Chander et al. 2014). Previous research has established military workloads, however, the effect of a military workload on balance while donning a minimalist boot compared to a standard issue military boot has yet to be explored (DeMaio et al. 2009).

CHAPTER II

REVIEW OF LITERATURE

The purpose of this chapter was to complete an investigation of previous literature concerning the effect of footwear on balance and the postural control system after an applied workload. This chapter is divided into five major sections. The first three sections analyze balance, footwear, and workload separately, while the final two sections investigate balance in relation to footwear, and balance in relation to workload.

Balance and Postural Control

In the realm of biomechanics, Winter's ideals and descriptions of balance and postural control are widely accepted. The human body is naturally unbalanced as two-thirds of the mass of the body remains at two-thirds of the height (Winter 1995). Maintaining erect bipedal stance can be recognized in two respects, static posture, or maintenance of posture without locomotion and dynamic posture, or maintenance of posture during locomotion. According to Horak and colleagues, the ability to maintain erect bipedal stance is controlled by the central nervous system including passive biomechanical components, muscles, and sensory systems (Horak et al., 1997). The primary goal of postural control is to preserve the vertical orientation of the head so that the eyes are oriented in a proper gaze (Di Fabio & Emasithi, 1997). Being structurally unbalanced, the human body must compensate to maintain balance and postural control through three major sensory systems: visual, somatosensory, and vestibular (Simeonov et al., 2008). The visual system utilizes the eyes, and its primary purpose is locomotion and avoiding obstacles (Winter, 1995). The somatosensory system utilizes the peripheral nervous system to analyze position and velocity of body segments, contact, and orientation of gravity, while the vestibular system relies on the ears to sense linear and angular accelerations (Winter, 1995). The combination of systems allows for postural and balance reactions to a variety of stimuli.

Human balance is based on the ability of the body to maintain the center of gravity (COG) within the base of support (BOS). The COG and center of pressure (COP) of the human body are constantly shifting causing the body to sway anteriorly, posteriorly, medially, and laterally. To remain balanced, the human body aims to keep the COG within the BOS. During quiet stance, as the COG moves anterior to the COP, the COP moves anteriorly by muscular contractions of the plantar flexors to maintain the COG within the BOS (Caron 2003 & Winter, 1995). Conversely, as the COG moves posteriorly to the COP, the dorsiflexors contract to assure the COG does not move out of the BOS posteriorly (Winter, 1995). This constant movement of the COP and COG anteriorly and posteriorly causes the body to sway, postural sway, which has been described as an inverted pendulum of balance; this movement can be explained using the following equation (Kincl, Bhattacharya, Succop, & Clark 2002):

$$Rp - Wg = I\alpha \tag{2.1}$$

where: R represents vertical reaction force, p distance from the ankle joint; W represents body weight, g distance from the ankle joint; I represents the moment of inertia of the body about the ankle joint; α represents angular acceleration of the inverted pendulum (Winter, 1995).

The medial-lateral transfer of COP and COG during quiet stance is much the same in that the goal is to maintain the COG within the BOS. The ankle inverters cause the COP and, likewise, the COG to move medially, while the ankle evertors cause the lateral transfer of the COG and COP, but the ankle evertors and invertors of each foot work separately of the contralateral limb so that COP is represented as COP_r and COP_l (Winter, 1995). A major difference between anteroposterior and mediolateral sway is that the musculature of left and right ankles work in tandem to manipulate COP during anteroposterior sway while the mediolateral ankle musculature are completely out of phase when manipulating COP (Winter, 1995). This suggests the dominant control of COP in the M/L direction is the loading/unloading mechanism, shifting of body weight from one limb to the contralateral limb, which can be represented with the following equation:

$$COP_v = COP_{net} - COP_c \tag{2.2}$$

where: COP_v is the contribution from the loading/unloading of each limb

COP_c control from each limb ($COP_c = COP_l \times 0.5 + COP_r \times 0.5$) (Winter, 1995). Motion of the ankle in plantarflexion and dorsi flexion is substantially larger than motion medially and laterally. Plantarflexion range of motion (ROM) in males age 20-44 has been reported to be about 54.6° and dorsiflexion ROM about 12.7°, with a total ROM of about 67° (Soucie et al., 2011). However, calcaneal eversion has been found to have a ROM of about 5°-10° and calcaneal inversion about 20°-30° (Valmassy, 1995, Myerson & Shereff, 1989 & Perry, Antonelli, Ford 1975). The limitation in ROM in the medial-lateral directions is due to strenuous ligamentous support, and the extension of the distal fibula inferiorly causing a decrease in lateral ROM.

As previously explained, the ankle strategy is the main strategy used to maintain quiet stance balance. Although ankle strategies are optimal for quiet stance, when postural perturbations, which are an abrupt adjustment in conditions that causes the body posture to move from equilibrium, are introduced, the ankle strategy isn’t capable of maintaining the center of mass (COM) within the BOS through alterations of the COP (Horak, Henry, & Shumway-Cook, 1997). When maintaining equilibrium, the strategies work from distal to proximal locations (Horak et al., 1997). In response to anteroposterior postural perturbations in which the ankle cannot create enough torque at the ankle and knee to maintain equilibrium, the hip strategy is employed causing torque at the knee and hip to maintain equilibrium (Horak et al., 1997). The hip strategy relies on the abdominals and rectus femoris for flexion while relying on the hamstrings and erector spinae for extension (Winter, 1995). When the distance or velocity of COM motion is too great to be controlled by the hip strategy, the stepping strategy must be employed. The stepping strategy consists of taking a step with one of the legs in order to increase the BOS. A larger BOS increases the area in which the COG can be maintained; therefore, balance and postural control are maintained through the stepping strategy (Horak & Nashner, 1986).

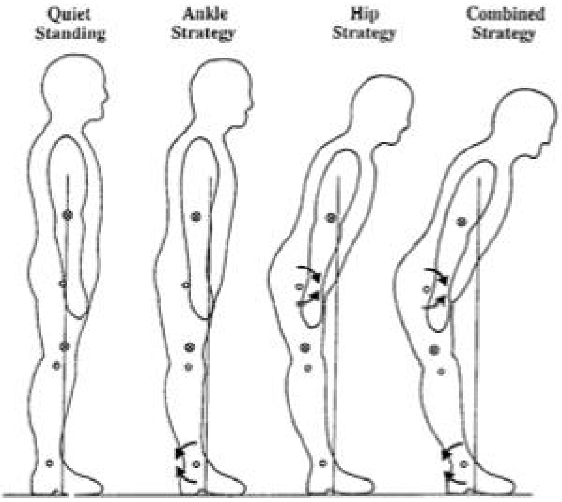

Figure 1. Model of Balance Strategies

Winter et al. 1995

Balance can be evaluated by tracking forces within the area in which the body makes contact with the ground. In the case of static erect bipedal stance, the contact area consists of the feet to the surface of a force plate. As force is applied to the force plate, ground reaction forces (GRF) act back on the body at the point of contact with the force plate. The force plate is able to measure the GRF necessary to counter the force acting on the force plate. As previously discussed, the COP tracks behind the COG to maintain balance through postural control synergies. With an erect bipedal stance, the force plate measures the GRFs of the averaged COP of both feet with respect to time. In the case of an erect unipedal stance, the force plate measures the GRFs of the COP of a single foot. The data collected by the force plate is transferred to a computer monitor that displays the motions of the COP in the anterior, posterior, medial, and lateral directions. The larger the deviation in the COP and the larger the deviation in the COP with respect to time, the lesser the ability to maintain balance through postural control.

Postural control in the maintenance of balance can be inhibited by external and internal factors that displace the COM. External forces interacting with balance maintenance include gravity and forces that occur with interaction with the environment. Internal forces that act to destabilize the body include any movement by the body such as breathing that displaces the body's COM (Horak et al., 1997). In order to measure balance, postural perturbations are used to simulate external factors that one may experience. Postural perturbations are aimed at limiting the somatosensory, and/or visual systems to observe the human body's utilization of each system. Standing on a piece of foam, placed on a force plate, is a standard method of perturbing the somatosensory system (Horak et al., 1997). The foam's constant motion causes a disturbance in the proprioceptive surface feedback, which suggests an inability to use the ankle strategy efficiently (Horak et al., 1997). The loss of effective proprioceptive feedback causes balance to be controlled primarily by the vestibular and visual systems. A loss of somatosensory feedback would suggest a decrement in postural control and balance. Other internal and external factors can be manipulated while the participant is standing on the foam surface. Standing with only one leg on the foam surface will decrease the BOS and shift the position of the COP, COM, and COG. Closing the eyes will inhibit visual stimuli, causing balance to be primarily controlled by the vestibular and somatosensory systems. Finally, closing the eyes while standing on foam suggests balance would likely be maintained primarily by the vestibular system as both the visual and somatosensory systems would be receiving inadequate or inappropriate sensory feedback (Travis, 1945 & Nashner, 1982).

Footwear

Footwear characteristics change with the type of footwear that is chosen. Athletic shoes, typically worn during sporting events, have lower initial flex stiffness and masses as compared to work and safety boots (Simeonov, 2014). Simeonov et al. (2014) found the running shoe to have the lowest initial flex stiffness (0.17Nm/deg) and the lowest weight (312g). Low top shoes have a lower boot shaft height (9.5cm) as compared to tactical boots (16.5cm) and work boots (18.5cm) (Chander et al., 2014). Forefoot sole widths and heel sole widths can be different between footwear with Chander et. al (2014) finding the lowest forefoot sole width in a low top shoe (10.5cm) and both Chander et al. (2014) and Simenov et al. (2008) found the lowest heel sole width in the low top shoe and running shoe (8.5cm). Finally, midsole hardness (Robbins, Waked, Gouw, & McClaran, 1994 & Perry et al., 2007), the relative hardness of the midsole, and midsole thickness (Robbins et al., 1994) have been shown to affect balance in participants with harder, thinner soles relating to better balance.

The type of footwear worn is dependent on the environment and the desirable effects of the footwear. Occupational footwear can be determined by regulations set by the government such as in the case of firefighters who must follow OSHA (Occupational Safety and Health Standards) regulations (OSHA, 2008). These regulations state the footwear must be slip-resistant, water-resistant 12.7 cm or more above the bottom of the heel, and must protect against a size 8D nail (OSHA, 2008). Regulations such as these cause an elevated heel height, limited sole material, and changes in boot mass.

Much like the occupational regulations placed on firefighter footwear, the type of military boot that can be worn is specified for each branch of the military. Branches of the military must follow OSHA regulations as well as specific requirements by each branch such as AR 670-1 for the army. This document gives specific information about the specificities footwear such as types of materials (cow-skin) and boot shaft heights (between 8 and 10 inches). According to the AR 670-1, the army requires each soldier to have a pair of hot weather and cold weather boots that meet the requirements of the AR 670-1. The cold weather boot includes characteristics differing from the hot weather boot with the inclusion of a thermal layer being the major difference.

Workload

Each occupation has different physiological workloads associated with their work-time that may be fatiguing or non-fatiguing. Generally aimed fatiguing conditions have been employed in research for a long period of time (Nardone, Tarantola, Giordano, & Schieppati, 1997 & Caron, 2003). A workload that is aimed at fatiguing a particular muscle or muscle group that has previously been utilized in research is the isometric contraction. In a study by Caron (2003), participants were required to complete three maximum voluntary contractions (MVC) of the soleus muscle 3min apart, followed by a 60% MVC for as long as possible. The 60% MVC were continued 3min apart until the isometric contraction only lasted a standard time (40-60s). Fatigue was assumed because the participants were only able to perform an isometric contraction for a fraction of the original 60% MVC (Caron, 2003). Other authors have utilized $\%VO_{2max}$, to assess fatigue. Participants in the study conducted by Nardone et al. rode a cycle ergometer or exercised on a treadmill for 25min, and fatigued was assumed when the participants reached 60% VO_{2max} (Nardone et al., 1997).

As physiological and biomechanical research progressed, workloads were altered from general fatiguing conditions to workloads chosen to exemplify a workload that a professional might encounter in an occupational setting. Chander et al. (2014) examined three footwear types, low top shoe, tactical boot, and work boot, assuming an occupational environment that consisted of walking for long period of time. Participants were required to walk at a self-selected pace for 4 hours with breaks of only 1-2min. During this period, they did not sit or remove themselves from the vinyl testing floor. The participants completed the 4 hour walking workload in each footwear type (Chander et al., 2014). The fatiguing condition relied less on an exercise protocol but, instead, relied on a workload that simulated the workload of specific occupations such as careers in a factory. In another occupation focused research experiment, a firefighter specific workload was employed to test how unique occupational fatiguing conditions would affect balance when wearing two types of footwear, currently worn leather and rubber firefighter boots (Garner, Wade, Garten, Chander, & Acevedo, 2013). Participants completed 2 sessions of stair climbing at 60steps/min while wearing over 55kg of weights to simulate firefighters climbing stairs while wearing their gear. Participants alternated between the 2 boots used for testing, rubber boots and leather boots, wearing one type during separate testing sessions (Garner et al. 2013).

As with many other occupations, military workloads have been established in literature ((Birrell et al., 2007, Harman et al., 1999, & Demaio et al., 2009). A vital aspect of the military workload is the load that must be carried, which can vary in different military scenarios. Birrell et al. (2007) measured ground reaction forces with varying carrying loads. The minimal load, 0kg, consisted of non-restrictive clothes and military boots, while the maximal load, 40kg, consisted of a rifle, 16kg webbing, and 24kg backpack (Birrell et al., 2007). In a comparison of 11 different boot types, including several military boots, participants carried a 27.3kg backpack (about 60lbs) while running 400m and walking 9.7km (Harman et al., 1999). Finally, a more modest workload was implemented in a research study by DeMaio et al. (2009) in which participants wore personal protective equipment (PPE) consisting of a helmet and vest with ceramic plates (PPE total weight 9.8kg ± 0.9kg). Participants walked on a treadmill dressed in his or her PPE for multiple 3min stages beginning at 4.8kph and 0% grade, followed by 6.4kph and 0% grade and an increase of 5% grade each stage thereafter until 20% grade was reached (DeMaio et al., 2009). A workload, such as that employed in the DeMaio et al. (2009) study, is assumed to provide a similar workload as would be expected of military personnel in a combat scenario.

Balance and Footwear

As discussed previously, varying footwear types have certain characteristics that affect balance such as sole thickness, sole hardness, boot shaft stiffness, and heel height. Perry et al. examined 12 healthy young females as they wore simulated foot beds ranging from soft to hard and walked down an 8 m hallway, terminating gait to the sound of a buzzer (Perry, Radtke, & Goodwin, 2006). Results indicated all sole materials caused a detriment in balance compared to the barefoot condition, and soft soles lessened the range in COM over BOS (as compared to hard soles) indicating an inability to control COM as well during balance (Perry et al., 2006). A similar study was performed as 17 healthy adult men walked down a 9 m-long balance beam at 0.5m s^{-1} while barefoot and wearing shoes of varying midsole thickness and midsole hardness. (Robbins et al., 1994). Results suggested shoes with soft and thick midsoles inhibited balance the most, which was supported by a finding of a 217% increase in balance failure frequency when participants changed from the softest and thickest midsole shoe to the hardest and thinnest midsole shoe (Robbins et al., 1994). A final significant finding in the literature associated with the thickness of soles and balance was reported by Menant and colleagues (Menant, Lord, Steele, Munro, & Menz, 2008). Twenty-nine elderly participants (79.1yrs ± 3.7) wore 8 different shoes including elevated heel, soft sole, hard sole, flared sole, beveled heel, high heel-collar, and tread sole while researchers measured postural sway, maximal balance range, coordinated stability, and choice-stepping reaction time (Menant et al., 2008). The results of the study showed the shoe with an elevated heel of 4.5cm increased postural sway and inhibited performance in balance tests (Menant et al., 2008).

In a research study executed by You et al., 10 participants from a local university (6 participants with healthy ankles; 4 participants with chronic ankle stability (CAI)) were asked to reposition his or her ankle in a previously placed position under two conditions:1) circumferential ankle pressure (CAP) by a pediatric blood pressure cuff during initial target ankle position; 2) no CAP during initial target ankle position (You, Granata, & Bunker, 2004). Participants with CAI significantly increased postural stability and proprioceptive acuity when under the CAP condition, while those without CAI had no increase, causing the authors to postulate that the increase in postural stability was due to neuromuscular factors (You et al., 2004). Meanwhile, Bohm and Hosl (2010) conducted a study comparing the ROM of the ankle (Anteroposterior; medial/lateral) when wearing two hiking boots, one with a soft shaft and one with a hard shaft, while walking on gravel. A significant difference was found only in the anteroposterior ROM between boot shaft types ($p = 0.04$) with the soft shaft allowing for a larger ROM (Bohm et al., 2010). The hard boot shaft significantly decreased the eccentric energy at the ankle ($p = 0.02$) and increased the eccentric energy of the knee joint ($p=0.03$) (Bohm et al., 2010). The results of the study allowed the authors to theorize that a soft boot shaft might be preferable, and that a hard boot shaft shouldn't necessarily be associated with safety (Bohm et al., 2010).

A final factor associated with footwear characteristics and balance is the weight of the footwear. In the 1980s, EC Frederick and associates compiled the surmounting data on the influence of the weight of footwear and fatigue (Frederick, Daniels, & Hayes, 1984). The research found across an array of running speeds, VO_2 increases ~1% for each 100g of mass added to the shoe. Therefore, footwear that has less mass reduces the fatigue on participants who are running at varying speeds.

Balance and Workload

In previous investigations, balance has been shown to be affected by workloads applied. In a study conducted by Lepers et al., 9 trained athletes (4 athletes; 5 triathletes) completed Pre- and Post- sensory organization tests (SOT) after running 25km, and the triathletes completed Pre- and Post- SOT tests after riding a cycle ergometer for the same duration as the run (Lepers, Bigard, Dilard, Gouteyron, & Guezennec, 1997). Results showed a significant difference ($p<0.05$) in the vestibular condition of the SOT Post- 25 km run which was hypothesized to have occurred because of the constant motion of the head (Lepers et al., 1997).

As previously explained, occupational workloads have been implemented in studies to simulate working environments. In the study by Garner et al. (2013) that simulated stair climbing with over 55 kg of added weights, the type of footwear worn (rubber boots vs. leather boots) resulted in differences in balance after the simulated occupational conditions. The rubber boots resulted in significantly worse balance between stair climbing intervals and as compared to the leather boots. Likewise, in a study by Chander et al. (2014) where participants walked for 4 hrs in three types of footwear (low top shoe, tactical boot, and work boot), the workload affected balance and the footwear type affected the decrement in balance. All three footwear types presented decrements in balance from the workload, but the work boot and tactical boot resulted in smaller decrements as compared to the low top shoe (Chander et al., 2014).

Finally, an occupational workload which was designed to simulate a typical military workload was implemented in the research study by DeMaio et al. (2009) in which participants wore PPE while walking on a treadmill at varying speeds and percent grades. Balance was assessed utilizing the Star Excursion Balance Test, Balance Error Scoring System, and NeuroCom Smart Balance Master Sensory Organization Test Pre- and Post- for both conditions (Wearing PPE; Not Wearing PPE) in which fatigue was assumed as there was a significant change in mean COP motion for both anteroposterior and medial-lateral direction when wearing PPE and after fatiguing conditions (DeMaio et al., 2009). Likewise, postural sway in the anteroposterior and medial-lateral directions increased after fatiguing conditions and when the participants were wearing PPE, again suggesting fatigue from workload (DeMaio et al. 2009).

Conclusion and Expected Findings

As previously explored, balance can be affected by multiple variables including workload and shoe characteristics. Workloads can be prescribed in methodology as to represent an occupational workload, even if the workload contains aspects of physical performance such as would be found in the military. As found by (Bohm et al., 2010 & Perry et al., 2007) thinner, harder midsoles and boot shafts supporting the ankle allow for greater balance through proprioceptive feedback. Since these characteristics can all be found in the minimalist combat military boot, the hypothesis was the minimalist combat military boot would provide a lesser decrement in balance due to workload.

CHAPTER III

METHODOLOGY

Participants

Twenty-four healthy male adults (age range: 18-35 years) with no history of any musculoskeletal, neurological, cardiovascular or vestibular disorders were included in the study. Participants must have maintained a physical fitness status above recreationally trained ((>3-4 days/week with consistent aerobic (150min) and resistance training (at least 2 days) for the at least the last 3 months) (Ferguson 2014). To determine sample size, G-Power statistical software was utilized with a desired power of 0.8, a desired effect size of 0.25 and at an alpha level of 0.05.

Table 1

Participant Descriptive Data

Participant Descriptive Data					
	Height (cm)	Weight (kg)	Shoe Size (STD)	Shoe Size (MIN)	Age
Mean	176.694	79.809	10.318	10.636	22.136
STD DEV	6.818	9.700	0.733	0.743	2.678

Study Design and Instrumentation

The study followed a pre-test - post-test repeated measures design with the participants tested in two footwear conditions before and after a simulated workload. The footwear used in the study were; Boot #1: Belleville 310 Hot Weather Tactical Boot and Boot #2: Tactical Research MiniMil Ultra-Light Minimalist Tactical Military Boot TR101. The two boots utilized comply with the US Army's standard for footwear under the AR670-1 document which states the boots must include: an elevated boot shaft of 8-10 inches, rubber or polyether polyurethane outsole with the sole not exceeding 2 inches in height and not extending up the back of the heel or over the top of the toe, and the upper made of leather or non-mesh fabric. Balance kinetics were collected using a dual AMTI force plate (Watertown, MA).

hart Area ille 310 Hot Weather Tactical Boot	Tactical Research MiniMil Ultra-Light Minimalist Tactical Military Boot TR101
	

Figure 2. Military Boot Designs

(BellevilleBoots.com)

Experimental Procedures

Participants participated in a familiarization day in which they were familiarized with experimental protocol and had anthropometric data collected. Participants were tested on two days, which were separated by at least a week's time, donning one boot type each day. A counter balanced design was implemented to assure randomization of boot type with respect to day. Each testing session began with an initial warm up protocol of 10min consisting of body weight squats, high-knees, jogs, gait swings and exaggerated lunges. Following the counter-balanced boot assignment and placing on an ROTC backpack with 16kg of weight, participants balance was analyzed. Balance analysis included bilateral and unilateral stance for 3 trials of 20 seconds performed on the AMTI force plate in the following conditions; two legs, eyes open (2L EO), two legs, eyes closed (2L EC), two legs, foam eyes open (2L FEO), two legs, foam eyes closed (2L FEC), left, one leg, eyes open (L_1L EO), left, one leg, eyes closed (L_1L EC), left, one leg, foam eyes open (L_1L FEO), right, one leg, eyes open (R_1L EO), right, one leg, eyes closed (R_1L EC), and right, one leg, foam eyes open (R_1L FEO), and also include the Star Excursion Balance Test (SEBT). After the balance trials, participants were guided to a treadmill where they performed the simulated physiological workload of walking on the treadmill while wearing the boots and the weight military back pack. The walking protocol adapted from DeMaio et al. 2009 (DeMaio et al. 2009) consists of 3min increment periods starting at 4.8kph at 0% grade, and increases to 5.6kph and 6.4kph at 0% grade until minute 9, following which the grade increases by 5% every 3min until minute 18. When the walking protocol was completed, the participants completed the same balance tests as a post-test measure.

Statistical Analysis

The dependent kinetic variables from balance tests were analyzed using a 2 x 2 [2 (Boot #1 x Boot #2) x 2 (Pre-test x Post-test)] Repeated Measures Analysis of Variance (RM ANOVA) independently. Post-hoc pairwise comparisons were performed using a Bonferroni correction if interaction/main effect significance was found. All statistical analysis was performed using SPSS 21 (IBM® SPSS® V20.0, Armonk, New York 10504-172).

CHAPTER IV

RESULTS

Repeated measures revealed significant main effect differences for time and boot type for 95% ellipsoid, displacement in the x direction, displacement in the y direction, anterior-posterior velocity, medial-lateral velocity, anterior-posterior root mean square (RMS), medial-lateral RMS, and for time alone for average velocity.

95% Ellipsoid Area

Boot type differences for 95% ellipsoid area were seen during 2L EC [F (1,21) = 5.283, p = 0.032, η^2 = .201], and L1_L EO [F (1,21) = 4.895, p = 0.038, η^2 = 0.189]. No significant boot type differences were found for 2L EO, 2L FEO, 2L FEC, L_1L EC, L_1L FEO, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed STD demonstrated greater 95% ellipsoid area compared to MIN for 2L EC and L_1L EO. Time differences for 95% ellipsoid area were seen during 2L EO [F (1,21) = 12.53, p = 0.002, η^2 =0.374], 2L EC [F (1,21) = 12.018, p = 0.002, η^2 = 0.364], and 2L FEO [F (1,21) = 5.841, p = 0.025, η^2 = 0.218]. No significant time differences were found for 2L FEC, L_1L EO, L_1L EC, L_1L FEO, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed Time 2 (T2) demonstrated greater 95% ellipsoid area compared to T1 in 2L EO, 2L EC, and 2L FEO.

Average Velocity

No significant boot type differences for average velocity were found. Time differences for average velocity were seen during 2L EO [F (1,21) = 12.087, p = 0.002, η^2 = 0.365], 2L FEO [F (1,21) = 7.347, p = 0.013, η^2 = 0.259], and L_1L FEO [F (1,21) = 9.913, p = 0.005, η^2 = 0.321]. No significant time differences were found for 2L EC, 2L FEC, L_1L EO, L_1L EC, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed T2 demonstrated greater average velocity than T1 for 2L EO and 2L FEO, and T1 demonstrated greater average velocity than T2 for L_1L FEO.

Displacement in the X Direction (X-Displacement)

Boot type differences for x-displacement were seen for 2L EC [F (1,21) = 5.534, p = 0.028, η^2 = 0.209]. No significant boot type differences for x-displacement were seen for 2L EO, 2L FEO, 2L FEC, L_1L EO, L_1L EC, L_1L FEO, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed STD demonstrated greater x-displacement compared to MIN for 2L EC. Time differences for x-displacement were seen for 2L EO [F (1,21) = 30.127, p = 0.000, η^2 = 0.589], and 2L EC [F (1,21) = 9.262, p = 0.006, η^2 = 0.306]. No significant time differences were found for 2L FEO, 2L FEC, L_1L EO, L_1L EC, L_1L FEO, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed T2 demonstrated greater x-displacement compared to T1 for 2L EO and 2L EC.

Displacement in the Y Direction (Y Displacement)

Boot type differences for y-displacement were seen for L_1L EO [F (1,21) = 5.584, p = 0.028, η^2 = 0.210] and L_1L FEO [F (1,21) = 5.480, p = 0.029, η^2 = 0.207]. No significant boot type differences for y-displacement were seen for 2L EO, 2L EC, 2L

FEO, L_1L EC, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed STD demonstrated greater y-displacement compared to MIN for L_1L EO, but MIN demonstrated greater y-displacement compared to STD for L_1L FEO. Time differences for y-displacement were seen for 2L EO [F (1,21) = 5.892, p = 0.024, η^2 = 0.219], 2L EC [F (1,21) = 7.041, p = 0.015, η^2 = 0.251], 2L FEO [F (1,21) = 7.037, p = 0.015, η^2 = 0.251], R_1L EC [F (1,21) = 4.778, p = 0.040, η^2 = 0.185], and R_1L FEO [F (1,21) = 5.008, p = 0.036, η^2 = 0.193]. No significant time differences were found for 2L_FEC, L_1L EO, L_1L EC, L_1L FEO, and R_1L EO. Pairwise comparisons revealed T2 demonstrated greater y-displacement compared to T1 for 2L EO, 2L EC, 2L FEO, R_1L EC, and R_1L FEO.

Anterior-Posterior Velocity (AP Velocity)

Boot type differences for AP velocity were seen for L_1L EC [F (1,21) = 8.279, p = 0.009, η^2 = 0.283] and L_1L FEO [F (1,21) = 9.596, p = 0.005, η^2 = 0.314]. No significant boot type differences were found for 2L EO, 2L EC, 2L FEO, 2L FEC, L_1L EO, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed MIN demonstrated greater AP velocity compared to STD for L_1L EC and L_1L FEO. Time differences for AP velocity were seen for 2L EO [F (1,21) = 7.152, p = 0.014, η^2 = 0.254], 2L FEO [F (1,21) = 9.102, p = 0.007, η^2 = 0.302], and L_1L FEO [F (1,21) = 13.636, p = 0.001, η^2 = 0.394]. No significant time differences were found for 2L EC, 2L FEC, L_1L EO, L_1L EC, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed T2 demonstrated greater AP velocity compared to T1 for 2L EO and 2L FEO, but T2 demonstrated greater AP velocity compared to T2 for L_1L FEO.

Medial-Lateral Velocity (ML Velocity)

Boot type differences for ML velocity were seen for L_1L EO [F (1,21) = 7.687, p = 0.011, η^2 = 0.268] and L_1L FEO [F (1,21) = 8.074, p = 0.010, η^2 = 0.278]. No significant boot type differences were found for 2L EO, 2L EC, 2L FEO, 2L FEC, L_1L EC, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed STD demonstrated greater ML velocity compared to MIN for L_1L EO and L_1L FEO. Time differences for ML velocity were seen for 2L EO [F (1,21) = 7.414, p = 0.013, η^2 = 0.261] and L_1L FEO [F (1,21) = 5.494, p = 0.029, η^2 = 0.207]. No significant time differences were found for 2L EC, 2L FEO, 2L FEC, L_1L EO, L_1L EC, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed T2 demonstrated greater ML velocity compared to T1 for 2L EO, but T1 demonstrated greater ML velocity compared to T2 for L_1L FEO.

Anterior-Posterior Root Mean Square (AP RMS)

Boot type differences for AP RMS were seen for L_1L EO [F (1,21) = 7.249, p = 0.014, η^2 = 0.257], L_1L EC [F (1,21) = 5.782, p = 0.026, η^2 = 0.216], and L_1L FEO [F (1,21) = 4.714, p = 0.042, η^2 = 0.183]. No significant boot type differences were found for 2L EO, 2L EC, 2L FEO, 2L FEC, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed STD demonstrated greater AP RMS compared to MIN for L_1L EO, but MIN demonstrated greater AP RMS compared to STD for L_1L EC and L_1L FEO. Time differences for AP RMS were seen for 2L EO [F (1,21) = 5.248, p = 0.032, η^2 = 0.200], 2L EC [F (1,21) = 5.659, p = 0.027, η^2 = 0.212], 2L FEO [F (1,21) = 7.276, p = 0.013, η^2 = 0.257], and R_1L EC [F (1,21) = 4.486, p = 0.046, η^2 = 0.176]. No significant time differences were found for 2L FEC, L_1L EO, L_1L EC, L_1L FEO, R_1L EO, and R_1L FEO. Pairwise comparisons revealed T2 demonstrated greater AP RMS compared to T1 for 2L EO, 2L EC, 2L FEO, and R_1L EC.

Medial-Lateral Root Mean Square (ML RMS)

Boot type differences for ML RMS were seen for 2L EC [F (1,21) = 4.958, p = 0.037, η^2 = 0.191]. No significant boot type differences were seen for 2L EO, 2L FEO, 2L FEC, L_1L EO, L_1L EC, L_1L FEO, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed STD demonstrated greater ML RMS compared to MIN for 2L EC. Time differences for ML RMS were seen for 2L EO [F (1,21) = 24.753, p = 0.000, η^2 = 0.541] and 2L EC [F (1,21) = 6.032, p = 0.023, η^2 = 0.223]. No significant time differences were found for 2L FEO, 2L FEC, L_1L EO, L_1L EC, L_1L FEO, R_1L EO, R_1L EC, and R_1L FEO. Pairwise comparisons revealed T2 demonstrated greater ML RMS compared to T1 for 2L EO and 2L EC.

Star Excursion Balance Test, Reach Distance

No significant boot type or time differences were seen for anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), lateral (L), or anterolateral (AL) for left stance leg (LSL) or right stance leg (RSL).

Boot Sole Surface Area

A paired-samples T test revealed significance in boot sole surface area difference for STD (M= 288.640, SD= 7.801) and MIN (M= 235.428, SD= 4.086) conditions; t= 13.651, p= 0.001.

Table 2

Boot Sole Surface Area

Boot Sole Surface Area						
Size	**Type**	**SA (cm^2)**		**Size**	**Type**	**SA (cm^2)**
9.5	MIN	224.010		9.5	STD	268.529
10.5	MIN	237.015		10.5	STD	292.502
11	MIIN	237.249		11	STD	287.308
11.5	MIN	243.436		11.5	STD	306.222
	Mean	235.428			**Mean**	288.640
	STD DEV	8.172			**STD DEV**	15.602

Boot Mass

A paired-samples T test revealed significance in boot mass difference for STD (M= 801.125, SE= 14.283) and MIN (M= 500.125, SE= 8.530) conditions; t= 46.485, p= 0.000.

Table 3

Boot Mass

Boot Mass							
Size (US)	**Type**	**Left Mass (g)**	**Right Mass (g)**	**Size (US)**	**Type**	**Left Mass (g)**	**Right Mass (g)**
9.5	MIN	463	476	9.5	STD	750	754
10.5	MIN	487	499	10.5	STD	788	791
11	MIIN	508	508	11	STD	800	813
11.5	MIN	526	534	11.5	STD	861	852
	Mean	500.125			**Mean**	801.125	
	STD DEV	24.127			**STD DEV**	40.400	

Workload Duration

A paired-samples T test revealed significance in boot mass difference for STD (M=901.227, SE= 30.383) and MIN (M= 933.727, SD= 24.27.035) conditions; t= -2.624, p= 0.016.

Table 4

Descriptive statistics (Mean±Standard Deviation) for Standard Tactical Boot and Minimalist Tactical Boot from static balance while standing.

Balance Variables												
	PRE-WORKLOAD						POST-WORKLOAD					
	STANDARD			MINIMALIST			STANDARD			MINIMALIST		
	Mean ± SD			Mean ± SD			Mean ± SD			Mean ± SD		
	2L	L_1L	R_1L	2L	L_1L	R_1L	2L	L_1L	R_1L	2L	L_1L	R_1L
VARIABLE												
95% Ellipsoid Area												
EO	2.633±1.824*	11.443±4.439†	10.664±4.497	2.473±2.765*	9.885±3.961†	10.747±5.353	4.282±3.261*	13.807±9.266†	11.011±4.544	3.757±4.048*	10.445±4.131†	9.190±3.343
EC	3.537±2.609†*	33.751±14.836	39.543±16.284	2.762±1.925†*	55.502±47.249	48.842±42.131	4.864±3.517†*	44.701±28.324	57.074±55.368	3.457±2.322†*	55.650±60.384	55.229±48.453
FEO	6.861±3.530*	15.033±5.067	15.754±5.617	7.716±5.125*	18.196±6.368	16.335±7.551	9.359±6.461*	16.651±7.711	19.256±11.082	8.863±6.370*	16.958±8.507	18.732±15.323
FEC	14.022±6.614			16.508±7.393			16.864±11.139			17.237±9.964		
Average Velocity												
EO	1.874±0.328*	5.019±1.076	5.036±1.609	1.999±0.472*	4.760±0.999	4.897±1.271	2.098±0.465*	5.006±1.290	4.573±1.019	2.085±0.453*	4.777±0.883	4.588±0.793
EC	2.113±0.339	10.054±2.142	10.713±1.931	2.230±0.393	11.281±3.470	10.880±3.455	2.252±0.508	10.216±2.260	13.659±14.077	2.230±0.462	10.492±2.774	16.938±22.569
FEO	2.458±0.389*	7.008±1.432*	6.698±1.873	2.500±0.419*	6.894±1.530*	6.144±1.528	2.651±0.521*	6.468±1.540*	6.360±1.632	2.593±0.492*	6.403±1.642*	7.076±5.254
FEC	3.527±0.662			3.715±0.566			3.590±0.746			3.597±0.663		
Displacement X												
EO	0.223±0.103*	0.613±0.230	0.548±0.102	0.212±0.142*	0.574±0.101	0.559±0.113	0.296±0.129*	0.616±0.177	0.573±0.123	0.282±0.190*	0.595±0.162	0.534±0.083
EC	0.236±0.126†*	1.057±0.257	1.166±0.245	0.214±0.100†*	1.313±0.480	1.192±0.557	0.301±0.141†*	1.159±0.277	1.210±0.459	0.236±0.099†*	1.259±0.706	1.222±0.546
FEO	0.423±0.135	0.714±0.133	0.691±0.122	0.428±0.139	0.742±0.134	0.705±0.181	0.449±0.162	0.723±0.171	0.728±0.199	0.461±0.181	0.695±0.168	0.683±0.150
FEC	0.519±0.169			0.567±0.161			0.559±0.182			0.570±0.197		
Displacement Y												
EO	0.386±0.131*	0.733±0.229†	0.635±0.141	0.381±0.176*	0.600±0.136†	0.653±0.222	0.477±0.204*	0.684±0.169†	0.663±0.149	0.447±0.195*	0.656±0.246†	0.607±0.171
EC	0.465±0.181*	1.085±0.228	1.165±0.269*	0.410±0.121*	1.318±0.493	1.268±0.409*	0.515±0.175*	1.300±0.339	1.371±0.582*	0.476±0.202*	1.347±0.437	1.362±0.420*
FEO	0.573±0.175*	0.729±0.176†	0.769±0.205*	0.611±0.235*	0.854±0.230†	0.783±0.181*	0.674±0.238*	0.777±0.230†	0.895±0.331*	0.629±0.205*	0.837±0.285†	0.847±0.290*
FEC	0.887±0.218			0.964±0.249			0.972±0.282			1.000±0.350		

Two Legs (2L), Left One Leg (L_1L), and Right One Leg (R_1L) with Eyes Open (EO), Eyes Closed (EC), Foam Eyes Open (FEO), and Foam Eyes Closed.

Table 4 (Continued)

Anterior-Posterior Velocity													
EO	1.300±0.242*	2.915±0.628†	3.071±1.001	1.411±0.395*	2.945±0.691†	3.080±0.954		1.437±0.333*	3.051±0.909†	2.844±0.647	1.475±0.367*	2.946±0.646†	2.885±0.586
EC	1.536±0.256	5.945±1.516	6.470±1.512	1.646±0.307	7.408±2.900	7.260±2.822		1.595±0.336	6.190±1.712	9.070±12.924	1.625±0.382	6.889±2.322	12.497±19.496
FEO	1.647±0.262*	3.616±0.622†*	3.672±1.139	1.666±0.281*	4.076±0.755†*	3.834±1.091		1.772±0.338*	3.332±0.725†*	3.378±0.884	1.740±0.304*	3.654±0.716†*	4.305±4.015
FEC	2.544±0.483			2.690±0.418				2.606±0.561			2.599±0.522		
Medial-Lateral Velocity													
EO	1.101±0.194*	3.501±0.839	3.406±1.153	1.137±0.225*	3.146±0.651	3.184±0.698		1.235±0.318*	3.288±0.833	3.023±0.720	1.183±0.217*	3.151±0.554	2.989±0.510
EC	1.153±0.192	6.842±1.389†	7.005±0.991	1.182±0.216	6.832±1.506†	6.560±1.641		1.258±0.374	6.659±1.287†	7.385±2.846	1.209±0.224	6.380±1.323†	8.219±6.413
FEO	1.506±0.287	5.203±1.284†*	4.785±1.305	1.538±0.268	4.686±1.251†*	4.140±1.248		1.600±0.344	4.845±1.316†*	4.479±1.159	1.580±0.346	4.442±1.376†*	4.658±2.577
FEC	1.943±0.471			2.030±0.374				1.962±0.442			1.957±0.429		
Anterior-Posterior Root Mean Square													
EO	0.485±0.158*	0.869±0.228†	0.801±0.175	0.474±0.230*	0.748±0.189†	0.819±0.265		0.581±0.240*	0.862±0.220†	0.825±0.187	0.554±0.226*	0.795±0.240†	0.742±0.195
EC	0.593±0.223*	1.357±0.296†	1.500±0.336*	0.518±0.150*	1.659±0.648†	1.598±0.537*		0.638±0.206*	1.604±0.427†	1.857±1.258*	0.596±0.238*	1.711±0.540†	1.805±0.726*
FEO	0.711±0.192*	0.912±0.205†	0.976±0.262	0.756±0.297*	1.063±0.276†	0.996±0.249		0.831±0.286*	0.987±0.274†	1.127±0.422	0.775±0.240*	1.045±0.336†	1.050±0.363
FEC	1.114±0.262			1.200±0.290				1.235±0.351			1.241±0.426		
Medial-Lateral Root Mean Square													
EO	0.296±0.167*	0.728±0.160	0.703±0.163	0.270±0.180*	0.712±0.139	0.703±0.171		0.374±0.195*	0.788±0.295	0.707±0.154	0.349±0.224*	0.718±0.146	0.667±0.102
EC	0.308±0.156†*	1.273±0.302	1.390±0.283	0.275±0.131†*	1.566±0.609	1.408±0.629		0.372±0.174†*	1.373±0.317	1.463±0.620	0.307±0.128†*	1.493±0.781	1.499±0.704
FEO	0.518±0.157	0.896±0.165	0.858±0.157	0.538±0.175	0.914±0.190	0.900±0.356		0.567±0.198	0.890±0.177	0.876±0.236	0.573±0.228	0.859±0.184	0.852±0.210
FEC	0.660±0.212			0.719±0.205				0.705±0.225			0.712±0.241		

* denotes significant time main effect difference, † denotes significant boot type main effect difference.

CHAPTER V

DISCUSSION

The purpose of this study was to analyze the effects of two military type boots, standard tactical military boot and minimalist tactical military boot, on balance in healthy young male adults before and after a simulated military workload. Center of pressure excursions were measured during unilateral and bilateral stance on a hard surface and foam surface with the eyes open and closed. Results suggest the minimalist tactical military boot demonstrated greater balance performance on the hard surface; however, the standard tactical military boot performed superiorly on the foam surface. These results are likely related to the footwear characteristics of each boot such as boot mass, sole surface area, midsole thickness and resiliency, boot drop, and boot shaft material composition, which are further individually discussed in this section. Moreover, the simulated military type workload demonstrated significant decrements in balance performance. These results are likely related to the fatiguing protocol and the impact of muscular fatigue on balance performance. The discussion section is broadly split into a two categories, (I) Impact of military footwear on balance and (II) Impact of military type occupational task on balance, and concludes with a global conclusion section including limitations and future research.

Impact of military footwear on balance:

Surface Area of Boot Sole

Described as an inverted pendulum, human structure dictates that the center of mass sways anterposteriorly and mediolaterally about the talocrural joint and subtalar joint respectively to maintain the center of mass within the base of support (Winter, 1990). Generally, an increase in the area of base of support increases balance performance because the center of mass can traverse in any direction in greater magnitude without challenging the boundaries of the base of support (Horak, 2006). The base of support was different for each type of the military boot was different, even for the same shoe sizes.

The surface area of each boot was determined by tracing the sole of the boot onto a plain white piece of paper. A horizontal line was drawn across the width of the tracing at the midpoint of the mid-foot curvature, dividing the tracing into two portions. The anterior portion, representing the anterior portion of the sole, and the posterior portion, representing the posterior portion of the sole, were divided into 1.5 cm sections. Measurements were started at the original horizontal midpoint and continued towards the anterior and posterior ends of the boot. The width at each 1.5 cm section was measured, and the average of the widths for each section was multiplied by the length of the section. The standard tactical boot was found to have a greater surface area (288.640 cm^2 ± 15.602) when compared to the minimalist tactical boot (235.428 cm^2 ± 8.172). Both boots had similar percentages for anterior and posterior lengths of the respective boot soles (STD: Anterior Length Percentage (Anterior Sole Length/Total Sole Length)

57.1%, Poster Length Percentage (Posterior Sole Length/Total Sole Length) 42.9%; MIN: Anterior Length Percentage 57.6%, Poster Length Percentage 42.4%)

Equation for Sole Surface Area

$$\overset{\textbf{Anterior}}{(\text{Sole Width Average}) * (\text{Sole Length})} + \overset{\textbf{Posterior}}{(\text{Sole Width Average}) * (\text{Sole Length})} = \tag{5.1}$$

As previously explored, greater footwear sole surface area increases the base of support, as well as, balance performance which has been explored, most notably, in the elderly (Tencer et al., 2004). Tencer et al. studied falls in older adults which revealed donning footwear with greater contact area, which is the area of the sole of the footwear that contacts the floor surface, demonstrated significantly greater balance when compared to footwear with lesser contact area. These findings suggest a greater contact area allows for superior balance performance which is supported by the results of this study which found better balance performance while wearing the standard boot on an unstable, foam surface. These findings suggest the greater surface area of the standard boot provided a larger base of support, likely stabilizing the talocrural joint, demonstrating less of a need for plantarflexion and dorsiflexion to maintain balance even when standing on foam. However, these results were contradicted by the finding of greater mean values for the standard boot center of pressure excursions in the anteroposterior directions for the left leg suggesting lesser balance in the in these directions while donning the standard boots with the eyes open.

Boot Heel-Midfoot Drop

Footwear drop height represents the difference in sole height between the heel and forefoot sections. The Belleveille boot company reports a heel drop height of approximately 18mm and 2mm for the standard tactical and minimalist tactical, respectively. In a study concerning the effect of heel height on balance during unilateral standing, results suggested increasing heel height up to 15 mm caused a migration of center of pressure medially; however, at 15 mm heel height, the center of pressure began shifting anteriorly (Shimizu & Andrew, 1999). A shift of the center of pressure anteriorly would suggest a reduction in postural sway in the posterior direction. Wearing the standard boot would cause a similar anterior shift of center of pressure and restriction of posterior sway because, as previously noted, the standard boot incorporates a large 17-18 mm drop height shifting the center of mass anteriorly. Additionally, a large drop height forces the foot to utilize a substantial portion of plantarflexion range of motion, minimizing the ability to plantar flex to force the center of pressure posteriorly. While wearing the minimalist boot, with a small 2 mm drop height, participant results demonstrated center of pressure excursions on foam and with the eyes closed on a firm surface in the anteroposterior directions suggesting greater sway. Therefore, the large drop of the standard tactical boot may have reduced sway because of decreased plantarflexion range of motion, as the foot is already slightly plantar flexed due to the higher heel. However, our findings did represent contradictory evidence with center of pressure excursions increased with eyes open while wearing standard tactical boots. These contradicting results might be the product of increased surface area and/or midsole thickness and resiliency in the standard boot, and/or greater available sensory input while wearing minimalist tactical boot.

Boot sole thickness and resiliency

Human erect stance relies heavily on cutaneous receptor signaling from the soles of the feet. It has been suggested that midsole thickness, the layer between the outsole and the insole, affects balance and postural control (Robbins et al., 1994). Robbins et al. explored this notion with participants who walked across a 9-meter balance beam in shoes differing in midsole thickness and hardness. Results suggested footwear with thin, hard midsoles provide greater stability, likely from increased cutaneous receptor signaling. These findings are supported by findings of a study which suggest the plantar sole is a “dynamometric map” (Kavounoudias, Roll, & Roll, 1998). Stimulation of particular portions of the plantar sole resulted in whole body tilt in the counter direction such that nervous stimulation to one portion of the sole caused the center of pressure to transfer in the opposing direction. These findings demonstrate that plantar cutaneous receptors play a role in balance and postural control which is in congruence with findings from textured insole research (Corbin et al., 2007). The results from the textured insole experiment conducted by Corbin et al. (2007) suggested participants demonstrated greater area and velocity of center of pressure excursions with eyes closed during bilateral stance only when the participants were not wearing textured insoles suggesting improved somatosensory feedback while donning textured insoles.

The findings of current literature are in agreement with the results of this research. Statistical significance found in two leg stance demonstrated worse balance for standard tactical boots while the eyes were closed. These results suggest it is likely that the thick, cushioned midsole of the standard tactical boot resulted in less somatosensory feedback, impairing balance performance. The finding of increased sensory feedback in the minimalist boots is of elevated importance to military personnel who must operate in dark conditions where visual stimuli is reduced or obsolete. However, unlike Corbin et al, 2007, the results of this research showed significance in unilateral stance, but only in the left leg which may be explained by opposing leg differences in balance performance.

Balance and opposing legs

Though there was no recording of leg dominance, it is likely the sample was mostly right leg dominant. Lesser development of motor control in the left (non-dominant) leg may have exacerbated participant postural sway resulting in significant findings for worse balance in the left leg; however, current literature does not support the notion of significant balance performance differences between dominant and non-dominant lower limbs (Hoffman, Schrader, Applegate, & Koceja, 1998, Gstottner et al., 2009). Though, one study did find reaction time of the right leg was always significantly faster, regardless of leg dominance (Rein et al., 2010). With a possibility of variable postural control and balance performance between opposing lower limbs, this research finds it crucial for further investigation of individual lower limb impact on balance performance.

Boot Mass

The mass of the two boots was substantially different with a mean mass of 800.125g ± 40.400 for a single standard tactical boot and 500.125g ± 24.107 for a single minimalist tactical boot, equaling an average difference of 301.000g ± 18.315. Increased footwear mass has been shown to increase energy demands by about one percent for every additional 100g of added mass (Frederick, Daniels, & Hayes, 1984). Jones et al.

found similar results when added weight to running shoes demonstrated increased energy expenditure (Jones et al, 1984). Like previous literature, this study found that the heavier boot, standard tactical, presented greater center of pressure excursions when compared to the lighter minimalist tactical boot. These results are to be expected as the weight added to the end of the lower leg caused greater resistance at the distal end of the lever arm of a third class lever. Therefore, greater force must be generated to move the lower leg when donning the standard tactical boot, likely causing greater fatigue and lesser balance performance. Continuing, when participants wore the heavier standard boot during the simulated military workload, they demonstrated lower time to volitional fatigue (Figure 1J.). These results were contradicted by worse balance performance in the anteroposterior directions in the left leg. This is likely due to the majority of participants being right leg dominant, and a discrepancy between legs as was discussed in "Boot sole thickness and resiliency. Unfortunately, this study did not record leg dominance.

Boot Shaft

The military type tactical boots utilized in this study incorporated eight inch boot shafts. Circumferential pressure above the ankle, as occurs when boot shafts are properly tightened, has been suggested to increase the somatosensory feedback and increase balance performance (You et al., 2004). Pressure applied to the ankle region likely increased proprioceptive feedback, as well as, stabilized the ankle joint, improving postural stability and balance performance. These notions are supported by a dearth of literature which demonstrates the inclusion of a boot shaft increases postural stability and balance performance (Cikajlo & Matjacic, 2007, Bohm & Hosl, 2010, & Chander et al., 2014). In this study, the standard tactical military boot had a thicker, stiffer boot shaft, while the minimalist boot had a thin mesh shaft with elastic strapping across the medial and lateral malleoli. However, the standard boot provided worse balance in a majority of the balance testing conditions. The boot shafts of minimalist and standard tactical boots were eight inches in height, and both boots likely provided a similar amount of pressure around the lower leg and upper ankle because similar lacing was utilized with both footwear; additionally, participants were encouraged to tighten the boots so that a snug fit was reached. Therefore, it is reasonable that proprioceptive feedback was similar between boots, leaving shaft stiffness as the remaining component possibly impacting balance performance. Although the standard boot was composed of a stiffer material, it is likely that the elastic straps across the malleoli were sufficient to cause a comparable range of ankle immobility potentially negating any large differences caused by the boot shafts alone.

Impact of military type occupational task on balance

Military Workload

Military personnel is a broad term that encompasses a multitude of occupational duties. A large percentage of U.S. Army injuries are due to slips, trips, and falls, or a loss of balance (Dada-Laseinde, Canham-Chervak, & Jones, 2009). It is fair to assume portions of military tasks were not included in the protocol utilized in this study; however, this study incorporated many components of a typical military operation and training operation including military boots, inclined surface, walking to jogging, and load carriage in a healthy young population who fit the ACSM criteria of physical fitness for recreationally trained and who could potentially be considered as new army recruits. The protocol utilized has been accepted as simulated military workload in the current literature when it was previously published (DeMaio et al., 2009).

Workload, Muscular Fatigue and Balance

Workload is an important component in balance performance studies which aim to analyze the effects of fatigue on postural control and balance. Studies have shown aerobic and anaerobic exercise are capable of causing neuromuscular fatigue great enough to induce postural control and balance decrements denoted by increased sway velocities after aerobic and anaerobic workloads (Fox et al., 2008). Nonetheless, the workload must be adequately intense to cause a great enough amount of neuromuscular fatigue so that postural control and balance decrements can occur (Nardone, Tarantola, Giordano, & Schieppati, 1997). Sufficient intensity to cause increased center of pressure excursions has been accomplished by long workload duration, load carriage, surface inclination, and increased gait velocity, along with many other introduced variables (Chander et al., 2014, Garner et al., 2013, & Goldman & Iampietro, 1962). This study incorporated a high intensity workload that encompassed many of these variables like load carriage, surface inclination, and continuously increasing ambulation velocity that have been suggested to promote fatigue. Results from this study support the notion that including these variables in a high intensity workload may cause postural control and balance decrements as post workload balance performance was significantly worse.

Occupational Task and Balance

Research on the effects of physiological workloads on balance have shown that walking and running are detrimental to postural stability and balance performance

(Chander et al., 2014 & Lepers et al., 1997). More recently, ergonomic research has focused on the effects of occupational tasks on balance performance. Research has shown physiologically demanding tasks of military personnel and firefighters may provoke balance and postural control decrements due to fatigue (Garner et al., 2013 & DeMaio et al., 2009). Results from this study support the notion of balance and postural control decrements due to simulated occupational physiologically demanding tasks, as balance performance after the simulated workload was significantly worse.

Load Carriage and Balance

It is a necessary for military personnel to wear a rucksack when on patrol so they can carry imperative supplies for successful completion of the mission; however, load carriage on the back, an extrinsic factor on patrols, may cause biomechanical and physiological alterations. It has been suggested an increase in load carriage causes an increase in energy expenditure which may be augmented by surface inclination (Goldman & Iampietro, 1962). This is due to greater required force production to complete a similar task, such as propelling the center of mass anteriorly and superiorly in human gait. This is supported by findings of increased gastrocnemius muscle activity, and increased ground reaction forces when loads were increased (Harmen et al., 1992). Load carriage on the upper back, as was required in this study, has been shown to lead to forward bending to maintain the center of mass within the base of support. This forward bending has been hypothesized to reduce stride length, making ambulation less efficient (Knapik, Harman, & Reynolds, 1996). In accordance with the aforementioned increased muscle force development and activation and energy expenditure, this study found the participants' balance to be worse after carrying a load on the upper back. A similar finding was demonstrated in a firefighter load carriage study, where stair ambulation was utilized in place of an inclined surface (Garner et al., 2013). This would be expected as increased energy expenditure and muscle activation likely lead to fatigue, a detrimental factor in postural stability and balance performance.

Inclined Surface and Balance

The biomechanics of human gait is altered during uphill ambulation. It has been suggested hip, knee, and ankle extensor activity is increased during uphill walking when compared to human gait at zero degree inclination (Franz & Kram, 2012). This distinct strategy of increased extensor activation propels the center of mass superiorly and anteriorly; whereas, normal gait center of mass propulsion requires less superior displacement. The human uphill ambulation strategy requires an increased energy expenditure with greater oxygen consumption and heat production as compared to zero degree inclination surface gait (Johnson, Benjamin, & Silverman, 2002). Increased energy expenditure is to be expected because greater muscle activation is necessary to walk at the same velocity. Additionally, increased walking velocity requires greater energy expenditure at any inclination. The results from this study suggest the constant increased velocity and surface inclination provoked by the simulated military workload generated greater fatigue precipitating decreased balance performance and increased center of pressure excursions after the workload.

Boots and Balance

In this study, participants wore high top, military type, tactical boots instead of low top athletic shoes. Military personnel are required to wear footwear that meet the guidelines of the branch they are serving under, and the majority of military personnel must wear tactical boots. To simulate actual military operation, high top, military type, tactical boots were chosen as the footwear. Critically, boots have been shown to increase energy expenditure even when compared to athletic shoes of equal mass (Jones et al., 1984). Therefore, participant utilization of military type boots was pertinent to maintaining authenticity in military operations simulation. It is probable that boots require a greater amount of energy expenditure when compared to athletic, low top shoes because of a restriction of ankle mobility causing inefficient gait mechanisms. Human gait requires adequate plantarflexion and dorsiflexion to maintain optimal gait, and reduced plantarflexion and dorsiflexion range of motion causes a shortened stride length. This inefficient gait, which likely occurred during the simulated military workload used in this study, likely caused increased fatigue which is supported by the decrease in balance performance post workload.

Conclusion

The findings from this study demonstrate the characteristics of a military tactical boot will likely affect military personnel balance performance. The longstanding design of the military standard issue boot comprised of the characteristics of the standard tactical boot may provide superior balance and postural control on unstable terrains due to an increased surface area. However, the characteristics of the minimalist tactical boot design provided superior balance and postural control in nearly all other conditions even after participants completed significantly longer durations of physiological exertion during the simulated military workload. These findings suggest military personnel would benefit from a boot design with lesser mass, a low measure of heel-midfoot drop, and thin, hard midsole.

The demands of the military require personnel to meet high physiological demands, and much of the equipment they utilize enhances their performance. A boot with lower mass, such as the minimalist tactical boot, would likely allow personnel to successfully operate for longer durations without fatiguing as quickly. Continuing, a low heel-midfoot sole drop would allow for less postural muscle activation, likely reducing time to fatigue. Likewise, military operations, at times, require maneuvering under the cover of darkness where visual stimuli is quite low. The minimalist design of hard, thin midsoles increases somatosensory feedback which would potentially lead to greater balance and less injury. The military should consider a footwear design that minimizes contribution to physiological fatigue and enhances balance performance so that personnel can perform operations and jobs with greater success. The findings of this research suggests an optimal military tactical boot should include low mass, low heel-midfoot drop, an adequately stabilizing and compressive boot shaft, thin, hard midsole, and a sole surface area large enough to allow for stabilization while traversing unstable terrain.

Limitations and Future Research:

Attempting to simulate physiological workloads in a laboratory setting can be challenging as many internal and external environmental components are absent. Military operations are generally performed outside or within buildings where the ground surface is variable and, at times, constantly changing. In order to standardize the military simulation, this study utilized a treadmill which provided a single surface, controlled velocity, and surface inclination. Likewise, the laboratory conditions provided a quiet environment, absent of typical military noises such as gunfire, explosions, and yelling. Participants were required to wear shorts, a t-shirt, and a backpack weighing 32kg which are all components likely differing depending on the military operation. Finally, only two boots were utilized in this study to represent the characteristics of the "typical" standard issue tactical military boot and a minimalist designed military tactical boot. There are a large number of military boots which military personnel can choose, so these boots did not have represent every characteristic or combination of characteristics available.

In order to improve this study's design, a similar study could be conducted that incorporated more internal and external environmental conditions that were more natural to real world scenarios. The participant sample should consist of individuals who regularly wear tactical boots under physiological demands. The study could be completed as a field experiment where natural noises, surface, and lighting conditions are present. Finally, participants should be required to wear the standard outfit and carry all necessary equipment such as a utility belt, helmet, and weapon.

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APPENDIX A

95% ELLIPSOID AREA FIGURES

Figures A1-A10 represent mean values for 95% Ellipsoid Area for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

Table A1

Figure Key

FIGURE KEY	
*	TIME MAIN EFFECT
†	BOOT TYPE MAIN EFFECT

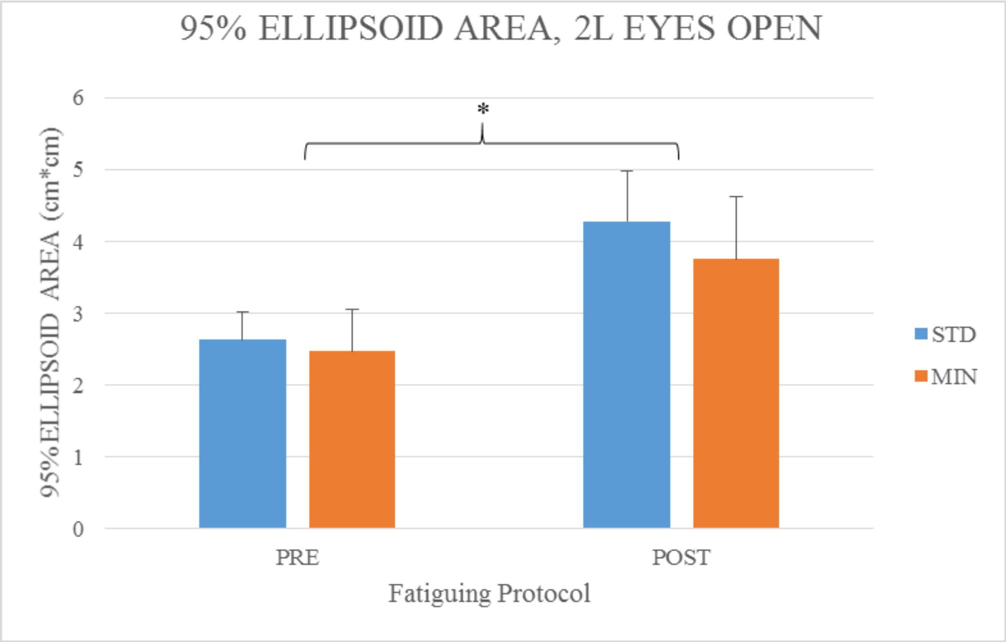

Figure A1. 95% Ellipsoid Area, 2L Eyes Open

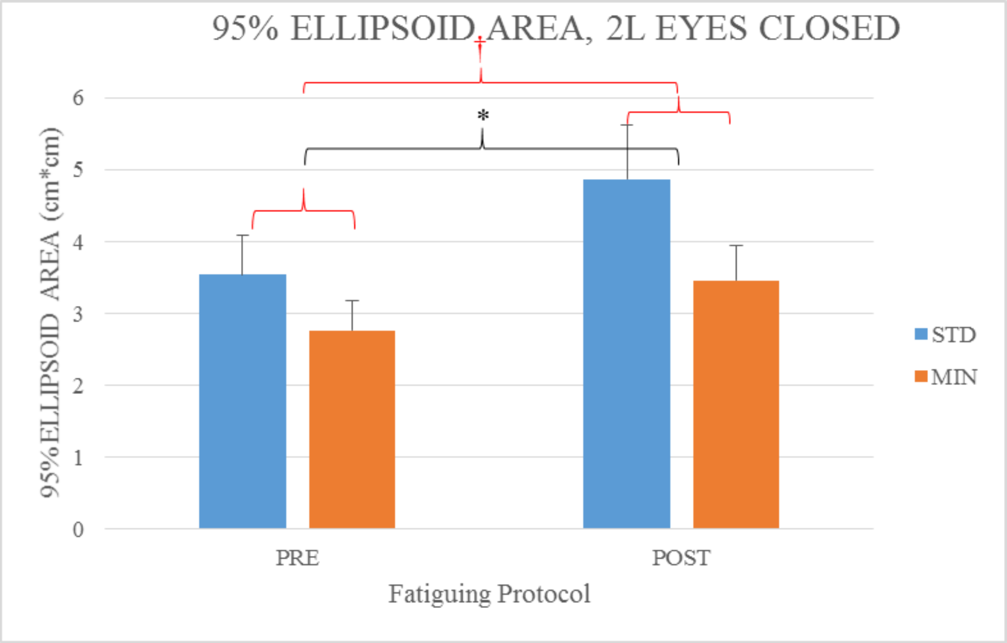

Figure A2. 95% Ellipsoid Area, 2L Eyes Closed

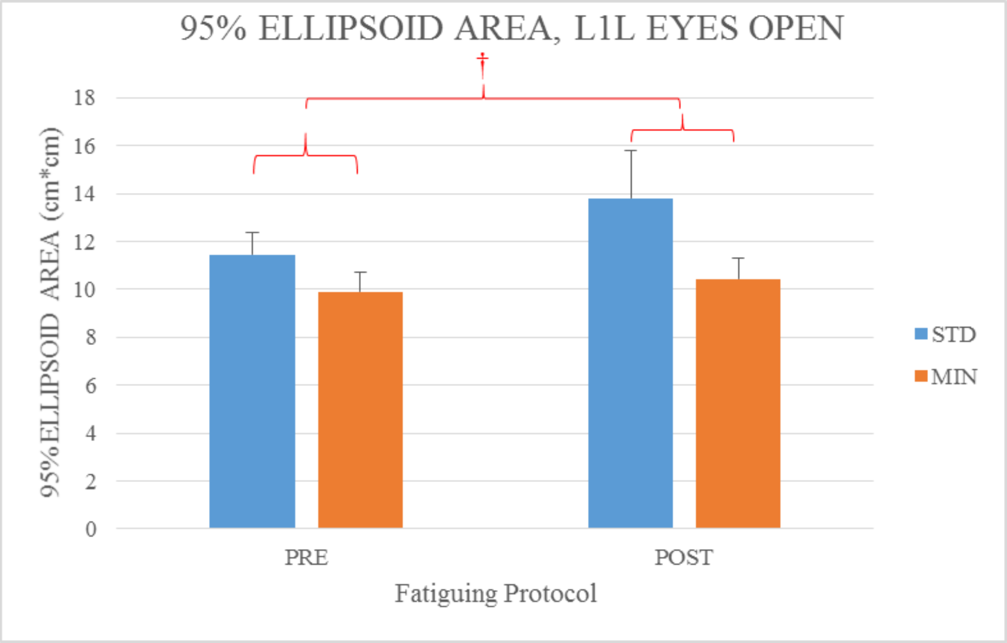

Figure A3. 95% Ellipsoid Area, L1L Eyes Open

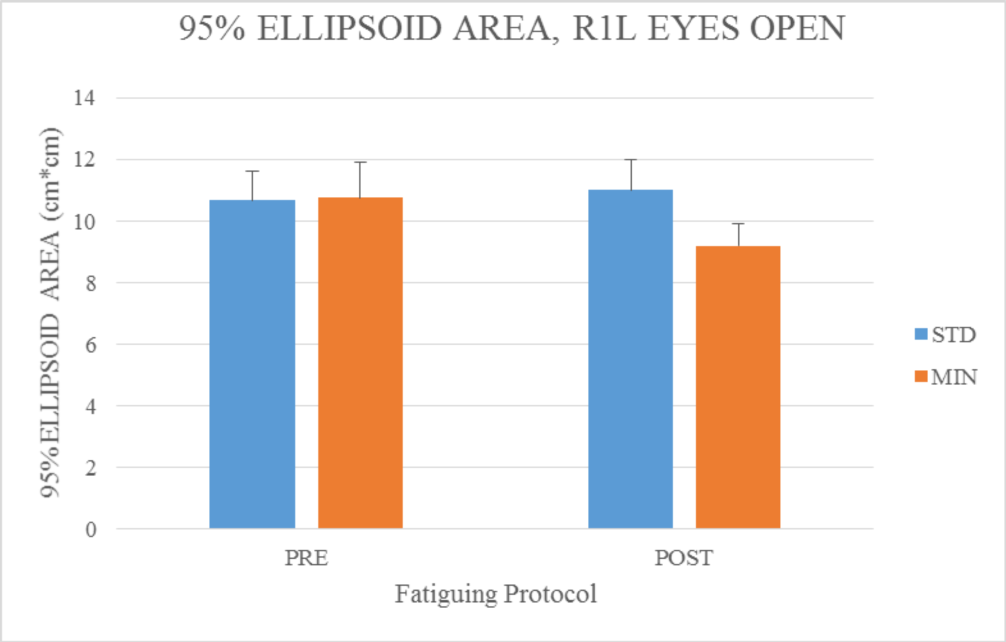

Figure A4. 95% Ellipsoid Area, R1L Eyes Open

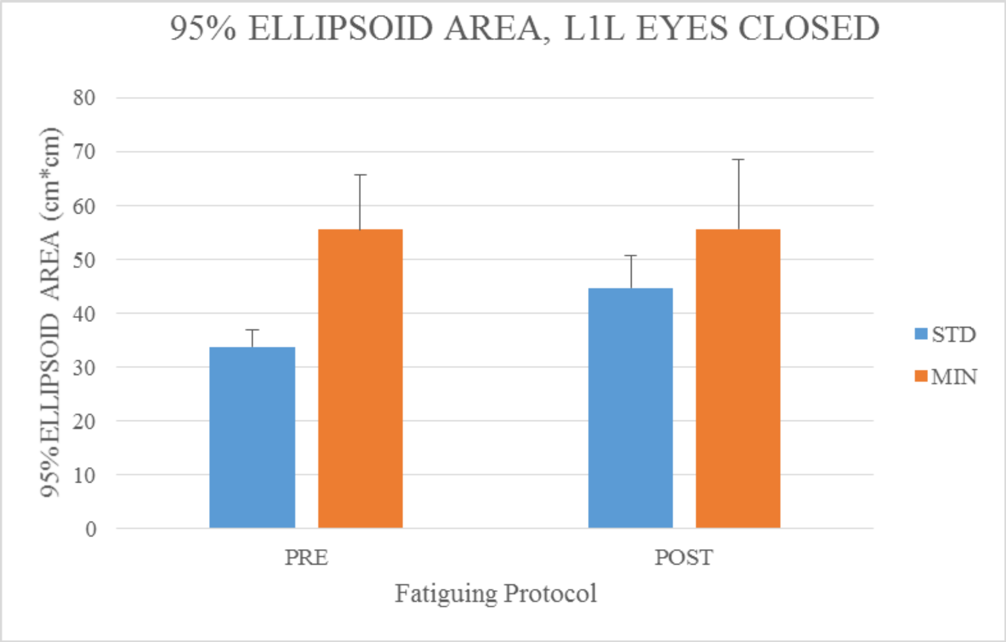

Figure A5. 95% Ellipsoid Area, L1L Eyes Closed

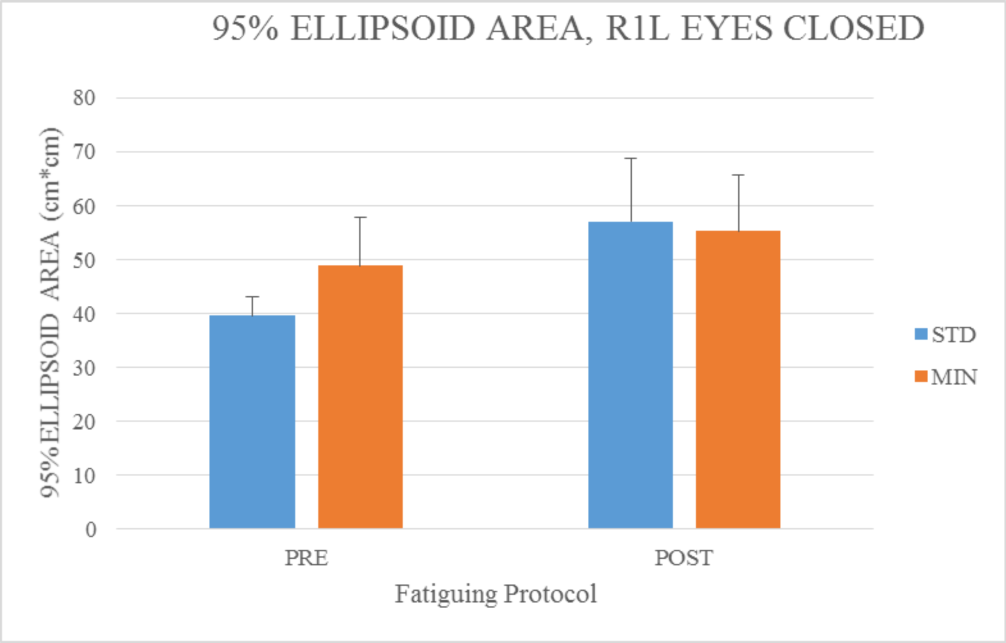

Figure A6. 95% Ellipsoid Area, R1L Eyes Closed

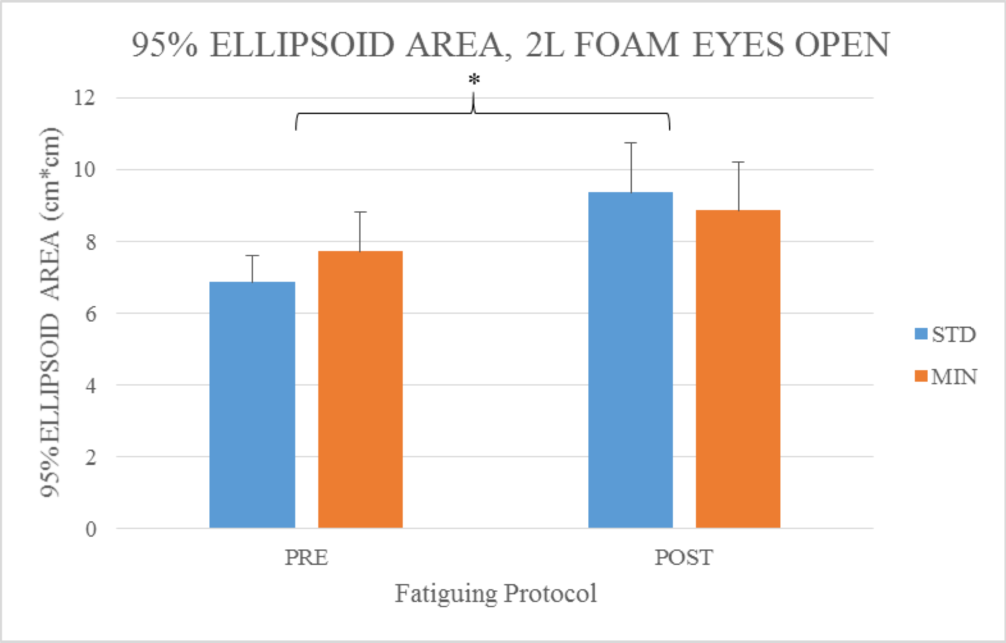

Figure A7. 95% Ellipsoid Area, 2L Foam Eyes Open

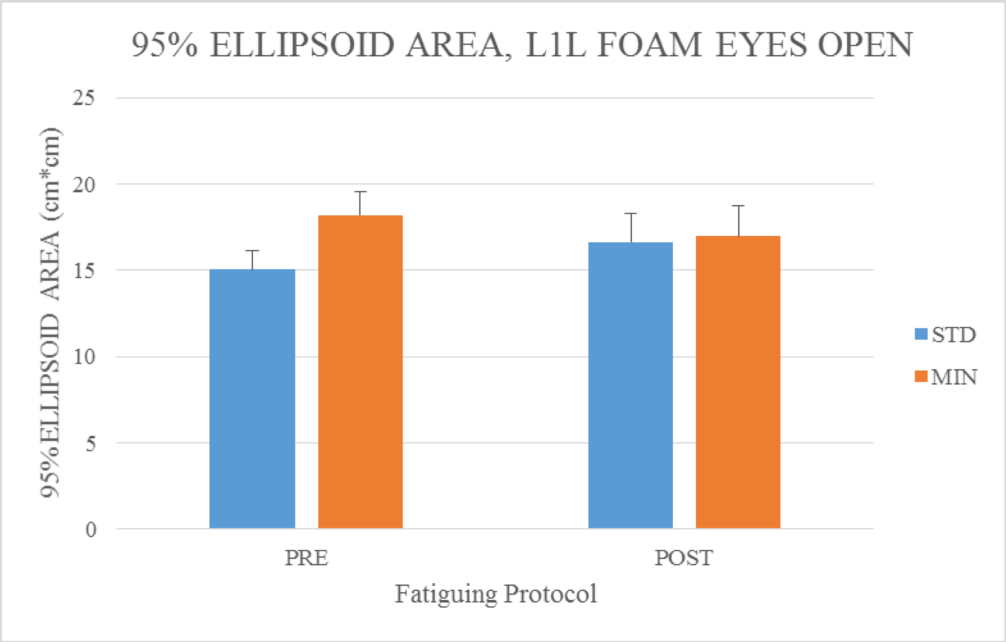

Figure A8. 95% Ellipsoid Area, L1L Foam Eyes Open

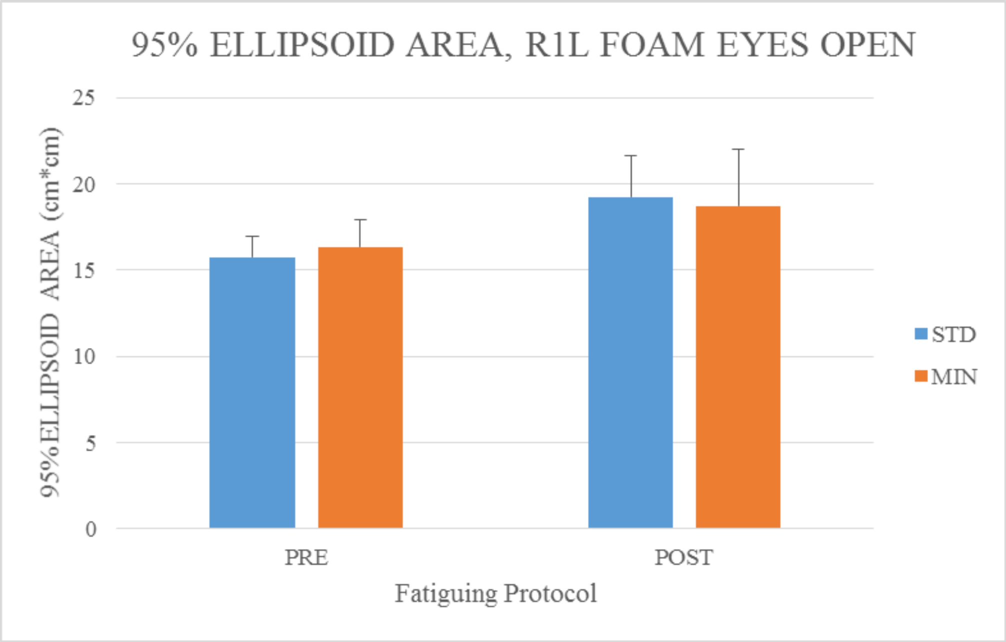

Figure A9. 95% Ellipsoid Area, R1L Foam Eyes Open

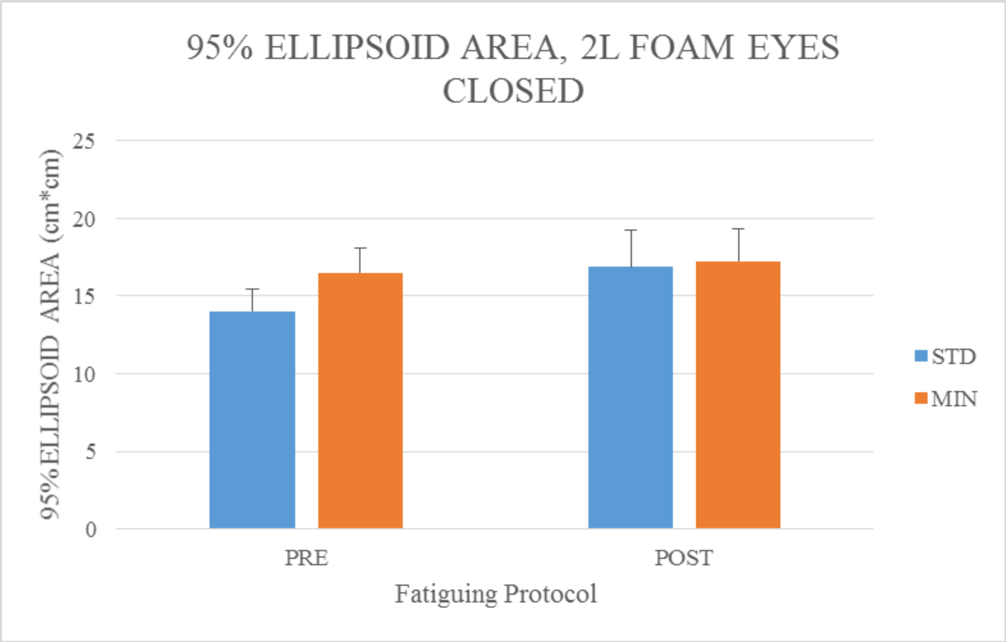

Figure A10. 95% Ellipsoid Area, 2L Foam Eyes Closed

APPENDIX B

ANTERIOR-POSTERIOR ROOT MEAN SQUARE FIGURES

Figures B1-B10 represent mean values for Anterior-Posterior Root Mean Square for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

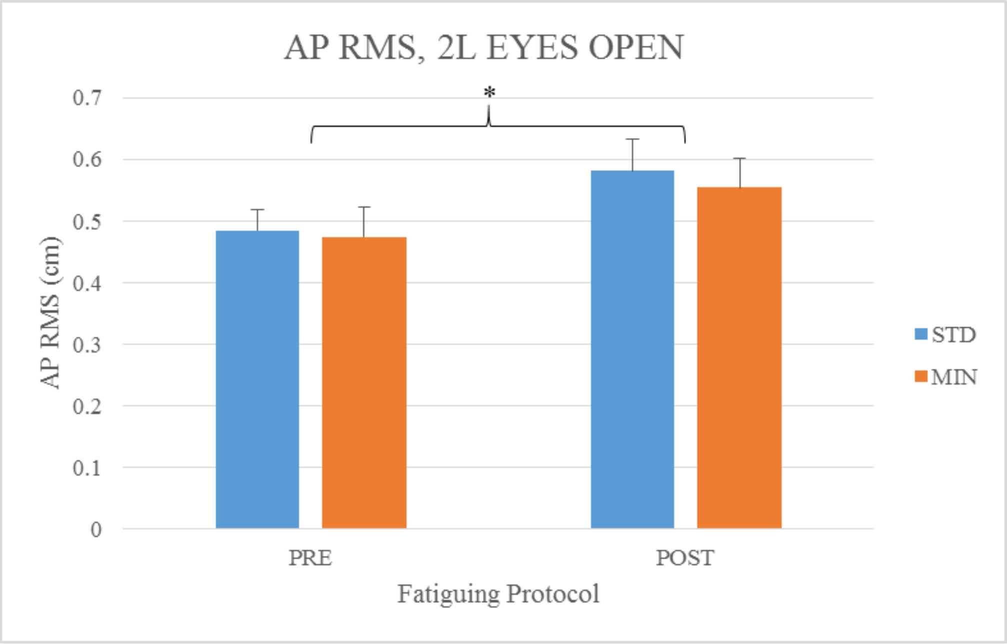

Figure B1. AP RMS, 2L Eyes Open

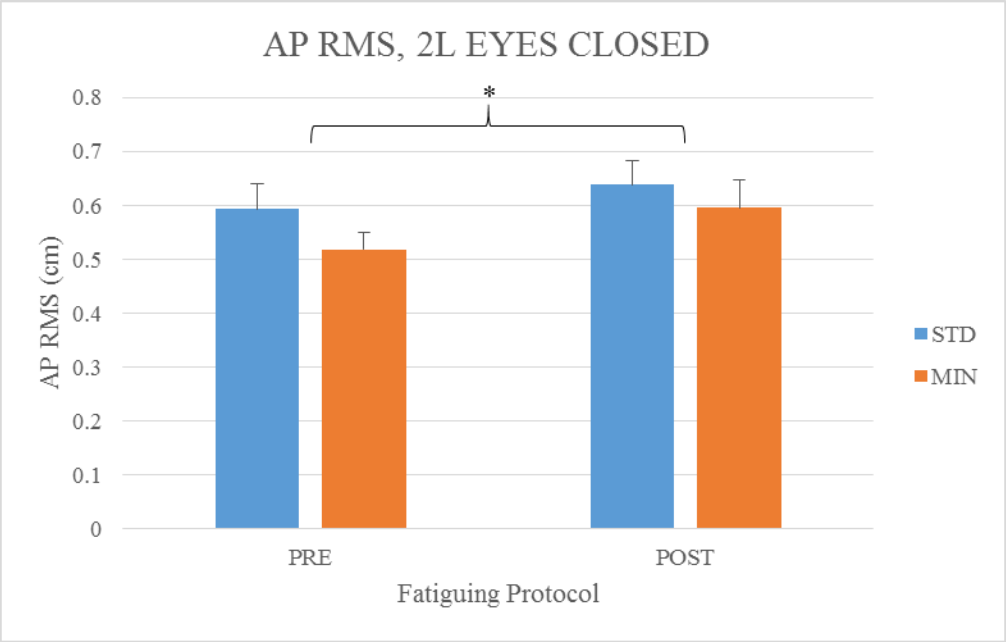

Figure B2. AP RMS, 2L Eyes Closed

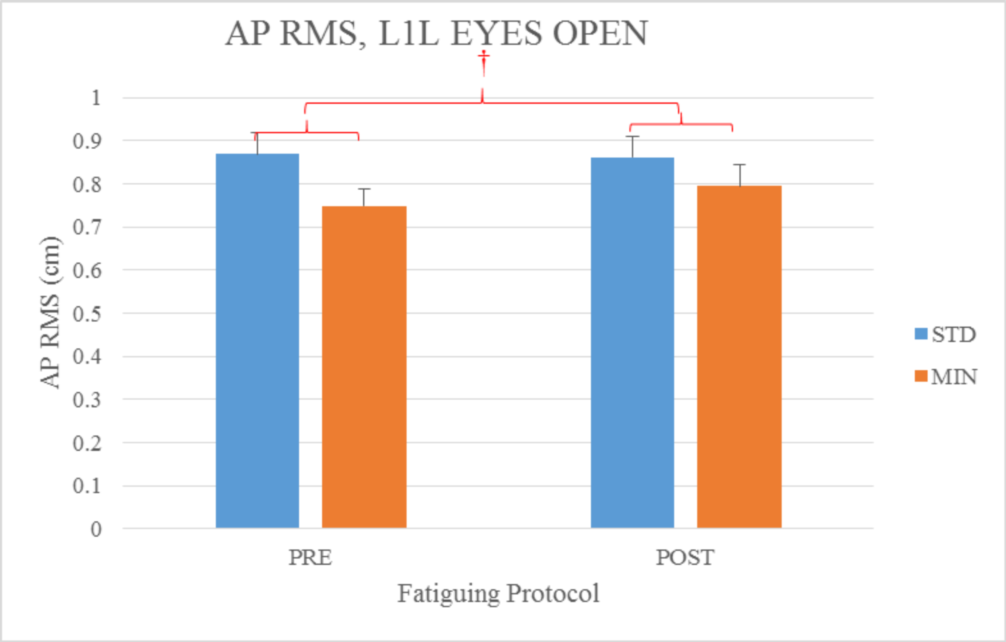

Figure B3. AP RMS, L1L Eyes Open

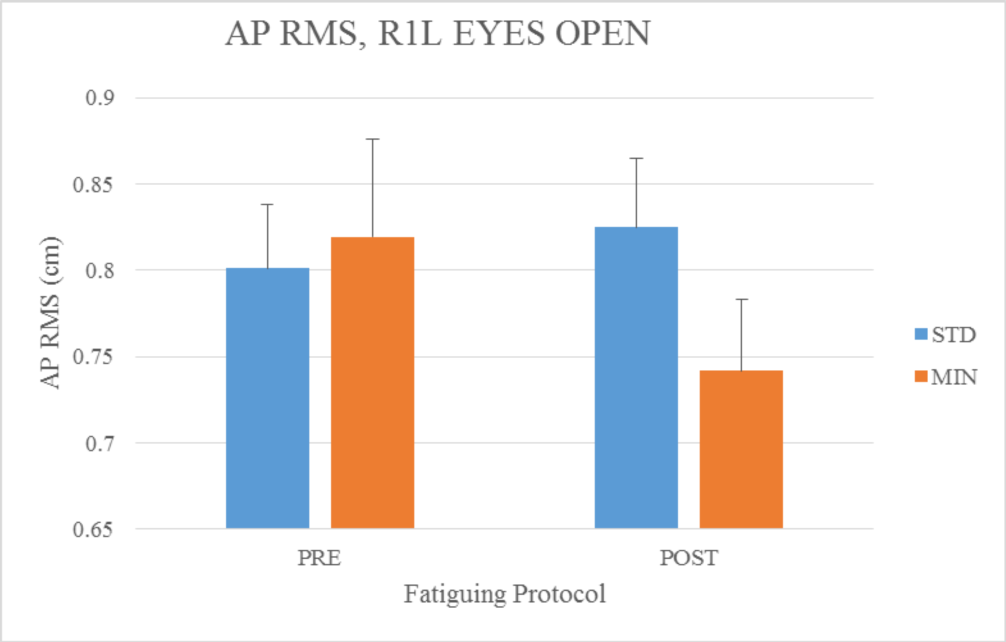

Figure B4. AP RMS, R1L Eyes Open

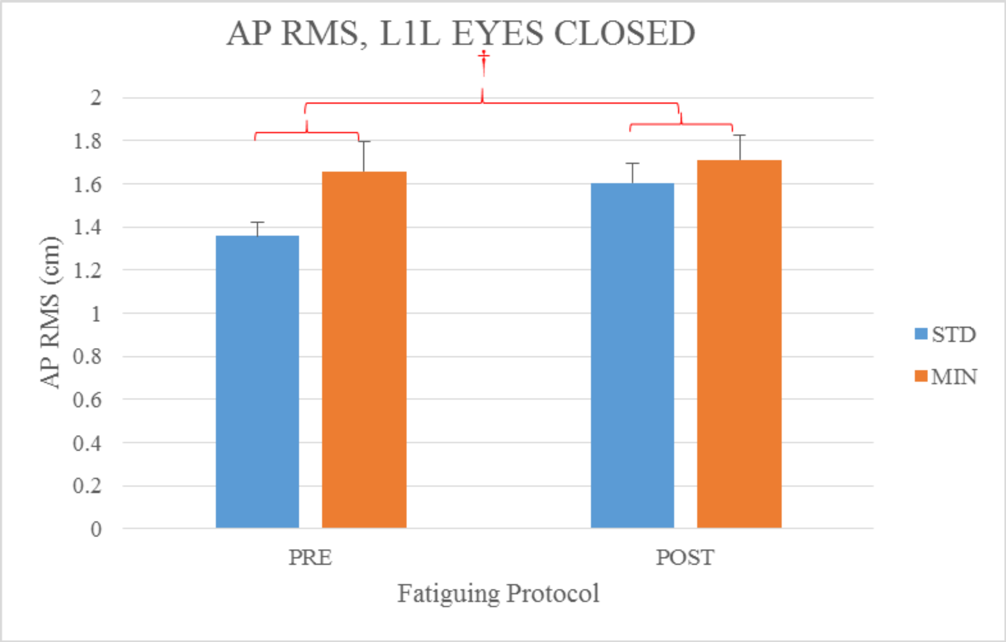

Figure B5. AP RMS, L1L Eyes Closed

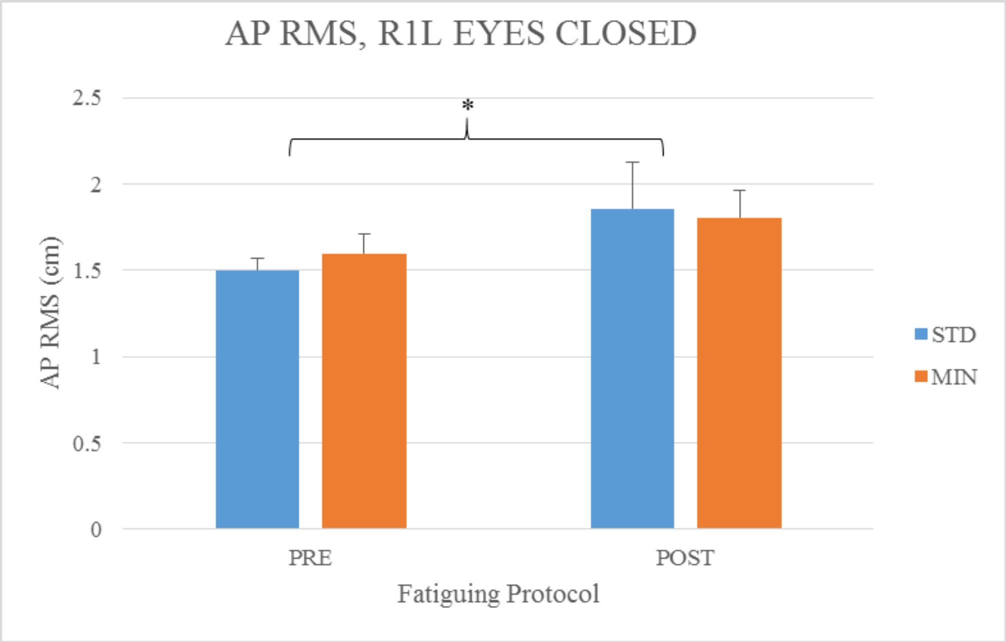

Figure B6. AP RMS, R1L Eyes Closed

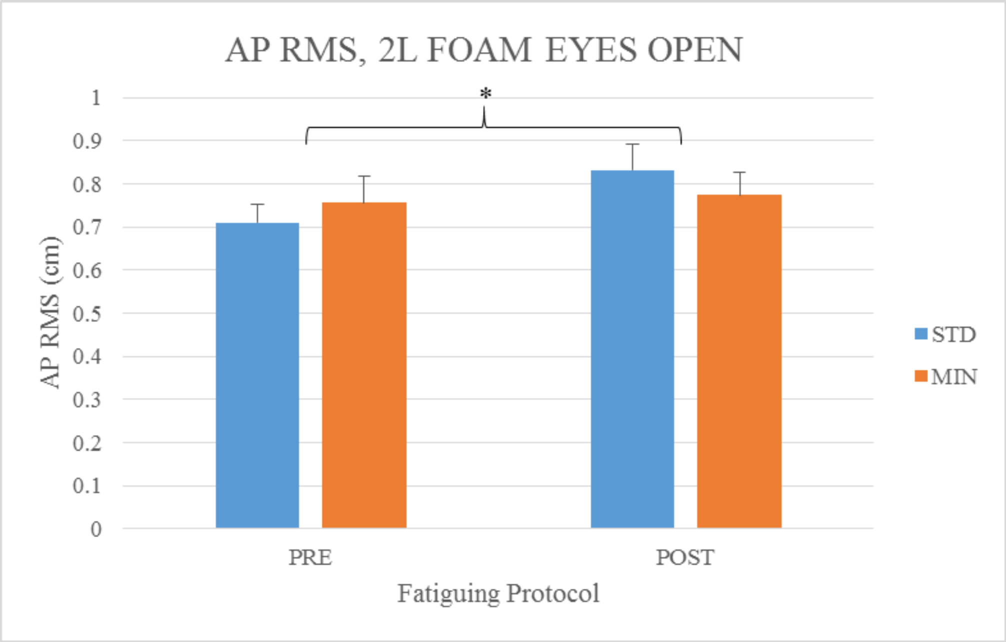

Figure B7. AP RMS, 2L Foam Eyes Open

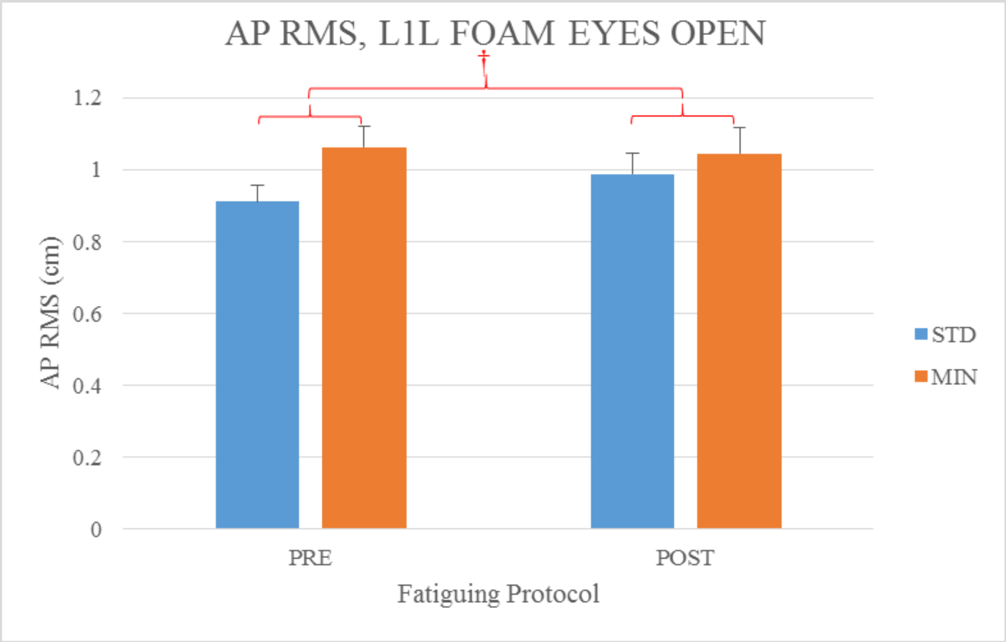

Figure B8. AP RMS, L1L Foam Eyes Open

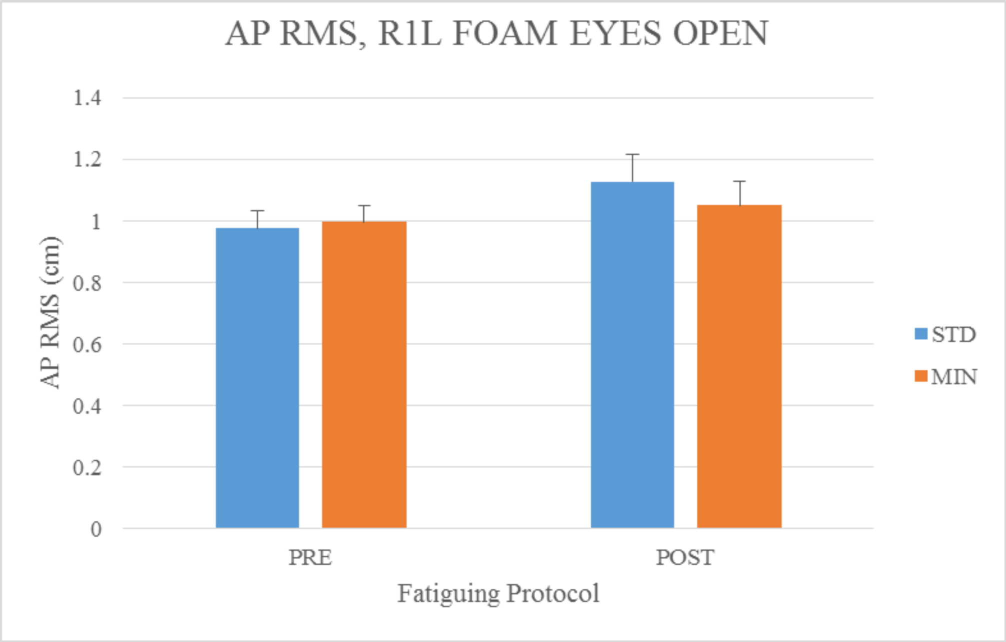

Figure B9. AP RMS, R1L Foam Eyes Open

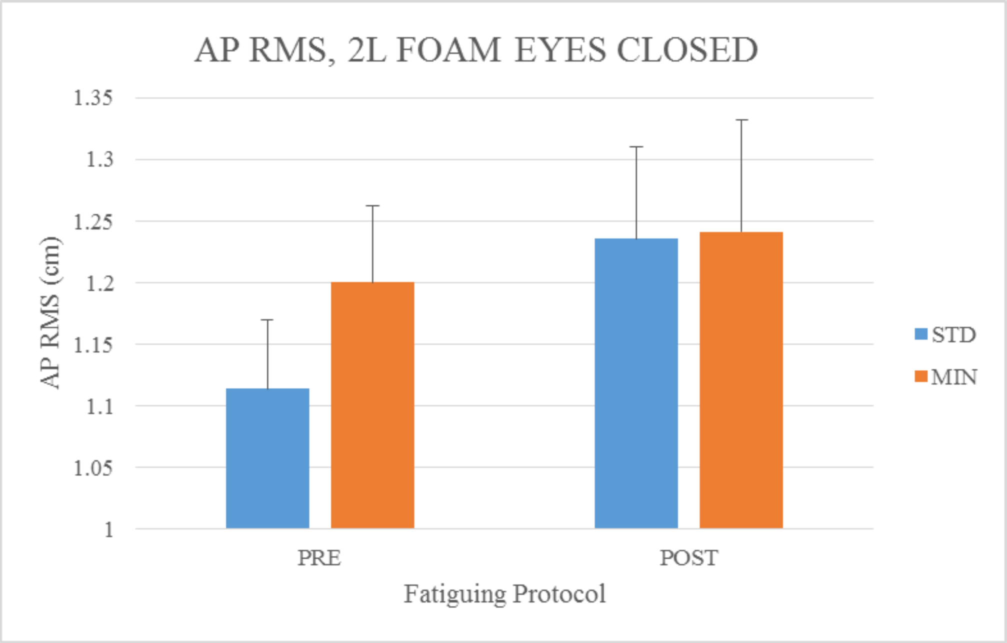

Figure B10. AP RMS, 2L Foam Eyes Closed

APPENDIX C

ANTERIOR-POSTERIOR SWAY VELOCITY FIGURES

Figures C1 – C10 represent mean values for Anterior-Posterior Sway Velocity for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

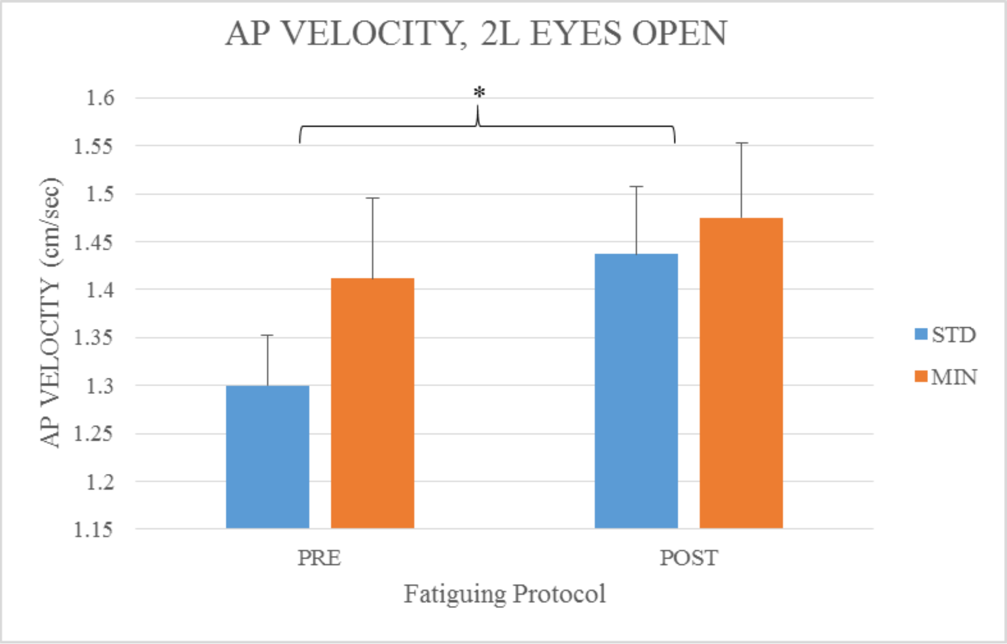

Figure C1. AP Velocity, 2L Eyes Open

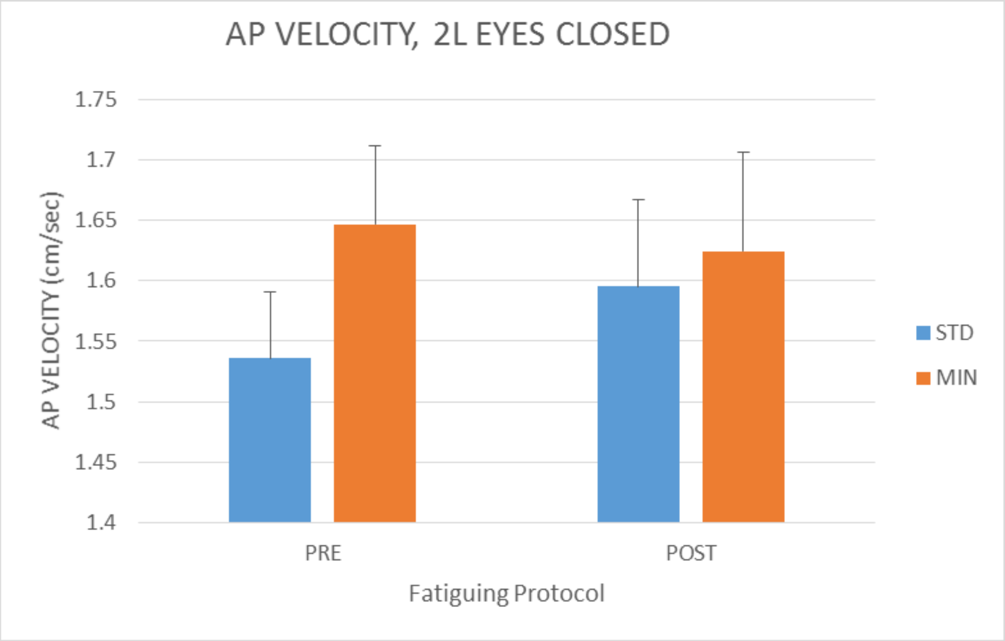

Figure C2. AP Velocity, 2L Eyes Closed

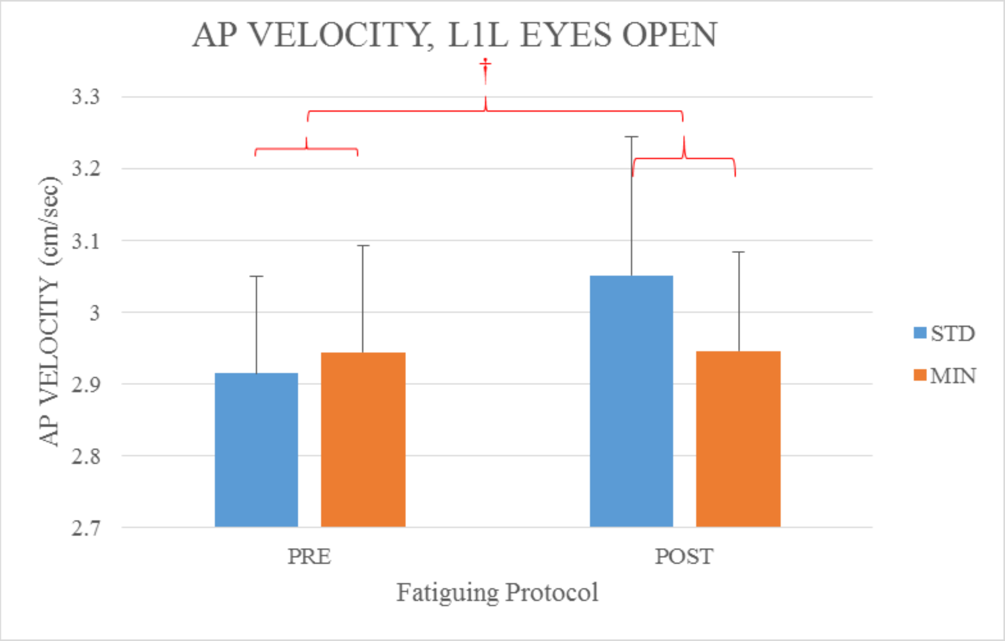

Figure C3. AP Velocity, L1L Eyes Open

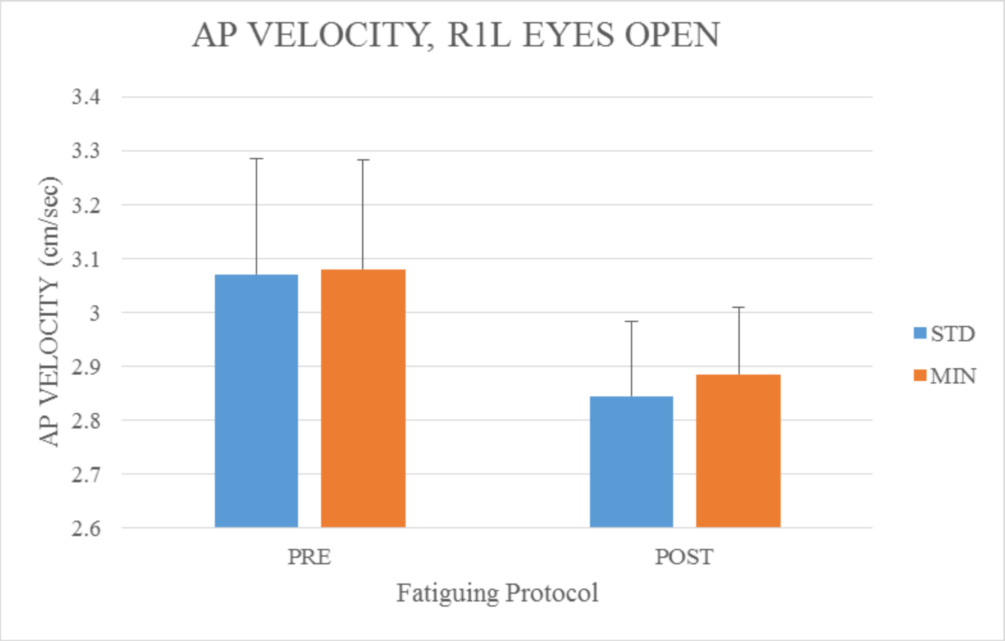

Figure C4. AP Velocity, R1L Eyes Open

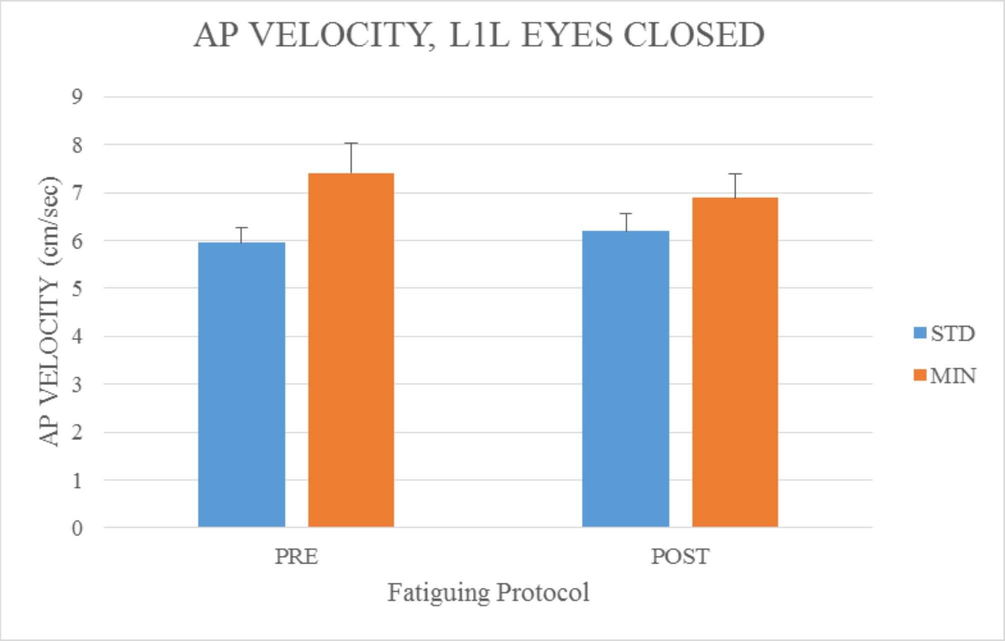

Figure C5. AP Velocity, L1L Eyes Closed

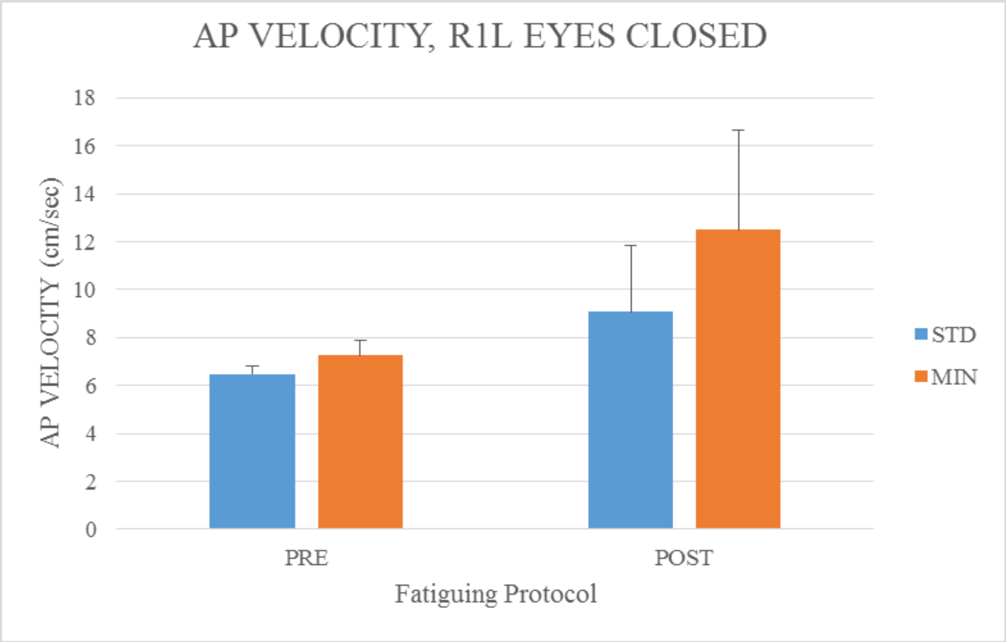

Figure C6. AP Velocity, R1L Eyes Closed

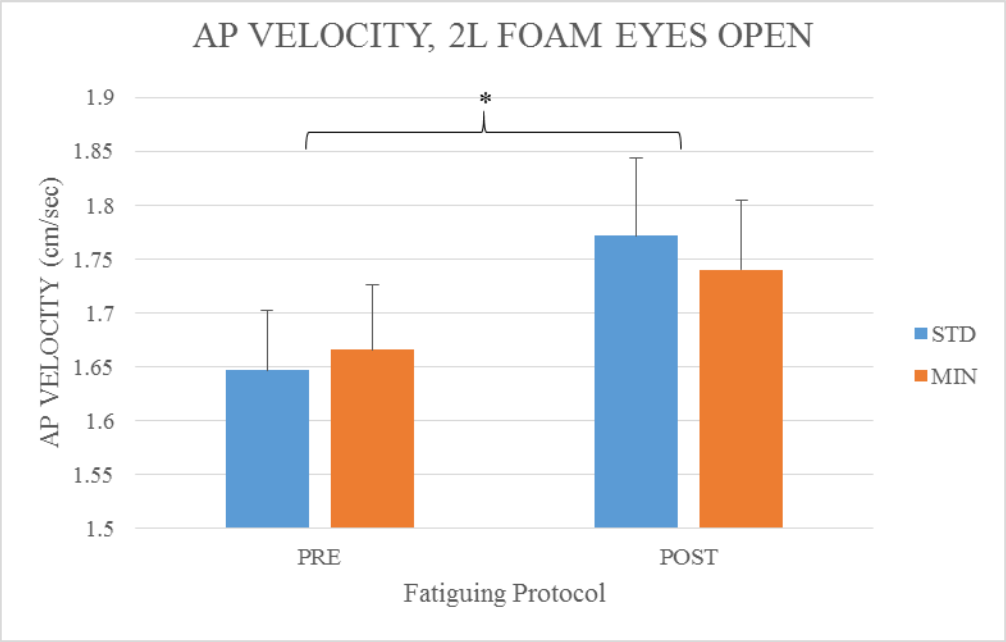

Figure C7. AP Velocity, 2L Foam Eyes Open

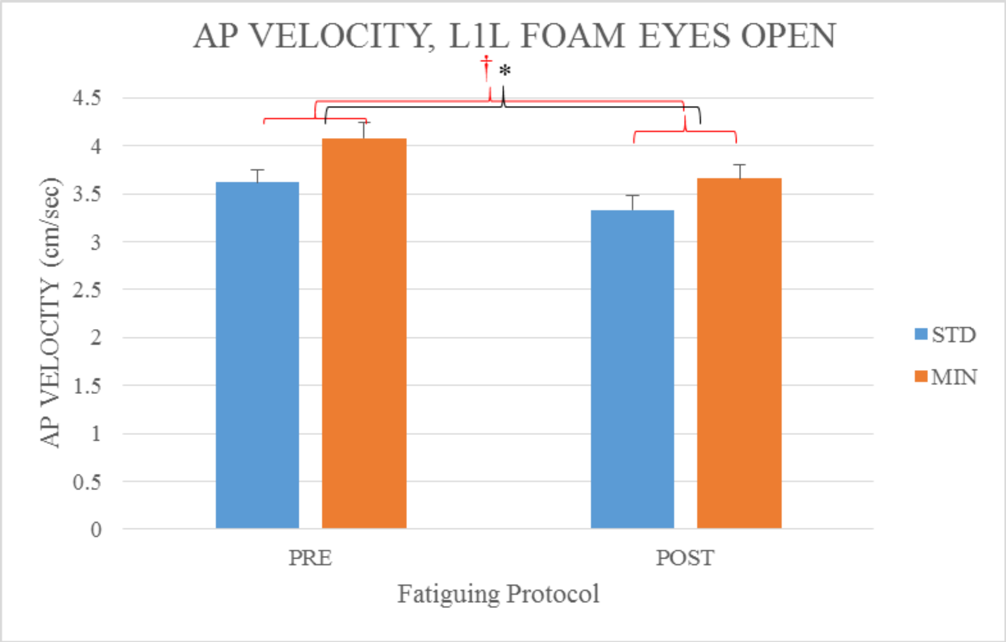

Figure C8. AP Velocity, L1L Foam Eyes Open

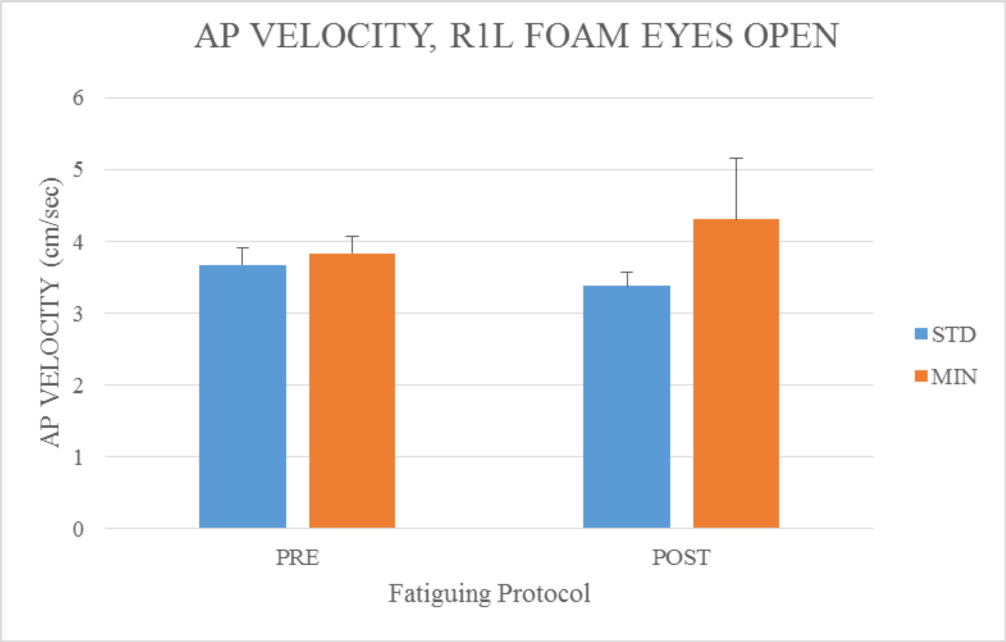

Figure C9. AP Velocity, R1L Foam Eyes open

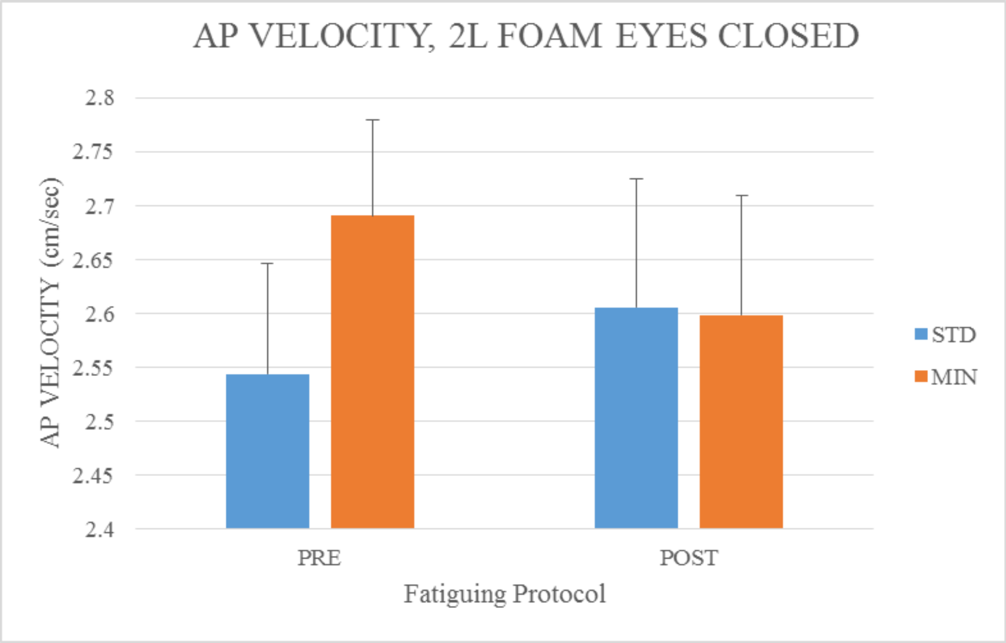

Figure C10. AP Velocity, 2L Foam Eyes Closed

APPENDIX D

AVERAGE SWAY VELOCITY FIGURES

Figures D1 – D10 represent mean values for Average Sway Velocity for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

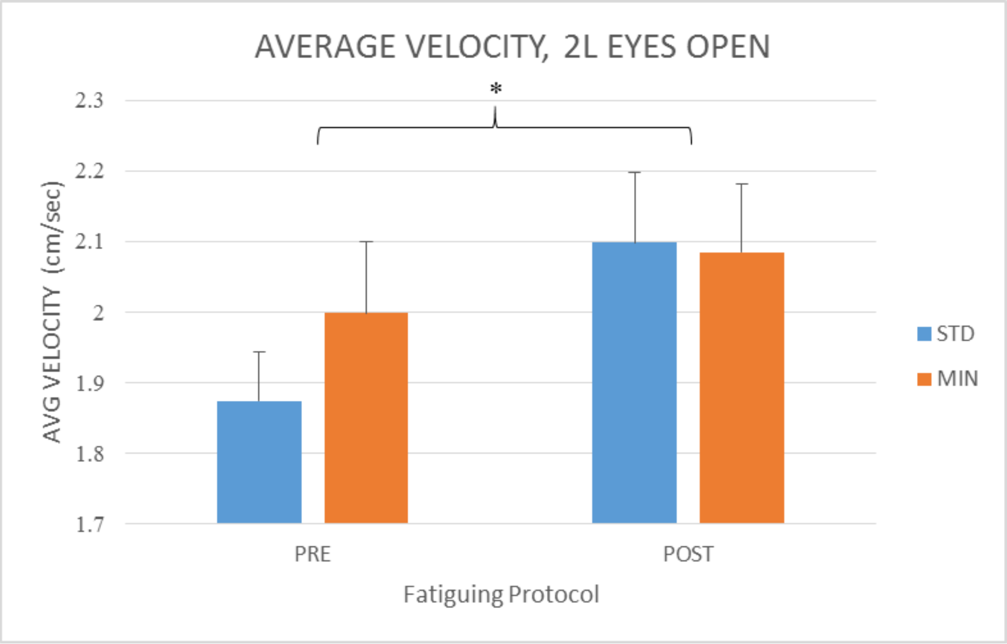

Figure D1.	Average Velocity, 2L Eyes Open

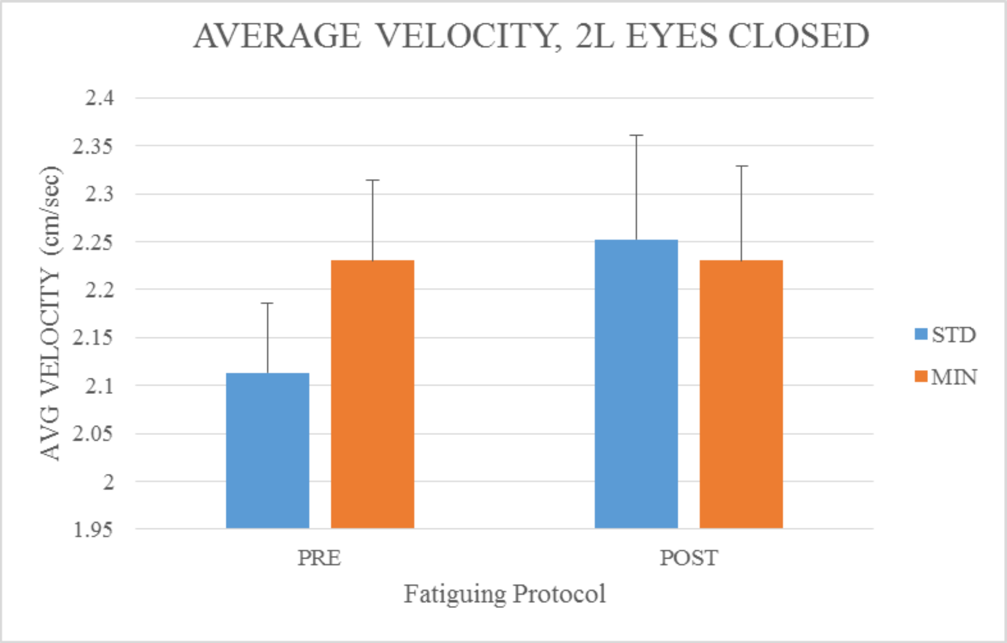

Figure D2. Average Velocity, 2L Eyes Closed

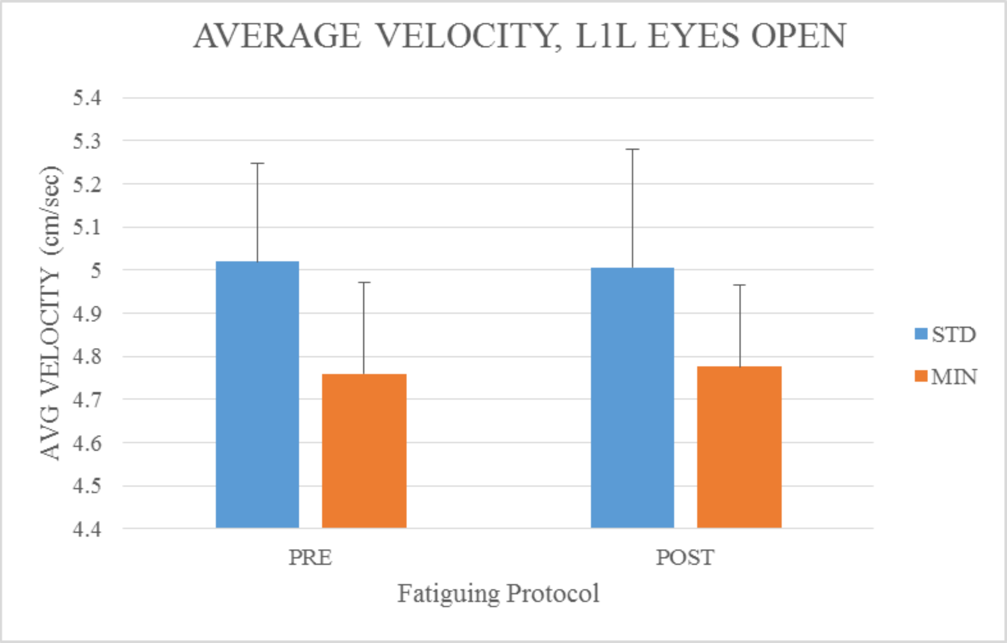

Figure D3. Average Velocity, L1L Eyes Open

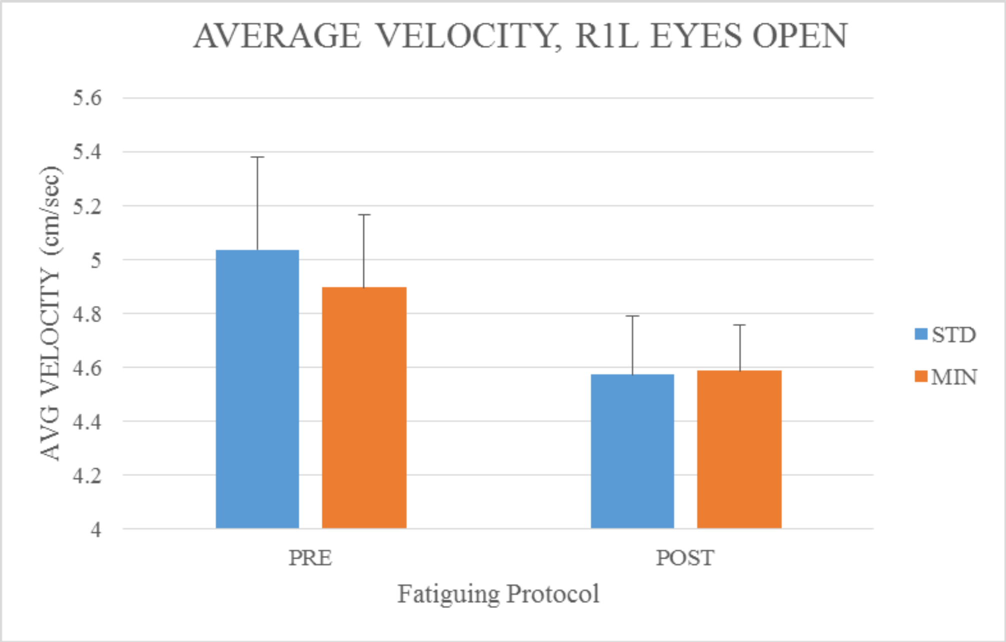

Figure D4. Average Velocity, R1L Eyes Open

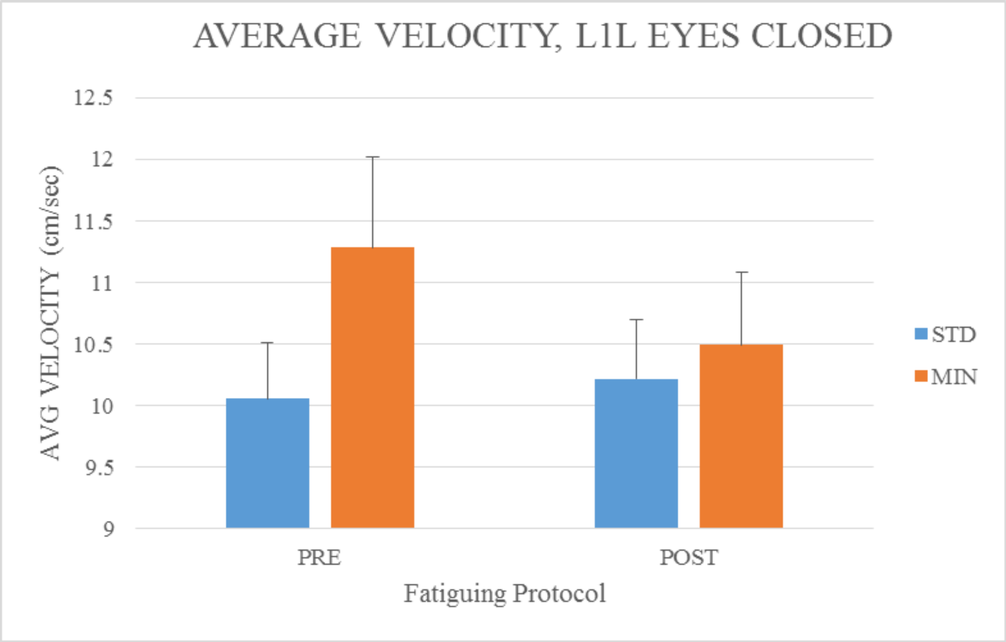

Figure D5. Average Velocity, L1L Eyes Closed

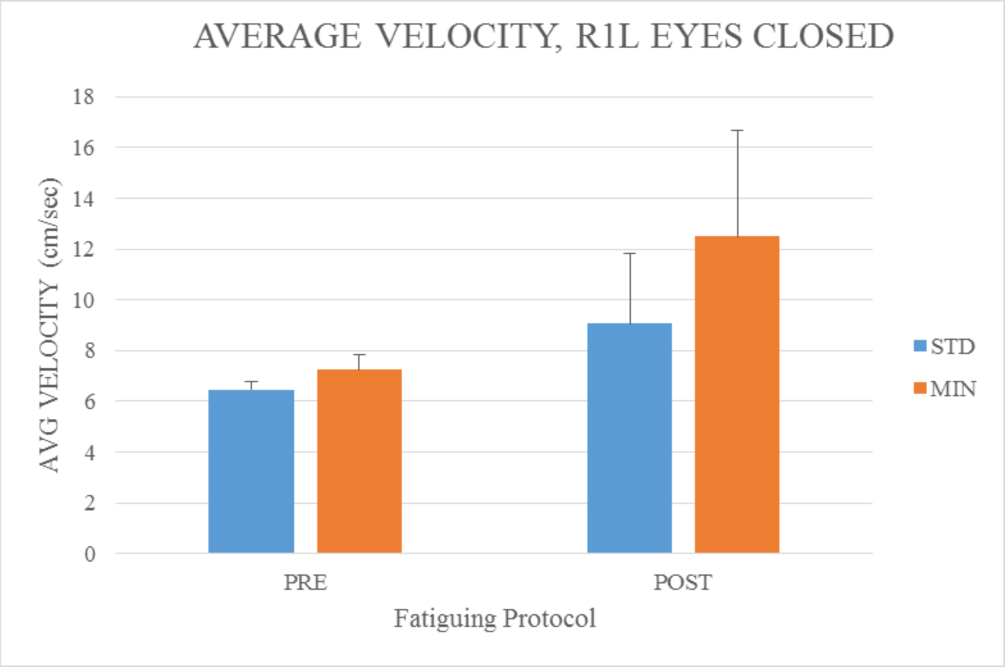

Figure D6. Average Velocity, R1L Eyes Closed

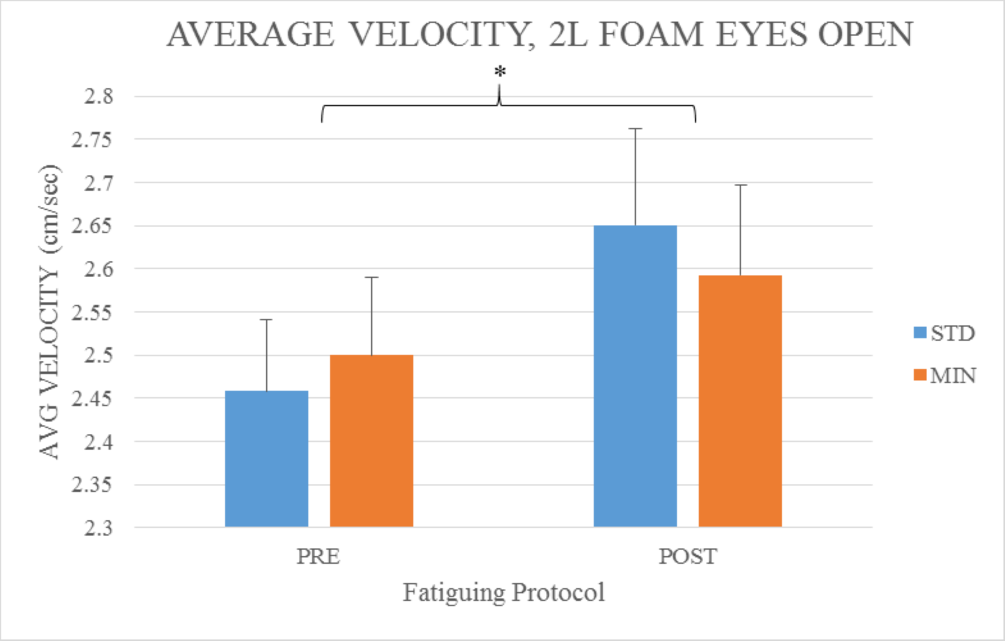

Figure D7. Average Velocity, 2L Foam Eyes Open

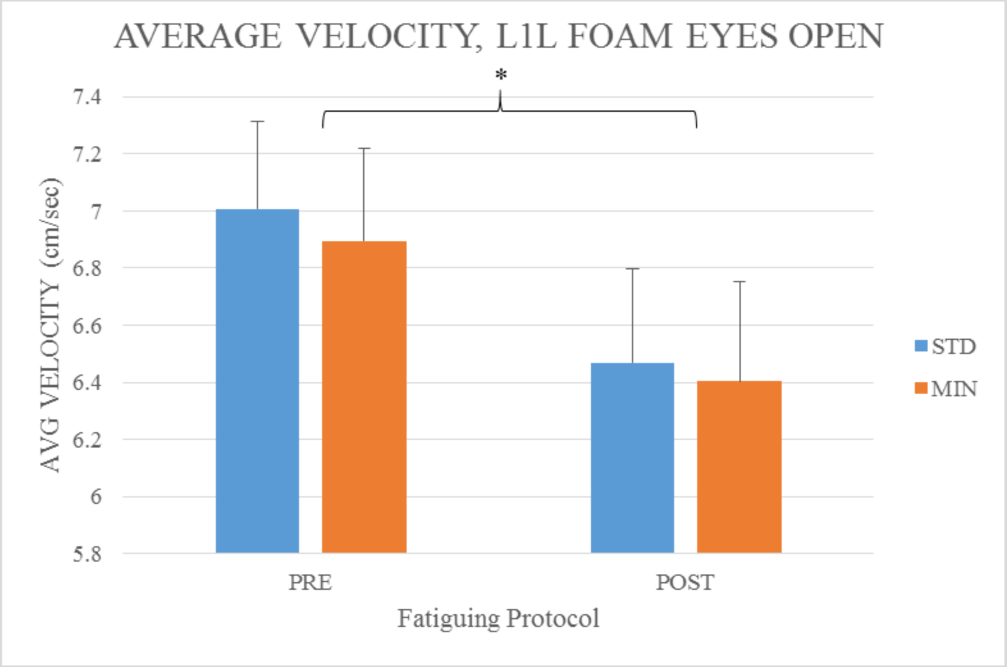

Figure D8. Average Velocity, L1L Foam Eyes Open

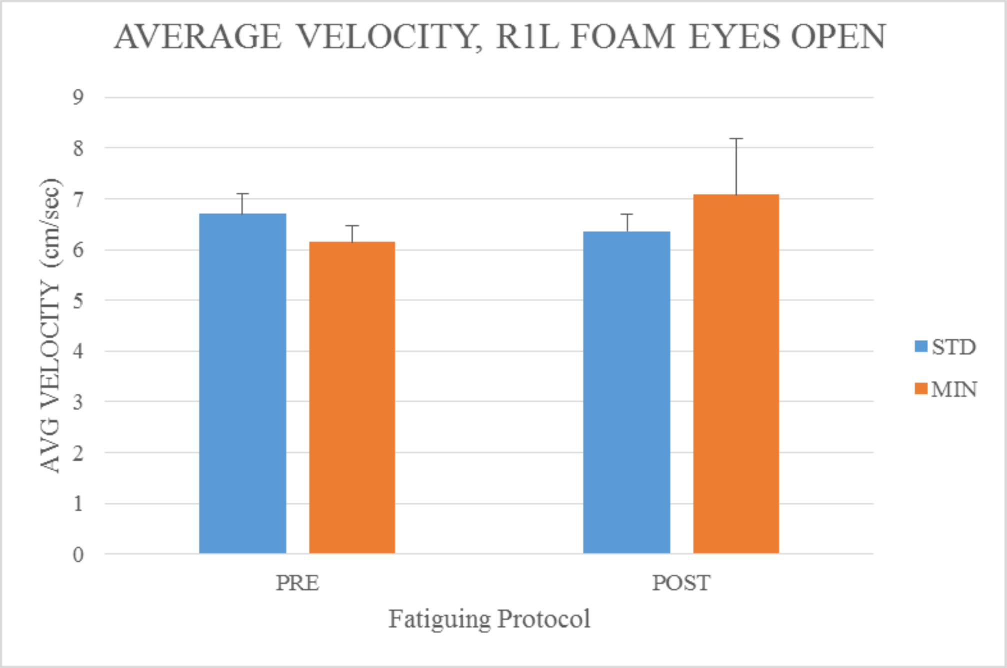

Figure D9. Average Velocity, R1L Foam Eyes Open

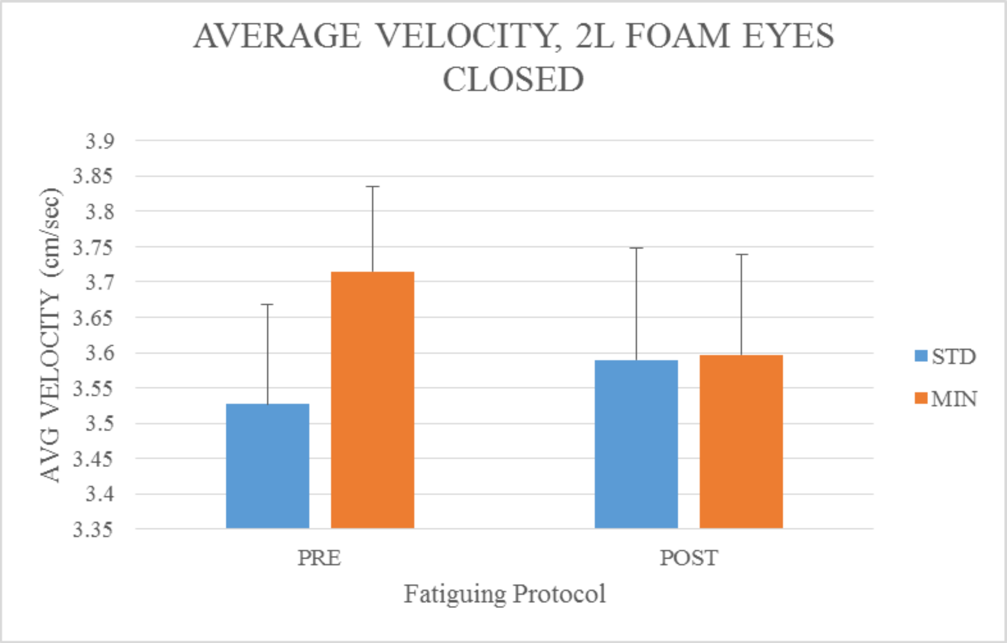

Figure D10. Average Velocity, 2L Foam Eyes Closed

APPENDIX E

DISPLACEMENT IN X DIRECTION FIGURES

Figures E1-E10 represent mean values for Displacement in X Direction for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

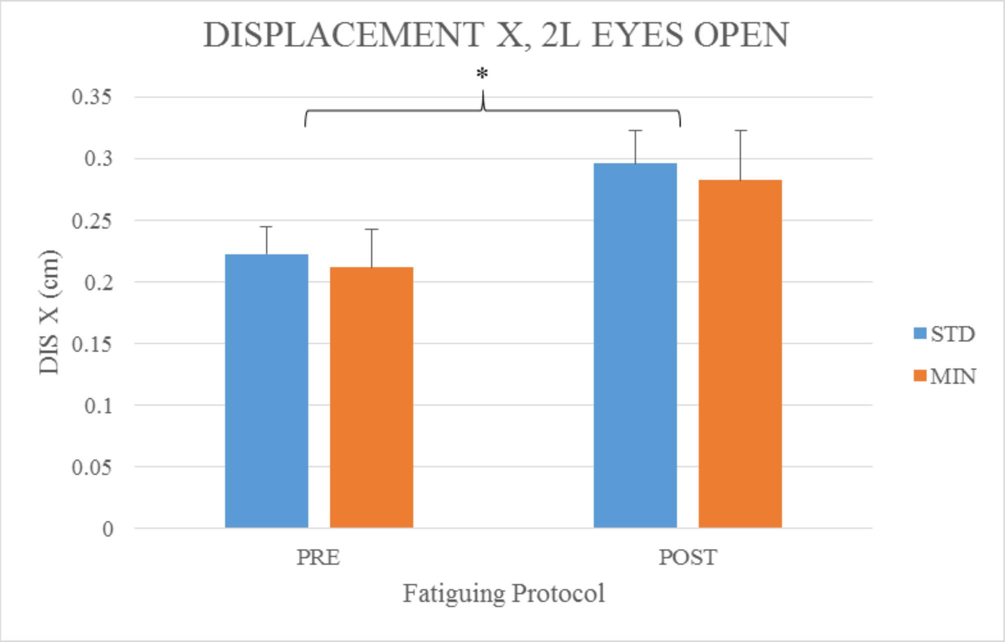

Figure E1. Displacement X, 2L Eyes Open

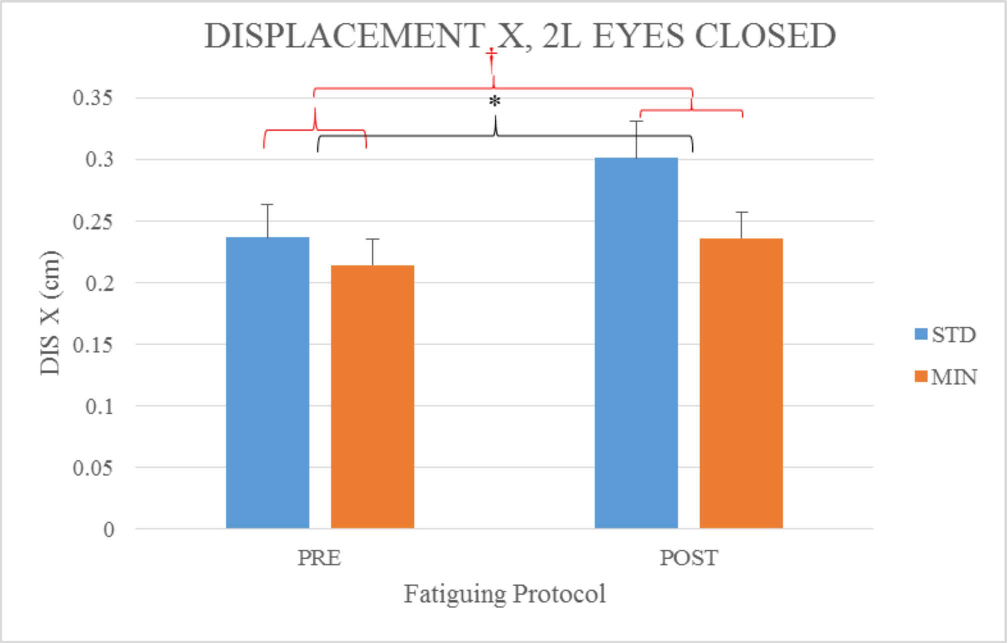

Figure E2. Displacement X, 2L Eyes Closed

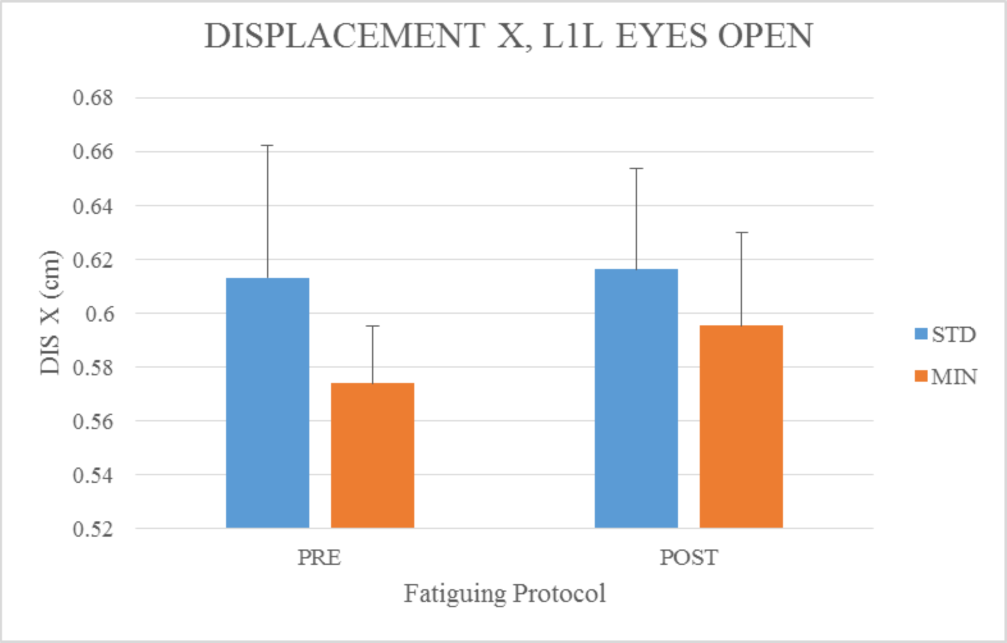

Figure E3. Displacement X, L1L Eyes Open

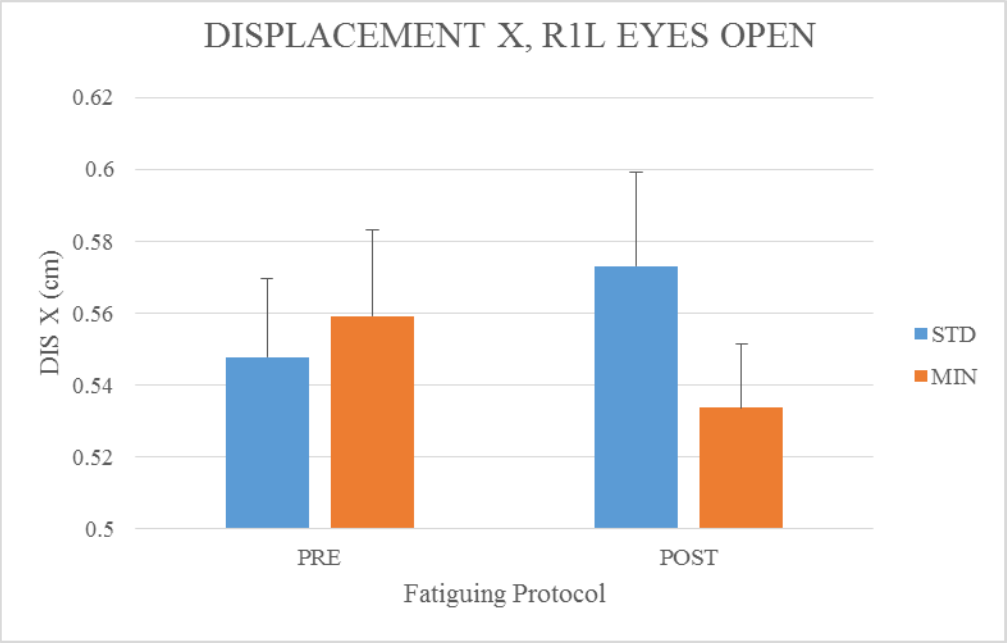

Figure E4. Displacement X, R1L Eyes Open

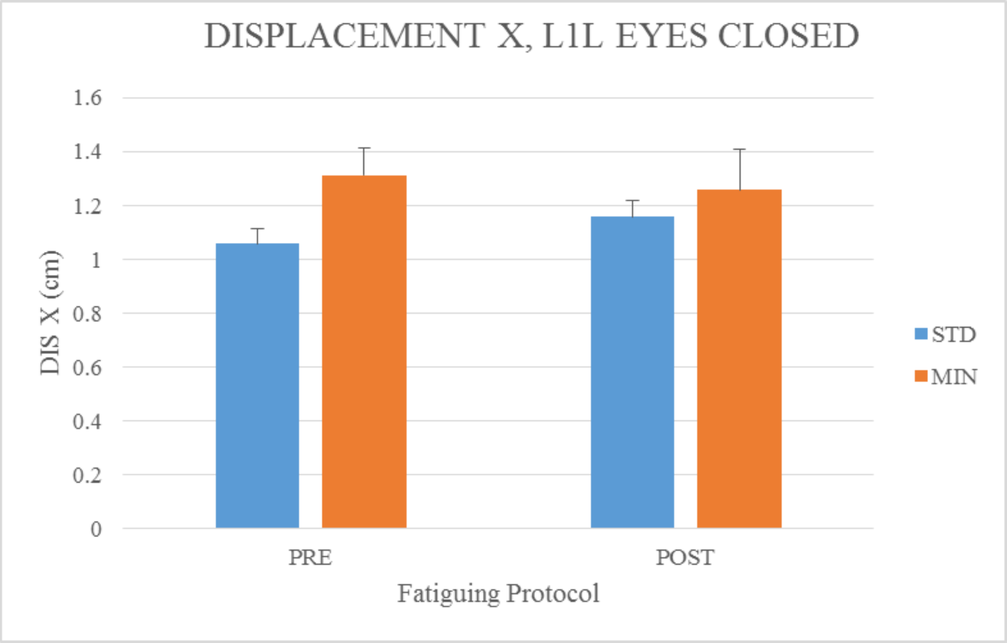

Figure E5. Displacement X, L1L Eyes Closed

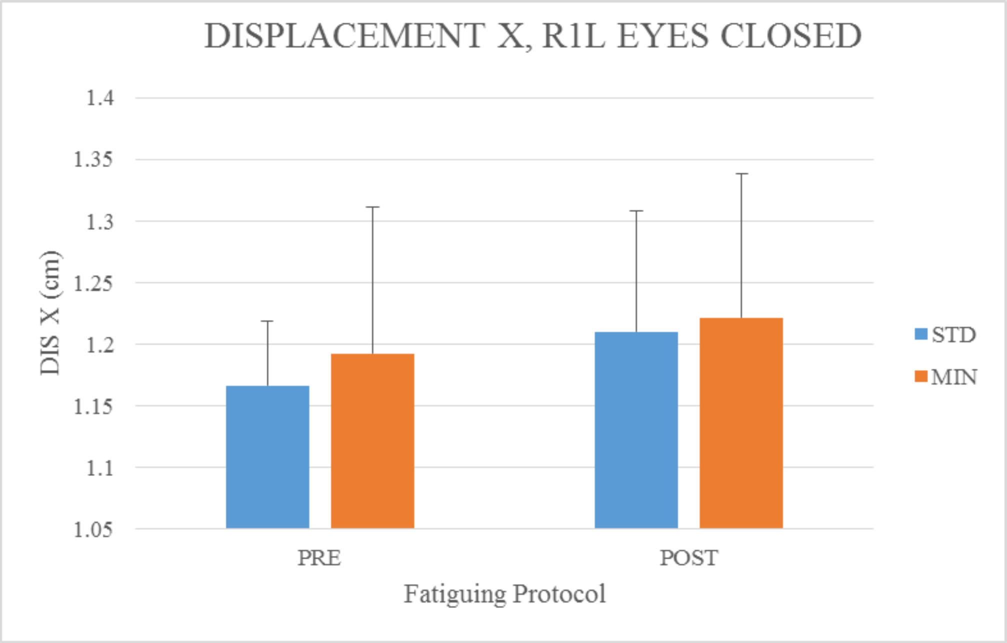

Figure E6. Displacement X, R1L Eyes Closed

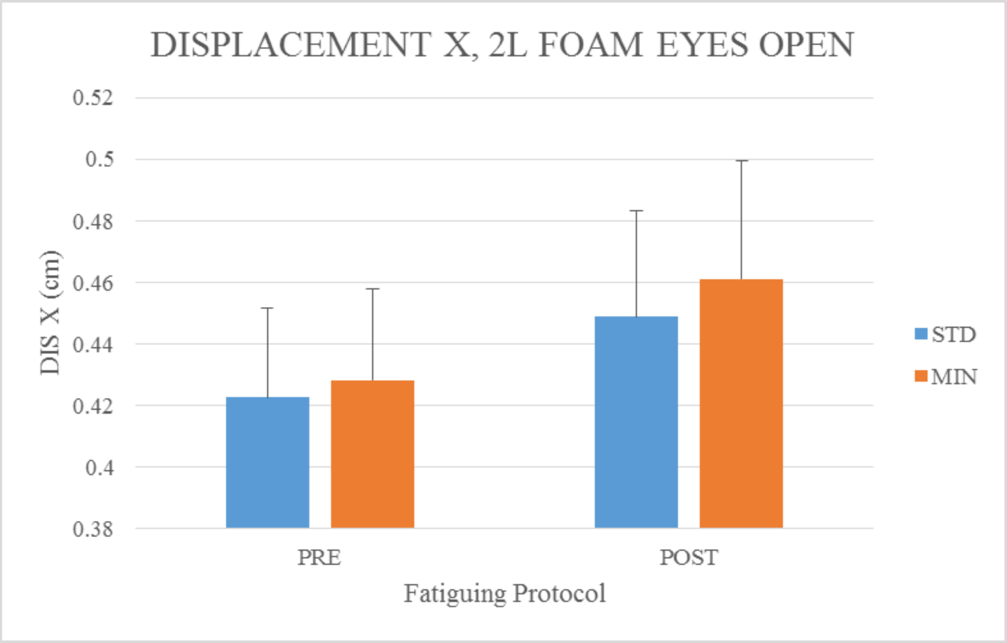

Figure E7. Displacement X, 2L Foam Eyes Open

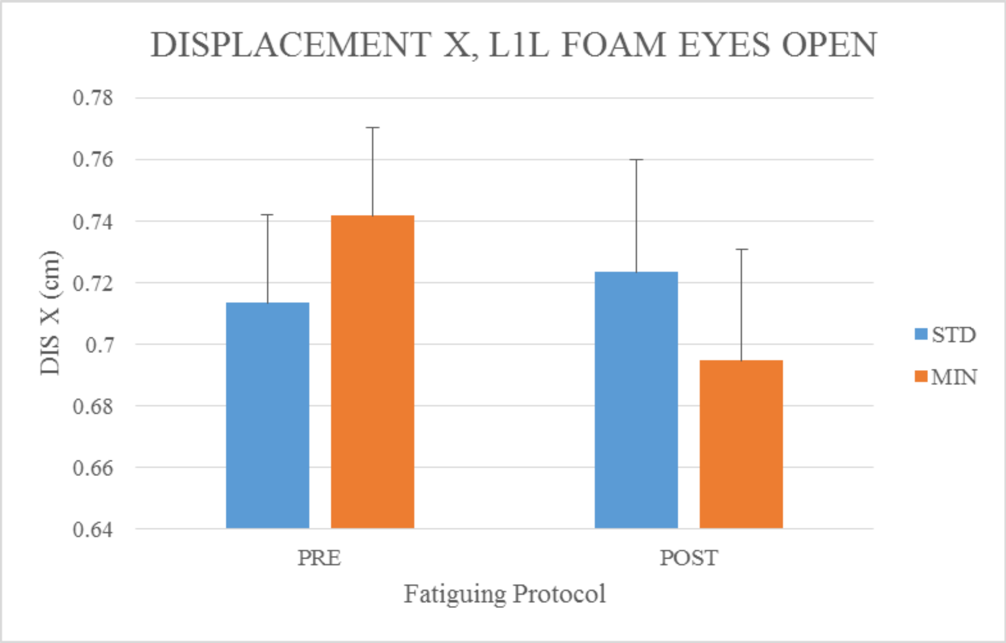

Figure E8. Displacement X, L1L Foam Eyes Open

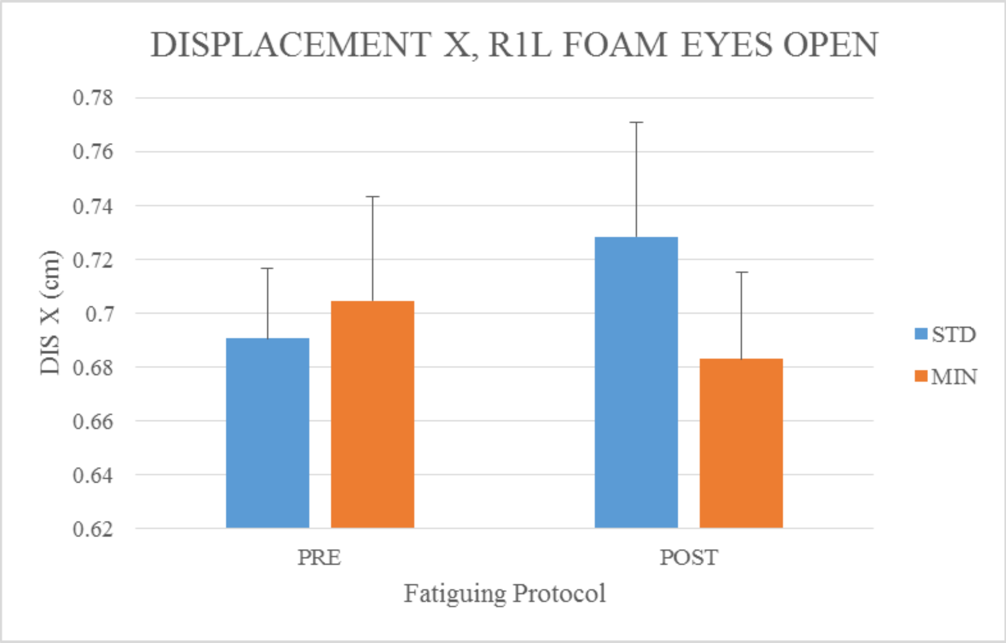

Figure E9. Displacement X, R1L Foam Eyes Open

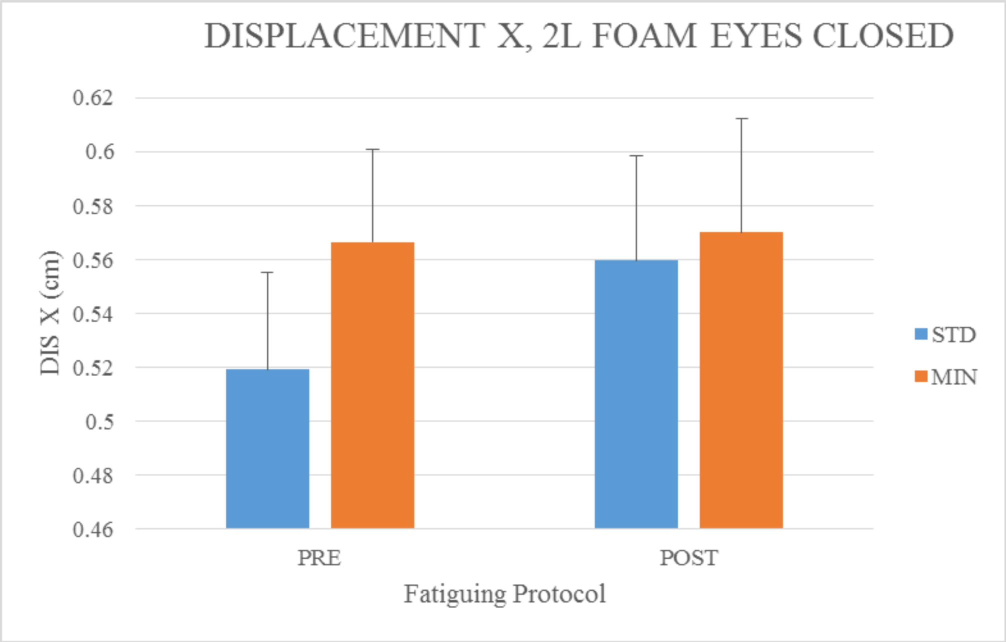

Figure E10. Displacement X, 2L Foam Eyes Closed

APPENDIX F

DISPLACEMENT IN Y DIRECTION FIGURES

Figures F1-F10 represent mean values for Displacement in Y Direction for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

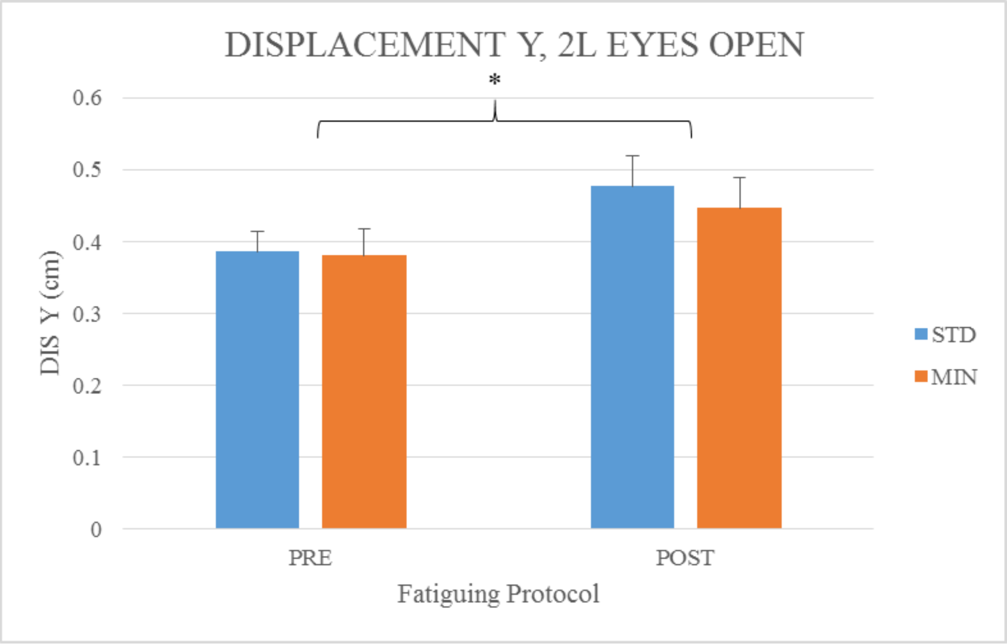

Figure F1. Displacement Y, 2L Eyes Open

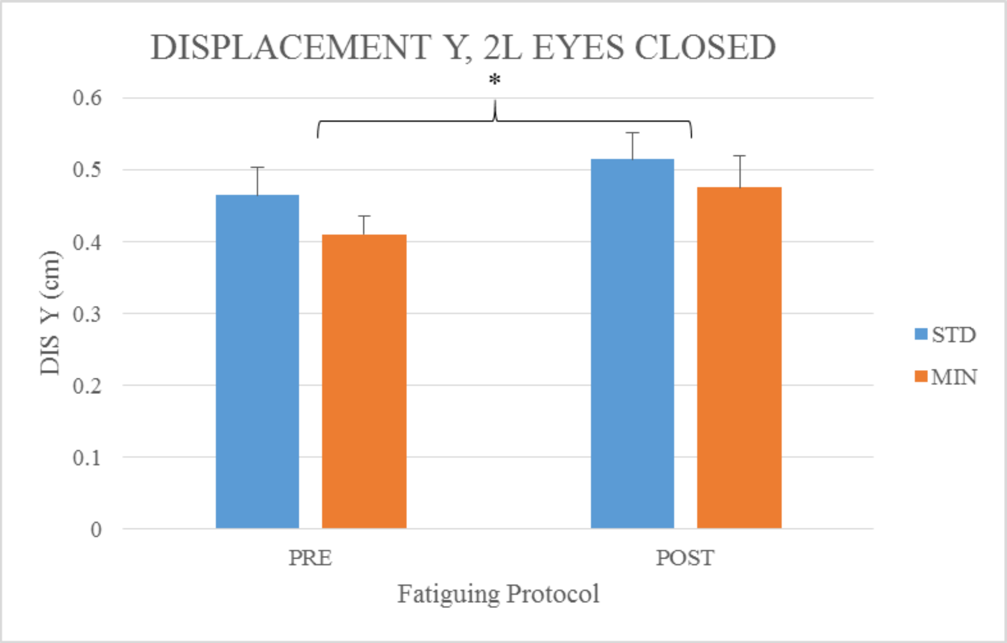

Figure F2. Displacement Y, 2L Eyes Closed

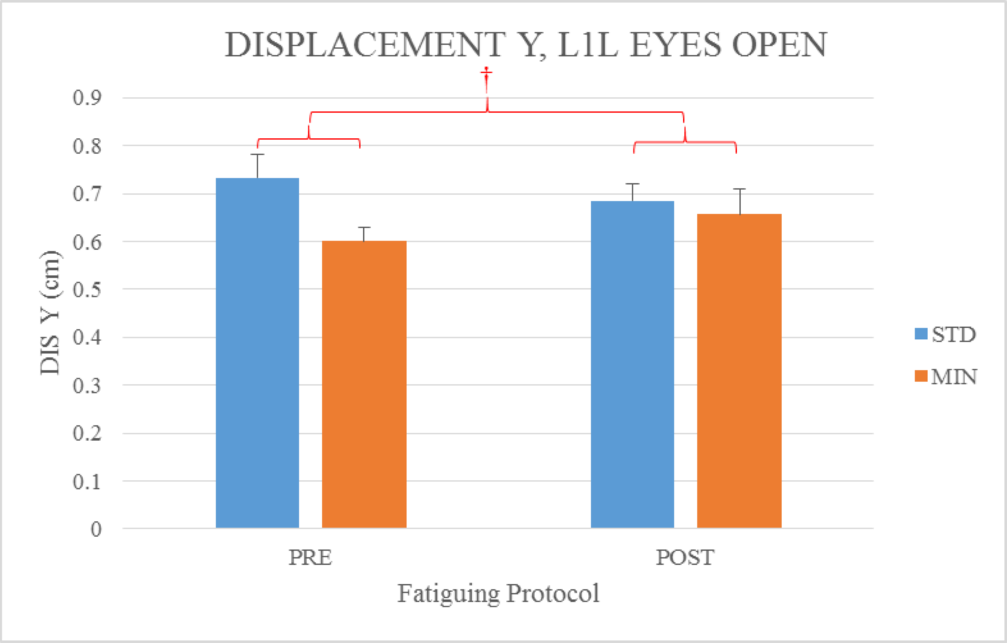

Figure F3. Displacement Y, L1L Eyes Open

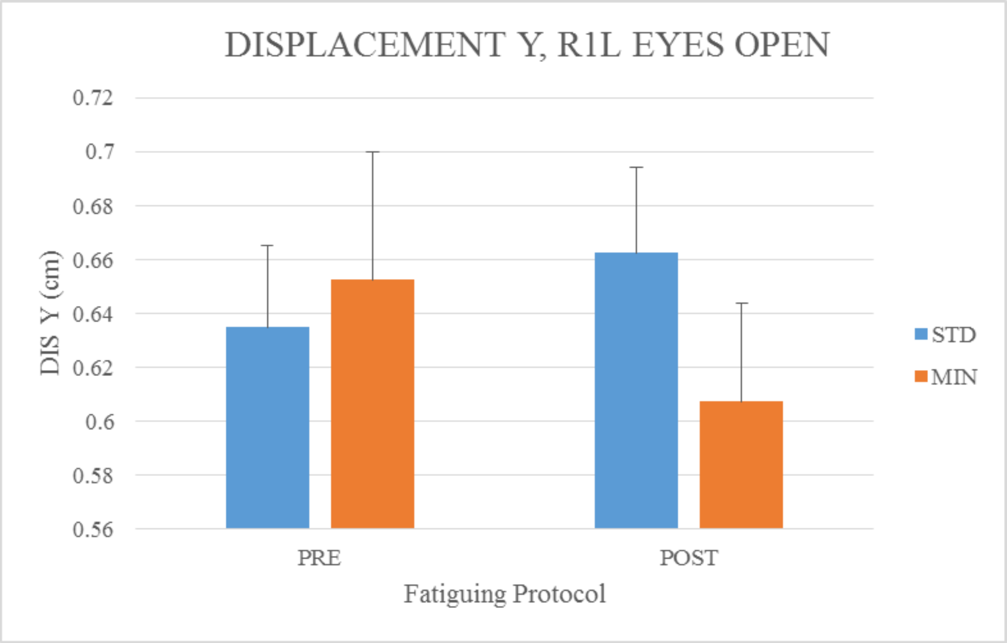

Figure F4. Displacement Y, R1L Eyes Open

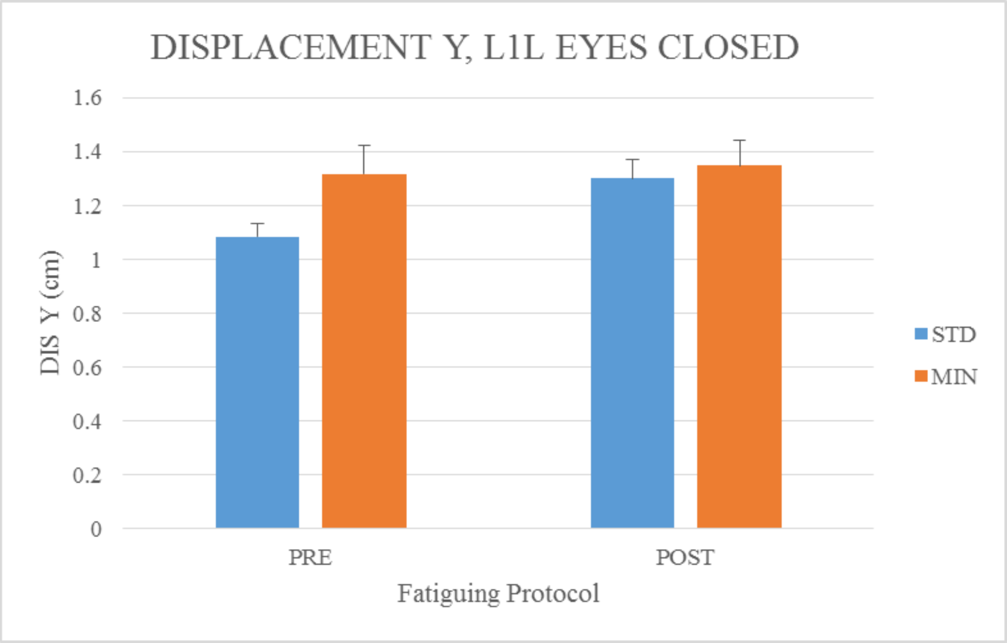

Figure F5. Displacement Y, L1L Eyes Closed

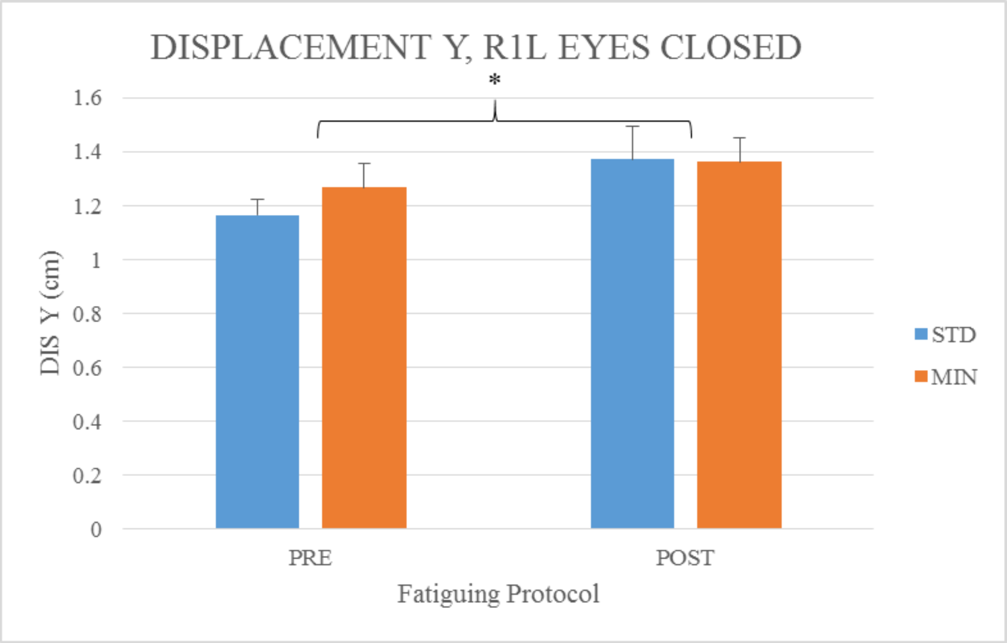

Figure F6. Displacement Y, R1L Eyes Closed

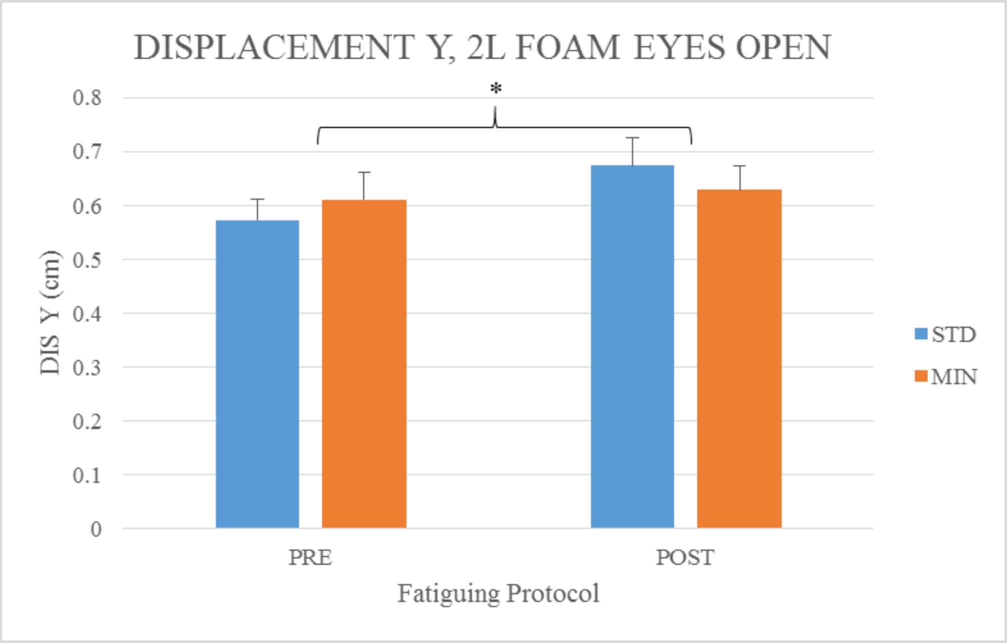

Figure F7. Displacement Y, 2L Foam Eyes Open

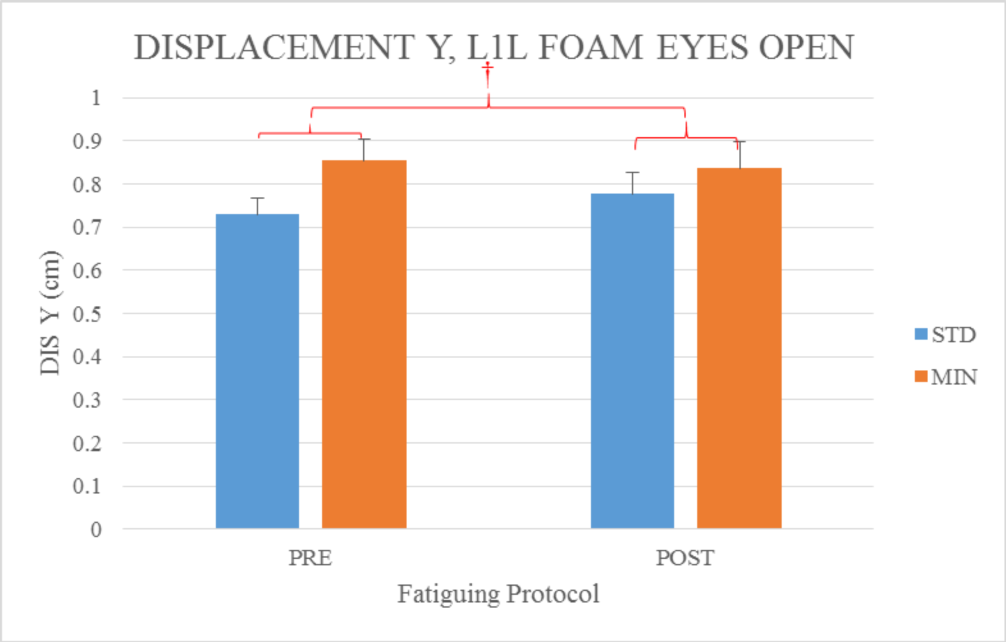

Figure F8. Displacement Y, L1L Foam Eyes Open

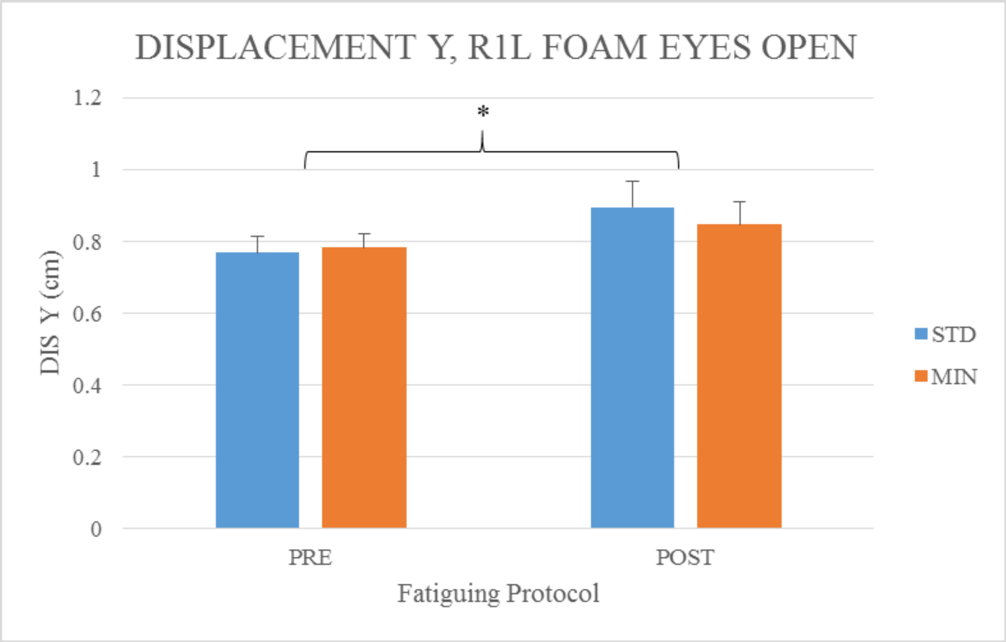

Figure F9. Displacement Y, R1L Foam Eyes Open

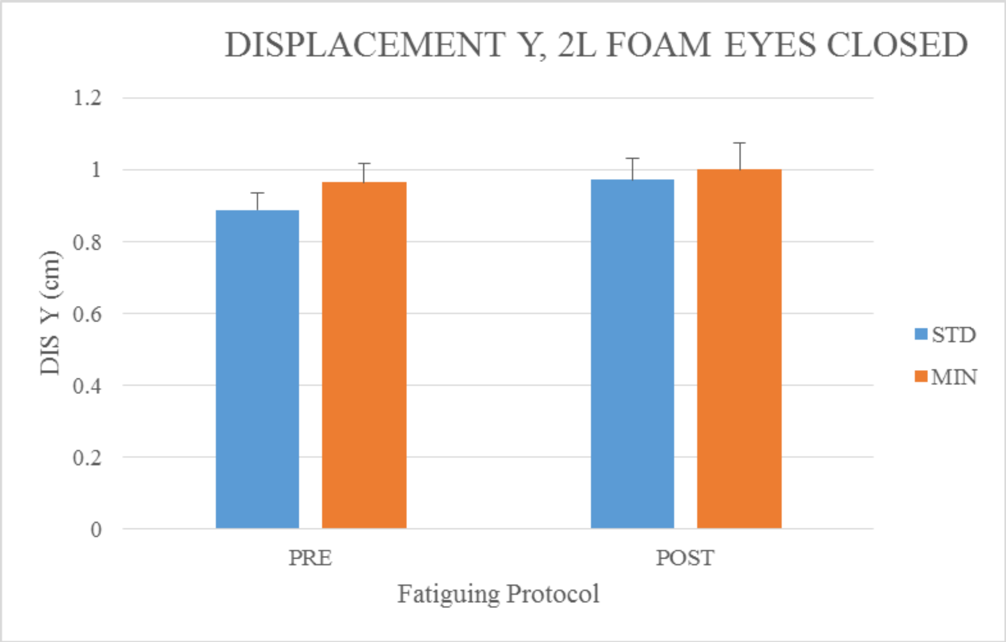

Figure F10. Displacement Y, 2L Foam Eyes Closed

APPENDIX G

MEDIAL-LATERAL ROOT MEAN SQUARE

Figures G1-G10 represent mean values for Medial-Lateral Root Mean Square for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

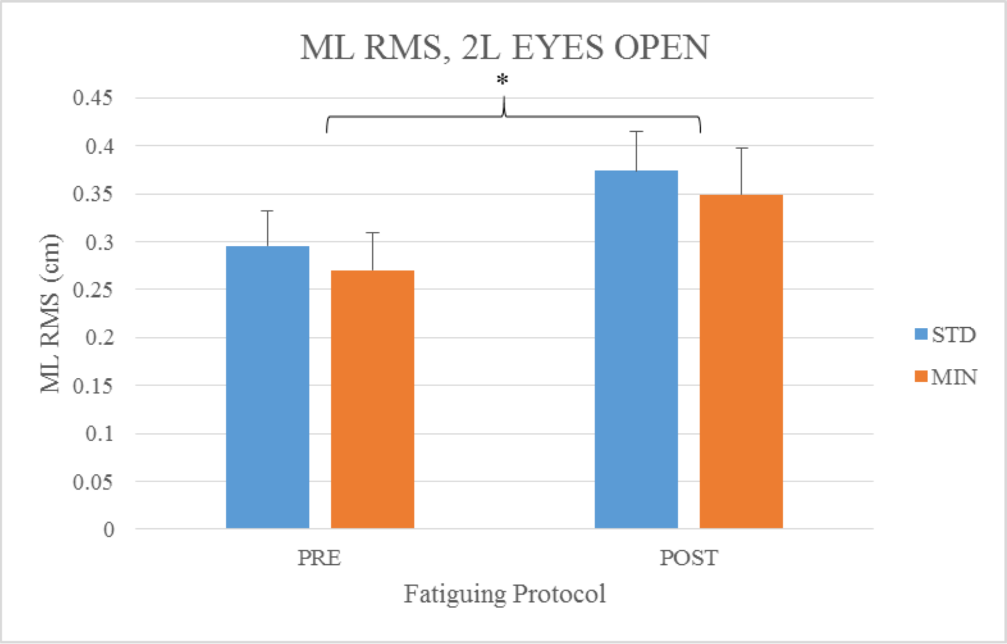

Figure G1. ML RMS, 2L Eyes Open

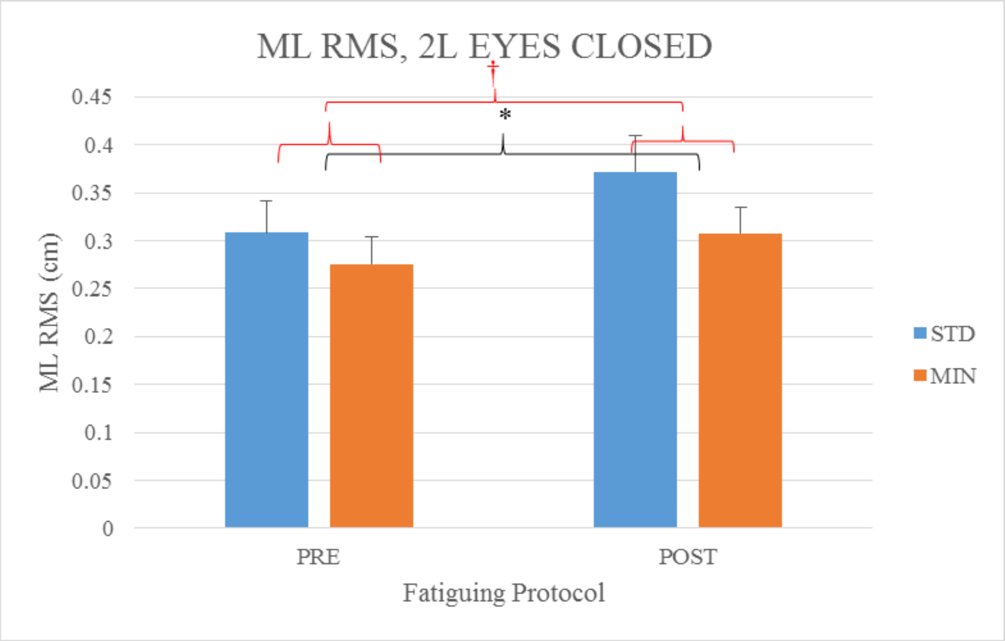

Figure G2. ML RMS, 2L Eyes Closed

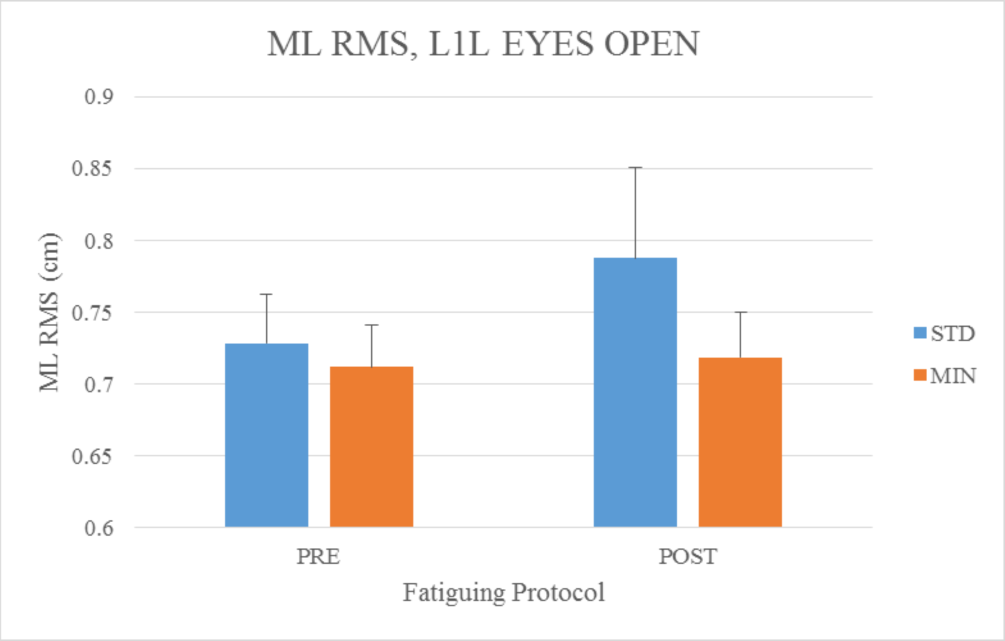

Figure G3. ML RMS, L1L Eyes Open

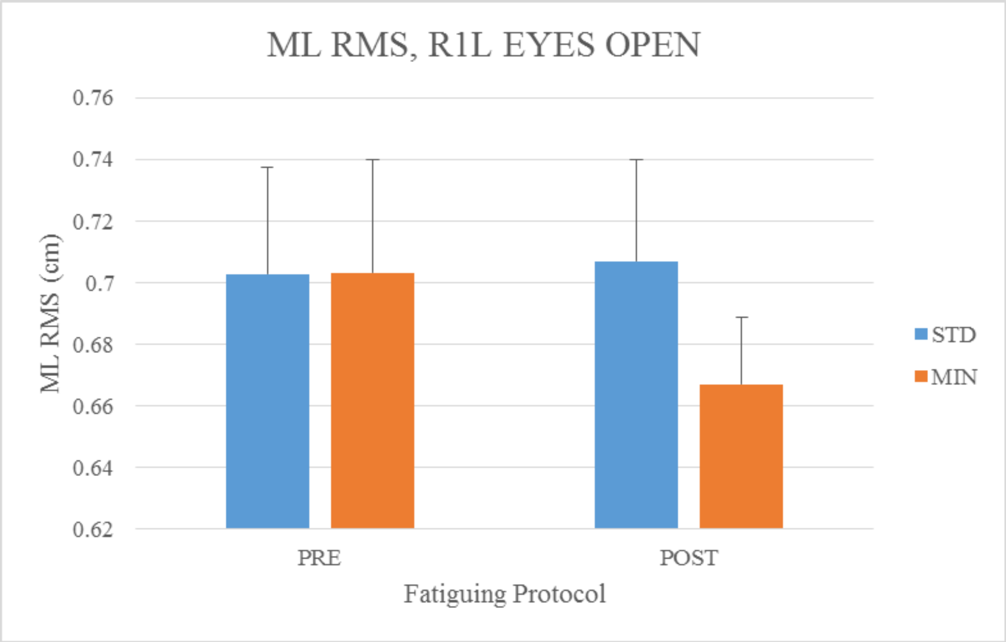

Figure G4. ML RMS, R1L Eyes Open

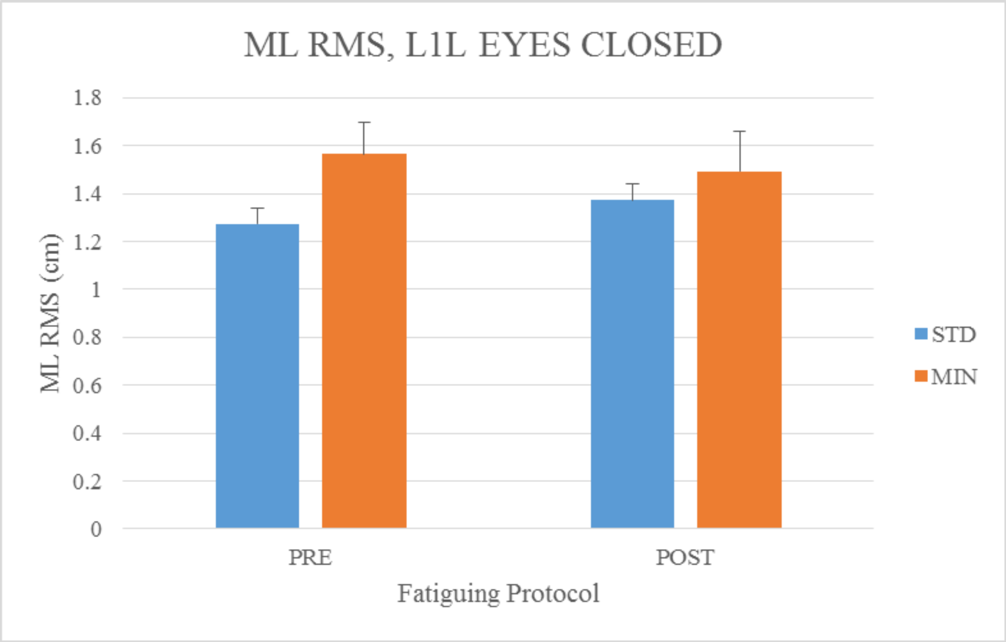

Figure G5. ML RMS, L1L Eyes Closed

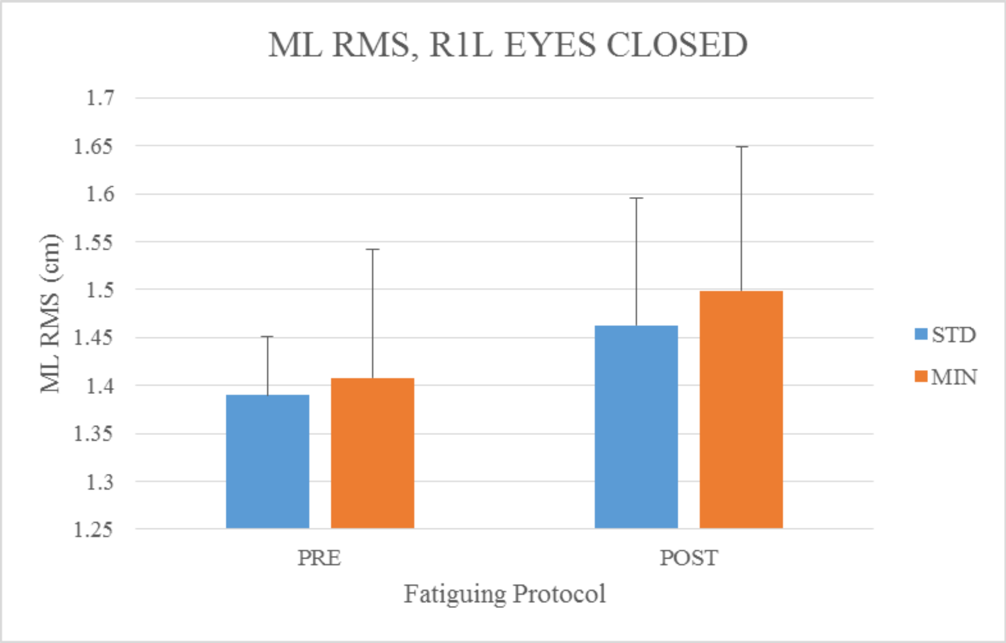

Figure G6. ML RMS, Eyes Closed

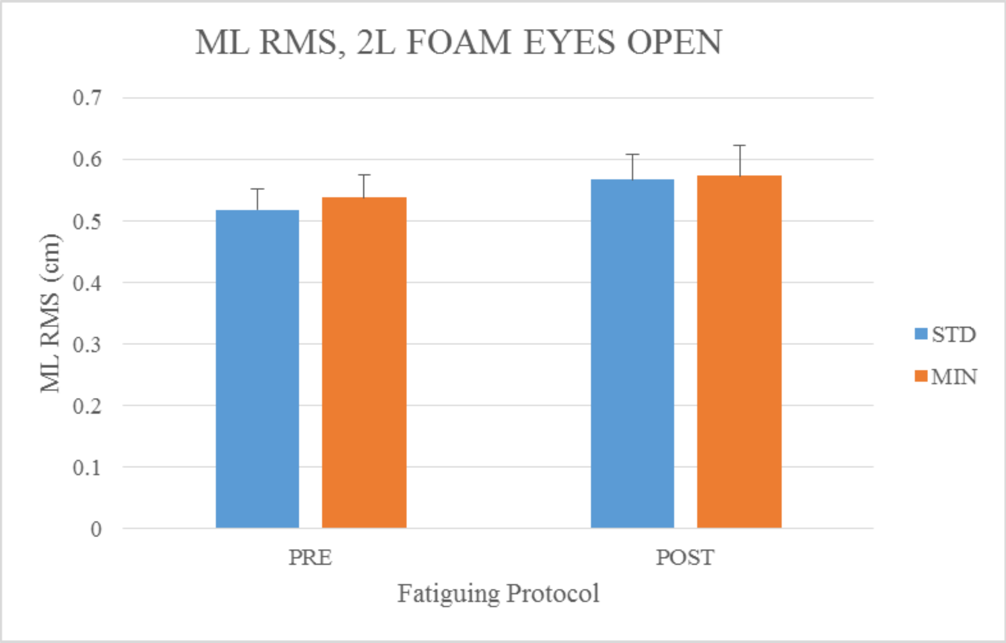

Figure G7. ML RMS, 2L Foam Eyes Open

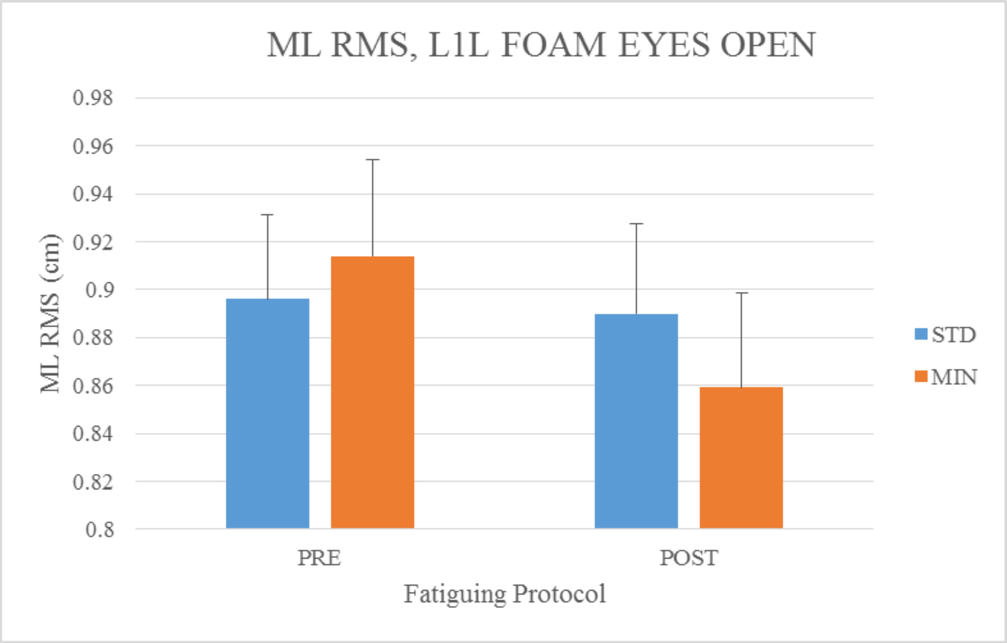

Figure G8. ML RMS, L1L Foam Eyes Open

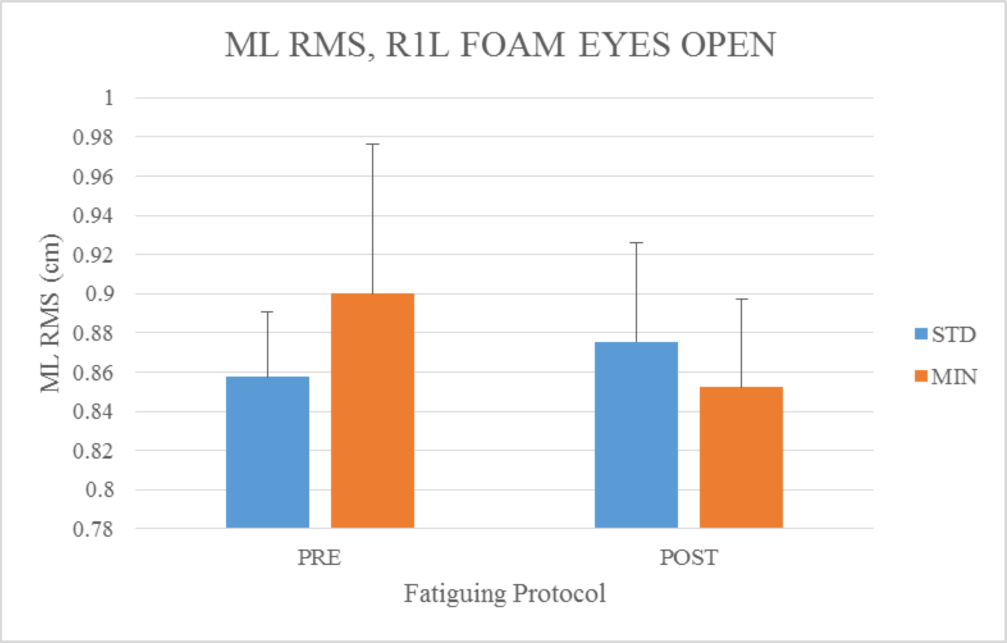

Figure G9. ML RMS, R1L Foam Eyes Open

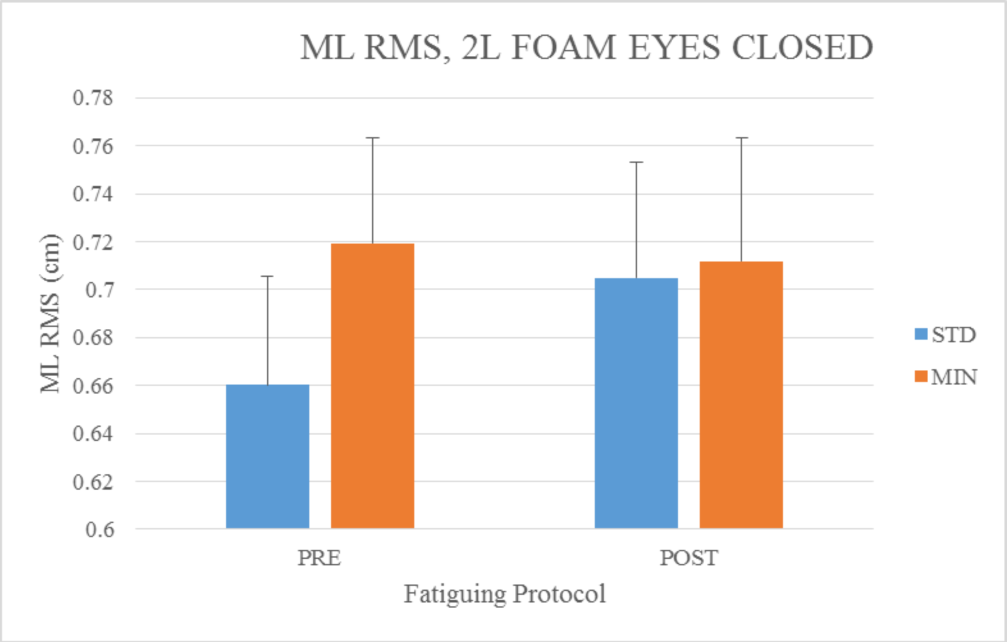

Figure G10. ML RMS, 2L Foam Eyes Closed

APPENDIX H

MEDIAL-LATERAL SWAY VELOCITY MEAN SQUARE

Figures H1-H10 represent mean values for Medial-Lateral Sway Velocity for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

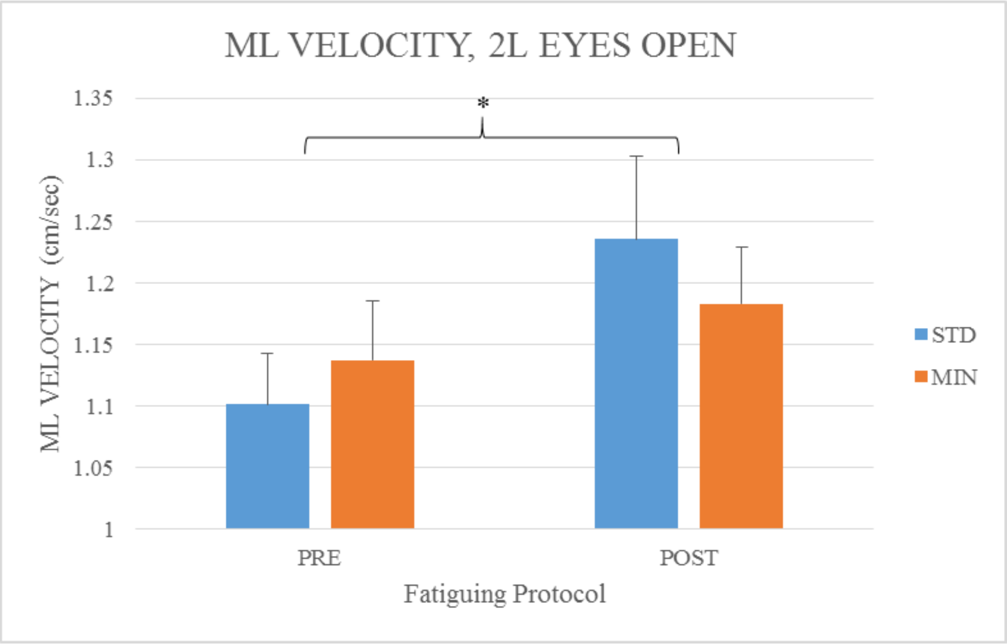

Figure H1.	ML Velocity, 2L Eyes Open

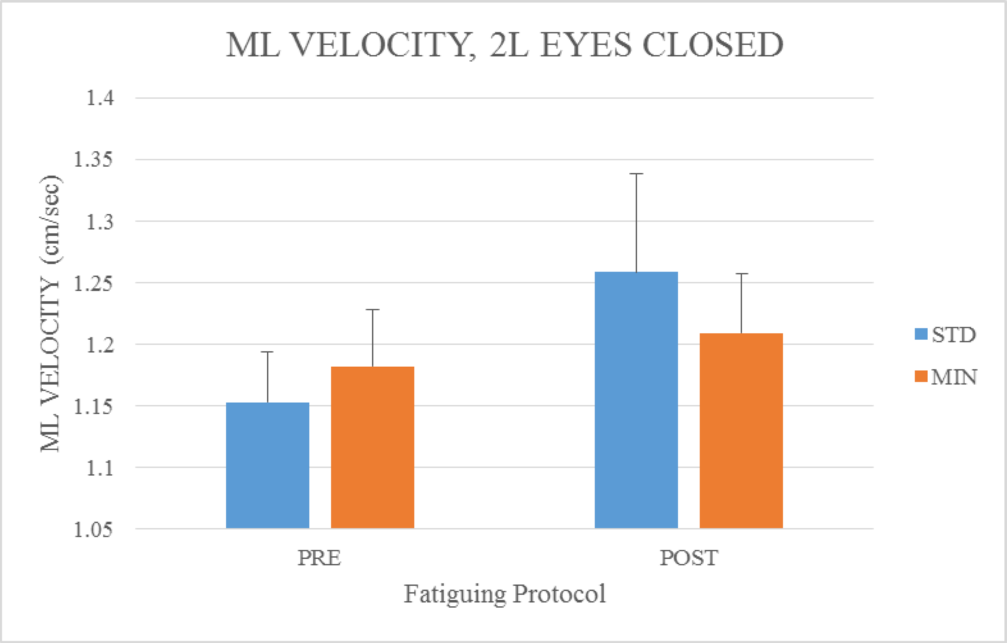

Figure H2. ML Velocity, 2L Eyes Closed

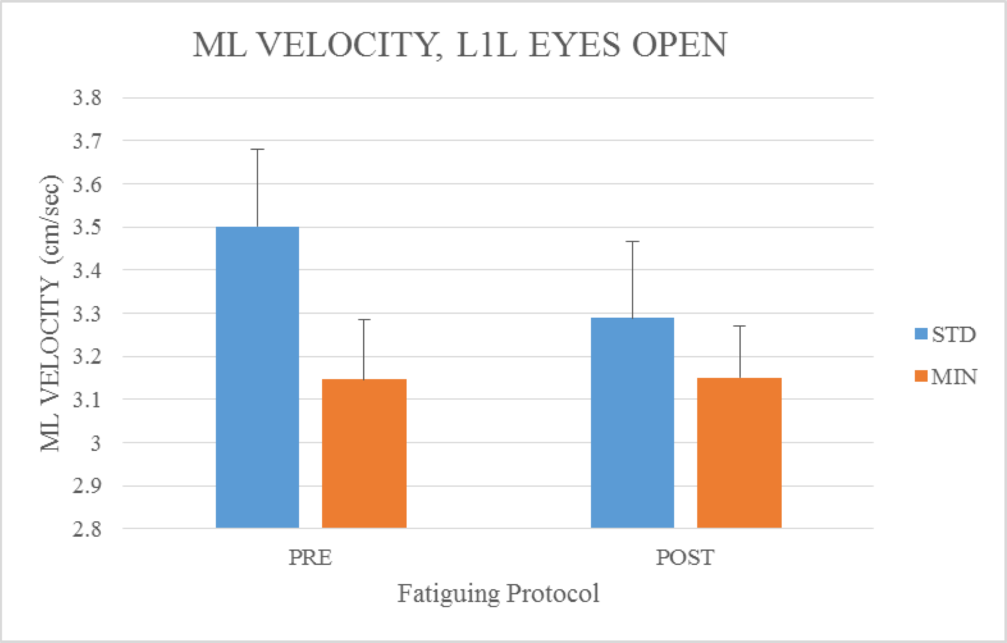

Figure H3. ML Velocity, L1L Eyes Open

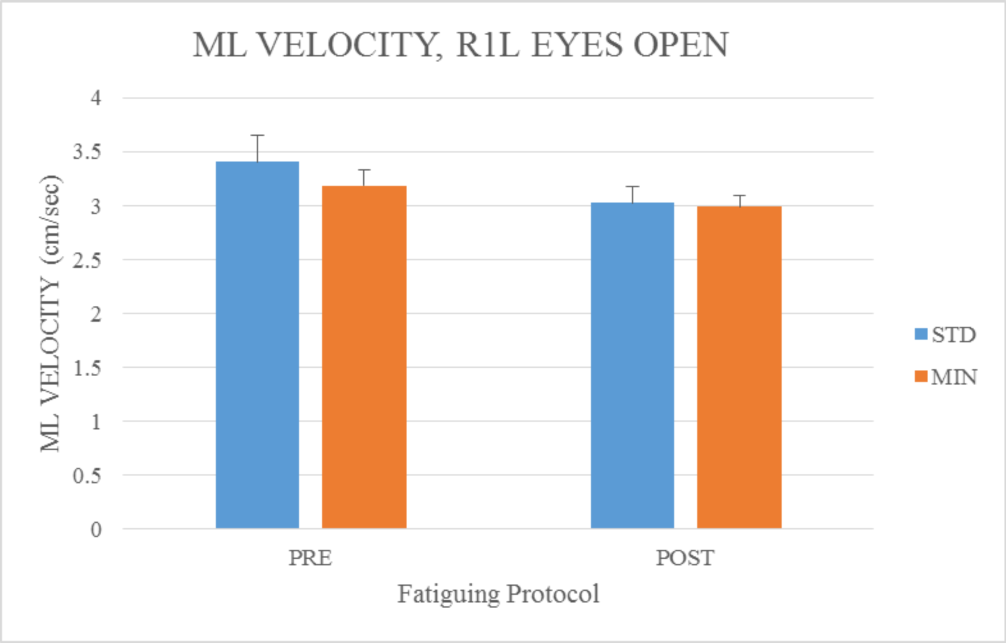

Figure H4. ML Velocity, R1L Eyes Open

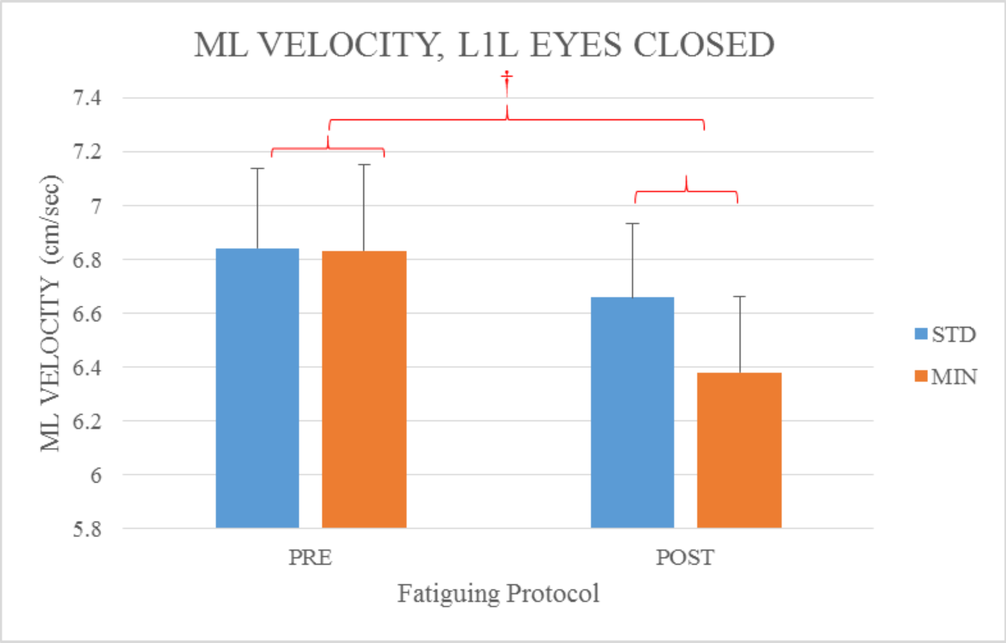

Figure H5. ML Velocity, L1L Eyes Closed

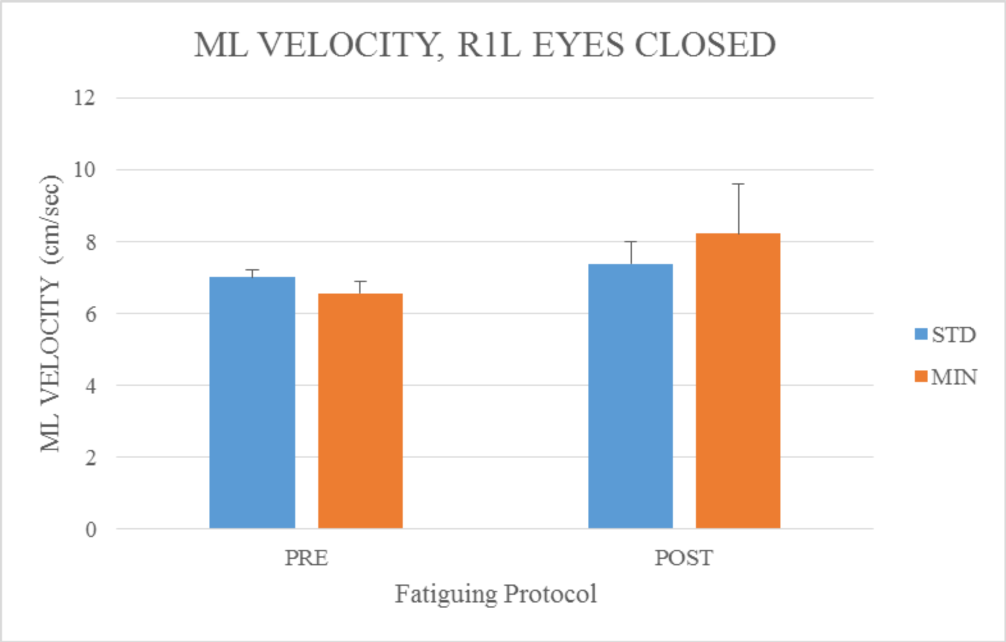

Figure H6. ML Velocity, R1L Eyes Closed.

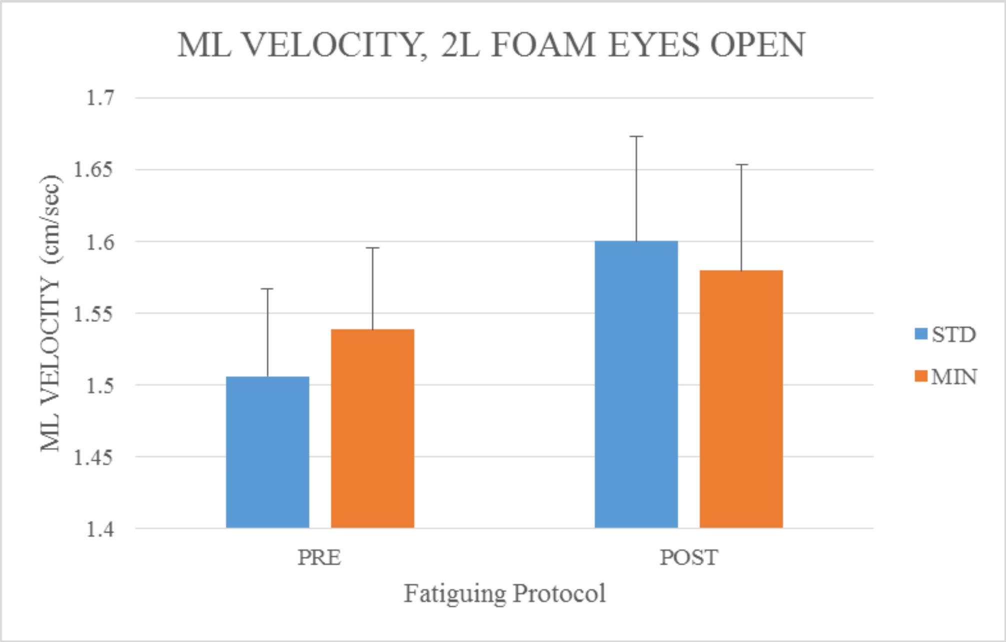

Figure H7. ML Velocity, 2L Foam Eyes Open

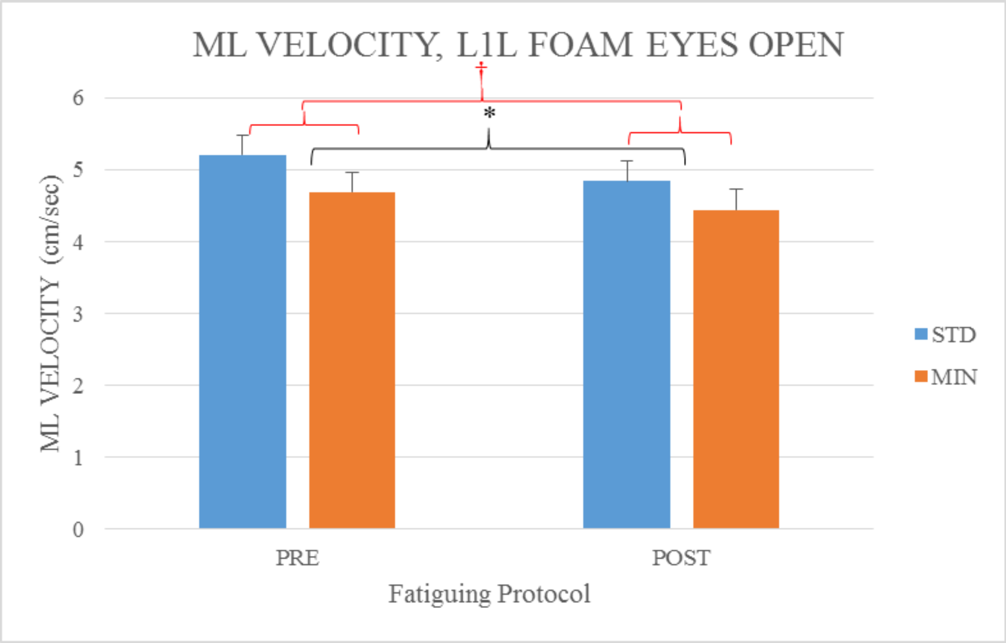

Figure H8. ML Velocity, L1L Foam Eyes Open

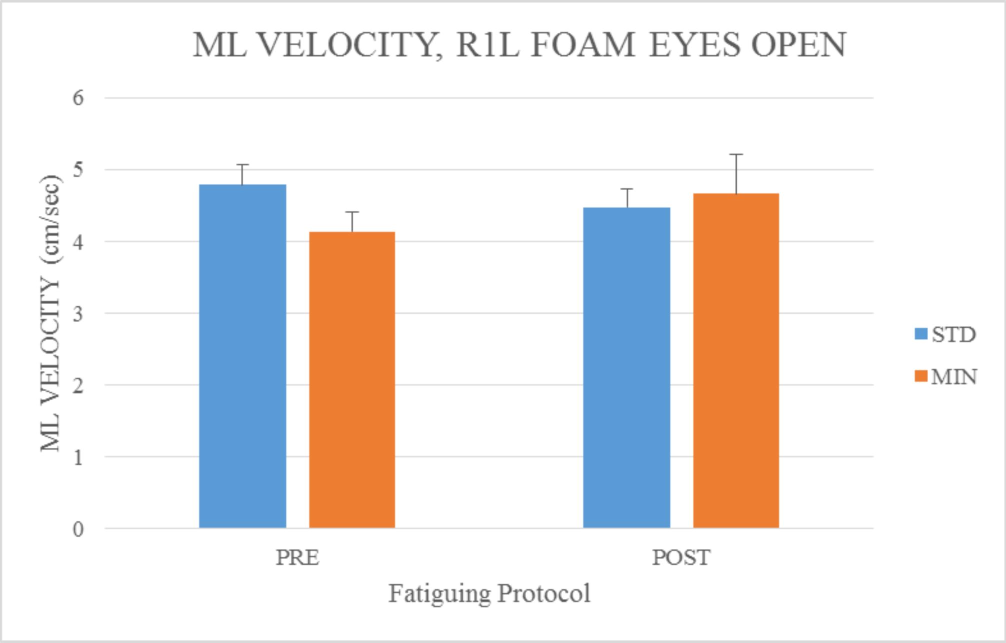

Figure H9. ML Velocity, R1L Foam Eyes Open

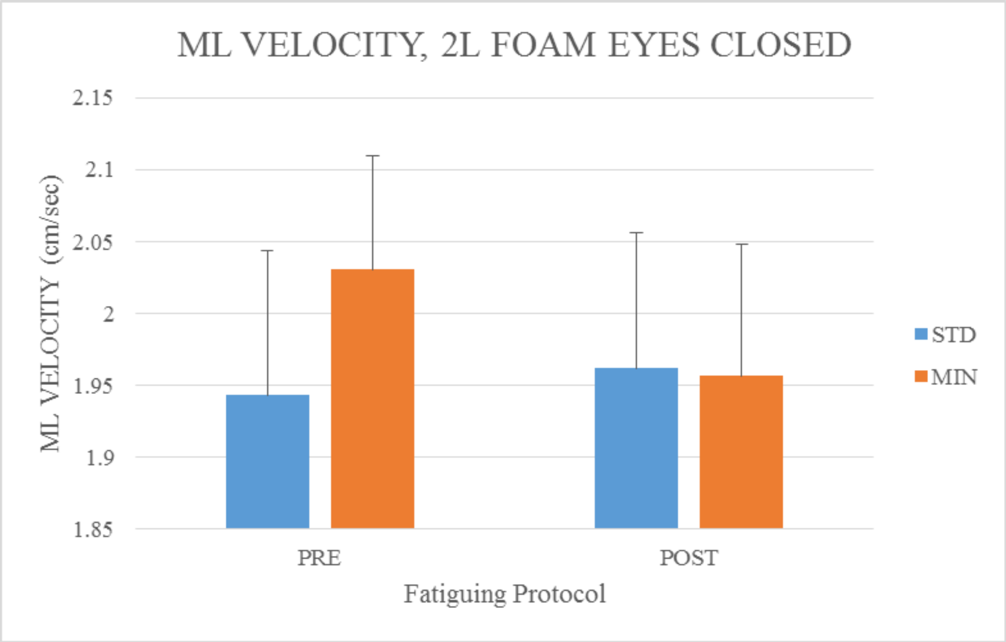

Figure H10. ML Velocity, 2L Foam Eyes Closed

APPENDIX I

STAR EXCURSION BALANCE TEST, REACH DISTANCE

Figures I1-I16 represent mean values for Star Excursion Balance Test, Reach Distance for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

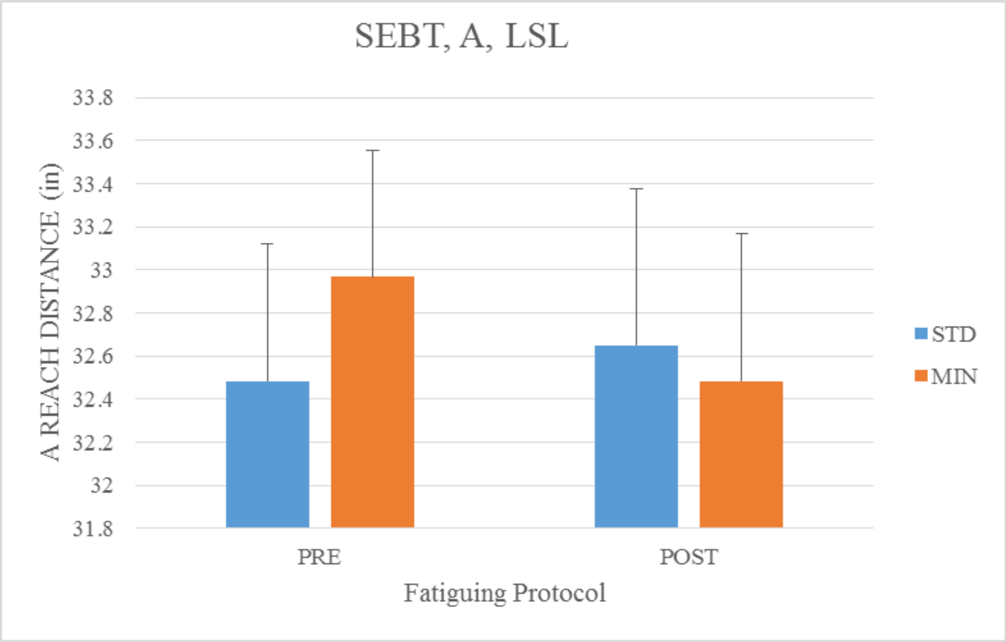

Figure I1. SEBT, A, LSL

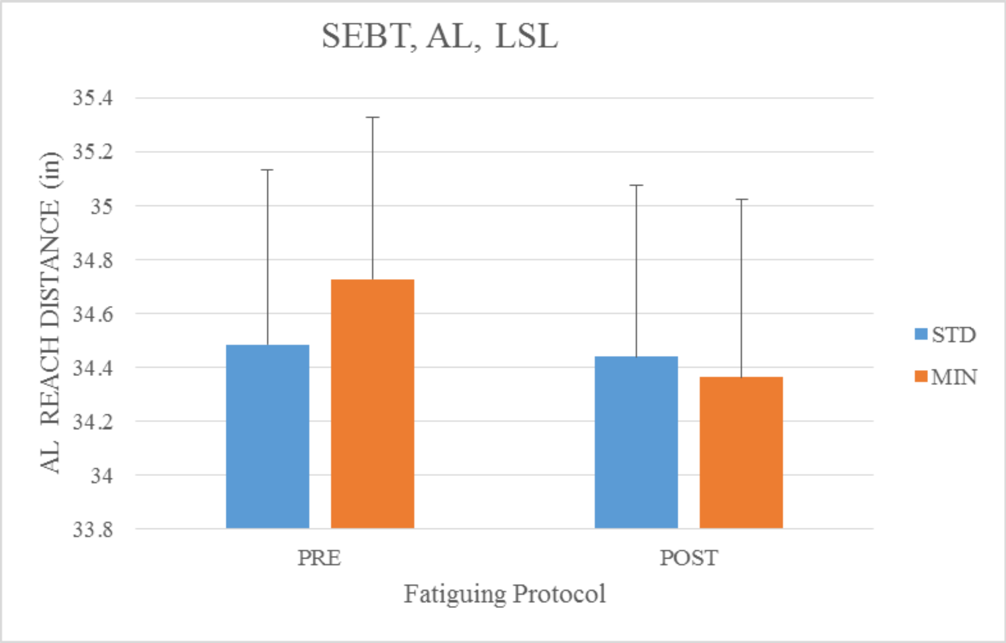

Figure I2. SEBT, AL, LSL

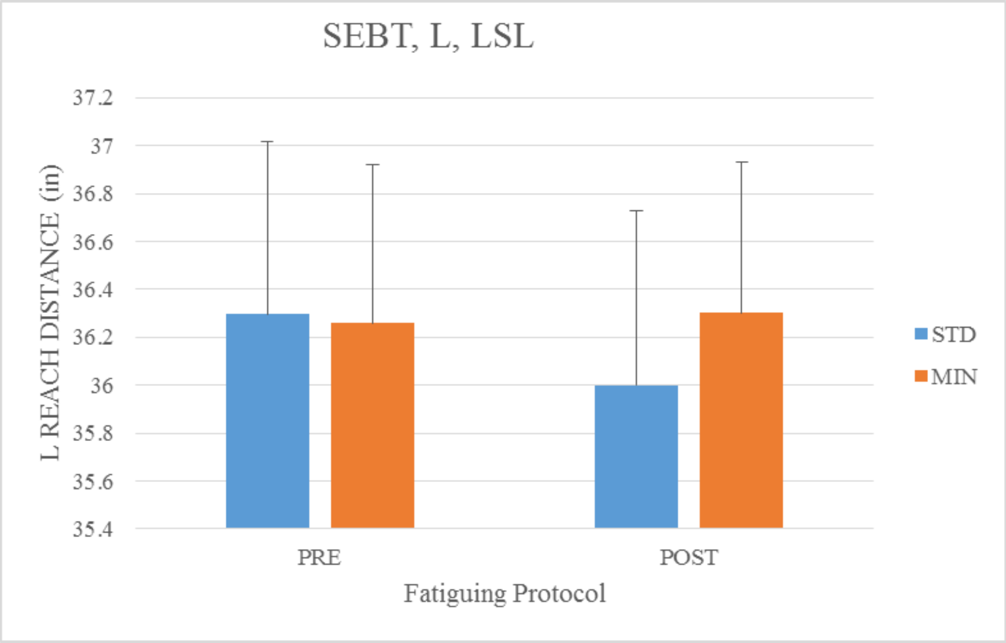

Figure I3. SEBT, L, LSL

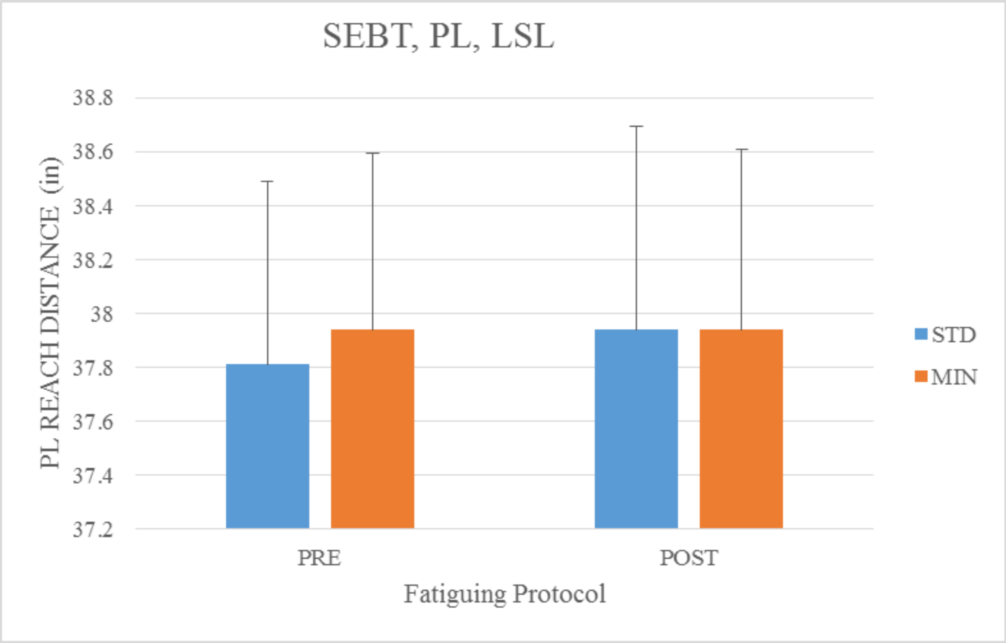

Figure I4. SEBT, PL, LSL

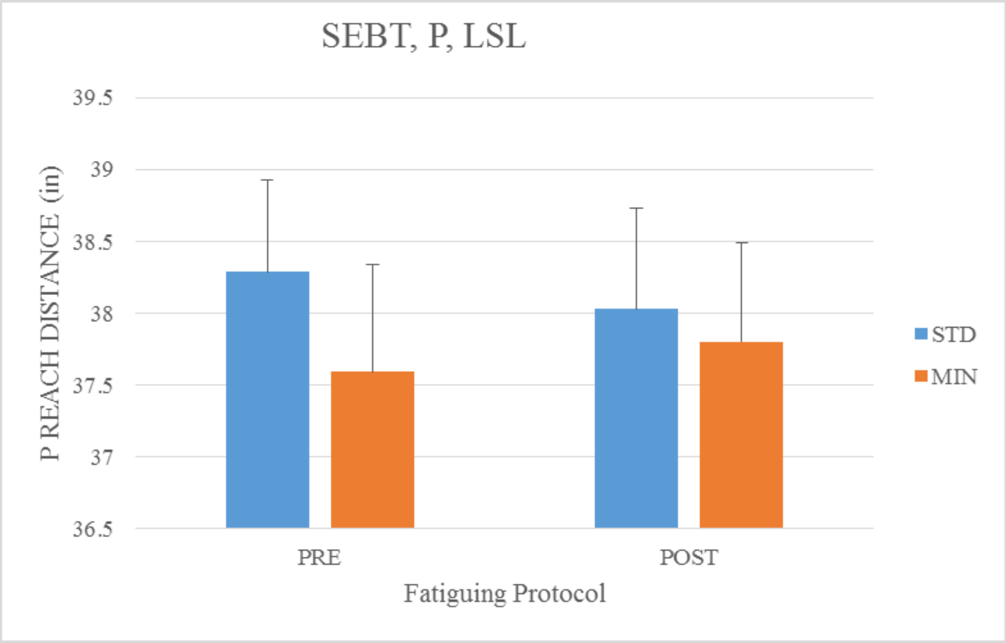

Figure I5. SEBT, P, LSL

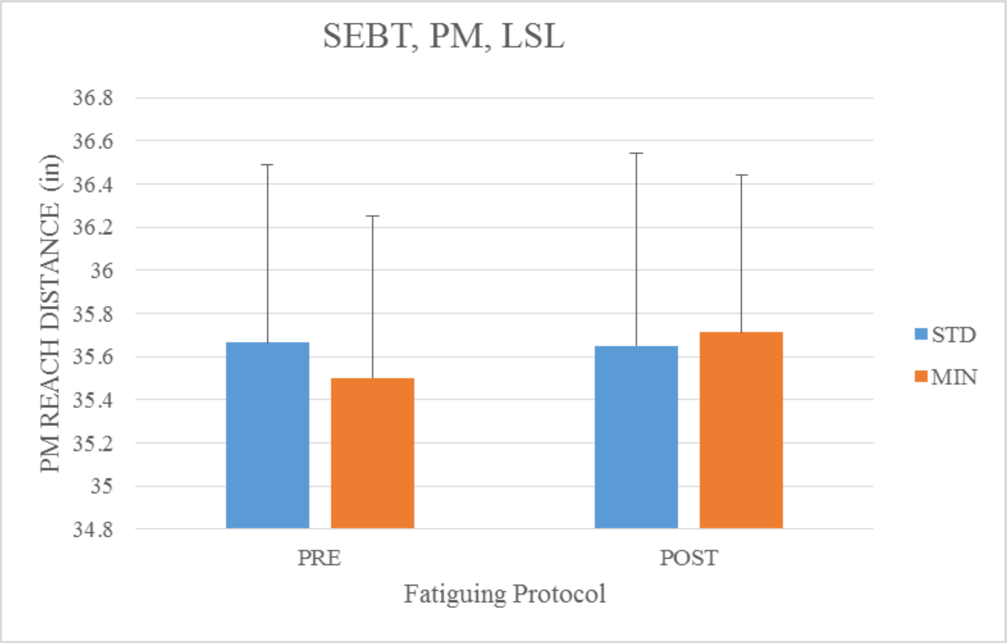

Figure I6. SEBT, PM, LSL

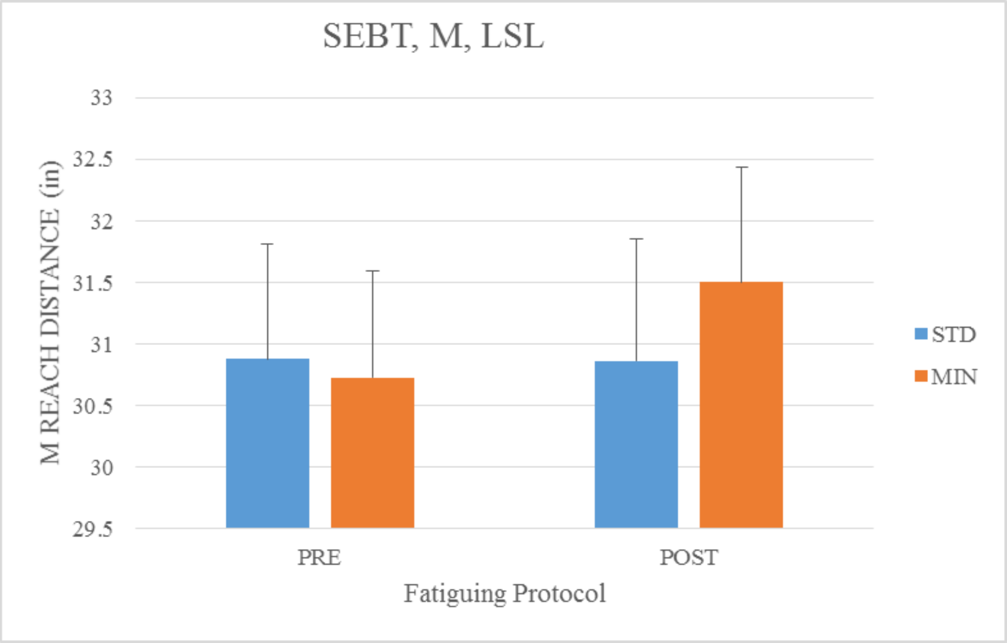

Figure I7. SEBT, M, LSL

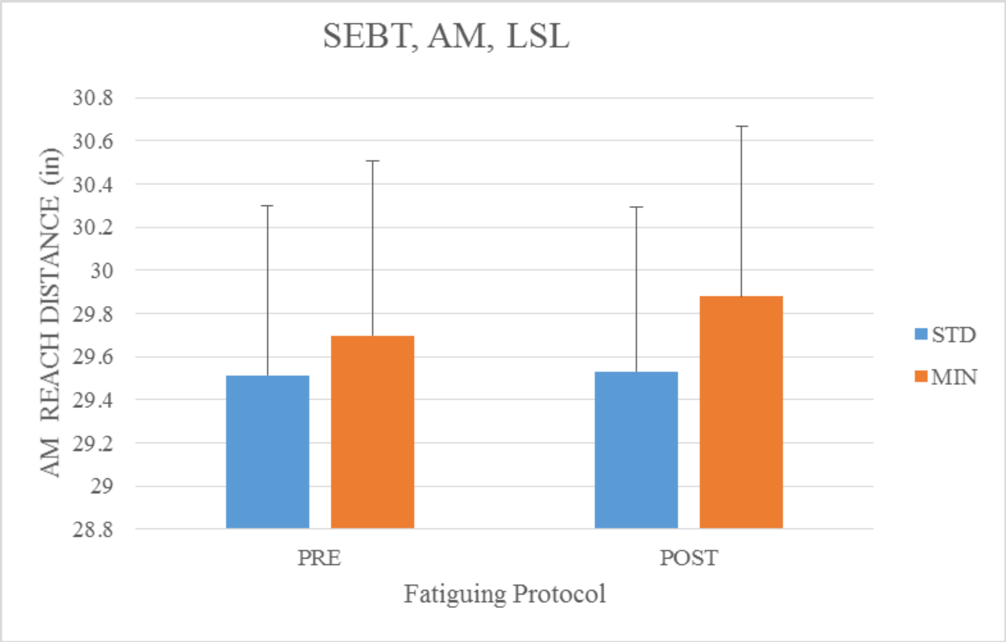

Figure I8. SEBT, AM, LSL

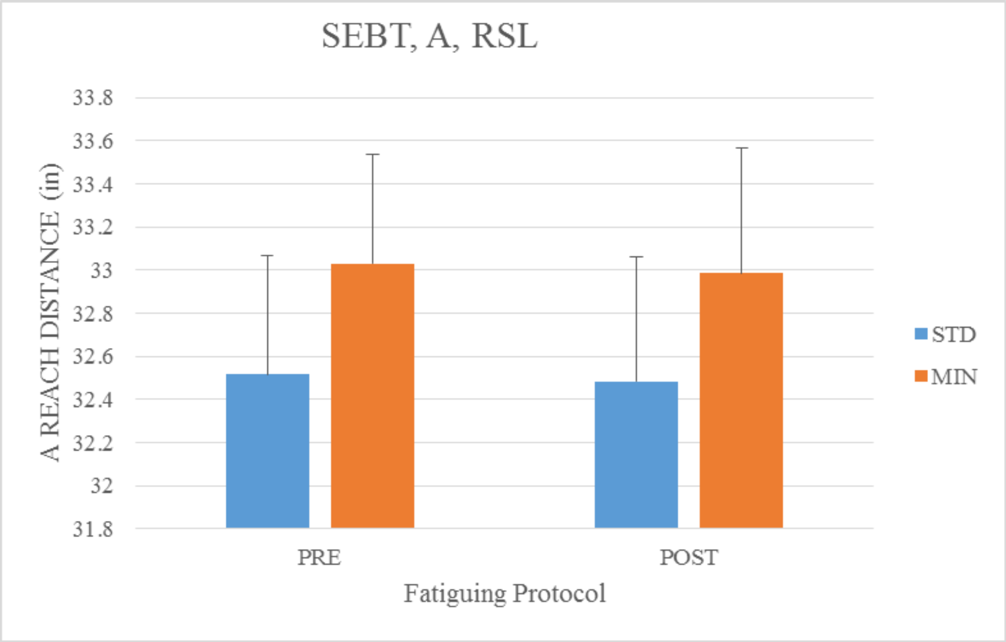

Figure I9. SEBT, A, RSL

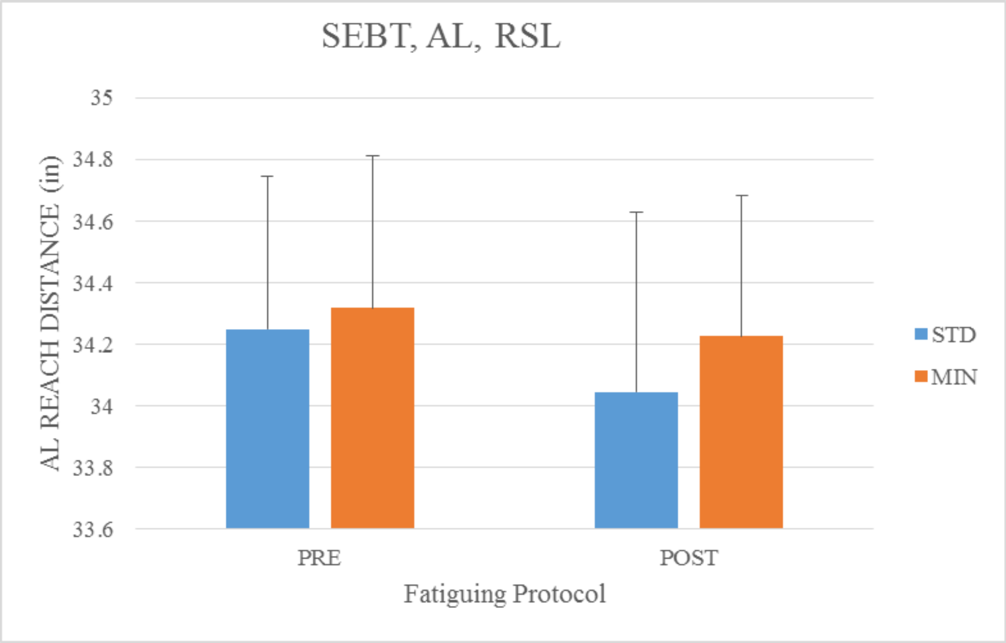

Figure I10. SEBT, AL, RSL

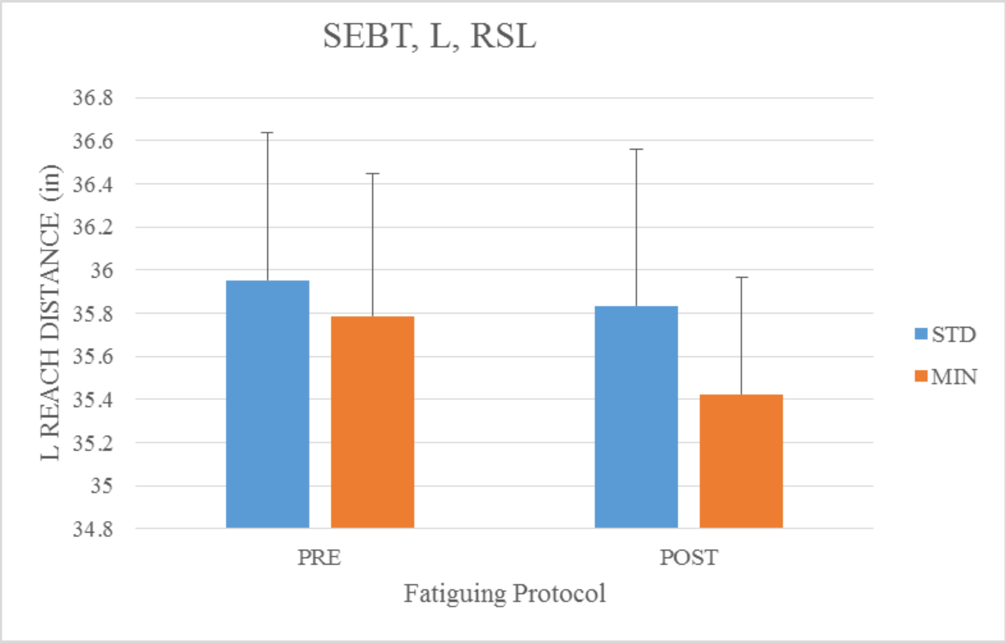

Figure I11. SEBT, L, RSL

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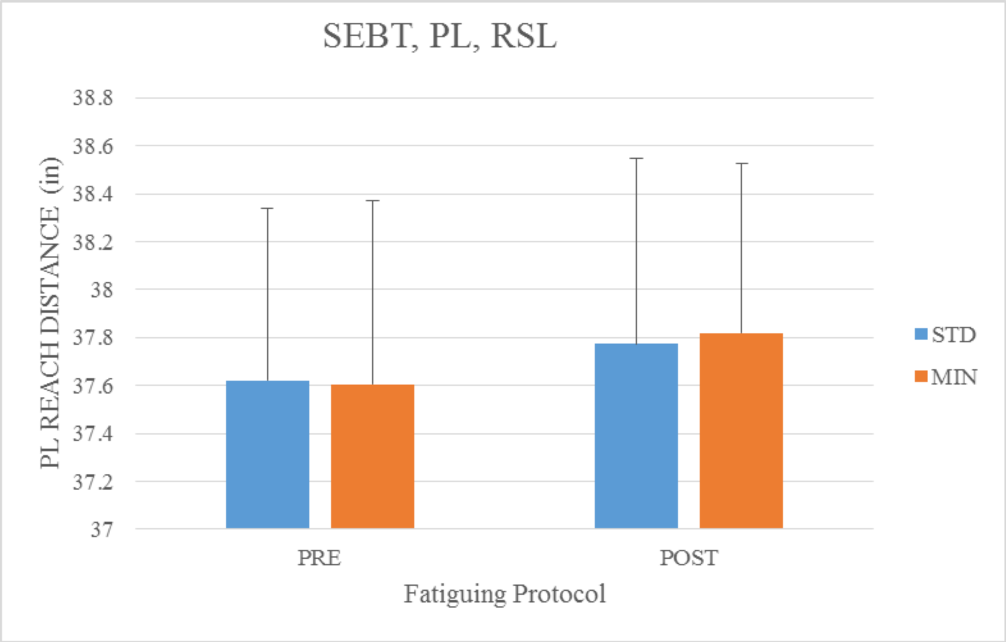

Figure I12. SEBT, PL, RSL

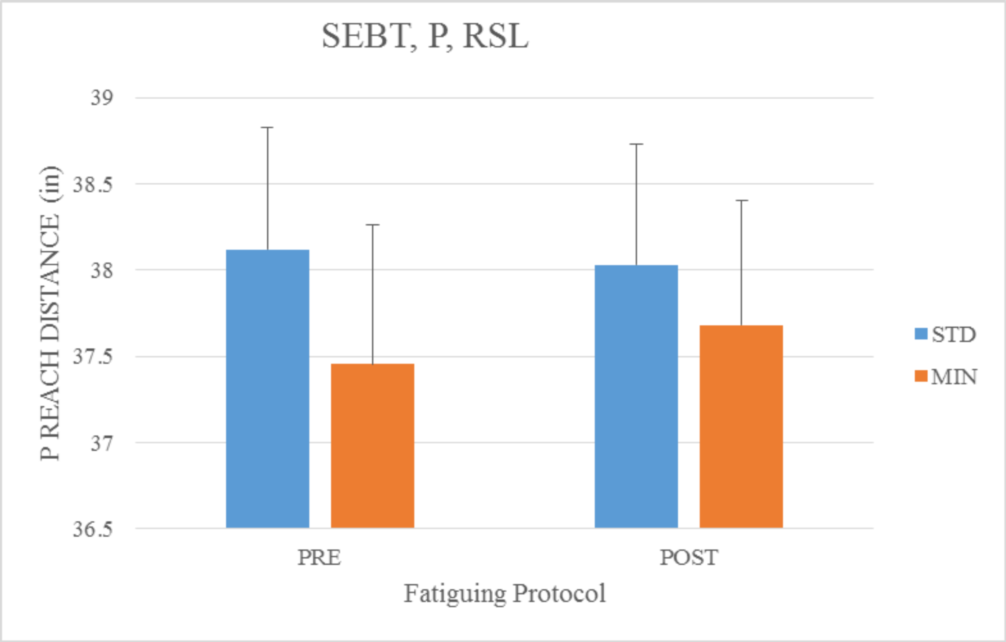

Figure I13. SEBT, P, RSL

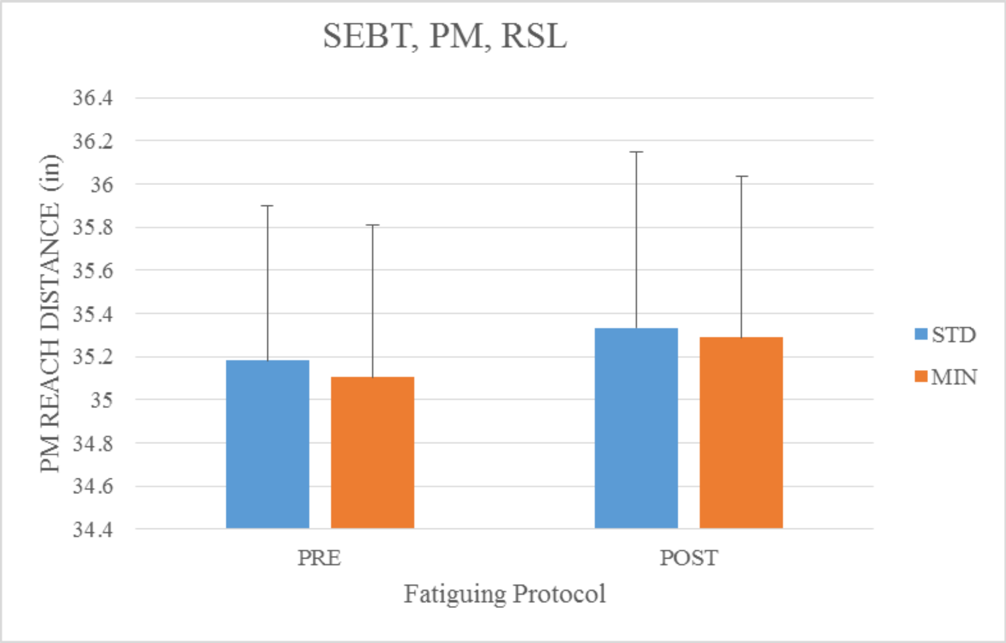

Figure I14. SEBT, PM, RSL

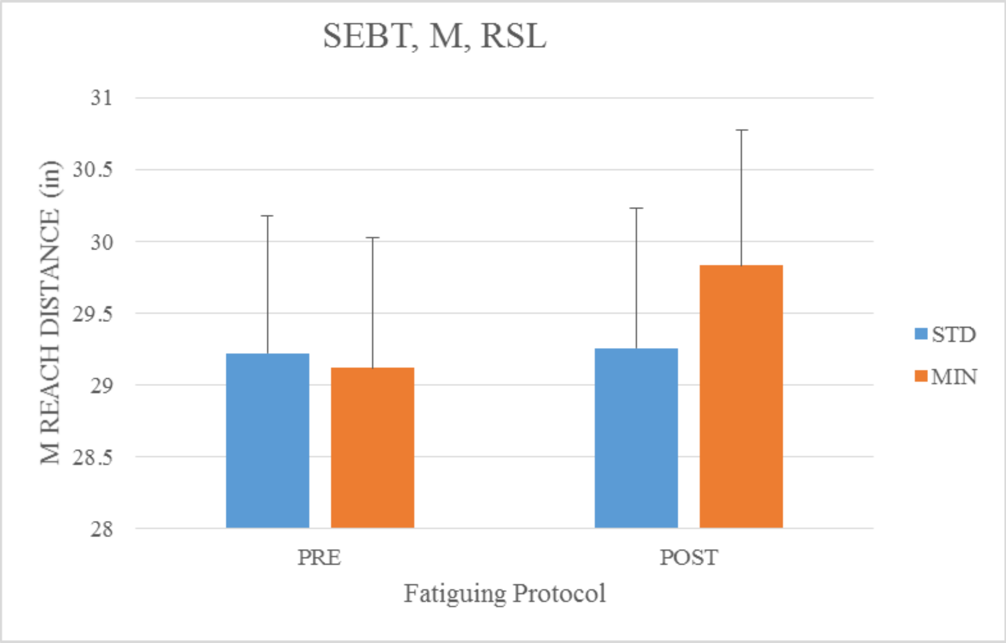

Figure I15. SEBT, M, RSL

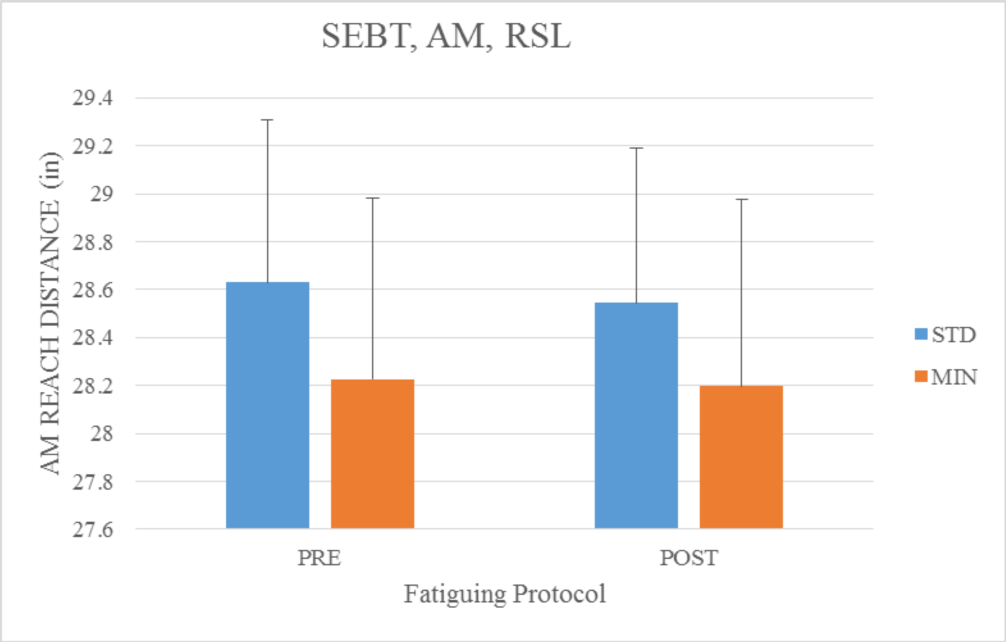

Figure I16. SEBT, AM, RSL

APPENDIX J

WORKLOAD DURATION WHILE WEARING STD AND MIN BOOTS

Figure J1 represents mean values for Workload Duration for STD and MIN in pre and post conditions. * represents time main effect and † represents boot type main effect. Bars represent standard error.

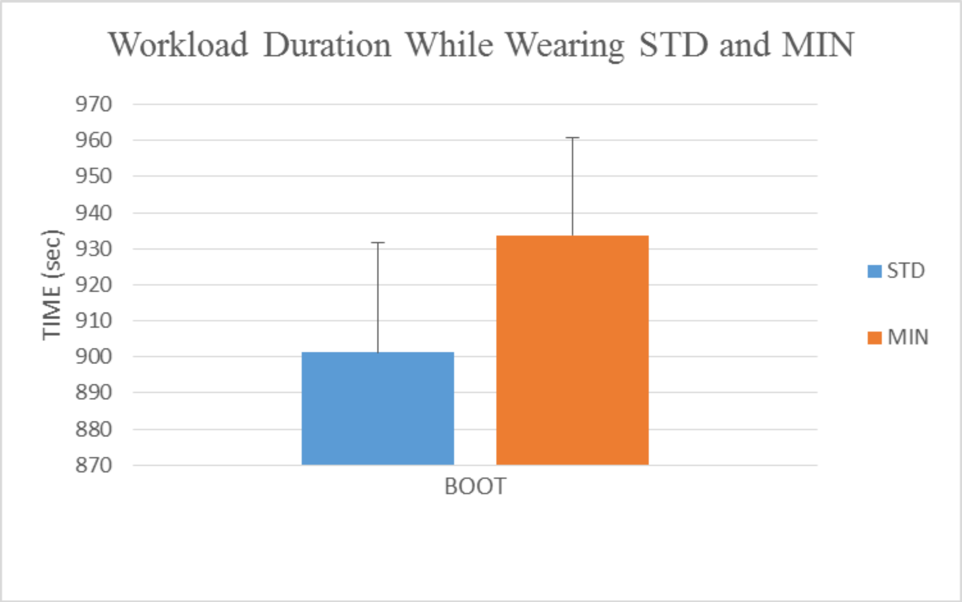

Figure J1. Workload Duration While Wearing STD and MIN