A Thesis

Entitled

The Effects of Five Toed Socks on Motor Neuron Pool Excitability in the Lower Leg

By

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Submitted to the Graduate faculty as partial fulfillment of the requirements

for the Masters of Science Degree in Exercise Science

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An Abstract of

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Postural control deficits occur after musculoskeletal injuries, and it may be related to neuromuscular function alteration. While five toed socks may be a viable option for increasing motoneuron pool excitability (MNPE) and balance, there is little scientific research that has been conducted. The purpose of this study is to determine if the application of five toed socks alters MNPE in the lower extremity muscles, if application of those socks alters balance, or if changes in MNPE are related to changes in balance in healthy subjects. Fourteen subjects (5 males, 9 females; age 22.9±3.4 years; height 170.1±7.3 cm, weight 67.6±9.5 kg; BMI 23.4±3.5) performed pre-condition balance test, pre-condition MNPE test, post-condition balance test, and post-condition MNPE test. They repeated the process in different days with randomly assigned sock conditions; five toed socks with textures (FSG), five toed socks without textures (FS), regular socks (RS), and no socks (NS). Percentage changes in H:M ratio between pre- and post- condition and percentage changes in center of pressure (COP) velocity between pre- and post-condition were analyzed. Results showed that there were no significant differences

between sock conditions for MNPE ($P>.05$) or for balance ($P>.05$). Although there were some correlation between peroneus longus H:M ratio and anterior/posterior direction COP velocity in applying FSG ($r=-.60$, $r^2=.36$, $P=.02$) and between tibialis anterior H:M ratio and anterior/posterior direction COP velocity in applying FS ($r=-.63$, $r^2=.40$, $P=.02$), it is unable to say if correlations were due to socks or if these physiologic factors are related. Five toed socks with and without textures are not interventions to affect postural control in healthy subjects. Also, changes in MNPE are not likely to be the mechanism of improving balance.

Content

List of Tables

Chapter 1

Introduction

Postural control is a complex system that senses and modulates the orientation and the equilibrium of the body during an upright stance.[1] This system consists of sensory input, central processing, and neuromuscular responses.[2] A deficit in this system may result in a difficulty to maintain balance, which may lead to serious injury. This is important as falls rank among the leading causes of death in the elderly population.[3] Various pathologies can cause a deficit in this system. It has been reported that patients with musculoskeletal injuries, such as acute ankle sprain[4], chronic ankle instability[5,6], and anterior cruciate ligament (ACL) deficiency[2,7], exhibit postural control deficits. Also, it has been reported that patients with diabetes mellitus often suffer from postural control deficits.[3,8-12] Therefore, it is important to develop interventions to improve postural control for the purpose of injury prevention.

It has been reported that lateral ankle sprains cause impairments in muscles that stabilize ankle including decreased motor neuron pool excitability (MNPE)[13], delayed reaction time[14,15], decreased nerve conduction velocity[16,17], and strength deficits.[18] These decreased neuromuscular functions may result in postural control deficits. It is important to increase neuromuscular function to improve postural control.

Increasing MNPE through the use of various forms of afferent stimulation has previously been hypothesized to improve neuromuscular function.[19-22] Various interventions have been reported to increase neuromuscular function by increasing MNPE. Both cryotherapy and transcutaneous electrical nerve stimulation (TENS) increase muscle activation in inhibited musculature around the injured joints.[23-27] These modalities are theorized to increase the excitatory stimuli from cutaneous receptors and to increase MNPE of the muscles around the injured joints.[25]

Similarly, five toed socks, equipped with tactile material on the plantar surface, have previously been reported to improve both static and dynamic postural control.[28-30] It is hypothesized that five toed socks improve postural control by separating the toes, potentially increasing the proprioceptive and cutaneous inputs to the central nervous system (CNS), thereby enhancing the perception of the ground and providing better grip. However, there is little scientific research focusing on the effects and the mechanisms of associated postural control improvements reported with five toed socks use.

The plantar surfaces of the feet serve as an interface between the body and the ground. The contribution of afferent input from the plantar cutaneous surface of the foot to postural control has been studied through various methods, such as local anesthesia and ischemic blocking[31], while others have evaluated the effect of hyperstimulating plantar afferent receptors through stimuli such as vibration.[32] The five toed socks are thought to increase the contact area with ground by separating the toes, and the five toed socks with textures increase the stimuli from plantar cutaneous surface. While increasing afferents with TENS has been found to improve MNPE, no studies have examined if five toed socks improve MNPE. Greater MNPE in muscles around the ankle joint may improve postural control. However, the ability of five toed socks to increase MNPE are still unclear.

1.1 Statement of Problem

While there is recent evidence to suggest that five toed socks with tactile plantar texture may improve postural control, there is little evidence regarding the mechanisms that may cause these improvements. Modalities altering afferent stimuli have previously been reported to increase MNPE, suggesting that changes in MNPE may be the mechanism that causes postural control improvements found following five toed socks application.

1.2 Statement of Purpose

1. To determine if the application of five toed socks with and without plantar tactile textures alters MNPE in the anterior tibialis, peroneus longus, and soleus muscles during double leg stance compared to wearing regular socks or no socks in healthy subjects.
2. To determine if the application of five toed socks with and without plantar tactile textures alters center of pressure (COP) velocity during single leg balance task compared to wearing regular socks or no socks in healthy subjects.
3. To determine if changes in MNPE are related to changes in COP velocity in healthy subjects.

1.3 Research Hypotheses

1. a. Application of five toed socks with plantar tactile textures would increase MNPE in the anterior tibialis, peroneus longus, and soleus muscles compared to wearing regular socks or no socks in healthy subjects.

   b. Application of five toed socks without plantar tactile textures would increase MNPE in the anterior tibialis, peroneus longus, and soleus muscles compared to wearing regular socks or no socks in healthy subjects.

   c. Application of five toed socks with plantar tactile textures would increase MNPE in the anterior tibialis, peroneus longus, and soleus muscles compared to five toed socks without plantar tactile textures in healthy subjects.

2. a. Application of five toed socks with plantar tactile textures would decrease COP velocity during single leg balance task compared to wearing regular socks or no socks in healthy subjects.

   b. Application of five toed socks without plantar tactile textures would decrease COP velocity during single leg balance task compared to wearing regular socks or no socks in healthy subjects.

c. Application of five toed socks with plantar tactile textures would decrease COP velocity during single leg balance task compared to five toed socks without plantar tactile textures in healthy subjects.

3. Changes in MNPE will be related to changes in COP velocity in healthy subjects.

1.4 Limitations

All the subjects of this study were healthy (no lower leg injuries or neuropathology). This might decrease the generalizability of the outcome.

The data of this study was collected from subjects in a stable position (single leg stance and double leg stance), which might limit the application of the results to more functional tasks, such as walking or running.

Single leg stance was used to measure COP velocity while double leg stance was used to measure MNPE. Different types of stance might influence the correlation between COP velocity and MNPE.

1.5 Significance of the Study

If application of five toed socks improves balance due to increase in MNPE, this intervention may be used to affect postural control deficits in those with balance impairments. Also, five toed socks will be considered as an intervention to decrease arthrogenic muscle inhibition (AMI) after joint injury.

1.6 Definitions

Hoffmann reflex (H-reflex):

H-reflex is an electrically induced reflex that is similar to the mechanically induced spinal stretch reflex. H-reflex is a measure of motoneuron pool excitability.[23,33,34] This measurement does not directly equate to changes in functional strength, but it does equate to state changes to the motoneuron pool, which affect strength, muscle wasting, and mobilization.

H-reflex and M-wave:

When low intensity electric stimulus is delivered to the tibial nerve, action potentials are elicited selectively in afferent neurons due to their large axon diameter. These action potentials travel to the spinal cord, where they cause a reflex response, in turn eliciting action potentials, which travel down the alpha motor neuron (αMN) axons toward the muscle. The volley of these action potentials is recorded in the muscle as an H-reflex.

When middle intensity electric stimulus is delivered to the tibial nerve, action potentials occur in efferent neurons, which travel directly toward the muscle. The volley of these action potentials is recorded as an M-wave. At the same time, action potentials propagate antidromically (backward) in the αMN toward the spinal cord to collide with the action potentials of the evoked reflex response, thereby resulting in partial cancellation of the H-reflex.

When high intensity electric stimulus is delivered to tibial nerve, orthodromic (toward the muscle) and antidromic (toward the spinal cord) action potentials occur; the orthodromic action potentials cause a M_{MAX}, whereas the antidromic action potentials result in complete cancellation of the H-reflex.[33]

H_{MAX} and M_{MAX}:

H_{MAX} is a measure of maximal reflex activation and an estimate of the number of motoneurons one is capable of activating in a given state.

M_{MAX} represents activation of the entire motoneuron pool and maximal muscle activation.[33]

H_{MAX}/M_{MAX} Ratio:

The ratio calculated from the Hoffmann reflex normalized to the muscle response (H:M) is an estimate of the motor neuron pool excitability of the muscle. Increases in the H:M are indicative of increased excitability while decreases in the H:M are indicative of decreased excitability.[33]

Arthrogenic muscle inhibition (AMI):

AMI is a presynaptic, ongoing reflex inhibition of joint musculature after distension or damage to that joint. AMI is a neural mechanism designed to protect an injured joint. However, the neural inhibition that results from joint injury creates many rehabilitation problems for the patient, including muscle weakness, atrophy, and decreased neuromuscular control.[19,23,34]

Chapter 2

Literature Review

2.1 Introduction

This literature review is divided into three sections. The first section discusses H-reflex and motoneuron pool excitability (MNPE) associated with musculoskeletal injuries and therapeutic modalities. Previous literatures demonstrated that those musculoskeletal injuries and therapeutic modalities altered MNPE. The second section discusses balance deficits associated with ankle injury, knee injury, and diabetes. Previous literatures demonstrated that patients with ankle injuries, knee injuries, or diabetes tended to suffer from balance deficits. The third section discusses cutaneous inputs, which is afferent information from cutaneous receptors. Previous literatures demonstrated that changes in cutaneous inputs caused changes in postural control and MNPE.

2.2 H-Reflex

H-reflex is an electrically induced reflex that is similar to the mechanically induced spinal stretch reflex. H-reflex is a valuable tool in assessing modulation of monosynaptic reflex activity in the spinal cord. H-reflex is an estimate of alpha motoneuron (αMN) excitability.[33] This measurement can be used to assess the response of the nervous system in various conditions, such as musculoskeletal injuries,[19,21,34-36] application of therapeutic modalities[23,24,26,37], and exercises.[38]

When low intensity electric stimulus is delivered to the nerve, action potentials are elicited selectively in afferent neurons due to their large axon diameter. These action potentials travel to the spinal cord, where they cause reflex response, in turn eliciting action potentials, which travel down the αMN axons toward the muscle. The volley of these action potentials is recorded in the muscle as an H-reflex. When middle intensity electric stimulus is delivered to the tibial nerve, action potentials occur in efferent neurons, which travel directly toward the muscle. The volley of these action potentials is recorded as an M-wave. At the same time, action potentials propagate antidromically (backward) in the αMN toward the spinal cord to collide with the action potentials of the evoked reflex response, thereby resulting in partial cancellation of the H-reflex. When high intensity electric stimulus is delivered to tibial nerve, orthodromic (toward the muscle) and antidromic (toward the spinal cord) action potentials occur; the orthodromic action potentials cause a M_{MAX}, whereas the antidromic action potentials result in complete cancellation of the H-reflex.[33]

H_{MAX} is a measure of maximal reflex activation and an estimate of the number of MNs one is capable of activating in a given state, and M_{MAX} represents activation of the entire MN pool and maximal muscle activation.[33]

The ratio calculated from the Hoffmann reflex normalized to the muscle response (H:M) is an estimate of the motor neuron pool excitability of the muscle. Increases in the H:M are indicative of increased excitability while decreases in the H:M are indicative of decreased excitability.[33]

2.2.1 Musculoskeletal Injury

Motoneuron pool excitability (H-reflex) is altered after musculoskeletal injuries, such as lateral ankle sprain and anterior cruciate ligament (ACL) deficiency.[13,19,21,34,35] It has been reported that joint musculoskeletal injuries cause arthrogenic muscle inhibition (AMI), is a presynaptic, ongoing reflex inhibition of joint musculature after distension or damage to that joint. AMI is a neural mechanism designed to protect an injured joint. However, the neural inhibition that results from joint injury creates many rehabilitation problems for the patient, including muscle weakness, atrophy, and decreased neuromuscular control.[23,34,36]

Hall et al.[35] conducted a study to determine relationships between ankle swelling and flexor digit rum longus (ankle inverter) and peroneus longus (ankle everter) H-reflex. Fifteen subjects with acute grade I or II inversion ankle sprains participated in this study. Paired t-tests were used to compare mean differences in ankle girth (swelling) and ankle invertor or evertor H-reflex amplitude and latency between the involved and uninvolved limbs. Pearson product moment correlations were used to assess relationships between swelling and H-reflex variables. The flexor digitorum longus H-reflex latencies of the involved ankles were delayed (0.72±0.7 ms) compared to the involved ankles. There was a moderate positive association (r=0.73) between the latency delay in the involved ankle flexor digitorum longus and swelling. Although peroneus longus H-reflex latencies demonstrated a greater mean delay between the involved and uninvolved ankle, the results were not statistically significant. H-reflex amplitude did not demonstrate statistically significant differences between the involved and uninvolved ankle for either muscle ($P \geq .0125$). In this study, grade I or II inversion sprains and the related swelling altered motoneuron excitability.

McVey et al.[13] conducted a study to determine the relationship between arthrogenic muscle inhibition (AMI) and functional ankle instability. Twenty-nine subjects (15 with unilateral functional ankle instability and 14 healthy control subjects) participated in this study. Bilateral soleus, peroneal, and tibialis anterior H-reflex and M-wave recruitment curves were obtained. Maximal H-reflex and maximal M-wave values were identified, and the H:M ratios were calculated for data analysis. The soleus and peroneal H:M ratios in subjects with functional ankle instability were smaller in the injured limb when compared to the uninjured limb ($p<0.05$). There were no limb differences for the tibialis anterior H:M ratio in subjects with functional ankle instability ($p=0.904$). In this study, AMI was present in subjects with functional ankle instability.

Palmieri et al.[19] conducted a study to determine if AMI is present in the soleus, peroneus longus, and tibialis anterior musculature after a simulated ankle joint effusion. Eight neurologically sound subjects participated in this study. Maximum H-reflex and maximum M-wave measurements were collected using surface electromyography after delivery of a percutaneous stimulus to the sciatic nerve before its bifurcation into the common peroneal and posterior tibial nerves. The results showed that the H-reflex and M-wave measurements in all muscles increased ($p \leq 0.05$) after the simulated ankle joint effusion. However, these results suggested that AMI was not present in the soleus, peroneus longus, and tibialis anterior musculature during an ankle joint effusion, which was contradictory to the results of Hall's and McVey's studies.

Alteration of MNPE exists not only in ankle injuries but also knee injuries, and knee injuries may alter motoneuron pool excitability in ankle musculatures.[21,34] Hopkins et al.[21] conducted a study to compare changes in the magnitude of soleus motoneuron excitability in subjects with simulated knee joint effusion. Eleven healthy subjects with no lower extremity pathology participated in this study. The maximal H-reflex was measured five times at the same stimulus intensity with 20-second rest intervals. This measurement was recorded before injection of sterile saline to knee joint and at 1-hour intervals following the injection for 4 hours. An overall difference between groups was found. Maximal H-reflex measurements from hours 3 and 4 were significantly higher than the pre-injection measurements ($p \leq .05$). In this study, although soleus does not cross the knee joint, soleus H-reflex was affected by simulated knee joint effusion. This facilitation could be the result of a compensatory reaction by the soleus in response to inhibited quadriceps. Hopkins et al.[34] also conducted a similar study and revealed that all vastus medialis H-reflex measures after effusion (30 min 4.23±0.94 V; 90 min 4.15±1.11 V; 150 min 4.16±0.57 V; and 210 min 4.99±1.23) were decreased in relation to the pre-effusion measure (5.88±1.44 V; $P \leq 0.05$).

However, knee injuries do not alter MNPE of contralateral knee musculatures. Palmeieri et al.[36] conducted a study to investigate bilateral neuromuscular activity in the vastus medialis in subjects with simulated knee joint effusion. Sixteen subjects (8 for knee effusion group, 8 for control group) participated in this study. The effusion group had 60 ml of sterile saline injected into their superolateral knee joint capsules. The control group rested for 8 minutes. Bilateral recruitment curves for H-reflex and M-wave were obtained before and 10, 20, and 30 minutes after the effusion or rest. The H_{MAX} and M_{MAX} were collected, and the H:M ratios were calculated for data analysis. The results showed that H_{MAX} and H;M ratios decresed in the vastus medialis of ipsilateral limb, whereas no changes were detected in the vastus medials of contralateral limb.

2.2.2 Therapeutic Modality

Motoneuron pool excitability (H-reflex) is altered in the application of therapeutic modalities. Hopkins et al.[23] conducted a study to investigate the effects of cryotherapy and transcutaneous electric nerve stimulation (TENS) on AMI using the knee joint effusion model. Thirty healthy subjects participated in this study. H-reflex measurements were collected using a percutaneous stimulus to the femoral nerve and surface electromyography of the VM at pre-injection, post-injection, and 15, 30, 45, and 60 minutes after injection. The results showed that both cryotherapy and TENS disinhibited the quadriceps after knee joint effusion, and cryotherapy further facilitated the quadriceps motoneuron pool. Cryotherapy treatment resulted in facilitation of the VM motoneuron pool during the post-treatment phase. The TENS treatment failed to disinhibit the VM motoneuron pool by 30 minutes post-injection.

Also, alteration of MNPE with cryotherapy occurs in ankle joint, which is correlated with skin temperature of the ankle. Krause et al.[37] conducted a study to determine the relationship between skin temperature and MNPE. Ten healthy subjects participated in this study. Soleus H-reflex and ankle skin interface temperature were measured during ice application and rewarming. Electrical stimulation was delivered to produce 75% of each subject's maximum H-reflex. Ankle cooling ($r = -.95$, $P < .05$) exhibited a strong inverse relationship with soleus H-reflex. A positive correlation was observed between rewarming ($r = .74$, $P < .05$) and soleus H-reflex. In this study, temperature accounted for nearly 90% ($R^2 = .90$) of the variability in the soleus H-reflex during cooling and 55% ($R^2 = .55$) during rewarming, suggesting that more motoneurons were recruited as temperature decreases.

Motoneuron pool excitability (H-reflex) alters in exercises. Trimble et al.[38] conducted a study to determine the relationship between MNPE and exercise. Thirteen healthy subjects participated in this study. They were asked to balance on a specially designed balance board, and muscle activity of the triceps surae and tibialis anterior was measured. Subjects performed three blocks of standing control trials with the balance board supported, and seven blocks of balancing trials. Results indicated that the subjects were able to significantly reduce ($p < .001$) the gain of the soleus H-reflex while balancing and after the balance training. As a group, the subjects decreased their peak to peak amplitude of the soleus H-reflex by 26.2 percent from the initial standing block to the last balancing block. This result may represent functional adaptation in the central nervous system.

2.3 Balance Deficit

Sensorimotor system normally uses inputs from three afferent systems; vestibular system, visual system, and somatosensory system. Somatosensory system is damaged in ankle and knee injuries. Once somatosensory system damage occurs, the other two intact systems compensate for the somatosensory system to some extent. However, in most cases, it is not sufficient, leading to balance deficit.[4]

2.3.1 Ankle Injury

Ankle injury is one of the risk factors of balance deficit.[39] When lateral ankle sprain occurs, structural damage not only occurs to the ligamentous tissue, but also to the nervous and musculotendinous tissue around the ankle complex. While injury to the ligaments may result in laxity of the joints of the ankle complex, neuromuscular deficits are also likely to occur due to the injury to the nervous and musculotendinous tissue. These neuromuscular deficits may be manifested as impaired balance, reduced joint position sense, slower firing of the peroneal muscles to inversion perturbation of the ankle, slowed nerve conduction velocity, impaired cutaneous sensation, strength deficits and decreased dorsiflexion range of motion.[39]

There are two strategies to maintain balance: ankle strategy and hip strategy. Ankle strategy occurs when muscle contractions first occur at the ankle and cause a torque which rotates the body towards the support surface following a perturbation. This ankle strategy is generally used by healthy adolescents and young adults. On the other hand, hip strategy occurs when hip flexion or extension are performed in the direction of a perturbation. This hip strategy is not as effective as the ankle strategy, and it is typically used by the elderly and those with balance disorders.[39] Pinstaar et al.[40] revealed that individuals with lateral ankle sprain tended to use the hip strategy of balance maintenance more than the ankle strategy when balancing on their injured limbs.

Ross et al.[41] conducted a study to identify force plate measures that discriminate between ankles with functional instability and stable ankles. Twenty-two subjects without a history of ankle injury and 22 subjects with functional ankle instability (FAI) participated in this study, and performed a single-leg static balance test and a single-leg jump-landing dynamic balance test. Static force plate measures analyzed in both anterior/posterior (A/P) and medial/lateral (M/L) directions included the following: ground reaction force (GRF); center-of-pressure (COP); mean, maximum, and total COP excursion; and mean and maximum COP velocity. COP area was also analyzed for static balance. A/P and M/L time to stabilization quantified dynamic balance. Greater values of force plate measures indicated impaired balance. The FAI group had greater values than the stable ankle group for A/P GRF ($P = 0.027$), M/L GRF ($P = 0.006$), M/L COP ($P = 0.046$), A/P mean COP velocity ($P = 0.015$), M/L mean COP velocity ($P = 0.016$), A/P maximum COP velocity ($P = 0.037$), M/L mean COP excursion ($P = 0.014$), M/L total COP excursion ($P = 0.016$), A/P time to stabilization ($P = 0.011$), and M/L time to stabilization ($P = 0.040$).

Docherty et al.[5] conducted a study to determine if postural control deficits are present in participants with functional ankle instability (FAI) as measured by the Balance Error Scoring System (BESS). Sixty collegiate Division 1 athletes participated in this study. Thirty participants had functional ankle instability and thirty participants had no history of ankle injuries. Postural control was measured using the BESS. The BESS test battery requires participants to stand unsupported on two different surfaces (firm and foam) in three different stances (double, single, and in tandem). Each condition lasted 20 seconds. The number of errors were calculated for each individual condition and then summed to produce a total BESS score. The results showed that a significant group by condition interaction ($F_{5, 290} = 5.12$, $P < 0.001$) and significant main effects for group ($F_{1,58} = 16.01$, $P < 0.001$) and condition ($F_{5,290} = 228.88$, $P < 0.001$). Post hoc analyses revealed that subjects with functional ankle instability scored more errors (poorer balance) on the single stance firm condition (2.9±2.1 versus 1.6±1.3 errors), tandem stance foam condition (4.3±2.4 versus 2.7±1.6 errors), single stance foam condition (7.0±1.6 versus 5.6±1.8 errors), and total BESS score (15.7±6.0 versus 10.7±3.2).

Thus, balance deficit was detected in FAI subjects by using both forceplate and BESS.

2.3.2 Knee Injury

Knee injury is one of the risk factors of balance deficit. Herrington et al.[7] conducted a study to determine if decrements Star Excursion Balance Test (SEBT) reach distance is associated with ACL deficiency (ACLD). SEBT has been used to assess dynamic postural control. Twenty-five ACDL patients and twenty-five matched controls participated in this study. The analysis revealed that there were significant differences between the control group and the ACLD limb for the limb movement directions of anterior (p=0.0032), lateral (p=0.005), posterior-medial (p=0.0024) and medial (p=0.001). There were also significant differences between the control limbs and uninjured limb of the patients for the directions of medial (p=0.001) and lateral (p=0.001). ACLD patients appeared to have deficiencies in their dynamic postural control when compared to normal asymptomatic subjects. This balance deficit may be due to the deficiency of mechanical property of ACL itself and the disruption of mechanoreceptors in the knee.[42]

Lysholm et al.[2] conducted a study to determine postural control in the sagittal plane in chronic ACLD patients compared to in control subjects. Twenty-two ACLD patients and 20 uninjured subjects participated in this study. Measurement of the body sway was done on a fixed and sway-referenced force plate in both single-limb and two-limb stance, with the eyes open and closed, respectively. Further, an analysis of the postural reactions to perturbations backwards and forwards, respectively, was made in single-limb stance. The results showed that patients with ACLD had an impaired postural control in the antero-posterior direction in single-limb stance on their injured leg. They also showed a greater body sway and a prolonged reaction time when subjected to antero-posterior perturbations when standing on their injured leg.

2.3.3 Diabetes

Diabetes is one of the risk factors of balance deficit. Agrawal et al.[3] conducted a study to determine the prevalence of vestibular dysfunction among US adults, evaluate differences by sociodemographic characteristics, and estimate the association between vestibular dysfunction and risk of falls. In this study, they included data from the 2001-2004 National Health and Nutrition Examination Surveys, which were cross-sectional surveys of US adults aged 40 years and older (n = 5086). The main outcome measure was vestibular function as measured by the modified Romberg Test of Standing Balance on Firm and Compliant Support Surfaces. The results showed that odds of vestibular dysfunction were 70.0% higher among people with diabetes mellitus. Diabetes has been postulated to be vestibulotoxic because of its microangiopathic effects, which lead to ischemia of the vestibular structures. In addition, impaired glucose metabolism has been suggested to alter the metabolism of inner ear fluids, leading to labyrinthine dysfunction.

In the diabetic population, it is frequent to observe a distal symmetric primarily sensory polyneuropathy, with a reduction of the nerve conduction velocity. The degeneration of both the afferent and efferent nerves causes a greater sway during quiet standing task and a greater risk of falls.[8,9] However, it is still controversial that diabetes itself causes this balance deficit. Simoneau et al.[10] reported no significant difference during quiet standing task between diabetic patients without polyneuropathy and control subjects. Furthermore, Di Nardo et al.[11] reported the same conclusion when comparing control subjects with insulin-dependent diabetes mellitus patients without polyneuropathy. On the other hand, some studies did reported that neuromuscular system was affected in a diabetic population even without polyneuropathy. Simoneau et al.[10] reported weaker ankle dorsiflexor and plantarflexor torques during quiet standing task in diabetic patients without polyneuropathy compared to a control group. Furthermore, Centomo et al.[12] reported type-2 diabetic patients without polyneuropathy had significantly higher COP velocity, root-mean-square (RMS) amplitude, and range of COP displacements after a self-initiated reaching task compared to a control group. This study showed that type-2 diabetic subjects without peripheral neuropathy might have difficulties regaining their stability after a self-reaching task.

2.4 Cutaneous Input

Cutaneous input is afferent information from plantar cutaneous receptors. Different types of mechanoreceptors (plantar surface receptors and deep receptors) are involved and are widely distributed on the sole of the foot. Plantar surface receptors are mainly involved in the evaluation of the support surface whereas deep receptors are mainly involved in the evaluation of COP displacement. This information is sent to central nervous system (CNS) and integrated.[43]

2.4.1 Effects on Balance

Plantar cutaneous sensation is important for maintaining postural control. Plantar cutaneous afferents could potentially provide valuable feedback to the postural control system regarding the production of ankle torque, weight transfer between the legs, the rate of limb loading, and/or the nature of the support stance. Perception of forces under the feet is used to provide very detailed spatial and temporal information about the support surface properties and about the variations of pressure under the feet that directly result from a shift of COP displacement, which is used to generate internal estimate of the COP location.[32,44]

Palluel et al.[43] conducted a study to investigate the contribution of plantar cutaneous inputs induced by a spike support surface to the control of stance. Nineteen elderly (mean age 69.0 years, range 62–80) and 19 young adults (mean age 25.9 years, range 21–32) participated in this study. Subjects were instructed to stand (*standing* session) or to walk (*walking* session) for 5 min with sandals equipped with spike insoles (*spike* condition). Both sessions also involved a *no spike* condition in which participants stood or walked for 5 min without these insoles (*no spike* condition). The results provided evidence that wearing sandals with spike insoles can contribute, at least temporally, to the improvement of unperturbed stance in the elderly with relatively intact plantar cutaneous sensation, and also in young adults. As well as electric stimulation, spike insole increased afferent information by increasing pressure distribution on plantar surface of the foot.

Also, Corbin et al.[45] conducted a study to investigate the effect of textured insoles on postural control in double and single leg stance. Thirty-three healthy subjects participated in this study. Subjects performed 24, 10-second double and single stance balance trials with eyes opened and eyes closed, with and without a textured insole in subjects' shoes. Average COP velocity was calculated. The results showed that increased afferent information from textured insoles improved postural control in bilateral stance. The mechanism might be the same as Palluel's study.

Meyer et al.[44] conducted a study to investigate the role of plantar cutaneous sensation in unperturbed stance. This study revealed that forefoot cutaneous sensation produced mostly mediolateral postural effects while whole sole cutaneous sensation produced mostly anteroposterior postural effects.

2.4.2 Effects on H-reflex

Hiraoka[46] conducted a study to investigate the effect of the placement of a plate under the sole of the forefoot on the soleus MNPE in stance. Eight neurologically sound subjects participated in this study. A square plate (30 x 30 mm), either 3 mm or 6 mm in thickness, was placed under the left medial plantar eminence, under the left lateral plantar eminence, or under the left forefoot sole between the eminences, or a rectangular plate (120 x 30 mm), either 3 mm or 6 mm in thickness, was placed under the left metatarsal heads, and the Hmax/Mmax ratio was estimated. The result showed that a square plate placed under the lateral plantar eminence inhibited the ipsilateral soleus MNPE in stance. The decreased MNPE could be mediated by the afferent nerve fibers of the lateral plantar nerve. Two types of receptors could be related to the decreased MNPE: proprioceptive receptors in the intrinsic muscles and cutaneous receptors in the sole of the foot. A small plate placed under the lateral plantar eminence presses the skin over the plate, thus increasing cutaneous afferent discharge. Also, the plate stretches the intrinsic muscle, stimulating muscle spindle. These stimulation might enhances the presynaptic inhibitory pathway, resulting in decreased MNPE.

Chapter 3

Methods

3.1 Experimental Design

We used a crossover design with a single one-within subjects factor being sock condition (4 levels: five toed socks with textures (FSG), five toed socks without textures (FS), regular socks (RS), and no socks (NS)). We assessed changes in H:M ratio between pre- and post-conditions and changes in COP velocity between pre- and post-conditions. This study consisted of four separate sessions conducted 24 hours apart. Each session had pre-condition balance test, pre-condition MNPE test, post-condition balance test, and post-condition MNPE test. All sessions were conducted at the same time of the day (within two hours).

3.2 Subjects

Seventeen healthy subjects between the ages of 18-35 years were used for this study. Subjects were excluded if they had suffered a previous ankle sprain, had a history of lower extremity fracture or surgery, or were currently seeking medical attention for any lower extremity injury. We also excluded all participants with neurological pathologies, vestibular disorders, or concussions within the past 6 months.

Demographics including height, weight, body mass index (BMI), sex, and age were collected from each subject. All subjects signed an informed consent form approved by the institutional review board at the University of Toledo prior to being included in the study.

3.3 Randomization

All participants performed each sock condition. The order of sock condition was randomized using a 4x4 Latin square technique. The order was determined on the first session following consent into the study. There was a minimum of 24 hours between each testing session. All subjects were tested at approximately the same time of the day (within 2 hours of the time the baseline test was performed) to help minimize diurnal effects on the central nervous system.

3.4 Instrumentation

Motor Neuron Pool Excitability

H-reflex and muscle response (M-wave) measurements were collected with surface electromyography (EMG) (MP100C, BIOPAC Systems Inc, Santa Barbara, California, USA). Analog to digital signal conversion was processed with a 16 bit converter (MP150, BIOPAC Systems Inc). Signals were amplified (EMG100A, BIOPAC Systems Inc; gain 1000) from disposable pre-gelled Ag/AgCl electrodes (BIOPAC Systems Inc). The electrodes were positioned 1.75 mm apart over the muscle bellies of the tibialis anterior, peroneus longus, and soleus. The EMG signal was filtered from 1 to 5000 Hz and was sampled at 2000 Hz with a common mode rejection ratio of

20 dB. Reflexes were elicited with the BIOPAC stimulator module (STIM100C, BIOPAC Systems, Inc.), a 200 volt maximum stimulus isolation adaptor (STIMSOC BIOPAC Systems, Inc), a 2 mm shield disk electrode, (EL254S BIOPAC Systems, Inc.) and a 7 cm carbon impregnated dispersive pad.

COP Velocity

COP velocity was collected with a Bertec 4060-NC forceplate (Bertec Cop.; Columbus, OH) and the signal was collected and processed with the Motion Monitor software (Innovative Sports Training, Inc., Chicago, IL) and MATLAB software (The Mathworks Inc., Natick, MA). The COP velocity signal was sampled at 50 Hz and filtered from 1 to 10 Hz.

Socks

The five toed socks with textures on the plantar surface (Grip Five Toed Socks, Tabio Corporation, Osaka, Japan), the five toed socks without textures on the plantar surface (Plain Five Toed Socks, Tabio Corporation, Osaka, Japan), and the regular socks (Cotton 100% Plain, Tabio Corporation, Osaka, Japan) were worn during the measurement of MNPE and COP velocity.

3.5 Informed Consent

Prior to any of the following procedures potential participants must begin the informed consent process by providing written informed consent prior to being included into the study. A form approved by the University of Toledo Biomedical Institutional

Review Board (#**106645**) must be signed prior to participation for each subject. The researchers answered any questions the subject has regarding the study at this time.

3.6 Subject Preparation

Four locations were shaved, abraded with fine sandpaper, and cleaned with isopropyl alcohol for the application of the EMG electrodes. Surface EMG electrodes were placed 1.75 cm apart on the tibialis anterior, peroneus longus, and soleus musculature to capture the maximum peak-to-peak amplitude of the H-reflex and M-wave for each muscle. The tibialis anterior electrodes were positioned at the approximate midpoint of the muscle belly. The peroneus longus electrodes were positioned 2–3 cm distal to the head of the fibula. The soleus electrodes were positioned 2–3 cm distal to the medial head of the gastrocnemius. A ground (reference) electrode was placed on the ipsilateral medial malleolus.[19]

A stimulating electrode (cathode) was placed in the superior portion of the popliteal fossa in order to access the sciatic nerve before its bifurcation into the common peroneal and tibial nerves.[19] The corresponding anode was paced superior to the patella. In order to find the sciatic nerve bifurcation, the stimulating electrode was placed at the fibular head. A 1ms square wave pulse, with an intensity to elicit a muscle response in the tibialis anterior and the peroneus longus was delivered. The electrode was then manually moved in a superior medial direction, periodically administering stimulation to the common peroneal nerve. The electrode continued to be moved until a muscle response could be elicited in all three muscles, indicating that the stimulating electrode was over the sciatic nerve prior its bifurcation. Adhesive tape was applied to the stimulating electrode to maintain its position for the duration of data collection.[36]

3.7 Procedures

This study consisted of four sessions. Each session had pre-condition balance test, pre-condition MNPE test, post-condition balance test, and post-condition MNPE test. All sessions were conducted on the same time of the day (within two hours). Subjects were instructed not to consume caffeine that day because caffeine might influence MNPE.[47,48]

The dominant leg, which was defined as the stance leg when kicking a soccer ball, was tested in both balance test and MNPE test.[45]

Pre-condition balance test

The subjects were tested wearing no socks. The subjects performed single leg balance on a force plate, with their hands on their iliac crests, with their eyes closed. The subjects were instructed to keep the non-test limb off the ground in a comfortable position without the limb touching the floor. The subjects stood as stable as possible for 15 seconds. If a subject felt unstable and touched down with the non-test limb or moved the stance foot out of position, the trial was discarded and repeated. The subjects performed 3 acceptable trials with at least 1-minute rest between trials. For each trial, the COP data was collected, and the average for the 3 trials was calculated.

Pre-condition MNPE test

The subjects were tested wearing no socks. The subjects performed double leg stance on a force plate, with their hands on their iliac crests, with their eyes open while electric stimulation is elicited on the sciatic nerve. During the trials, subjects were instructed to focus on a large "X" positioned on the wall 3.5 m in front of them and 1.5 m from the floor. The subjects were instructed to "clear their mind" and attempted to not think about anything to minimize potential influence on the measured variables.

In order to obtain H_{MAX}, the stimulation started with 2.0V and increased voltage by 0.2V until it causes maximal peak-to-peak value of H-reflex. Once it reached the voltage to cause maximal peak-to-peak value of H-reflex, the stimulation with the voltage was delivered 5 times. For these 5 trials, H-reflex data was collected, and the average for the 5 trials was calculated. The interval between stimulations was set at least 20 seconds. Then, in order to obtain M_{MAX}, the stimulation started with 7.0V and increased voltage by 0.2V until it causes maximum peak-to-peak value of M-wave. Once it reached the voltage to cause maximal peak-to-peak value of M-wave, the stimulation with the voltage was delivered 5 times. For these 5 trials, M-wave data was collected, and the average for the 5 trials was calculated.

<u>Post-condition balance test</u>

The subjects were tested wearing five toed socks with textures, five toed socks without textures, regular socks, or no socks. The subjects performed single leg balance, and COP data of 3 trials was collected in the same manner as the pre-condition test.

<u>Post-condition H-reflex test</u>

The subjects were tested wearing five toed socks with textures, five toed socks without textures, regular socks, or no socks. The subjects performed double leg stance, and 5 H_{MAX} and 5 M_{MAX} data was collected in the same manner as the pre-condition test.

3.8 Statistical Analysis

All statistical analysis was performed with the Statistical Package for the Social Sciences for Windows (version 17.0; SPSS Inc, Chicago, IL). Means and standard deviation (SD) were calculated for H:M ratio and COP velocity for all 4 conditions. A one-way ANOVA was used to compare percent changes of H:M ratio and COP velocity between conditions. Independent variables was condition (4-levels); five toed socks with textures, five toed socks without textures, regular socks, and no socks. Dependent variables was changes in H:M ratio and percent changes in COP velocity between pre-condition and post-condition. Post hoc analysis was performed to determine differences between conditions. Bivariate Pearson Product Moment Correlations were used to determine the relationship between the changes in H:M ratio and changes in COP velocity. Correlation coefficients were set as following: 0.00-0.25 is little or no relationship, 0.25-0.50 is fair relationship, 0.50-0.75 is moderate to good relationship, and 0.75-1.00 is good to excellent relationship.[49] A priori alpha level was set at $P < 0.05$. Also, effect sizes were calculated ((sock conditions – no sock condition)/ pooled standard deviation) with 95 percent confidence intervals.

Chapter 4

Results

Seventeen subjects volunteered to participate in this study. However, data for three of the volunteers could not be used because one did not display an obtainable H-reflex reflex, one strained hamstring muscles in his daily exercise and subsequently dropped out of the study, and one felt too dizzy to participate in data collection. Fourteen subjects (5 males, 9 females; age 22.9±3.4 years; height 170.1±7.3 cm, weight 67.6±9.5 kg; BMI 23.4±3.5) completed all 4 sessions, and data for those subjects were analyzed.

Mean values and standard deviations for percentage changes of H:M ratio and COP velocity are presented in Table 1 and Table 2. There were no significant differences between sock conditions for tibialis anterior H:M ratio ($F_{3,55}$=.252, P=.860), peroneus longus H:M ratio ($F_{3,55}$=.77, P=.56), or soleus H:M ratio ($F_{3,55}$=.40, P=.76). There were no significant differences between sock conditions for Medial/Lateral direction COP velocity ($F_{3,54}$=1.40, P=.25) or anterior/posterior direction COP velocity ($F_{3,54}$=.19, P=.91). Post Hoc test revealed that there were no significant differences between any two conditions (P>.05). All effect sizes are presented in Table 3 and Table 4. Effect for FSG on MNPE are weak to small (-.06 to -.28), effect for FS on MNPE are weak to small (.02 to .49), and effect for RS on MNPE are weak to small (-.05 to -.35). Effect for FSG on balance are weak to small (-.11 to -.24), effect for FS on balance are small to moderate (-.37 to -.57), and effect for RS on balance are weak to moderate (-.07 to -.70). All 95 percent confidence intervals cross zero.

There was a significant negative correlation between percent change in peroneus longus H:M ratio and percentage change in anterior/posterior direction COP velocity ($r=-.60$, $r^2=0.36$, $P=.02$) in the five-toed socks with texture (FSG). In applying five-toed socks without textures (FS), there was significant negative correlation between percentage change in tibialis anterior H:M ratio and percentage change in anterior/posterior direction COP velocity ($r=-.63$, $r^2=.40$, $P=.02$), which is fair relationship. In applying regular socks and no socks, there were no significant correlation between percentage change in H:M ratio and percentage change in COP velocity ($P>.05$).

Table 1. % Change in H:M ratio, Mean (SD)

	TA	PL	Soleus
FSG	5.62 (20.23)	7.07 (26.73)	9.77 (17.77)
FS	0.33 (24.61)	14.56 (28.51)	10.90 (37.06)
RS	6.92 (26.32)	1.01 (27.82)	0.86 (17.68)
NS	8.59 (33.66)	0.40 (29.17)	13.09 (45.71)

*TA=Tibialis anterior, PL=Peroneus longus

Table 2. % Change in COPV, Mean (SD)

	ML Direction	AP Direction
FSG	-5.43 (11.83)	-8.11 (31.61)
FS	-11.09 (14.16)	-7.11 (12.72)
RS	-11.71 (11.74)	-3.92 (28.17)
NS	-4.26 (9.39)	-2.32 (13.07)

Table 3. Effect Sizes of % Changes in H:M Ratio (95% Confidence Intervals) for FSG, FS, and RS

	TA	PL	Soleus
FSG	-0.11 (-0.85 to 0.64)	-0.28 (-1.02 to 0.47)	-0.06 (-0.79 to 0.69)
FS	0.24 (-0.51 to 0.97)	0.49 (-0.27 to 1.23)	0.02 (-0.72 to 0.76)
RS	-0.10 (-0.83 to 0.65)	-0.05 (-0.79 to 0.69)	-0.35 (-1.09 to 0.40)

* TA=Tibialis anterior, PL=Peroneus longus

*Positive numbers indicate increased MNPE compared to NS condition

>.8=strong, .5-.8=moderate, .2-.5-small, and <.2=weak

Table 4. Efefct Sizes of % Changes in COPV (95% Confidence Intervals) for FSG, FS, and RS

	ML Direction	AP Direction
FSG	-0.11 (-0.85 to 0.64)	-0.24 (-0.98 to 0.51)
FS	-0.57 (-1.31 to 0.20)	-0.37 (-1.11 to 0.39)
RS	-0.70 (-1.47 to 0.11)	-0.07 (-0.84 to 0.70)

*Negative numbers indicate improved balance compared to NS condition

*>.8=strong, .5-.8=moderate, .2-.5-small, and <.2=weak

Chapter 5

Discussion

5.1 Motoneuron Pool Excitability

Application of five toed socks with and without textures did not change MNPE of the anterior tibialis, peroneus longus, and soleus muscles during double leg stance compared to wearing regular socks or no socks in healthy subjects as reported in previous studies using cryotherapy and TENS.[23,37] All conditions showed non-significant increases in MNPE percent change scores of three lower extremity muscles. For tibialis anterior, NS improved H:M ratio the most (FSG increased H:M ratio 5.62%, FS increased 0.33%, RS increased 6.92%, and NS increased 8.58%). For peroneus longus, FS increased H:M ratio the most (FSG increased H:M ratio 7.07%, FS increased 14.56%, RS increased 1.01%, and NS increased 0.40%). For soleus, NS increased H:M ratio the most (FSG increased H:M ratio 9.77%, FS increased 10.90%, RS increased 0.86%, and NS increased 13.09%). Previously, Hopkins et al[23] suggested that cryotherapy-induced MNPE facilitation was likely caused by increased excitatory stimuli to the central nervous system (CNS) from a combination of mechanoreceptors and thermoreceptors facilitation in the periphery. It was thought that textures of five toed socks may cause hyperethesia of the plantar surfaces of the feet, resulting in increased cutaneous afferent receptor activity[45]. Also, individually wrapped toes may increase proprioceptive and cutaneous inputs by enhancing tactile sensations and providing pressure to the skin between toes[28-30]. Because of the lack of facilitation in MNPE found after the five toed socks application, it is reasonable to hypothesize that although five toed socks with and without plantar textures increases cutaneous afferent receptor activity, it may be interpreted differently by the CNS compared to cryotherapy or TENS.[23,37] Also, it is possible that textures of five toed socks stimulated fewer receptors than cryotherapy or TENS in previous studies reporting increased MNPE[23,37]. Cryotherapy stimulates thermoreceptors, which may activate more nerve fibers than textured socks.

Weak to small negative effect sizes were found in applying five toed socks with textures, suggesting that MNPE changes in five toed socks with textures was smaller in the experimental condition compared to the no sock condition in all three muscles. The decrease in all conditions may have been due to a learning effect. Weak to small positive effect sizes were found in applying five-toed socks without textures, suggesting that MNPE changes in five toed socks without textures was larger in the experimental condition compared to the no sock condition in all three muscles. Weak to small negative effect sizes were found in applying regular socks, suggesting that MNPE changes in regular socks was smaller in the experimental condition compared to the no sock condition in all three muscles. Decreased MNPE may be necessary to perform balance task with external support, such as five toed socks with textures. Gripping ability from the plantar textures may produce more stabilization of the foot against the floor, resulting in decreased necessity of muscle response. On the other hand, increased MNPE may be necessary to perform a balance task without external support. Increased afferent stimuli from cutaneous receptors are integrated in CNS and efferent stimuli are delivered to peripheral muscles to maintain balance. Increased reflex excitability of muscle fibers might be used to maintain balance in the presence of less reflex excitability. However, all 95% confidence intervals crossed zero, which indicates that it is possible that any sock conditions can increase or decrease MNPE.

5.2 Balance

Application of five toed socks with and without plantar textures did not improve single leg balance either in medial/lateral oranterior/posterior directions compared to wearing regular socks or no socks in healthy subjects. All conditions showed non-significant decreases in COP velocity percent change scores. For medial/lateral direction, RS decreased COP velocity most (FSG decreased COP velocity 5.43%, FS decreased 11.09%, RS decreased 11.71%, and NS decreased 4.26%). For anterior/posterior direction, FSG decreased COP velocity most (FSG decreased COP velocity 8.11%, FS decreased 7.11%, RS decreased 3.92%, and NS decreased 2.32%). Previously, Shinohara et al[28-30] suggested that five toed socks improved static and dynamic balance because individually wrapped toes may increase proprioceptive and cutaneous input by enhancing tactile sensations and providing pressure to the skin between toes. Also, Corbin et al[45] suggested that textured insoles improved balance during bilateral stance because textured insoles increased cutaneous afferent receptor activity, especially with eyes-closed situation. Also, Palluel et al[43] suggested that plantar surface receptors are mainly involved in the evaluation of the support surface whereas deep receptors contribute to the continuous control of COP displacements, and textures may stimulate deep receptors and enhance balance. However, our results were different from those previous studies. It is possible that our task (single leg balance for 15 seconds with eyes closed) was too easy. In the current study, no subjects had chronic ankle instability (CAI) or substantial balance deficits. Our subjects may have completed single leg balance without any difficulty in all sock conditions. Therefore, future study should focus on not only static balance, but also dynamic balance. Also, it is possible that most of the subjects had not experienced this enhanced sensation around the toes. This enhanced sensation may be interpreted differently by the CNS. Therefore, in the future study, subjects should have time to get used to five toed socks with and without textures.

Weak to small negative effect sizes were found in applying five toed socks with textures, suggesting that five toed socks with textures provided better balance compared to no sock condition. Small to moderate negative effect sizes were found in applying five toed socks without textures, suggesting that five toed socks without textures provided better balance compared to no sock condition, especially medial/lateral direction. Small to moderate negative effect sizes were found in applying regular socks, suggesting that regular socks provided better balance compared to no sock condition, especially medial/lateral direction. However, all 95% confidence intervals crossed zero, which indicates that sock conditions may affect single leg balance both positively and negatively.

5.3 Correlation

In applying five toed socks with textures, there is a fair negative relationship between peroneus longus MNPE and anterior/posterior COP velocity. It may indicate that five toed socks with textures increased peroneal longus MNPE, resulting in improved anterior/posterior direction single leg balance. However, we are unable to conclude if correlations were due to socks or if these physiologic factors are related. Previously, Shinohara et al[29,30] reported that five toed socks improved anterior and posterolateral direction dynamic balance. Results of the current study are similar to his studies in the way that five toed socks increased anterior direction balance. Although current study investigated static balance, it can be hypothesized that textures of the five toed socks may increase cutaneous afferent receptor activity by increasing contact surface between floor and foot or stimulating deep receptors, and then increased cutaneous input may activate more efferent motoneurons to peroneus longus, which assists in anterior/posterior stability as a concentric plantar flexor or eccentric dorsiflexor, resulting in decreased anterior/posterior direction COP velocity.

In applying five toed socks without textures, there is a fair negative relationship between tibialis anterior MNPE and anterior/posterior COP velocity. It may indicate that five toed socks without textures increased tibialis anterior MNPE, resulting in improved anterior/posterior direction single leg balance. However, we are unable to conclude if correlations were due to socks or if these physiologic factors are related. It can be hypothesized that separated toes may increase contact area between toes and floor, and increased sensory information from separated toes may improve anterior/posterior direction balance by increasing reflex activity of tibialis anterior, which works as a concentric plantar flexor or eccentric dorsiflexor, resulting in decreased anterior/posterior direction COP velocity.

All changes occurred in the anterior/posterior direction only. It is possible that subjects did not have balance deficits or challenge maintaining balance in the medial/lateral direction. Therefore, there may not have any room for significant improvement in medial/lateral direction balance.

5.4 Clinical Importance

In the current study, five toed socks with and without textures did not change MNPE and did not change COP velocity during single leg static balance in healthy subjects. Five toed socks with and without textures should not be used to improve postural control. Because of the lack of increase in MNPE, five toed socks with and without textures should not be used to decrease AMI in rehabilitation of ankle injuries.

5.5 Conclusion

In the current study, five toed socks with and without textures did not change MNPE and did not change COP velocity during single leg static balance in healthy subjects. Some correlations were found between changes in MNPE and changes in COP velocity; however changes in MNPE are not likely to be the mechanism of improving postural control.

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