LONG-TERM EFFECTS OF EXTERNAL ANKLE SUPPORT USE ON MUSCLE STRENGTH
AND ACTIVITY

A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Science in Kinesiology

By
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ABSTRACT

LONG-TERM EFFECTS OF EXTERNAL ANKLE SUPPORT USE ON MUSCLE STRENGTH AND ACTIVITY

By
Ashley Meyer
Master of Science in Kinesiology

One of the most commonly used methods of both prevention and rehabilitation of ankle sprains is the use of external ankle support, typically in the form of taping or prophylactic ankle braces. Short-term effects of external ankle support have been studied extensively. However, research is lacking in terms of the long-term effects. It is the goal of the present study to determine the long-term effects of external ankle support on evertor strength and muscle activity. It is hypothesized that, due to reliance of the ankle musculature on the external ankle support to prevent excessive inversion, strength will decrease and that this strength deficit will lead to compensatory increases in muscle activity during a functional task.

A total of 38 healthy, college-aged, physically active participants were utilized to analyze these effects. Participants had no history of ankle injury within the past six months and were removed from the study if they incurred an injury that
prevented them from full participation in physical activity. Participants underwent pre- and post-application testing before and after an eight-week period, during which the participants in the treatment group wore a prophylactic ankle brace on either the dominant or non-dominant ankle. Testing consisted of eccentric isokinetic peak torque testing at 90 degrees/second for both inversion and eversion, and electromyography (EMG) analysis while completing the Balance Error Scoring System (BESS) test.

Following the intervention period, it was found that participants in the treatment group exhibited significantly decreased eccentric eversion strength ($p = 0.002$). The control group did not exhibit significant differences in any of the testing variables. None of participants in the treatment group exhibited significant changes in their eccentric inversion strength, EMG activity during the BESS test, or in balance testing scores. It is concluded that long-term external ankle support application may cause eccentric eversion strength deficits. Due to the results of the study, clinicians may look to other methods of prevention and rehabilitation of inversion ankle sprains other than external ankle support in order to avoid potential long-term strength deficits.
INTRODUCTION

Due to the high incidence of ankle injuries found in athletic participation, extensive research has been conducted examining these injuries. Much of the focus of this research has been on inversion ankle sprains due to their higher frequency (Cordova, Ingersoll, & Palmieri, 2002). Researchers have extensively studied different methods in which these injuries can be prevented and to what extent these methods are effective. One of the most common methods of prevention is providing external stabilization of the ankle joint via application of athletic tape or a prophylactic brace. By providing proprioceptive feedback and restricting range of motion in the ankle joint, the use of external ankle support has been found to be successful in preventing injury to the ankle (Cordova et al., 2002). However, the long-term effects of external ankle support have not been studied as extensively as the immediate effects. It is thought among clinicians that long-term application of external ankle support may lead to weakened ankle musculature due to dependency on the external support (Cordova & Ingersoll, 2003). It is speculated that this decrease in ankle strength would cause a compensatory increase in muscle activity during functional tasks. An increase in muscle activity could lead to increased rates of fatigue and, in turn, increase the risk of injury. Most of the research in this area has focused on the muscle activity of the ankle evertors, specifically the peroneus longus. However, the effects of long-term application on evertor muscle strength have not been a focus of this research to date. Therefore, the purpose of this study
is to investigate the long-term effects of external ankle support on the strength and muscle activity of ankle musculature. It is hypothesized that, after eight weeks of external ankle support application during all sport-specific activity, ankle evertor muscles will undergo a decrease in strength and an increase in muscle activity during a balance task.
REVIEW OF LITERATURE

Ankle anatomy

The ankle complex is made up of three separate joints, or articulations (Fong, Chan, Mok, Yung, & Chan, 2009). The distal tibiofibular syndesmosis is the articulation formed between the distal portions of the tibia and fibula in which only slight rotational motions occur to allow for maximal articulation at the talocrural joint. The talocrural joint consists of an articulation of the dome of the talus with the malleoli of the tibia and the fibula, also known as the ankle mortise (Golano, Vega, de Leeuw, Malagelada, Manzanares, Gotzens & Niek van Dijk, 2010). This joint behaves like a hinge joint and allows plantar flexion and dorsiflexion to occur. Pronation and supination occur at the subtalar joint, which is comprised of the calcaneus and distal talus (Fong et al, 2009).

The three ligament groups of the ankle that support each of these joints can be categorized according to their anatomical orientation. The syndesmotic ligament complex supports the distal tibiofibular syndesmosis and is comprised of the anterior tibiofibular, posterior tibiofibular, and interosseous tibiofibular ligaments. The deltoid ligament joins the medial malleolus via three bands of tissue that connect to the talus, calcaneus, and navicular bones (Golano et al., 2010). The lateral ligaments are comprised of the anterior talofibular, calcaneofibular and posterior talofibular ligaments (Fong et al., 2009).

Ankle injury

An ankle sprain, or injury to the ligaments of the ankle, is the most common
injury to the ankle, as well as the most common injury reported by collegiate athletes (Fong et al., 2009). Because it is the weakest and most anatomically vulnerable ligament, the anterior talofibular ligament is the most commonly injured during an inversion ankle sprain. Eversion ankle sprains are not as prevalent as inversion ankle sprains due to the lateral bony block created by the lateral malleolus and calcaneus, which limits the range of eversion allowed in the joint (Fong et al., 2009). Therefore, the focus of ankle injury in this study will be on inversion ankle sprains.

The typical mechanism of injury for an inversion ankle sprain is excessive inversion of the ankle in the plantar flexed position, in which the anterior talofibular ligament is most commonly injured. When excessive inversion occurs in the dorsiflexed position, the calcaneofibular ligament is more prone to injury. Individuals suffering from an ankle sprain usually present with pain, swelling, an inability to walk, and the feeling of instability (Fong et al., 2009).

**Incidence of ankle injuries**

Ankle injuries have been found to be the most prevalent injuries incurred by athletes involved in sports that require running, jumping, and changing direction, especially when other players are close by (Nelson, Collins, Yard, Fields, & Comstock, 2007). Epidemiologic studies focusing on the incidence of ankle injuries in athletics have found that these injuries are the most common injuries in volleyball, basketball, football and soccer (McKay, Goldie, Payne, & Oakes, 2001; Nelson et al., 2007; Verhagen, Van der Beek, Bouter, Bahr, & Van Mechelen, 2004).
According to a study completed by Nelson et al. (2007), ankle injuries were reported as the most common types of injuries incurred by high school athletes over the course of a year, the majority of which were ankle sprains.

Studies examining the incidence of ankle injuries among basketball and volleyball players have found that the nature of these sports, in which players are required to jump and land often nearby to other players, puts athletes at an increased risk. Approximately half of the ankle injuries sustained by basketball and volleyball players occur during landing on either another player or the court surface. Additionally, players who have previously injured their ankles, especially within the past year, are at an increased risk for re-injury (McKay et al., 2001; Verhagen et al., 2004). History of a previous ankle injury, or sprain, has been identified as the most common risk factor for an ankle sprain (Willems, Witvrouw, Verstuyft, Vaes, & De Clercq, 2002). McKay et al. (2001) found that athletes who had a history of ankle injury had a fivefold increased risk of sustaining another injury as opposed to athletes who had no history of ankle injury.

Furthermore, ankle injuries are most commonly seen after the onset of fatigue. Gautrey, Watson & Mitchell (2014) found that both healthy individuals and those with functional ankle instability exhibited greater center of pressure excursion following localized and globalized fatigue. Medial, lateral and mediolateral excursion increased significantly in all participants due to globalized fatigue. Localized fatigue was found to increase excursion in the lateral and mediolateral directions for the functionally unstable ankle participants. Therefore,
fatigue induced by physical activity, specifically prolonged dynamic activity involving multiple joints, may increase the risk of ankle injury.

**Chronic ankle instability**

Chronic ankle instability (CAI) is defined as a neuromuscular deficit that encompasses the residual mechanical and/or functional instability present in individuals as a result of previous ankle injury (Delahunt, O’Driscoll & Moran, 2009). Willems et al. (2002) found that CAI is likely to predispose individuals to re-injury due to the lack of proprioception and evertor muscle strength. The decrease in proprioception seen with these individuals causes them to present with increased rear foot inversion before making contact with the ground after jumping, leaving them more vulnerable to inversion ankle sprains (Delahunt et al., 2009). David, Halimi, Mora, Doutrellot and Petitjean (2013) found that individuals with CAI exhibited significantly lower peroneus longus EMG activity and a 22% deficit in eccentric eversion strength during isokinetic testing compared to healthy controls. The authors of this study attributed these deficits in eversion strength and muscle activity to adaptations in neural drive following ankle injury, leading to impaired postural stability and re-injury of the ankle. Invertor weakness and balance deficits have also been found in subjects with chronically unstable ankles (Lin, Liu, Hsieh & Lee, 2007).

**Interventions for ankle re-injury**

Several interventions have been used in sports medicine in order to prevent
ankle re-injury, including proprioceptive training, technical training, strength training, and the use of ankle orthoses and/or taping (Mohammadi, 2007; Stasinopoulos, 2004).

When an athlete has sustained an ankle injury, proprioception decreases due to damage done to the mechanoreceptors, which decreases joint position sense and leaves the athlete vulnerable to re-injury (Mohammadi, 2007). According to Mohammadi (2007), proprioceptive exercises are intended to increase one's own awareness of the body in terms of its position in space and its movements and may include balancing on boards and/or disks. Balance is the body's ability to maintain and/or restore itself to equilibrium following a perturbation or during physical activity. Clinicians often use postural stability exams to assess an individual's ability to balance in order to determine risk of injury or to measure rehabilitative progress following an injury (Lin et al., 2009). Several different postural stability assessment tools are available to clinicians, including the Balance Error Scoring System (BESS), Single Leg Balance, (SLB), single-leg hop and Star Excursion Balance tests (SEBT). The BESS and SLB tests are static tests, whereas the SEBT and the single-leg hop tests are dynamic. All of these tests are correlated in their assessment of postural stability. However, the SEBT is the most difficult to administer of the four tests in terms of its time and equipment requirements and the SLB has poor test/retest reliability in comparison to the BESS (Clark, Saxion, Cameron, & Gerber, 2010).

The study conducted by Mohammadi (2007) found that, in comparison to no intervention at all, proprioceptive training is effective in reducing the rate of ankle
re-injury amongst soccer players who had previously sprained their ankles. The study done by Stasinopoulos (2004) also found that proprioceptive training was an effective intervention to reduce the incidence of ankle re-injury in female volleyball players in comparison to the sole use of orthoses, but was not as effective as technical training.

Technical training done by Stasinopoulos (2007) included the take-off and landing techniques of volleyball players, as well as lateral movements when preparing for a block. The players were taught to jump vertically as opposed to forwards when going up to hit ball so that landing on another player’s foot under the net could be avoided. In comparison to the interventions of proprioceptive training and orthoses, technical training was found to be the most effective in preventing ankle re-injury (Stasinopoulos, 2007).

The strength of the muscles responsible for ankle eversion has been linked to ankle re-injury. It has been found that the lateral ligaments in the ankle are protected when the evertors eccentrically contract during inversion that could potentially cause an inversion ankle sprain (Mohammadi, 2007). Mohammadi (2007) studied the effectiveness of strength training of the ankle evertors as an intervention for ankle re-injury. Soccer players in the strength-training group were required to complete resistance exercises emphasizing muscle contraction of the ankle evertors over the course of a season. No significant difference was found in the recurrence of ankle injury between the strength-training group and the group receiving no intervention (Mohammadi, 2007). However, Mohammadi (2007)
explained that the intervention may have been statistically insignificant due to the relatively small sample size used in the study but, given a larger sample size, may prove to be clinically significant.

The main reason for the use of orthoses in preventing ankle re-injury is to improve proprioception in addition to providing mechanical stability (Mohammadi, 2007; Stasinopoulos, 2004). However, both Mohammadi (2007) and Stasinopoulos (2004) found that the use of ankle orthoses was the least effective intervention in preventing ankle re-injury. In participants who had a history of more than three ankle sprains, orthoses were completely ineffective in preventing re-injury (Stasinopoulos, 2004). However, the widespread use of orthoses as the most commonly used preventative intervention is most likely due to its simple application, maintenance, and low cost (Mohammadi, 2007).

**Immediate effects of external ankle support**

As discussed earlier, taping and bracing are utilized to increase ankle proprioception via the stimulation of cutaneous mechanoreceptors (Cordova et al., 2002; Wilkerson, 2002). This increase in proprioception may allow for an increase in postural control, which has been linked to decreased recurrence of ankle sprains (Cordova et al., 2002). Taping may be more effective in providing proprioceptive feedback due to its ability to improve inversion position in comparison to ankle bracing (Wilkerson, 2002).

The acute biomechanical effects of ankle bracing and taping have been studied extensively. Research has shown immediate differences in the taped and/or
braced condition in ankle range of motion. It was found that the application of an ankle brace and/or taping reduces ankle inversion, eversion, plantar flexion and dorsiflexion (Delahunt et al., 2009; Zhang, Wortley, Silvernail, Carson, & Paquette, 2012). Decreasing inversion is beneficial, considering that the vast majority of ankle sprains are inversion ankle sprains. The decrease seen in plantar flexion is also beneficial in the prevention of ankle sprains, since the plantar flexed position is less stable than the neutral and dorsiflexed positions, and because more inversion can occur in the plantar flexed position (Zhang et al., 2012). It was found that taping effectively reduces plantar flexion both before and during initial contact when landing (Delahunt et al., 2009). Zhang et al. (2012) found that this decrease in plantar flexion during landing may be responsible for the increase found in peak vertical ground reaction forces due to the increased stiffness of the ankle joint.

Research has shown that taping may not be as effective as bracing in restricting range of motion after ten minutes of activity (Cordova et al., 2002).

Electromyography (EMG) studies have shown how taping and bracing may alter ankle eversion torque and peroneal stretch reflex amplitude. Due to proprioceptive feedback, some research has found that peroneal activation increases with the application of taping and bracing (Wilkerson, 2002). It has also been found that the maximal torque level achieved by the peroneal muscles can be reached in less time with the application of an ankle brace, meaning that bracing has the ability to enhance ankle inversion reaction time (Cordova et al., 2002; Konradsen, Peura, Beynnon, & Renstrom, 2005). Furthermore, the greater the
instability of the ankle joint, the greater the improvement seen with reaction time
due to the application of tape (Wilkerson, 2002). However, it was found in the same
study that pre-activation of the peroneal muscle group was even more efficient at
creating a reaction to sudden ankle inversion, showing that pre-activation training
may be more beneficial in preventing ankle sprains than using prophylactics
(Konradsen et al., 2005). Some research, on the other hand, has shown no effect on
peroneal activation (Wilkerson, 2002). A study done by Sefton, Hicks-Little, Koceja
and Cordova (2007) found no differences in the stretch reflex of the peroneus
longus between braced and unbraced conditions. Additionally, it has been found
that bracing has no effect on the reflexive responses of the peroneus longus and
peroneus brevis, as well as the tibialis anterior during sudden inversion and plantar
flexion (Kernozek, Durall, Friske, & Mussallem, 2008).

The immediate effects of ankle taping and bracing on sport specific skills
have also been studied. Researchers’ findings have been generally inconclusive as to
whether or not taping and bracing affect performance (Wilkerson, 2002). A study
by Jerosch & Schoppe (2000) examined the effects of bracing on the functional
performance of subjects during several different tests. The researchers utilized
static and dynamic balance testing, sidestepping, isokinetic force testing, angle
reproduction testing, a health questionnaire, and the Weber ankle score to
determine differences between the braced and unbraced conditions. They found
minimal to no differences on sport specific skills between the two conditions, as is
consistent with most research published on the topic (Wilkerson, 2002).
Long Term effects of ankle bracing

Clinicians have debated over the effects of long-term use of ankle braces and taping as to whether or not ankle musculature will weaken due to dependency on the application of outside support (Cordova, Ingersoll, & Palmieri, 2002). Several studies have researched the long-term effects of ankle bracing and taping on ankle musculature (Cordova & Ingersoll, 2002; Cordova et al., 2000; Mohammadi, 2007). A study conducted by Cordova et al. (2000) examined peroneus longus muscle latency in response to sudden ankle inversion before and after an 8-week trial of wearing ankle braces for at least 8 hours a day, five days a week. It was found that the long-term ankle brace use did not have an effect on peroneus longus reaction time (Cordova et al., 2000). A similar study that measured the effects of ankle bracing over a 5-week period found that the application of braces did not affect peroneus longus Hoffmann reflex or eversion strength (Brooks, De La Garza, Laramee, Cordova, Ingersoll, & Merrick, 2001). However, another study examining peroneus stretch reflex amplitude found that reaction time during sudden ankle inversion increased after prolonged ankle brace application (Cordova & Ingersoll, 2003).

DiStefano et al. (2008) conducted a study in which lower extremity kinematics and ground reaction forces were examined prior to and after the completion of an 8-week period in which participants wore ankle braces during all recreational activity. No effects on knee and ankle kinematics or ground reaction forces were found following the treatment period (DiStefano et al., 2008).
A study conducted by Jerosh & Schoppe (2000) examined the effects of long-term ankle bracing on sport-specific capabilities. It was found that the use of ankle braces during physical activity for three consecutive months increased sensorimotor and sport-specific capabilities, especially during testing that involved dynamic movements.

The studies conducted by Cordova et al. (2000) and Cordova & Ingersoll (2003) both used physically active college students as subjects without defining what defining “physically active” entailed. Additionally, both studies required the subjects to wear ankle braces 8 hours/day for 5 days/week. The subjects may not have been taking part in any sport-specific activity during this period of time. Furthermore, it is difficult to ascertain how compliant the subjects were in adhering to these time instructions. Jerosch & Schoppe (2000) utilized subjects that had a mean age of 30, most of whom only participated in sport specific activity about 3 hours/week. Although the subjects in this study were required to wear ankle braces specifically during physical activity for three consecutive months, averaging 3 hours/week in brace application may not be enough time to bring about any significant changes in the ankle musculature.

The only study utilizing subjects and procedures akin to that of athletes was conducted by DiStefano et al. (2008), in which collegiate volleyball and basketball athletes were required to wear ankle braces during all recreational activity for 8
consecutive weeks. These athletes reportedly participated in sport specific activity 1-2 hours/day, 3-4 days/week. However, this study only examined changes in kinematics and ground reaction forces due to long-term ankle brace application.

Due to the lack of quantity and consistency in the research on long-term effects of external ankle support on evertor muscle strength and activity, this study looks to examine these effects in physically active college students. It was hypothesized that, due to reliance on external ankle support, participants in the treatment group would undergo a decrease in eccentric eversion ankle strength. Additionally, it was hypothesized that peroneus longus muscle activity would increase during balance testing to compensate for the eversion strength deficit and balance testing scores will consequently decrease. Due to possible strength imbalance between dominant and non-dominant limbs found in previous studies (Blache & Monteil, 2011), a secondary, exploratory statistical analysis was used to determine if a difference existed between the dependent variable of the treatment group’s dominant and non-dominant ankles. The findings of this study will aid in the clinician's selection of preventative and rehabilitative methods when dealing with ankle injury, specifically the long-term application of external ankle support.
METHODS

Participants

A total of thirty-eight (30 men, 8 women) able-bodied college students (ages 18 to 26) who currently attend and participate in club or intramural sports at California State University Northridge volunteered to participate in the research study. Participants had a mean height of 174.57 ± 12.29 cm and a mean body weight of 73.02 ± 12.17 kg. All participants were required to read and sign an informed consent form, as well as fill out a Physical Active Readiness Questionnaire a health questionnaire provided by the researcher. Participants who had used any form of external ankle support in the past three months and/or had incurred an ankle injury in the past six months were excluded from the study. Any participants who incurred an injury during the treatment period that prevented them from participating in their physical activity or that required the use of external ankle support were removed from the study. Participants were classified as either part of the control or the treatment group, with 19 participants in each. Counter balancing was used to place those in the treatment group into either the dominant or non-dominant groups. Those in the dominant group were required to wear the ASO (Ankle Stabilizing Orthosis) Ankle Brace (Medical Specialties Inc., Charlotte, NC) on the dominant foot; those in the non-dominant group were required to wear the ASO Ankle Brace on the non-dominant foot. The participants in the treatment groups were required to wear the ankle braces during all physical activity. The dominant foot in this study was defined as the foot used to kick a ball.
Instrumentation

An Airex Balance Pad and a wristwatch were used during BESS testing. The Humac Norm (Computer Sports Medicine Inc., Stoughton, MA) was used for isokinetic and isometric strength testing, including the hip/knee stabilizer, ankle adapter, and footplate attachments. The Delsys Myomonitor IV and EMG Works 3.7 Recording Software were used to collect EMG data. ASO ankle braces were the selected form of external ankle support provided by the researcher.

Procedure

Participants underwent pre- and post-application testing procedures. These procedures began with the recording of participants’ height, weight and age. Area of electrode placement was shaved with a sterile disposable razor and cleaned with an alcohol prep pad. Bipolar electrodes were placed on the skin over the belly of the peroneus longus, parallel to the muscle fibers.

The order of the testing was counter balanced for each participant, but was kept consistent for the pre- and post-application testing. The BESS test was selected to assess the participants’ balance due to its use of an uneven surface (the foam Airex pad), which would cause the participants to dynamically stabilize the ankle, placing demand on the evertors. Before completing the BESS test, participants were read the BESS test instructions. The BESS test involves a series of three separate testing positions (double leg stance, single leg stance, tandem stance) in which the participants were required to maintain each position for 20 seconds with their hands on their hips and their eyes closed. Each test was completed on a firm surface (tile floor) and a foam surface
(Airex pad). The single leg stance was completed for both the dominant and non-dominant legs. An error was annotated if the participants opened their eyes, lifted their hands off of their hips, abducted or flexed the hip past 30 degrees, lifted the forefoot or heel off of the testing surface, remained out of the testing position for greater than 5 seconds, stumbled or fell. Total number of errors were recorded for each testing position and totaled (Clark et al., 2010).

For the isometric and isokinetic testing, participants were seated in an upright position on the Humac Norm utilizing the knee/hip stabilizer pad. The shod foot was placed in the footplate and secured, and the knee was flexed to 45 degrees. Range of motion limits were set according to individual’s active end range of motion for inversion and eversion. Bipolar electrodes remained on the skin over the belly of the peroneus longus.

Participants underwent isokinetic eccentric torque testing at 90 degrees/second for both eversion and inversion, as well as maximum voluntary isometric contraction (MVIC) testing of the evertor musculature. Participants were instructed regarding how to properly perform each test. Participants were allowed one trial for each test to get comfortable with the procedure. Both the dominant and non-dominant ankles were tested; order of testing was randomly selected. Participants were instructed when to begin and when to end muscle contraction. Each MVIC trial lasted a total of three seconds. Each ankle was tested in three trials, the average of which was used for analysis.

During the application period, participants in the treatment group were required to wear an ASO ankle brace for eight consecutive weeks during all physical activity. To control for adherence, both groups were sent a weekly adherence questionnaire
concerning each participants’ physical health and ability to continue physical activity and asking whether or not those in the treatment group had worn their ankle brace in the past week. Those who did not prove at least 90% compliance throughout the application period were dropped from the study. Those who did not continue physical activity due to injury or who did not wear their ankle brace were removed from the study.

**Statistical Analysis**

The independent variables were defined as the external ankle support condition and time. The dependent variables were the levels of EMG activity, BESS scores and peak torque produced during the testing trials.

Raw EMG data was normalized to the MVIC. The wireless data acquisition protocol included a sample frequency (1000 Hz), notch filter (60 Hz) and band pass filter (20-500 Hz). The root mean square (RMS) of the EMG data was calculated with a 125ms window to analyze data. The RMS values of the three sets for each condition were averaged using a Microsoft EXCEL spreadsheet, and formed the basis of the muscle activity analysis. Parametric data (differences between pre- and post-application BESS scores, EMG activity and isokinetic peak torque values) was analyzed using a 2x2 (condition by time) multiple analysis of variance (MANOVA) with repeated measures. A secondary exploratory analysis was conducted using a one-way ANOVA to measure any differences between those in the treatment group that had worn a brace either on the dominant or non-dominant limb. This analysis utilized the difference scores found by subtracting the pre-application scores from the post-application scores. Non-parametric
data (difference between conditions for change in BESS scores) was analyzed using an independent-samples Kruskal-Wallis test. The level of significance was set at $p < 0.05$ for each test. All tests were performed using PASW Statistics (version 18).
RESULTS

Of the original 38 participants, 7 participants did not complete the study. Two of these participants were lost due to injury not related to the study and 5 were lost due to non-compliance. A total of 31 participants completed the study, with 15 in the control group and 16 in the treatment group (8 with the dominant ankle braced, 8 with the non-dominant ankle braced). In the remaining participants, no significant differences were found among age, height or weight ($p > 0.05$), as seen in Table 1. Table 2 outlines the different types of physical activity that the subjects participated in throughout the study, which included a variety of varsity, club or recreational sports.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
<th>$p$ value</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>21.77 ± 2.85</td>
<td>0.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.57 ± 12.29</td>
<td>0.83</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.02 ± 12.17</td>
<td>0.85</td>
</tr>
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</table>

Table 1. ANOVA of subject characteristics.

<table>
<thead>
<tr>
<th>Physical Activity</th>
<th>Number of Subjects</th>
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<tbody>
<tr>
<td>Soccer (club/recreational)</td>
<td>8</td>
</tr>
<tr>
<td>Volleyball (varsity)</td>
<td>6</td>
</tr>
<tr>
<td>Basketball (club/recreational)</td>
<td>4</td>
</tr>
<tr>
<td>Baseball/Softball (club)</td>
<td>3</td>
</tr>
<tr>
<td>Trail running (recreational)</td>
<td>3</td>
</tr>
<tr>
<td>Cheerleading (varsity)</td>
<td>2</td>
</tr>
<tr>
<td>Football (recreational)</td>
<td>1</td>
</tr>
<tr>
<td>Rock climbing (recreational)</td>
<td>1</td>
</tr>
<tr>
<td>Tennis (recreational)</td>
<td>1</td>
</tr>
<tr>
<td>Jiu jitsu (recreational)</td>
<td>1</td>
</tr>
<tr>
<td>Circuit training (recreational)</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Types of physical activity.
**BESS Scores**

The single leg balance test on the Airex pad was used for statistical analysis due to the fact that all of the subjects were successful at maintaining this testing position and because it was the most dynamic of the testing positions. As seen in Table 3, the main effect for time \( p = 0.075 \) and condition by time interaction \( p = 0.823 \) were not significant during the primary analysis. The main effect for condition was found to be significant \( p = 0.029 \).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pre-Application</th>
<th>Post-Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5 ± 2</td>
<td>4 ± 1</td>
</tr>
<tr>
<td>Treatment</td>
<td>6 ± 3</td>
<td>5 ± 2</td>
</tr>
</tbody>
</table>

*Table 3.* Pre- and post-application BESS scores (tallied errors) for single leg balance on Airex pad.

During the secondary analysis, no significant differences were found amongst pre- and post-application BESS scores between or within the groups. No significant differences were found amongst any of the conditions between pre- and post-application testing for either the dominant \( p= 0.152 \) and non-dominant \( p = 0.103 \) legs.

**Isokinetic Peak Torque**

During the primary analysis of eversion isokinetic peak torque production, the main effect for condition \( p = 0.973 \), time \( p = 0.416 \), and condition by time \( p = 0.002 \) was found. As seen in Table 4, the treatment group exhibited a significant decrease in eversion strength by 17.19%, whereas the control group exhibited a non-significant increase in strength by 12.08%.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Pre-Application</th>
<th>Post-Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>31.44 ± 10.53</td>
<td>35.24 ± 12.21</td>
</tr>
<tr>
<td>Treatment</td>
<td>36.35 ± 10.72*</td>
<td>30.1 ± 7.6*</td>
</tr>
</tbody>
</table>

*Table 4. Pre- and post-application eversion isokinetic peak torque values. \( \ast p \leq 0.05 \)*

During the secondary exploratory analysis, significant differences were found between the groups for eccentric isokinetic peak torque production for both the dominant (\( p = 0.009 \)) and non-dominant (\( p = 0.016 \)) ankles during eversion. The dominant ankle braced group demonstrated significantly less peak torque during post-application dominant ankle eversion testing when compared to the control group (\( p = 0.02 \)) and the non-dominant ankle braced (\( p = 0.016 \)) group. The dominant ankle braced group demonstrated significantly less peak torque production during post-application non-dominant ankle eversion testing when compared to the control group only (\( p = 0.027 \)). The dominant ankle braced group’s eversion strength decreased significantly during eccentric peak torque testing of both the dominant (19.35%) and non-dominant (21.44%) ankles. The control group’s eversion strength increased non-significantly in both the dominant (11.04%) and non-dominant ankles (10.94%). The non-dominant ankle braced group’s eversion strength increased non-significantly in the dominant ankle (18.22%) and decreased non-significantly in the non-dominant ankle (14.79%).

No significant differences were found amongst the groups for inversion isokinetic peak torque production (\( p = 0.098 \)). Additionally, no significant differences were found for either the dominant (\( p = .22 \)) or non-dominant ankles (\( p = 0.562 \)) during inversion.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Eversion (Dominant)</th>
<th>Inversion (Dominant)</th>
<th>Eversion (Non-Dominant)</th>
<th>Inversion (Non-Dominant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.58±6.02</td>
<td>0.58±7.24</td>
<td>3.4±9.87</td>
<td>4.36±10.34</td>
</tr>
<tr>
<td>Braced (Dominant)</td>
<td>-7.42±10.55*</td>
<td>-4.75±3.58</td>
<td>-7.37±8.09*</td>
<td>-0.17±11.15</td>
</tr>
<tr>
<td>Braced (Non-Dominant)</td>
<td>5.56±10.54</td>
<td>-0.92±8.3</td>
<td>-5.08±6.93</td>
<td>2.96±9.52</td>
</tr>
</tbody>
</table>

**Table 5.** Difference between average pre- and post-application eccentric isokinetic peak torque production (mean ± SD).

* *p ≤ 0.05

**EMG Activity**

The main effects for condition (*p = 0.166*), time (*p = 0.254*), and condition by time interaction (*p = 0.337*) were not significant during the primary analysis.

Additionally, no significant differences were found amongst pre- and post-application peroneus longus EMG activity during the BESS tests for either the dominant leg (*p = 0.44*) or the non-dominant leg (*p = 0.705*).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pre-Application</th>
<th>Post-Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.53 ± 1.71</td>
<td>2.9 ± 1.45</td>
</tr>
<tr>
<td>Treatment</td>
<td>2.63 ± 1.34</td>
<td>2.57 ± 1.37</td>
</tr>
</tbody>
</table>

**Table 6.** Average EMG activity values of pre- and post-application single leg balance on Airex pad. All *p* > 0.05.
DISCUSSION

As stated previously, many clinicians have presumed that prolonged use of external ankle support would lead to neuromuscular remodeling and weakening of the supporting structures of the ankle, predisposing it to injury (Cordova et al., 2000). Therefore, it was hypothesized that, after eight weeks of external ankle support application during all sport-specific activity, ankle evertor muscles of the participants in the braced group (both dominant and non-dominant) would undergo a decrease in strength and an increase in muscle activity during a functional task. It was thought that, due to reliance on the brace, that the peroneus longus of the braced ankle would decrease in strength and that the muscular activity, in turn, would increase to make up for the lack in strength during a dynamic activity. A significant decrease was found in the eccentric eversion ankle strength of both the dominant and non-dominant ankles of those in the dominant ankle braced group. No other significant differences were found in terms of ankle strength, muscle activity or balance testing scores.

BESS Test

The results of this study are in agreement with past studies examining balance and postural sway. Studies that examined immediate effects of brace application on both static and dynamic balance found no differences between the braced and non-braced conditions (Cordova, Ingersoll & Palmieri, 2002). One study found that, after four days of brace application, no differences were found between treatment and control groups in postural sway (Palmieri, Ingersoll, Cordova & Kinzey, 2001). Furthermore, no differences have been found between dominant and
non-dominant limbs during single-leg balance testing (Lin et al., 2007).

**Isokinetic Peak Torque**

Previous studies have found no immediate effects of external ankle support on eversion and inversion strength in healthy subjects (Hume & Gerrard, 1998). However, no studies to date have been found examining the relationship between long-term external ankle brace application and evertor and/or invertor isokinetic eccentric peak torque. Therefore, this study is the first of its kind to analyze the long-term effects of external ankle support on eversion isokinetic peak torque, in which a significant difference was found for the treatment group.

Researchers have found no differences in the strength between dominant and non-dominant limbs. Lin et al. (2009) found no differences in the eversion to inversion strength ratio between dominant and non-dominant ankles of healthy young adults. The researchers similarly utilized an isokinetic dynamometer to test the strength of the subjects’ inversion and eversion at both 30 and 120 degrees per second. The researchers speculated that the testing could be flawed and that different results could potentially be found utilizing a more weight-bearing, dynamic test. However, McCurdy & Langford (2005) also found no differences in strength between dominant and non-dominant limbs. In this study, the researchers examined one repetition max single leg squats between the dominant and non-dominant legs of healthy men and women. The results of the present study are in agreement with these past studies in that no differences were found between the dominant and non-dominant limbs for each condition.
It is possible that the eversion strength deficits found in the dominant ankle braced group occurred due to the nature of the physical activity that the participants were partaking in during the application period. Blache & Monteil (2011) explain that functional muscle imbalances may differ amongst soccer players who play different positions on the field. It may be that the demands of the different types of physical activity that the participants took part in placed varying demands on their evertors and invertors. The spectrum of physical activities that the participants were partaking in included soccer, basketball, volleyball, trail running, rugby and cheer leading. Due to the demands of these sports, in which cutting and planting maneuvers are often used, it is possible that greater demand was placed on the participants’ evertors. This may explain why the dominant ankle braced group underwent decreases in their evortor muscle strength as opposed to the invertor strength.

Additionally, these effects may have been seen bilaterally due to a contralateral strength training effect. Due to the interaction between the right and left hemispheres of the brain via the corpus callosum, training on one side of the body may carry over to the other after much repetition (Carroll, Herbert, Munn, Lee, & Gandevia, 2006). If strength gains on the contralateral limb can be induced through increasing the demands on the unilateral limb via strength training, then it may be that decreasing the loads placed on the ipsilateral limb (in this case, the braced limb) could lead to strength deficits on the contralateral limb. Therefore, the
decrease in eversion strength in the non-dominant ankle of the dominant ankle braced group may be seen due to the decreased load on the dominant evertors. Furthermore, it has been found that contralateral strength gains are best observed when the right limb is the trained limb and the left limb is the untrained limb (Carroll et al., 2006). So, the reverse may be true when applying the effects of strength deficits, in that decreased strength due to decreased training (or loading) on the right limb may also be observed in the left limb. Since a great majority of the participants were right foot dominant, this may explain why a decrease in eversion strength was found in both ankles in the dominant ankle braced group and not in the non-dominant ankle braced group.

**EMG Activity**

As discussed earlier, the effects of external ankle support use on peroneus longus EMG activity has been studied fairly extensively. It has been shown that acute ankle brace application increases peroneal reaction time (Cordova et al., 2002; Wilkerson 2002). Studies examining the long-term effects of external ankle support on peroneal reaction time in physically active populations concurrently found no significant differences between braced and control subjects (Brooks et al., 2000; Cordova et al., 2000). Similarly, no significant differences in peroneal EMG activation were found amongst elite volleyball athletes who received external ankle support over the course of a season when compared to controls (Midgley, Hopkins, Feland, Kaiser, Merrill & Hunter 2007).
Limitations

Although the results of the study did not produce significant findings between the scores on the BESS test amongst the participants before or after the brace application period, it is possible that changes in balance would be found under different circumstances. For example, it may be that the test-retest reliability of the BESS test was not sound enough to prove changes in balance amongst the participants. Additionally, it may be that the BESS test was not dynamic enough to replicate the postural control the participants would use during their physical activity in the ankle braces. Measuring EMG activity during the participants’ physical activity may have been more effective in finding significant differences in postural control deficits after brace application. The researcher did not opt to do so due to time constraints.

Additionally, it may be that re-familiarization trials were necessary before the post-application testing was conducted. Although familiarization trials were conducted prior to the baseline testing of the inversion and eversion peak torque testing, none were conducted prior to the post-application testing. It is possible that the peak torque values collected during post-application testing are unreliable due to loss of familiarization during the eight-week application period. Also, the results of the study might have been different and more reliable if a great amount of participants was used and dominance was included as a dependent variable.

The use of healthy participants in this study could also be seen as a
limitation. Research has shown that individuals with CAI exhibit strength deficits in their evertors, invertors and plantar flexors, as well as lowered EMG activity of both invertors and evertors (Abdel-aziem & Draz, 2013; David et al., 2013). David et al. examined the differences in concentric and eccentric isokinetic strength and the EMG activity of both the tibialis anterior and the peroneus longus found a 26% decrease in the concentric invertor to eccentric evertor strength ratio in the subjects identified with CAI in comparison to healthy subjects. The study also found that the subjects with CAI exhibited decreased EMG activity in both the tibialis anterior and the peroneus longus during eccentric contractions. The authors of the study proposed that the damaged sensory receptors and neural inhibition within the capsule and ligaments of the previously injured ankle is the cause for this observable decrease in neural drive (2013). It may be that obvious changes in neuromuscular function in response to long-term external ankle support application would have been more evident in participants that have a history of CAI.

**Suggestions for Future Research**

Considering the fact that the present study only utilized physically active participants, future research should focus on the long-term effects of external ankle support on elite athletes. Examining these effects on subjects who participate in much greater volumes of functional, dynamic training may provide more reliable results that would be more applicable to the athletic population. Furthermore, it would be prudent for future researchers to utilize elite athletes that compete in the same sport and play the same position. This way, the researchers could ensure that
all of the participants’ evertors would be exposed to the same loads and stresses. If neuromuscular changes were to take place in the muscle, these changes would be more likely to be seen consistently in all the braced participants when compared to the controls. Including participants diagnosed with CAI in addition to the healthy participants, in both the treatment and control groups, as well as including ankle taping as another form of external ankle support, would also further our knowledge of the long-term effects of external ankle support. This way, results could be applied to the use of all types of external ankle support for both preventative and rehabilitative measures.

A longer application period would benefit future research. More longitudinal studies that examined the long-term effects of external ankle support over the course of at least the entirety of a sport’s season are recommended. It would be best to examine these effects over the course of several years, since many athletes are opt to or are required to wear external ankle support throughout their entire athletic career.

Researchers conducting similar studies in the future would also be advised to utilize a more dynamic and/or functional test to determine the long-term effects of external ankle support on evertor muscle activity, such as the SEBT. It would be ideal to measure EMG activity of the evertors throughout sport-specific activities, in which the muscles of the ankle would be loaded in the most functional positions and in which the effects of fatigue in addition to the external support could be observed.
In terms of isokinetic peak torque testing, future researchers should complete familiarization trials prior to both baseline and post-application testing. This way, any potential de-familiarization effects could be avoided. It may also be beneficial to test isokinetic eccentric peak torque at varying speeds, considering that studies in the past have found varying peak torque production ability dependent upon the testing speed (Lin et al., 2009).

Lastly, future research is needed to determine whether or not contralateral strength training effects could be reversed or, in other words, if decreased loading and/or training of a muscle could affect the same muscle on the contralateral limb. This would help to explain the eversion deficit found in the non-braced ankle of the dominant ankle braced participants in the present study.

Clinical Applications

The results of this study could be applied to the use of external ankle support during the rehabilitation of inversion ankle sprains. It would seem that long-term external ankle support application has little effect on balance and evertor muscle activation. However, clinicians should look to wean athletes off of external ankle support in order to avoid eversion strength deficits. Athletes may need to rely on external ankle support in the form of prophylactic braces or ankle taping during the first few weeks post-injury. However, it may be more beneficial to remove the external ankle support once full strength and proprioception have returned. Additionally, clinicians should remain cautious when using external ankle supports on healthy subjects due to the possible strength deficits that may develop over time.
CONCLUSION

In conclusion, this study aimed to examine peroneus longus muscle activity and isokinetic eccentric peak torque production following eight weeks of external ankle support application during physical activity. It was hypothesized that neuromuscular changes would take place in response to prophylactic brace application, and that balance and eversion strength would decrease and EMG activity would increase. It was found that long-term external ankle support had no significant effects on balance or EMG activity of the peroneus longus. However, eccentric isokinetic peak torque significantly decreased in the treatment group. Clinicians should take the results of this study into account when opting to utilize external ankle supports in both the prevention and rehabilitation of inversion ankle sprains seeing as how long-term use of ankle support may lead to deficits in evertor muscle strength.
References


