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The effects of an ankle strengthening and proprioception exercise protocol on peak torque and joint position sense

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Abstract

Ankle sprains are the most common injury seen in athletics. Because of this, devices such as external ankle supports have been developed to protect the ankle joint and prevent injury. Exercise protocols have also been developed to increase strength and proprioception at the joint, which has been shown to reduce injury risk. The purpose of this study was to examine changes in joint position sense (JPS) and peak plantar flexion and dorsiflexion torque following a six week strength and proprioception exercise protocol, as well as compare these results to those of a control group wearing ankle braces. The study consisted of 20 college aged students who had previously sprained one of their ankles twice. The subjects were divided into two groups, with one group performing exercises three times per week for six weeks while the other group wore ankle braces during physical activity. Testing was performed before the beginning of the protocol, after three weeks, and after completion of the six week protocol. A 3-way analysis of variance (ANOVA) was performed, with an alpha level of $p = 0.05$. This study found no significant changes in JPS following completion of the exercise group or compared to the brace group for the factors of time, group, and position ($p = 0.57$). There were significant improvements in peak plantar flexion ($p = 0.014$) and dorsiflexion ($p = 0.033$) torque for all subjects, but there was no significant difference between the two groups for either motion ($p =$ 0.33, 0.349). Based on these results, the exercise protocol used in this study should not be used as a substitute for external ankle supports. However, more research should be done to determine if alterations to the exercise protocol can elicit significant results.

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Chapter 1

The Problem and Its Scope

Introduction

Ankle sprains are the most common injuries seen in interscholastic and intercollegiate athletics, making up approximately 20 to 25 percent of all injuries involving time loss in sports involving running and jumping (Hertel, 2008; Mack, 1982; Kynsburg, Panics, & Halasi, 2009). The most common mechanism of injury seen in ankle injuries involves inversion and plantar flexion of the ankle, resulting in injury to the ligaments and/or muscles of the lateral ankle (Peterson et al., 2013). These injuries can result in missed time depending on the extent of the injury and can make athletes more susceptible to ankle injuries in the future or cause chronic ankle instability (Jerosch, Hoffstetter, Bork, & Bischof, 1995). In fact, one study of basketball players found that athletes who had previously sprained their ankle were five times more likely to suffer an ankle injury than those who had not suffered a prior injury (McKay et. al, 2001).

As a way of prevention of ankle injuries or protection of injured ankles, various types of external support devices, such as athletic tape or ankle braces, have been utilized to provide extra support to the ankle joint. Taping the ankle has been one of the most common methods, with several different types of tape utilized to provide ankle support depending on the severity of injury (Bot, Verhagen, & Van Mechelen, 2003). While ankle taping has been a mainstay in athletics, some studies have concluded that prophylactic ankle braces are just as effective as ankle taping, if not more effective, and are more cost-efficient for the athletic training budget (Mickel et. al, 2006, Rovere, Clarke, Yates, & Burley, 1988). Despite the benefits of using an ankle brace, there is some debate on whether bracing detrimentally affects athletic performance (MacKean, Bell, & Burnham, 1995). It has also been proposed that prolonged use of an ankle brace reduces the strength of the ankle joint over time and leads to chronic instability (Bot et al., 2003).

Better knowledge and utilization of effective rehabilitation techniques is another way athletes and athletic trainers have aimed to reduce the chronic effects of an sprained ankle, such as instability related to altered mechanical and functional factors. Many different types of exercise are used to rebuild strength and stability in the ankle, including strengthening exercises, range of motion exercises, or proprioception exercises (Kaminski et al., 2013). However, these exercises are often only used after an injury has occurred, and very rarely are implemented prior to injury for the prevention of ankle injuries. Similar with ankle braces over taping, if the use of exercise can be shown to be as effective at preventing ankle injuries as ankle taping or bracing, it could reduce the expenses on athletic trainers and athletes. However, no research has compared strengthening and proprioceptive exercises to ankle bracing for their effects on strength, range of motion, or joint position sense.

Purpose of this Study

The purpose of this study was to examine the effects of a six week ankle strengthening and neuromuscular control protocol on joint position sense acuity, ankle plantar flexion and dorsiflexion strength, and plantar flexion and dorsiflexion range of motion compared to the effects on these factors seen with the application of ankle braces.

Hypothesis

The regular application of ankle strengthening and proprioceptive exercises will show no difference in ankle joint position sense compared to the ankle brace group, indicating that the protocol improved ankle proprioception similarly to how an ankle brace does. The exercise protocol will also show significantly improved strength and range of motion in the ankle in comparison to the bracing group.

Significance of the Study

Ankle sprains account for a significant proportion of injuries seen in athletics every year. If the inclusion of these preventative exercises could decrease the risk of injuries, then these techniques could be utilized by coaches to limit the risk of injury for their athletes. This could also benefit people working to prevent athletic injuries since athletic trainers spend significant parts of their budget on tape, braces, or rehab supplies for ankle injuries (Mickel et al., 2006). Applying these techniques could reduce the instances and severity of ankle sprains in athletics as well as make it cost effective.

Limitations of the Study

The following limitations were considered for this study:

1. The application of an ankle brace can vary from person to person, as one subject may prefer the brace to be tighter than another. Therefore there could be a difference in how supportive the ankle brace is from subject to subject. To address this, all of the subjects in the bracing group were given the same instructions on how to apply the ankle brace.
2. The tension on the thera-band used in the exercise protocol was not controlled for, which has been done by prior studies (Docherty, Moore, & Arnold, 1998; Smith, Docherty, Simon, Klossner, & Schrader, 2012) Instead, the subjects were instructed to pull the band to a resistance level that provided the individual with a challenge, yet still allowed them to complete their sets. Future studies could attempt to control for band tension and see how the results differ from those in the current study.

3. The frequency, intensity, time and type of exercise performed by the subjects in this study varied greatly, as subjects were allowed to continue their normal routines. Since each individual person had different fitness levels and types of activities, this could potentially have an effect on the results of the study. Further research looking at subjects who participate in a specific sport or activity would give a better idea of the specific effects on that sport.
4. The past history of ankle sprains for each subject was based on that subject's testimony. As a guideline, subjects were instructed to count an injury as an ankle sprain if the injury caused pain, swelling, and loss of mobility for at least one week. However, each subject may have had some variance in how they determined if a past injury qualified them for this study. Any future studies aiming to compare ankle braces to exercise should select subjects who have had documentation for evaluated ankle sprains to ensure all subjects were appropriately qualified.

Definition of Terms

Anterior: On the front side (Starkey, Brown, and Ryan, 2010).

Avulsion: Forcefully tearing away a portion of a structure (Starkey, Brown, and Ryan, 2010).

Biomechanics: An area of science related to the application of mechanical principles of biology (Whiting and Zernicke, 2008).

Chronic Ankle Instability: The occurrence of repetitive bouts of lateral ankle instability, resulting in numerous ankle sprains (Hertel, 2002).

Closed Chain exercise: Exercise where the distal portion of the limb is in a fixed position (Kaminski et. al, 2013).

Concentric: Muscle contraction as the muscle shortens (Houglum, 2010)

Cryotherapy: A modality involving the use of ice or cold pack to reduce swelling or pain after injury (Kaminski et. al, 2013).

Distal: Far away from the center of the body (Starkey, Brown, and Ryan, 2010).

Dorsiflexion: ankle flexion, pulling the toes up (Starkey et al., 2010).

Eccentric: Muscle contraction as the muscle lengthens (Houglum, 2010).

Eversion: The plantar surface moves away from the midline of the body (Starkey et al., 2010).

Inversion: The plantar surface moves toward the midline of the body (Starkey et al., 2010).

Joint Position Sense: The ability of a subject to detect the orientation of a joint with their vision occluded (Konradsen, 2002)

Lateral: The outside part of the body, away from the midline (Starkey et al., 2010).

Medial: Toward the middle, on the midline of the body (Starkey et al., 2010).

Mortise: The space formed by the medial and lateral malleoli, where the talus fits (Whiting & Zernicke, 2008).

Neuromuscular control: Conscious control of a specific body movement

Open chain exercise: Exercise moving the distal portion of the limb (Kaminski et. al, 2013).

Palpation: inspecting the integrity of body structures through pinpoint touch with the fingers (Starkey et al., 2010).

Plantar: The surface on the sole of the foot (Starkey et al., 2010).

Plantar flexion: Ankle extension, described as pointing the toes (Starkey et al., 2010).

Posterior: On the back side (Starkey et al., 2010).

Proprioception: The ability to determine the position of bones, joints and muscles in space (Whiting & Zernicke, 2008).

Proximal: close to the center of the body (Starkey et al., 2010).

Range of Motion: The angle at which a joint is able to move in a specific motion (Starkey et al., 2010).

Sprain: Forceful distortion of an articulation that causes damage to the ligaments of a joint, but no dislocation (Starkey et al., 2010).

Strength: The ability of a muscle to generate force against resistance (Starkey et al., 2010).

Talocrural Joint: the ankle joint formed by the tibia, fibula, and talus (Starkey et al., 2010).

Chapter 2
Review of Literature

Introduction

There are a variety of factors that have an effect on the prevalence and severity of ankle sprains in athletes. The type of activity performed or the amount or type of intrinsic or extrinsic protection can have a significant impact on whether the ankle is exposed to traumatic forces and how it reacts in these situations. This chapter presents information regarding the anatomy and physiological function of the bones, ligaments and muscles of the foot and ankle joint. It will review the common causes for ankle sprains, as well as testing and evaluation procedures used to determine the severity of ankle sprain. This chapter will also examine methods for ankle taping and bracing, and look at the results of studies that have compared the effectiveness of the two injury prevention methods. Finally, this chapter will look at some of the common therapeutic modalities and exercises that are used in the rehabilitation of the ankle joint.

Anatomy of the Ankle Joint

Bony Anatomy

Two of the most important bones in the lower extremity are the tibia and fibula, which make up the structural component of the shank, or lower leg. A normal anatomical relationship between these two bones is required in order to have proper biomechanics of the knee proximally and the ankle and foot distally (Starkey et al., 2010). The tibia is the primary weight bearing bone of the shank, and is the attachment site of many of the muscles that act on the ankle, foot, and toes (Starkey et al., 2010). The fibula sits lateral to the tibia, and only bears some weight. It is a long, thin bone that serves as a site for muscular and ligamentous attachment, provides lateral stability to the ankle mortise, and serves as a pulley to increase the efficiency of the muscles that run posteriorly to it (Starkey et al., 2010).

The ankle joint is primarily formed by two articulations: the talocrural and subtalar joints. The talocrural joint consists specifically consists of the articulation between the tibia, fibula, and talus (Bullock-Saxton, Janda, & Bullock, 1994). These three bones articulate to allow for the sagittal plane range of motion needed for walking and running, though small amounts of frontal plane motions can occur as well (Hertel, 2002). The subtalar joint consists of the articulations between the talus, calcaneus, and the tarsals of the foot (Hertel, 2002). This joint primarily allows for inversion and eversion between the talus and calcaneus (Peterson et al., 2013). Together, along with the articulations of the tarsal bones of the foot, the talocrural and subtalar joint combine to produce the functional movements of pronation and supination (Starkey et al., 2010).

There are a few other bones that play important roles in ankle stability. The navicular, for example, serves as the attachment site for the tibialis posterior muscle, and also supports the medial longitudinal arch via the spring ligament (Starkey et al., 2010). Two other bones playing a role in ankle function are the cuboid and the fifth metatarsal. The fifth metatarsal is the attachment site of the peroneus brevis, and along with the cuboid provides a passageway for the tendon of the peroneus longus on the plantar aspect of the foot (Starkey et al., 2010).

Muscular Anatomy

The muscles acting on the ankle joint are divided into four groups based on their anatomical locations: the anterior compartment, lateral compartment, deep posterior compartment, and superficial posterior compartment (Brown, Ross, Mynark, &G uskiewicz, 2004). The muscles in each compartment all have one common action, though they may differ in other actions they assist in (Whiting & Zernicke, 2008). For example, the anterior compartment consists of the tibialis anterior, extensor digitorum longus, and extensor hallucis longus, which all act as dorsiflexors of the ankle (Starkey et al., 2010).

The peroneus longus and brevis, which are in the lateral compartment and primarily evert the ankle, are most commonly associated with ankle sprains. A study by Brown et al. (2004) aimed to analyze joint position sense and electromyography readings of ankle musculature in recreationally active subjects. They found that the peroneal muscles did not activate and stabilize as quickly in ankles that had functional instability as they did in ankles that were stable (Brown et al., 2004). Another study by Karlsson & Andreasson (1992) found that the reaction time of these muscles can be improved with the application of ankle support, although the reaction times were still slower than those seen in ankles without a history of injury. Another study determined that subjects with a history of chronically unstable ankles had weaker peroneal muscles concentrically and eccentrically than subjects with healthy ankles when compared to the bodyweight of the subjects (Willems et al., 2002).

Ligamentous Anatomy

Lateral ankle sprains account for almost 85% of all ankle sprains (Docherty et al., 1998), leaving the ligaments on the lateral side of the ankle most at risk of injury. Of these, the most commonly injured ligament is the anterior talofibular ligament (ATF) (Mickel et. al, 2006). The ATF originates at the anterolateral surface of the fibula and attaches to the talus near the sinus tarsi (Hertel, 2002). This ligament is tight during plantar flexion, and resists inversion and internal rotation of the talus within the ankle mortise (Starkey et al., 2010).

The next most commonly injured ligament is the calcaneofibular ligament (CFL) (Hertel, 2002). The CFL attaches to the outermost portion of the lateral malleolus of the fibula, and courses inferiorly and posteriorly to its connection on the calcaneus (Whiting & Zernicke, 2008). The CFL serves as the primary restraint against inversion within the midrange of talocrural motion (Kaminski et al., 2013).

The last major ligament on the lateral side of the ankle is the posterior talofibular ligament (PTF). This ligament arises from the posterior portion of the lateral malleolus and attaches inferiorly and posteriorly to the talus and calcaneus (Hertel, 2002). The PTF is responsible for limiting posterior displacement of the talus on the tibia, and is the strongest and most rarely injured of the lateral ankle ligaments (Fong et al., 2009).

The ligaments on the medial side of the ankle are injured less often for a few reasons. Because the lateral malleolus sits more inferior when compared to the medial malleolus, eversion is more restricted than inversion (Whiting & Zernicke, 2008). Another reason is the strength of the deltoid ligament. This ligament is comprised of four individual ligaments: the anterior tibio-talar, the tibio-calcaneal, the posterior tibio-talar, and the tibio-navicular ligament (Starkey et al., 2010). If the force of the injury is strong enough to sprain the deltoid ligament, it is highly likely that other ligaments, muscles, or bones are injured as well (Whiting & Zernicke, 2008). While the more common mechanism of injury for this ligament is eversion, pain is often seen in these ligaments after an inversion sprain due to a strong force as the ankle snaps back to its normal position (Starkey et al., 2010).

Ankle Sprains

Ankle sprains are one of the most common injuries seen in sports that involve running and jumping. Mack (1982) reported that about 20 to 25 percent of sports injuries were ankle sprains, which is slightly higher than recent reports of 15% found by Hootman, Dick, & Agel (2007) and 14% by Fong et al. (2009). However, in sports such as basketball or volleyball, ankle sprains are even more common due to a greater amount of jumping and cutting (Garrick & Requa, 1978). For volleyball in particular, Agel et al (2007) reported that over the course of 15 volleyball seasons, 44 percent of all match injuries and about 30 percent of all practice injuries were ankle sprains. McGuine & Keene (2006) reported that about one million grade school and high school athletes participating in soccer and basketball programs in the United States sustain ankle sprains each year. This section will review common mechanisms of injury, typical signs seen in the evaluation of ankle sprains, and a scale of severity of ankle sprains.

Common Mechanisms of Injury

When determining the mechanism of injury, it is important to get as much detail about what position the athlete was in and what position their ankle went into as possible. Doing so can narrow down the possibilities of injury and provide insight into the severity of the injury (Turco, 1977). The most common mechanism of injury in ankle injuries is forced inversion possibly also involving plantar flexion (Peterson et. al, 2013). However, both inversion or eversion sprains are possible from landing, cutting, pushing off, or coming to a stop (Turco, 1977). A study looking at the effects of foot position on the likelihood of ankle injury (Wright, Neptune, van den Bogert, & Nigg, 2000) found that an increased plantar flexed position at touchdown can cause an increased occurrence of ankle sprains. With an ankle sprain, often times the injury occurs in instances where another athlete is involved. One example of this is in the sport of basketball, where an ankle sprain can often occur when a player jumps and lands on the foot of another player, causing his/her foot to invert or evert (Whiting & Zernicke, 2008).

A lack of range of motion can be a big factor that can lead to ankle injuries as well (Hale, Hertel, & Olmsted-Kramer, 2007). A meta-analysis on the effects of ankle sprains suggested that people with reduced ankle dorsiflexion range could be at an increased risk of ankle sprains, noting that a lack of flexibility at the ankle joint made people five times more likely to suffer an ankle sprain than subjects with normal ankle flexibility (de Noronha, Refshauge, Herbert, & Kilbreath, 2009).

Signs of Injury in Evaluation

Determining if the subject has a history of ankle sprains is important in the evaluation of an ankle injury. According to research, the most common predisposition to an ankle sprain, especially of the lateral ligaments, is at least one previous ankle sprain (Kaminski et al., 2013). After taking a thorough history, the next step is to take observation for swelling, discoloration, or deformity. In an acute ankle sprain, swelling is often present over the sight of injury (Starkey et al., 2010). Following this step is the palpation of the structures of the ankle, which localizes the area of pain (Turco, 1977). In an inversion ankle sprain, pain is most likely to be seen on the ATF and possibly over the CF as well (Starkey et al., 2010). Pain may also be seen across the anterior surface of the ankle as it is common for the extensor retinaculum to be damaged in an ankle sprain (Kaminski et al., 2013).

In an examination of ankle range of motion for inversion sprains, pain and decreased range of motion will most likely be produced in plantar flexion and inversion movements, though it is possible to see weakness in dorsiflexion as well (Starkey et al., 2010). For special tests, the main tests for determining ankle sprains are the anterior drawer, talar tilt inversion, and talar tilt eversion. In the anterior drawer, the ankle is anteriorly displaced by gripping the calcaneus and pulling towards the tester, which will produce pain and/or laxity if the ATF was damaged (Bahr et al., 1997). The talar tilt tests involve forcing the ankle into inversion and eversion, looking for pain and laxity at the site of the CF and deltoid ligaments when compared bilaterally (Bahr et al., 1997).

Severity of Ankle Sprains

Ankle sprains are classified as being either mild, moderate, or severe, often numbered as grade I, grade II, or grade III (Fong et al., 2009). In a grade I ligament sprain, the injured ligament or ligaments are stretched, which will cause point tenderness but no laxity (Chinn & Hertel, 2010). In these sprains, swelling often is not present or is very mild in nature, and subjects are often able to return to activity in less than a week (Starkey et al., 2010). In a grade II ankle sprain, there is a partial tear of the ligament which can be diagnosed with stress tests on the ankle for pain and laxity (Chinn & Hertel, 2010). Depending on the level of rehabilitation performed, athletes who suffer this type of injury are usually able to return in about 2-4 weeks (Kaminski et al., 2013). In a grade III ankle sprain, the ligament is completely torn, meaning stress tests would not cause pain but there would be no end point, indicating that the ligament is completely torn, which often times is associated with an avulsion fracture (Starkey et al., 2010).

Chronic Ankle Instability

Aside from the initial problems with ankle sprains, there are long-term issues that can also develop. Many patients who suffer ankle sprains will have continued instability of the ankle joint following recovery even in the presence of negative special tests and full ROM (Sekir, Yildiz, Hazneci, Ors, & Aydin, 2007). Chronic ankle instability (CAI) refers to the occurrence of repetitive bouts of lateral ankle instability (Hertel, 2002). CAI is believed to be the result of a combination of neural, muscular, and mechanical issues associated with repeated ankle trauma (Mattacola & Dwyer, 2002). If proper rehabilitation or protection is not given to the muscles and ligaments of the ankle after a sprain, this instability can result in ankles with a higher susceptibility to injury (Hertel, 2002). When it comes to CAI, there are two primary categories for the causes: mechanical instability and functional instability.

Mechanical Instability

Mechanical instability of the ankle joint is often the result of anatomical changes following the initial sprain (Hertel, 2002). These changes include pathologic laxity, arthrokinematic impairments, synovial changes, and degenerative bone disease (Tropp, Odenrick, & Gillquist, 1985).

Pathologic laxity is most commonly seen at the site of the anterior talofibular ligament, allowing for a greater range of plantar flexion and inversion of the ankle joint (Hertel, 2002). The amount of pathologic laxity in the lateral ligaments is usually related to the severity of the ankle sprain, and becomes an issue when the ankle is put in a vulnerable position during activity (Hertel, 2002). In a mechanically unstable ankle, these positions will lead to a greater risk and severity of ankle sprain compared to someone with a stable ankle (Tropp et al., 1985). Another potential cause is arthrokinematic impairments, which can occur at the tibio-fibular, talo-crural, or sub-talar joint in the lower leg and foot (Hertel, 2002). One noted example is the potential anterior and inferior displacement of the distal fibula in a chronically unstable ankle. This displaced position of the fibula would allow more slack on the anterior talofibular ligament and less stability of the ankle joint (Hertel, 2002). Hypomobility can also be an impairment leading to mechanical instability. de Noronha et al. (2009) found that a lack of flexibility at the ankle joint made subjects five times more likely to suffer an ankle sprain than subjects with normal ankle range of motion.

Mechanical issues may also arise due to synovial issues in the ankle joint. Synovial inflammation has been shown to cause frequent episodes of pain and instability of the ankle joint, often due to the impingement of the synovial tissue between the bones of the ankle complex (Hertel, 2002). It has even been reported that synovitis of the posterior subtalar joint, or sinus tarsi syndrome, may be caused by repetitive bouts of ankle instability (DiGiovanni, Fraga, Cohen, & Shereff, 2000). Degenerative issues of the bone are another issue that may lead to mechanical instability in the ankle. Gross and Marti (1999) found that former volleyball players with a history of ankle sprains showed more osteophytes and subchondral sclerosis when compared to a group of healthy controls, which they believed was a combination of chronic ankle instability and intensive volleyball training.

Functional Instability

Functional instability of the ankle joint often stems from adverse changes to the neuromuscular system that provides dynamic support of the ankle (Hertel, 2002). While this can be connected to mechanical issues or causes of instability, functional deficits can arise even when there are no signs of mechanical instability (Nakasa, Fukuhara, Adachi, & Ochi, 2008). The idea of functional instability was introduced by Freeman et al in 1965, and has been expanded on to examine what specific deficits cause this instability and what can be done to correct the issue. The primary causes of functional instability today are broken down to deficits in ankle proprioception and sensation, nerve conduction velocity, neuromuscular response times, and postural control and strength (Hertel, 2002).

Impaired position sense and kinesthesia of the ankle joint has been shown in subjects with a history of ankle sprains when compared to uninjured ankles (Lentell et al., 1995). This instability is believed to be caused by concomitant injury to the peroneal muscle tendons or the superficial peroneal nerve (Guitierrez, Kaminski, & Douex, 2009).This has been found with most studies examining proprioception in subjects with CAI (Hartsell, 2000; Willems et al., 2002), although the clinical relevance is not fully understood. Cutaneous sensation has been found to be an indicator of peroneal nerve palsy after ankle sprains as well (Bullock-Saxton et al., 1995). However, it is not known whether changes like this are associated with CAI or not, as more research is needed to determine if there was a connection (Hertel, 2002).

Nerve-conduction velocity and response time is another area where a deficit is seen with subjects who have CAI. Studies have shown that there is an impaired nerve conduction velocity in subjects between four and 22 days following inversion trauma (Mattacola & Dwyer, 2002). Karlsson & Andreasson (1992) also found that the time it took for the peroneal muscles to contract was significantly longer in subjects with ankle instability, though these deficits can be improved to some degree with the application ankle supports. This impaired peroneal function has been associated with impairments in proprioception and nerve-conduction velocity (Hertel, 2002).

Postural control impairments refer to bilateral deficiencies in a single-leg stance. The reason for this deficit is likely a combination of impaired proprioceptive and neuromuscular control (Hertel, 2002). Another reason is because subjects with CAI will often use the movement of their hip to balance themselves rather than the movement of their ankle, often because of neural adaptations, which provides a less efficient method to maintain balance (Pintsaar, Brynhildsen, & Tropp, 1996). Strength deficits have also been reported in people with chronic instability, although the reasons for these impairments are not clear (Hertel, 2002).

Ankle Support Methods

To combat the chronic instability seen in ankle joints, there are a few methods that attempt to provide additional support to the ankle joint. Two of the most common methods, which are ankle taping and bracing, have been shown to be effective in providing stability and increasing proprioception of the ankle joint (Mattacola & Dwyer, 2002). In this section, the methods and types of ankle taping and bracing will be reviewed, as well as the pros and cons of using each of these methods.

Ankle Taping

Ankle taping has long been a staple intervention in the protection of the ankle joint and prevention of ankle injuries for athletes. The use of ankle tape is primarily meant to reduce the ability of the ankle to plantar flex, invert, or evert (Mickel et. al, 2006). It has also been found to show an improvement in the balance and gait control in patients (Kim & Cha, 2015). There are several different techniques used to support the ankle, many of which are combined in a typical ankle taping. The most common technique used for taping is the basket weave, which involves a figure-eight motion around the foot and leg to provide support to the ankle joint (Wilkerson, 2002). Another technique that is used are stirrups, which are long strips running from the medial side of the shank under the calcaneus to the lateral side of the shank. These strips are meant to limit plantar flexion and inversion of the ankle (Callaghan, 1997). Heel locks, which are strips wrapped around the heel providing protection from inversion or eversion, are also a common technique used in ankle taping (Rovere et al., 1988).

Overall, ankle taping has been found to have positive effects other than providing stability to the ankle joint, such as improving joint position sense (Simoneau et al., 1997; Heit, Lephart, & Rozzi, 1996). Ankle taping has also been shown to improve the response time of the peroneal muscles based on EMG readings (Karlsson & Andreasson, 1992). A systematic review by Wilkerson (2002) also determined that taping procedures limit the strain on the anterior talofibular ligament and protect subtalar ligaments from excessive loading during competition. A literature review by Callaghan (1997) also found that tape could improve both mechanical and functional instability. However, some researchers have argued that the research on the effects of ankle taping, particularly because of inconsistent methods in the research, is inconclusive and needs to be explored further (Hughes & Rochester, 2008).

Despite the positive effects listed above, one of the biggest criticisms seen with ankle taping is that the tape can lose its strength at a rapid pace. One study that examined the strength of ankle tape before and after exercise have found that tape loses a significant amount of its support after varying periods of exercise (Callaghan, 1997). Another study found that while tape limited range of motion immediately after application, the support was lost after 30 minutes of exercise (Purcell et al., 2009). Bot et al. (2003) even reported that tape can lose some of its support after as little as five minutes of activity. As an alternative, many have started using prophylactic ankle braces as opposed to taping due to the fact that ankle braces do not lose their support with exercise (Wilkerson, 2002).

Ankle Bracing

The use of ankle braces has emerged in the last few decades as an alternative to ankle taping (Wilkerson, 2002). There are multiple types of braces, though the most common are lace-up and stirrup ankle braces. Lace-up braces consist of prophylactic material and use laces and Velcro straps to provide all-around support to the ankle (Mattacola & Dwyer, 2002). Stirrup braces, on the other hand, are made from a semi-rigid outer shell which encompasses the medial and lateral malleoli, limiting the amount of inversion and eversion allowed at the ankle (Verbrugge, 1996).

The use of ankle braces has been compared to ankle taping in a plethora of studies (Mickel et al., 2006; Rovere et al., 1988; Verbrugge, 1996). These studies have looked at the overall support provided by tape and braces before, during, and after exercise as well as effects on range of motion and prevention of injuries. One such study comparing ankle taping to ankle braces in high school football players (Mickel et al., 2006) found there was no statistical difference in the likelihood of ankle sprains between taping and bracing over the course of a single season’s worth of practices and games. These results differed from the results of a similar study of college football players by Rovere et al. (1988), which found that there was a greater prevalence of ankle sprains in ankles that were taped as opposed to braced ankles over the course of six football seasons of practices and games. Both of these studies, however, agreed that ankle taping was much more costly than ankle bracing (Mickel et. al, 2006 & Rovere et al, 1988). Rovere et al (1988) also estimated that taping both ankles for the course of a football season costed around $400, while it was only $60 or $70 to buy two ankle braces. Ankle braces also offer an advantage to taping because they can be re-adjusted during a practice or game if they become loose, where tape cannot be (Mickel et al., 2006).Another study by Verbrugge (1996) found that athletes were more comfortable with ankle braces than they were with taped ankles.

Just like with taping, the use of prophylactic braces has been shown to provide the athlete with neuromuscular stimulation and improved joint position sense (Chinn & Hertel, 2010). Heit et al. (1996) found that lace-up braces were as effective as taping at improving the ability of subjects to reproduce a specific plantar flexion joint angle. Another study looking at the effects of multiple types of ankle supports on patients with ankle instability found that the use of prophylactic ankle braces increased the proprioceptive perceptions of injured ankles to levels of a healthy one, while an aircast brace and ankle tape had no significant effects (Jerosch et al., 1995). Feuerbach, Grabiner, Koh, and Weiker (1994) found that an air stirrup brace increased the afferent feedback from cutaneous receptors of the foot, potentially leading to an improved ankle joint position sense.

However, a potential issue with ankle braces is the possibility that they hinder athletic performance, which has been inconclusive in the studies that have explored the subject. A study of women's basketball players found that the use of ankle supports adversely affects basketball-related performance tests, such as the vertical jump and time for running sprints (MacKean et al., 1995). On the contrary, a different study (Verbrugge, 1996) found no difference in agility and sprint run times between groups, and a small insignificant difference between vertical jump tests. Another possible issue with ankle braces is the lack of long-term research. Bot et al. (2003) highlighted this, concluding that while the use of ankle braces did not limit the functional ability of the athletes, they were concerned about the lack of long-term research, saying that some studies indicate ankle braces could have adverse effects on the muscular activity and biomechanics of the ankle.

Rehabilitation of Ankle Sprains

Proper rehabilitation of ankle sprains is crucial in returning athletes to full participation (Chinn & Hertel, 2010). The majority of grade I, II, or III ankle sprains can be treated without surgery, though there are some cases with people who have had severe ankle sprains where surgery and immobilization is advantageous (Peterson et. al, 2013). For grade II or III ankle sprains, the use of crutches or a walking boot is often used until the patient is able to walk with a normal gait pattern without pain (Kaminski et al., 2013). Besides the rare cases when surgery is necessary, most ankle sprains can be treated by the use therapeutic modalities and exercise (Peterson et al., 2013).

One of the most important purposes of ankle rehabilitation is to restore normal biomechanical function and neuromuscular control. After injury, an athlete may try to compensate for their injury by altering their mechanics so that they do not experience pain (Chinn & Hertel, 2010). While this may provide short-term pain relief, continuing to alter the normal biomechanics of the ankle joint can ultimately put more stress on different muscles, ligaments, cartilage, and bone, increasing the chance of future injury (Mattacola & Dwyer, 2002). Therefore, maintaining proper biomechanics as much as possible is essential for preventing further injury to the ankle joint long-term and restoring the ankle to full functional ability (Chinn & Hertel, 2010).

Strength and Range of Motion

Functional exercise is emphasized to begin as the patient is able, with the patient progressing from non-weight bearing to weight-bearing exercises. Studies that compared this approach with groups that were immobilized for 10 days found that the first group was able to return to play faster than the other group with no adverse consequences (Kaminski et. al, 2013). However, a specific method of how to progress these exercises has not been established. It is recommended that a variety of open and closed-chain exercises be used, as well as performing exercises emphasizing both concentric and eccentric motions to avoid muscular deficiencies (Kaminski et. al, 2013). Most commonly, many athletic training rooms will have subjects perform exercises with Thera-band tubing around the foot, working in the directions of plantar flexion, dorsiflexion, inversion, and eversion. As the strength increases, the thickness of resistance bands are increased to provide a greater challenge to the muscles (van der Wees et al., 2006). While this has been a common practice for athletic trainers, Mattacola & Dwyer (2002) reported that exercises with manual resistance from an athletic trainer were better for isolating the correct muscles in each movement.

In addition, range of motion should be worked on to make sure that there is not any functional impairment at the ankle joint (Hale et al., 2007). This is particularly important if the ankle has been immobilized for an extended period of time before beginning rehabilitation (Kaminski et al., 2013). Without the restoration of range of motion, the risk of re-injury in the ankle ligaments is significantly higher (de Noronha et al., 2009).

Neuromuscular Control and Stability

In people with ankle injuries, alterations have been identified in a spectrum of sensory motor deficits (Hertel, 2008). Gutierrez et al. (2009) concluded that ankle instability was caused by neuromuscular dysfunction associated with trauma to the ankle. It has also been found that both feedback and feedforward mechanisms of motor control are altered with ankle instability, though the specific origin of these deficits are unknown (Hertel, 2008). Therefore, an important part of the rehabilitation of an ankle sprain is to correct the neuromuscular deficits that occur due to the injury. One of the best ways to do this is through proprioceptive training and exercises (Kaminski et al., 2013).

Several studies have looked at the effects of proprioceptive training on preventing ankle injuries. One study found that the use of proprioceptive exercises utilizing multiple planes and joints will improve functional outcomes for patients (Hall et. al, 2015), while others have found that re-injury rates are lower in groups that perform neuromuscular control exercises (McGuine & Keene, 2006). In addition to these studies, a season long study of soccer players also revealed that proprioceptive training was significantly effective at reducing the rate of ankle sprains while strength training did not cause significant improvements (Mohammadi, 2007). Another study looking at balance testing on the strength and function (Holme et al, 1999) found that while no strength and postural control benefits were seen, the patients who underwent rehabilitation suffered fewer re-injuries twelve months after the protocol ended.

In order to improve proprioception of the ankle, one of the simplest exercises that can be done is having the athlete balance on their injured leg on an unstable surface (Kaminski et al., 2013). Devices such as an Airex mat, Dyna Disc, or Wobble Board are able to provide this instability, as the athlete is required to adjust ankle and body position to keep from losing their balance and falling over (Houglum, 2010). A literature review by van der Wees et al (2006) determined that while other exercise methods were inconclusive, the use of a wobble board was effective for improving functional instability and preventing ankle sprains.

As exercise progresses, the task can be made more difficult. Having the athlete remove visual cues for proprioception by closing their eyes is one way to increase the difficulty of these exercises (Mattacola & Dwyer, 2002). Another way is by providing light perturbations, or lightly pushing the athlete in different directions (Guitierrez et al., 2009). If the athlete participates in a sport that uses a ball, such as football or basketball, playing catch while performing balancing exercises can improve proprioception and functional ability (Kaminski et. al, 2013).

Another useful tool for proprioception is having the athlete perform hopping exercises. Since many sports require jumping of some sort, training the ankle to respond to pushing off and landing is crucial to returning to play (Houglum, 2010). With hopping exercises, there are many different types of patterns that can be used. The most common are having the athlete jump forwards and backwards or side-to-side, though the workout can be adjusted to include a variety like circles, squares, and many more (Houglum, 2010). To start off, these hopping exercises should be performed on a softer surface, such as a mat, while building up to the surface that the athlete's sport is played on (Houglum, 2010).

Joint Position Sense

Joint position sense represents the ability of the subject to detect the angle or position of the bones in a joint in space (Konradsen, 2002). This type of testing is primarily performed in a non-weight bearing position (Bernier & Perrin, 1998), though some studies have compared joint position sense findings in weight bearing and non-weight bearing positions (Holme et al., 1999). The subjects undergoing this testing are usually blindfolded in order to remove the possible impact that their vision can have on the results. The purpose of the testing is to determine the proprioceptive capabilities of a joint. The technique is often used to assess for differences between injured and non-injured limbs. This testing is used as a predictor of injuries at a joint, and for the ankle joint has been used to compare the effects of strength training, range of motion, and neuromuscular control (Kynsburg, Panics, & Halasi, 2009).

The exact procedures for a joint position sense test can vary. One of the most commonly used techniques was first described by Robbins, Waked, & Rappel (1995). This procedure involves the patient standing with the non-tested foot on a flat box with their knee fully extended. The other foot is then put onto a sloped box. This protocol uses 11 boxes with slopes between 0 and 25 degrees with a 2.5 degree difference (Kynsburg, Halasi, Ta’llay, & Berkes, 2006). These boxes are randomly placed under the subject, who assesses the amplitude on a scale between 0 (flat box) and 15 (37.5 degrees), meaning that the subject can possibly over-estimate the angle of the slope (Robbins, Waked, and Rappel., 1995). The sloped boxes can be adjusted to place the ankle in all four ranges of motion (flexion, extension, inversion, and eversion), allowing for 44 tests per ankle (Kynsburg et al., 2009).

Another common technique to assess joint position sense is having the subject actively attempt to recreate an angle that they have previously been taken to passively. In this procedure, the subject is taken passively into a range of motion, most commonly inversion, and instructed to concentrate on the position of their ankle before returning the ankle to a neutral position. The amount of time the subject is allowed to focus on the joint varies in the literature, with some articles allowing as long as 15 seconds (Docherty et al., 1998; Kaminski & Gerlach, 2001) and some allowing only one or two seconds (Holme et al., 1999, Konradsen & Magnusson, 2000). Most protocols, however, hold the subject in the passive position for five to ten seconds (Jerosch et al., 1995, Sekir et al, 2007). After returning to the neutral position, the subject is asked to actively recreate the previous position. The subject’s error score is then recorded for analysis (Konradsen & Magnusson, 2000). Trials at a particular ankle position are repeated multiple times in order to obtain an average error score for final analysis (Brown et al., 2004).

Functional instability of the ankle has been shown to lead to deficits in joint position sense testing. For example, Nakasa et al. (2008) found that subjects with functional instability had greater deficits of joint position sense in testing, regardless of the degree of mechanical instability the subject had.

Several studies have found a positive correlation between strength training and improved joint position sense. One study examining the effects of strength training (Docherty et al., 1998) divided its participants into an experimental and control group, where the experimental group performed strengthening exercises using Thera-Band tubing three times per week for six weeks. Aside from improving ankle strength, it was found that both inversion and plantar flexion joint position sense were improved in functionally unstable ankles. Studies that have looked at neuromuscular control (Holme et al., 1999; Bernier & Berrin, 1998) found that joint position sense is not significantly changed following a proprioception training protocol.

Studies looking at the effects of ankle taping and bracing on joint position sense have been inconclusive. While functionally unstable ankles have been shown repeatedly to perform worse on joint position tests than healthy ankles (Karlsson & Andreasson, 1992 & Lentell et al., 1995), studies looking at the effects after the application of ankle tape or a brace have varied between having significant effects on the ankle joint (Simoneau, Denger, Kramper, & Kittleson, 1997) and having no effect on the ankle joint when compared to a non-supported ankle (Kaminski & Gerlach, 2001). Variations have also been seen in studies comparing the two intervention methods. Kaminski and Gerlach (2001), for instance, determined that neither bracing nor taping had a significant effect on ankle joint position sense for female college athletes. Karlsson and Andreasson (1992) and Hartsell (2000) have found that ankle taping and bracing, respectively, significantly improve joint position sense in chronically unstable ankles.

Similar results were found studies conducted by Robbins et al. (1995) and Simoneau et al. (1997) utilizing taping, though the subjects in these studies did not have any history of chronic ankle instability.

Summary

There are a variety of bones, muscles, and ligaments that are around the ankle joint that help perform functions or prevent injuries. A sprain to the ankle often involves an inversion action, causing damage to the lateral ligaments of the ankle. Without proper rehabilitation, the athlete can develop chronic issues with ankle instability, which increases their risk of future ankle injuries. For the vast majority of ankle injuries, surgery is not necessary, and using appropriate modalities, support, and exercises can lead to a successful return to play. While both the use of ankle tape and prophylactic braces have their benefits, there have also been studies showing that they can have a negative effect on ankle function or not provide prolonged support. While exercises have been used to increase ankle strength and function after an athlete has sprained their ankle, these exercises are rarely performed to enhance the prevention of such injuries. This study was performed to determine if ankle strengthening exercises would lead to an improved joint position sense, ankle strength, and range of motion when compared to ankle bracing.

Chapter 3
Methods and Procedures

Introduction

The purpose of this study was to determine if using ankle strengthening exercises as a preventive measure could improve ankle joint position sense, strength, and range of motion when compared to ankle braces following a six week intervention period.

Description of Study Sample

The sample for this study consisted of 20 college students (average age: 23.12 ± 4.61 years, average height: 172.78 ± 10.04, average mass: 76.25 ± 14.33kg) recruited from Western Washington University in Bellingham, WA following approval of the study by the Institutional Review Board. Subjects were included in the study if they were at least recreationally active, and had suffered at least two ankle sprains to one of their ankles during their lifetime. Subjects were instructed to count an injury as a sprain if the injury resulted in pain, swelling, and loss of ability to perform activity for at least one week. On average, the subjects in this study had sustained 3.81 ± 1.46 reported sprains on the ankle that was tested, and reported an average of 10.39 ± 4.55 hours of exercise per week. Subjects who had undergone prior ankle surgeries were excluded from participating. Subjects who did not complete all of the pre and post-testing or training sessions were removed from the study.

Design of Study

A pre and post-testing randomized-controlled trial was performed to test the hypothesis that strength and proprioception training for the ankle would improve strength and joint position sense. All of the subjects were tested for a baseline measurement for each of these variables and then again three weeks and six weeks later for a comparison. All of the tests were performed on whichever foot the subject had a history of ankle sprains with. If the subject had a history of ankle sprains on both ankles, they were allowed to choose which one they wanted to be tested. For the baseline test, all of the subjects were divided into two groups. One group was given ankle braces (ASO, Charlotte, NC, USA) to wear on their previously injured ankle, while the other group was given nothing. The ankle brace group was tested with and without the ankle brace to determine if there were immediate differences between the two groups.

After the baseline testing, the groups were given two different workout plans. The ankle brace group did not have any other commitments in the lab, and were allowed to continue their normal activities outside of the lab. They were, however, asked to wear the ankle braces for any physical activity they participated in. The exercise group was asked to return to the lab three times per week to perform ankle rehabilitation exercises. These exercises consisted of a combination of strengthening and proprioceptive exercises, and the subjects were able to perform them in less than 30 minutes per day. The strengthening exercise protocol lasted six weeks, and the same exercises were performed in each testing session.

For the six week period, the subjects were allowed to maintain their personal exercise and activity levels. The subjects were retested twice, at three weeks and after completion of the six week trial. To account for possible differences in activity levels between the groups, all of the subjects were asked to record what activities they did and how long they participated in these activities.

Rehabilitation Training Protocol

For the subjects in the exercise group, exercises were performed to work on strength, range of motion, and proprioception of the ankle joint. For strength and range of motion, the subjects performed resistance band exercises using Thera-band tubing (The Hygenic Corporation, Akron, OH, USA). Subjects performed three sets of ten repetitions of plantar flexion, dorsiflexion, inversion, and eversion against the band resistance. This exercise was commonly used by other studies looking at the effects of strength training on joint position sense (Docherty et al., 1998; Smith, Docherty, Simon, Klossner, and Schrader, 2012).

In addition to the strength training exercises, the subjects also performed a neuromuscular training exercise focused on improving ankle proprioception. For this exercise, the subjects performed single leg balancing with their eyes open and their involved knee flexed slightly to place the subject in a more athletic position. The exercises were performed while standing on a Dyna-Disc (Exertools, Rocklin, CA, USA) to provide an unstable surface for the subject. This exercise was performed for three sets of 30 seconds each session with a rest time between 15 and 20 seconds. This type of exercise was highly recommended to reduce the occurrence of chronic ankle instability in the National Athletic Trainers Association position statement on the rehabilitation of ankle injuries (Kaminski et al., 2013). The exercises performed by the exercise group in this study are depicted in figure 1

Figure 1. Depictions of the single-leg balance (left) and four-way thera-band (right) exercises performed by the exercise group

Data Collection Procedures

Data was collected in the biomechanics lab at Western Washington University in Bellingham, WA. To begin, the protocol was explained to the subjects with an informed consent document that the subjects read and signed. The subject's age, height, and weight were recorded as well prior to testing. To warm-up, the subjects completed five minutes at a self-selected pace on an exercise bike. After this was completed, the range of motion was determined for each subject in the directions of plantar flexion and dorsiflexion. For these measurements, the subject was placed in a seated position with their foot hanging off a treatment table. Measurements were recorded using a hand-held goniometer, and were recorded three times for each motion to ensure accuracy. Once all of this was completed, the tests for strength and joint position sense were performed.

First, strength was tested for plantar flexion and dorsiflexion using a Biodex System 4 Pro (Biodex, Shirley, NY, USA) dynamometer machine. The subjects were in a seated position on the dynamometer machine with their affected ankle strapped to the machine. The subjects were placed in a position with both their hip and knee flexed to 90 degrees for the tests (Figure 2). After an explanation of the protocol, the subjects performed three trials of maximum isometric contractions in the directions of plantar flexion and dorsiflexion. In each trial, the subjects attempted to push as hard as they could for three seconds against an unmoving resistance, with the peak torque for the trial being recorded. The subjects were then allowed 15 seconds of rest between sets of maximum contractions in the same direction, with a two minute rest between sets of plantar flexion and dorsiflexion. The protocol was randomized so that some subjects performed isometric dorsiflexion first, while some started with isometric plantar flexion. This protocol was similar to the one used by Docherty et al. (1998). The results for the strength testing were saved onto the biodex computer before being exported to a Microsoft Excel (Microsoft, Redmond, WA, USA) spreadsheet for analysis.

Following the strength testing protocol, joint position sense testing data was collected using an application on an iPod touch (Apple Inc., Cupertino, CA, USA). This Method of measuring joint position sense was previously validated in our lab with a reported accuracy of up to 0.48 at 30 degrees of knee extension and up to 0.51 degrees at 60 degrees of knee extension, while ICC of 0.62 at 30 degrees and 0.76 at 60 degrees (Lyons, Cordell, Gossage, Suprak, & San Juan, 2016). However, their testing was done at the knee joint and not the ankle joint. The iPod was mounted to the lateral aspect of the subject’s injured foot using a Quad Lock mounting system (Quad Lock, Annex Products, Prahran, VIC, Australia). This mounting system was connected to a post-op shoe (Breg, Carlsbad, CA, USA) that could be adjusted to fit any size foot. For the procedure, the subject was placed in a prone position with their ankle hanging off of the table in a neutral position. The subject was asked to keep their eyes closed during the test to make sure they were not using visual cues (Figure 3). The subject was asked to move their foot into a position of either 20, 30, or 40 degrees of plantar flexion by instruction from the iPod. The ankle was held in that position for approximately three seconds, during which time subjects were instructed to concentrate on the position of the ankle, before returning to neutral position. The subject was then asked to return to the presented position without any feedback. This trial was repeated randomly for five trials of each angle, resulting in 15 total trials, which was similar to the protocol used by other studies (Holme et al., 1999; Kaminski & Gerlach, 2001). The data for the average absolute error score of the studies was recorded in a Microsoft Excel spreadsheet for later analysis.

Figure 2. Position of the subject during peak torque testing using the Biodex dynamometer

Figure 3. The position of the subject during joint position sense testing.

Data Analysis

The data was analyzed using SPSS version 23 software (IBM, Armonk, NY, USA). Utilizing this software, a three-way mixed analysis of variance (ANOVA) was used to analyze the data. The data were compared both between and within groups for each variable. The independent variables in this study were the two groups (the bracing group and the exercise group), as well as the three testing periods (baseline, three weeks, and six weeks) and position (20, 30, and 40 degrees). This comparison was done for the dependent variables of plantar flexion peak torque, dorsiflexion peak torque, and average absolute error scores at each angle during joint position sense testing. The Sphericity of the data was examined, and if it was violated then the Greenhouse-Geisser corrections were analyzed. Significance tests were examined using an alpha level of 0.05 as the point of significance, and effect size was utilized if there were any significant differences between the two groups.

Chapter 4

Results and Discussion

Introduction

The purpose of this study was to determine if the implementation of an ankle strength and proprioception protocol would be able to improve ankle joint position sense acuity as well as the application of an ankle brace. This study was also conducted to determine if such a protocol would be effective at significantly increasing peak plantar flexion and dorsiflexion peak torque when compared to the brace group. For joint position sense testing, the independent variables assessed for this study were group (exercise vs. brace), time (pre-test, mid-test, and post-test), and position (20, 30, and 40 degrees), while the dependent variable was absolute error score. For the strength measurements obtained on the Biodex, group and time were once again independent variables, with direction (plantar flexion and dorsiflexion) acting as the third independent variable. The dependent variable for this measurement was peak torque. A three-way mixed analysis of variance (ANOVA) was used to analyze any changes over time or any differences between the two groups.

Subject Characteristics

A comparison of the subject characteristics between the exercise and bracing groups is shown in table 1. Twenty-two subjects went through the first round of data collection, with eleven subjects placed in each group. Two subjects in the exercise group did not complete testing, leaving 20 total subjects who completed all rounds of data collection. There was no significant difference in the general characteristics of subjects in different groups. Furthermore, there was also no significant difference between the groups for average plantar flexion range of motion (F[2,34] = 0.274, p = 0.749, η^2_p = 0.082) and dorsiflexion range of motion (F[2,33] = 0.431, p = 0.653, η^2_p = 0.023). Throughout the duration of the study, the exercise group on average participated in more hours of physical activity than subjects in the brace group, though there was no significant difference between the two groups.

Table 1. Subject Characteristics for the exercise and bracing groups. All of the data in this table, with the exception of weekly physical activity, was obtained during data collection through either voluntary reporting of the subjects or measurements of the researchers. Weekly physical activity was determined based on exercise logs submitted by the subjects.

Variable	Exercise Group	Brace Group
Number of Subjects	9	11
Age	23.80 ± 6.49 years	22.45 ± 2.30 years
Height	169.8 ± 8.92cm	177.5 ± 10.81cm
Mass	72.35 ± 13.80kg	80.15 ± 14.34kg
Number of Ankle Sprains	3.9 ± 1.60 sprains	3.73 ± 1.35 sprains
Plantar Flexion ROM	55.00 ± 4.16 degrees	54.68 ± 1.71 degrees
Dorsiflexion ROM	12.90 ± 5.85	11.70 ± 4.46 degrees
Weekly Physical Activity	7.15 ± 3.67 hours	6.11 ± 2.23 hours

Joint Position Sense

Results from the joint position sense tests are shown in figure 4. Mauchly's test of sphericity indicated that sphericity was not assumed for group, time, or position, and a Greenhouse-Geisser correction was utilized. No significant effect was reported for the three-way interaction between the independent variables of time, group, and position on absolute error (F[1, 25] = 0.422, p = 0.698, η^2_p = 0.023). There were also no significant two-way interactions between time and group (F[1, 25] = 0.294, p = 0.663, η^2_p = 0.016), position and group (F[1, 25 = 0.568, p = 0.565, η^2_p = 0.031), nor time and position (F[1, 25] = 0.211, p = 0.851, η^2_p = 0.012) on absolute error. These findings indicate that there were no significant effects on joint position sense testing based on group, time, or position.

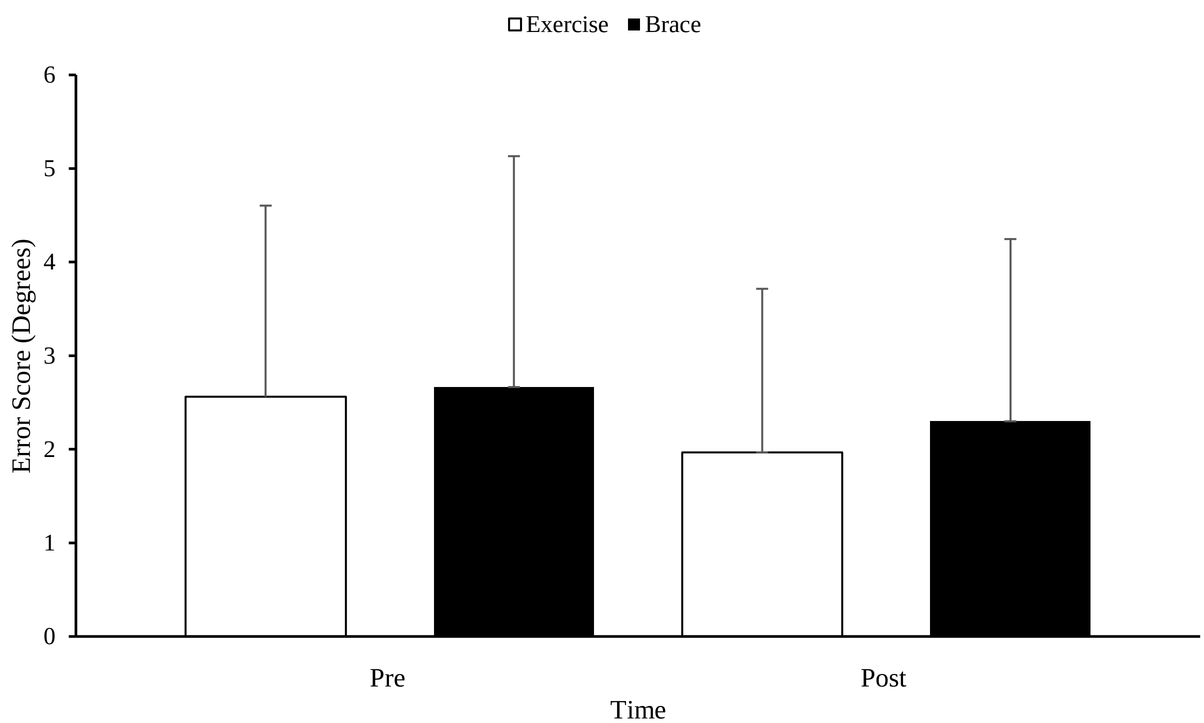

Figure 5. The average error score from joint position sense testing for the exercise group (white) and the brace group (black).

Peak Torque

The results for peak plantar flexion and dorsiflexion torque are depicted in figures 5, 6, and 7. Once again, sphericity was not assumed for the dependent variables of group, time, and direction, so a Greenhouse-Geisser correction was utilized for analysis. For the direction of plantar flexion, there was a significant increase in peak torque over time for all subjects (F[2, 30] = 4.064, p= 0.033, η^2_p = 0.184). However, there was no significance between the exercise and brace groups for changes in peak torque over six weeks (F[2, 30] = 1.057, p = 0.349, η^2_p = 0.055). For the analysis of dorsiflexion data, similar results were seen. Once again, no significant difference was seen between the exercise and brace groups over time (F[2, 34] = 1.133, p = 0.33, η^2_p = 0.059), although a significant increase in peak torque was seen across all subjects over the six week period (F[2, 34] = 4.984, p = 0.014, η^2_p = 0.217). These results indicate that the exercise protocol did not impact peak torque changes between the two groups.

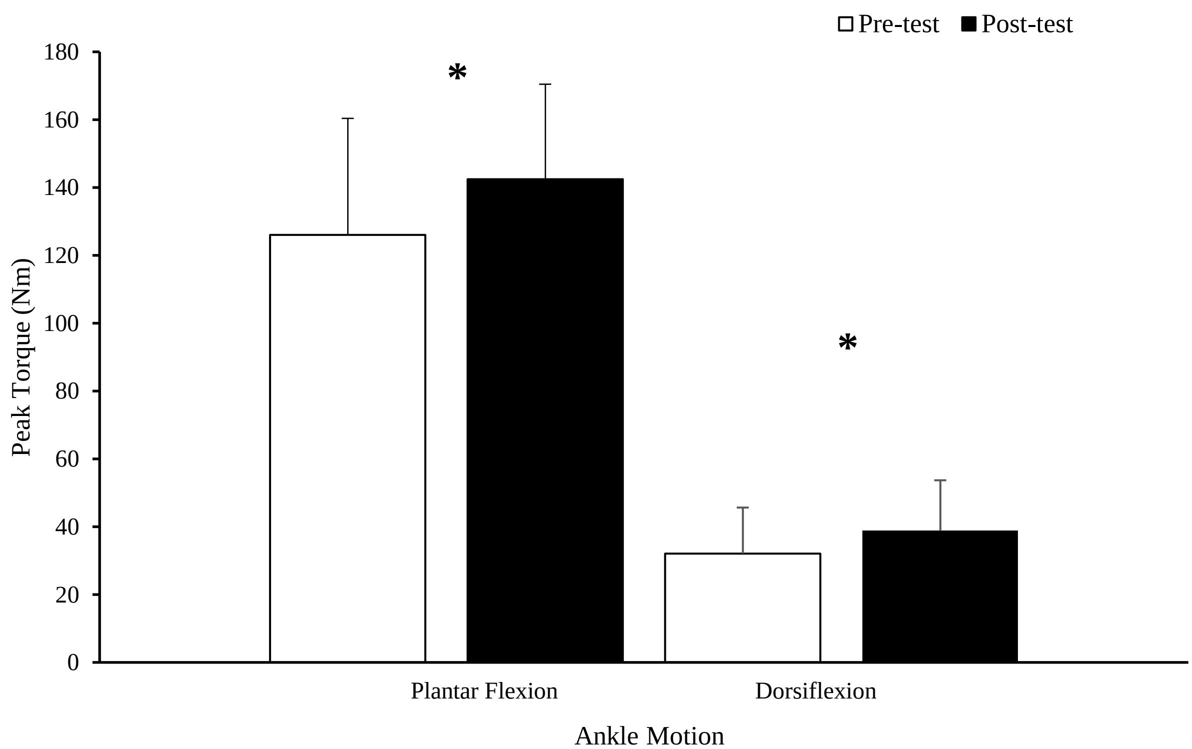

Figure 5. Average plantar flexion and dorsiflexion peak torque for all subjects during pre-testing (white) and post-testing (black).

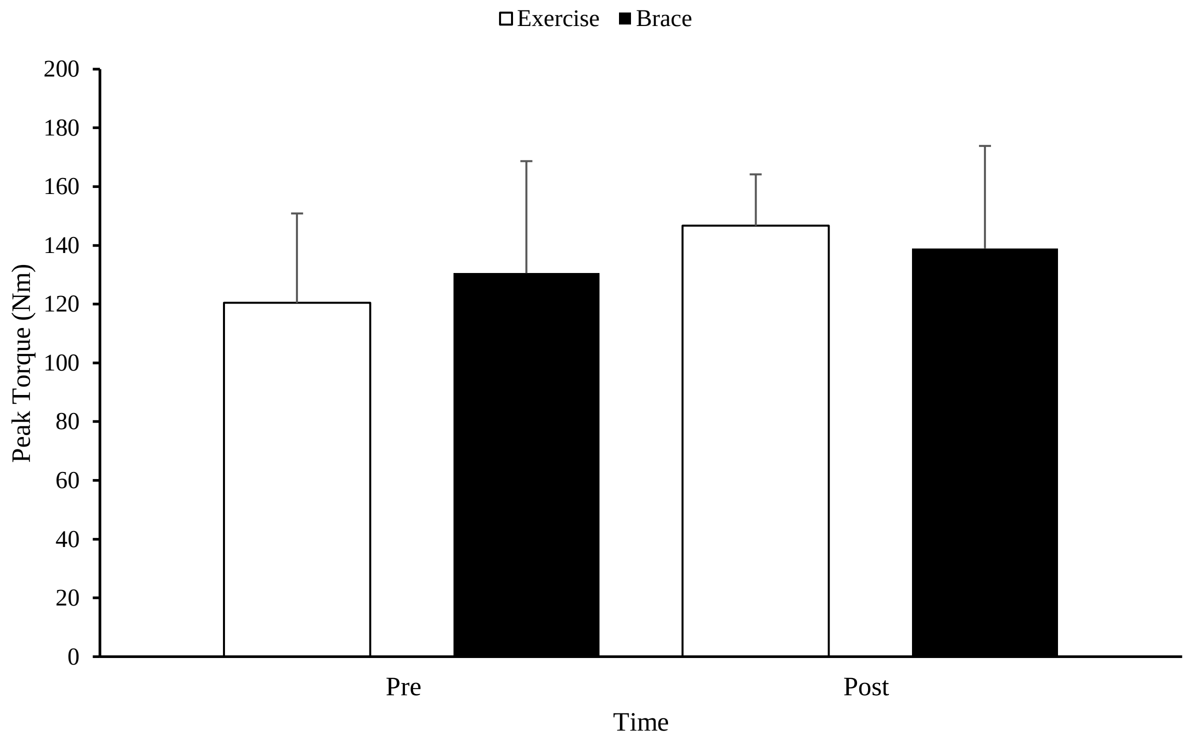

Figure 6. Results of peak torque testing on the Biodex dynamometer for plantar flexion between the exercise group (white) and brace group (black).

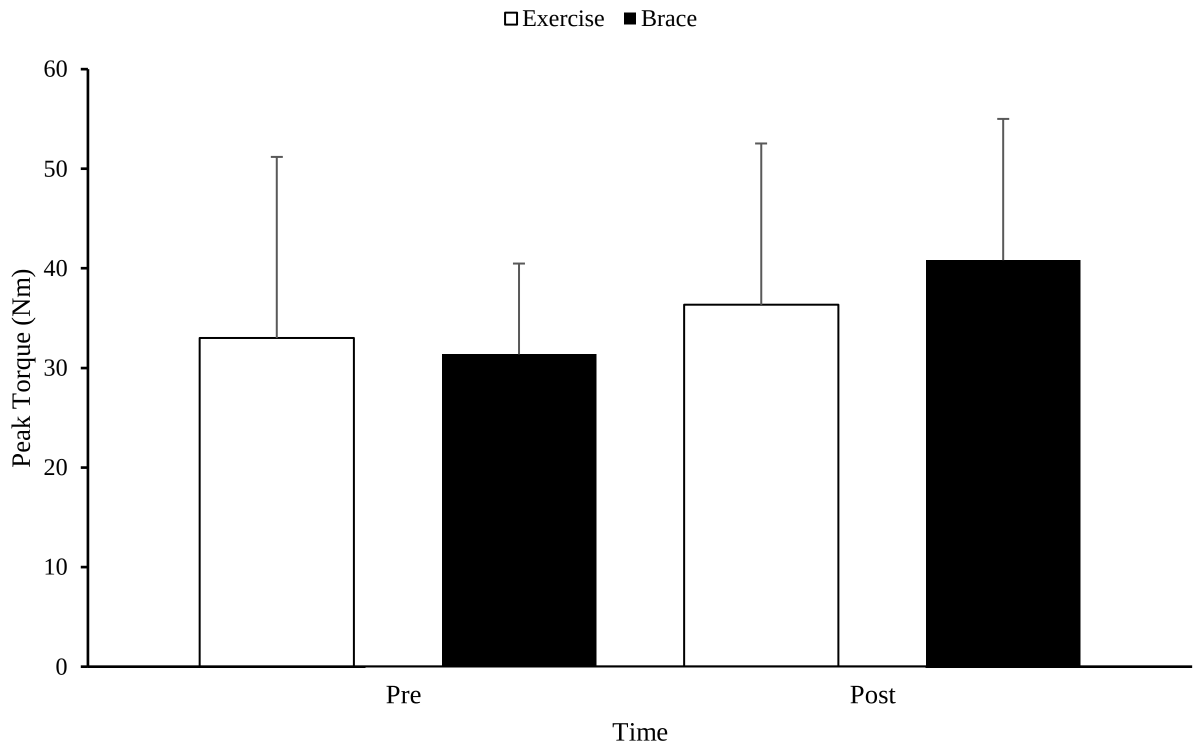

Figure 7. Results of peak torque testing on the biodex dynamometer for dorsiflexion between the exercise group (white) and brace group (black).

Discussion

Given the prevalence of ankle sprains in athletics, there is a high demand for interventions that can reduce the risk of injury from athletes and those who work with them. Because of this demand, there is a wide range of research on how different types of ankle supports or exercise protocols compare to each other. However, no prior research was seen comparing the effects of one type of ankle support to an exercise protocol. This study aimed to determine how six weeks of strength and proprioception training would affect JPS and peak torque compared to a control group wearing ankle braces. It was hypothesized that while the brace group may perform better during JPS testing initially, the exercise group would significantly improve to either the same level or surpass the bracing group following six weeks of exercise. It was also hypothesized that peak torque for plantar flexion and dorsiflexion would significantly improve for the exercise group over six weeks, and improve significantly more than the brace group.

Joint Position Sense

The main finding in this study was that ankle strength and proprioception exercises, despite causing an improvement, did not significantly improve joint position sense following six weeks of exercise training on the ankle. Likewise, there was no difference in average error score between the exercise group and brace groups after six weeks of training. This finding does not support our hypothesis that the exercise group would significantly improve their JPS over the course of the study and would perform better during JPS testing after six weeks of training than the brace group.

One of the surprising findings in this study was that during pre-testing, the exercise group actually performed slightly better than the brace group despite having not begun exercises, although the differences were not significant. The subjects in the brace group even performed better initially when they were tested without the ankle brace, but this only occurred during pre-testing. Prior research has suggested that the application of an ankle brace can increase the afferent feedback from cutaneous receptors of the foot, thus improving the proprioception of an ankle joint with chronic ankle instability to the levels of a healthy control (Feuerbach et al., 1994; Jerosch et al., 1995). It has also been reported that external ankle support decreases the reaction time of peroneal muscles in chronically unstable ankles (Karlsson & Andreasson, 1992). Therefore, it would have been expected that applying an ankle brace would have caused the subjects to perform better during initial JPS testing, which was not seen in the current study. One possible difference is that these studies used subjects who were currently diagnosed with chronic or functional ankle instability, while the current study required subjects who had sustained at least two ankle sprains during their lifetime. Recreating this study with subjects who had been clinically diagnosed with functional instability at the ankle joint could possibly lead to results similar to what these prior studies found.

The findings of our study were in agreement with a study conducted by Kaminski & Gerlach (2001). This study analyzed differences in JPS between different ankle support conditions, including taping and a neoprene ankle support. For each condition, the subjects were evaluated for both passive and active re-positioning error scores, for which there was no significant difference between any of the groups. They concluded that since they used a healthy female population, the subjects did not have as much room for improvement by putting on an ankle brace. This may have also been an issue in the current study. The subjects in our brace group had a much lower average error score when initially tested without the brace compared to the subjects in their study (2.29 degrees vs. 6.20 degrees), though this could have been due to a difference in testing methods..

It is possible that the brace had no initial effect because the subjects were either not used to wearing an ankle brace or this specific type of ankle brace. However, no other study reported such a finding, as most literature only looked at one round of testing in normal and different support conditions. More research regarding changes in JPS while wearing an ankle brace would need to be performed to better determine the effects braces have on proprioception at the ankle joint.

The findings of the current study were not in agreement with those of Docherty et al. (1998), who reported a significant improvement in both isometric ankle strength and joint position sense test results using a thera-band protocol. The current protocol was similar to the Thera-band protocol used in this study as it featured subjects performing three sets of ten repetitions for each ankle motion, three times per week for six weeks. One difference in the protocol, however, was that the researchers increased the strength of the Thera-band every two weeks, while the current study kept subjects on the same thera-band resistance level all six weeks. Creating an exercise program that progressively increases the intensity throughout the protocol could ultimately have a greater impact on strength and proprioception, and could be utilized in future studies comparing exercises to bracing. Another difference seen when looking at their research is that the subjects in their study had average error scores during the pre-test that were much higher than those seen by any group in the current study. During pre-testing, the subjects in their experimental group had average error scores between 6.8 and 7.9 degrees, while our exercise group had an average error score of 2.56 degrees. Their study also examined JPS using a dynamometer, while ours utilized an iPod that was attached to the subject's foot, which is a more recently developed method for assessing JPS. A future study could attempt to compare the results between these two methods and determine if they lead to similar results.

A study by Lee & Lin (2008) was also not in agreement with our study, as they reported significant improvements in postural sway and proprioception testing following the completion of their exercise protocol. Their study utilized a protocol that was three days per week for 12 weeks, which was twice as long as the current study. Their study also utilized subjects who were not physically active, while our study recruited subjects who were recreationally active. Another difference between the two studies was that their protocol also consisted of a variety of exercises performed using a biomechanical ankle platform system (BAPS) board, which can be used for balance and range of motion. A BAPS board can be easily adjusted to increase the difficulty of exercises, while the Dyna-disc used in this study could not. It is possible that creating a progression for the Dyna-disc, which could include adding perturbations, having the subject close their eyes, or performing functional exercises such as a squat, could enhance the challenge on a subject's neuromuscular system, leading to significant results.

Our study was in accordance with a study conducted by Bernier & Perrin (1998). While their study did find significant improvements in JPS for all of their subjects, they did not see significant differences in JPS following the completion of their six-week protocol compared to a sham treatment group and a control group. Their study was similar to the current study, as their subjects performed exercises three times per week and the protocol only lasted about 10 minutes per session. However, their protocol consisted entirely of balance exercises and no thera-band or resistance exercises. It is possible that their study did not include enough exercises to elicit proprioceptive changes, which may have also been the issue with the current study.

The current study is also in agreement with the results from a study by Holme et al. (1999), who reported no significant differences in improvements between their experimental and control groups after four months. Their study focused on the effects of a rehabilitation protocol consisting of comprehensive balancing exercises, running activities, and balancing while catching a ball, which were implemented twice per week while the control group used a basic exercise card provided by the emergency room. Even though they did not see significance initially, their study did show that the exercise group had a significantly lower risk of re-injury a year after their injury compared to the control group (Holme et al., 1999). Therefore, it is possible that performing these exercises reduced the risk of ankle injury for our subjects in the future.

Other studies examined the effects of different exercise protocols on the incidence of ankle sprains for athletes, which JPS testing attempts to predict. McGuine & Keene (2006) reported that single-leg balancing exercises decreased the rate of ankle injury when compared to normal conditioning exercises in high school athletes. Their study used a very extensive protocol compared to the current study, however, as it included subjects performing single-leg squats and sport-specific activity while balancing. Incorporating functional activities into balance exercises may be a way to elicit greater JPS improvements, and could also be considered. These exercises were also performed five times per week for the first four weeks, then three times per week through the remainder of their sport season, meaning that subjects completed a greater amount of exercise sessions, which could have had a greater impact on proprioception.

These effects have been reported in other sports as well. Verhagen et al. (2005) reported that a balance training program specifically designed for volleyball players led to a significantly lower injury rate than what was seen in the control group. The exercises consisted of both normal single-leg balancing and sport-specific motions while balancing, such as setting and spiking a ball. This protocol was much more specific for volleyball players than the current study, which was intended for a wide use. Another feature that was unique to this study was the fact that they included four different protocols, which the coach of the team would randomize on a weekly basis. Introducing variations on the exercises used in the current study and randomly administering them could allow for greater improvements in proprioception at the ankle joint.

Mohammadi (2007) was the only study that compared exercise groups to a bracing group, dividing subjects into an ankle proprioception group, an ankle strengthening group, an ankle bracing group, and a control group. This study found that the group performing proprioception exercises significantly reduced the number of ankle sprains seen in the group, while strengthening and bracing did not have significant differences compared to the control group. However, the results of the current study did not show any significant difference for the proprioception group related to the strength or brace group. When compared to the current study, Mohammadi's protocol utilized proprioception protocol that was performed for 30 minutes every single day and featured a greater variety of tools to progress the difficulty of the exercises. This again may indicate that the exercise program in the current study should progress in difficulty to further challenge the subjects, which may lead to more significant improvements in JPS.

Peak Torque

The current results indicated that peak plantar flexion and dorsiflexion peak torque were not affected by the exercise protocol although a statistically significant difference was seen between pre and post testing for all subjects. It is possible that this change was due to a learning effect, as subjects became more familiar with the Biodex testing protocol. Dorsiflexion is a particularly important area to focus because it has been shown to be one of the major areas for strength loss in subjects with chronic ankle instability (Negahban et al., 2013). Docherty et al. (1998) found that six weeks of Thera-band exercises significantly increased mean dorsiflexor strength. This was tested using a handheld dynamometer, however, which may have affected the results. As mentioned earlier, this protocol also progressively increased the resistance during ankle exercises, which could have increased the intensity of the exercise and led to the significant improvements seen in their study.

The current study is not in agreement with Kim et al. (2014), who found significant increases in peak torque following an ankle strengthening and proprioception exercises. The strengthening protocol was similar to the protocol in the current study, with the only differences being the duration of the protocol (four weeks) and the number of sets performed (four). They also used an isokinetic test to determine peak torque, which may have given different results than our isometric testing.

Our study was also not in agreement with Smith et al. (2012), who found significant increases in inversion and eversion isometric peak torque. For their study, they implemented a strength training protocol identical to the one of Docherty et al. (1998) with the addition of exercises performed on a multiaxial ankle exerciser (MAI), which may have provided more strength benefits than the resistance band protocol used in the current study. Another difference in their resistance band protocol was that they had all subjects stretch the band to a point 170% of the original length, while the current study instructed subjects to stretch the band to a resistance point that provided a challenge while still allowing them to complete the sets. Ensuring that subjects stretch the resistance band to a specific length could increase the intensity of the workout for some subjects, therefore positively affecting peak torque at the ankle joint.

Chapter 5

Summary, Conclusion, and Recommendations

Summary

Ankle sprains remain the most common injury seen in athletics today, particularly in sports involving running, jumping, and cutting motions (Hootman et al., 2007). Following an ankle sprain, an athlete can develop numerus deficiencies in ankle function, including loss of muscle strength (Holme et al., 1999), decreases in joint proprioception (Lentell et al., 1995), and muscle reaction time (Karlsson & Andreasson, 1992). Because of these possible deficiencies, ankle supports or ankle training protocols are needed to limit the instance and severity of ankle sprains in athletes.

Ankle braces have recently gained more favor than ankle taping due to the studies that have demonstrated that they are just as effective at preventing ankle sprains as taping, while allowing for simple adjustments to be made (Rovere et al., 1988; Verbrugge, 1996; Mickel et al., 2006). Ankle braces have also been shown to provide neuromuscular stimulation to the ankle and improve joint position sense in subjects with ankle instability (Heit et al., 1996; Chinn & Hertel, 2010). However, there is some debate in the literature regarding the effects of ankle braces on athletic performance (Verbrugge, 1996; MacKean, Bell, and Burnham, 1995). Furthermore, there is a lack of long-term research on the effects of ankle braces, so there is some concern pertaining to possible changes in lower limb function (Bot et al., 2003).

Researchers have also examined the effects of strength and proprioception exercise protocols for their ability to reduce the risks of ankle sprains. These exercises often consist of performing strengthening exercises using a resistance band (Docherty et al., 1998) and balance training using tools that provide an unstable surface (Kaminski et al., 2013). Prior research has demonstrated that implementing an exercise protocol reduces an athlete's risk of injury over the course of a season (McGuine & Keene, 2006; Mohammadi, 2007). Furthermore, joint position sense tests have shown that exercises can improve proprioception at the ankle joint, decreasing the risk of ankle sprains (Docherty et al., 1998; Lee & Lin, 2008; Kim et al., 2014). However, no prior research has been found comparing the effects of an external support such as an ankle brace to an exercise protocol on JPS and peak torque at the ankle joint.

Therefore, this study attempted to determine the effects of a six-week ankle strength and proprioception training protocol on joint position sense and peak torque for recreationally trained subjects. Furthermore, this study sought to compare these results to those of a control group that wore ankle braces during physical activity for six weeks. JPS testing was performed using an application on an iPod that was attached to the subject's foot, determining the average absolute error score during a pre, mid and post-test. Peak torque was assessed with a Biodex dynamometer during isometric plantar flexion and dorsiflexion protocols, which were performed at the same time intervals as JPS testing. The results indicated no significant changes in JPS over six weeks, as well as no differences in JPS between the exercise and brace group during pre, mid, and post-testing. This study also found that while the subjects collectively improved their peak torque for both plantar flexion and dorsiflexion, there was no significant difference between the two groups during pre, mid, and post testing.

Conclusion

The present study demonstrated that the implementation of a six-week ankle strength and proprioception training protocol did not significantly improve joint position sense, peak plantar flexion torque, or peak dorsiflexion torque in recreationally active college students. It also found that there were no significant changes in any of these areas when compared to subjects who wore ankle braces during exercise for a six-week period. Based on these results, this exercise protocol was no more effective at providing protection from ankle sprains than the application of a prophylactic ankle brace. Therefore, athletes should be cautious on utilizing this exercise protocol by itself as a substitute for ankle taping or bracing. However, based on prior research demonstrating the positive effects of strengthening and proprioception exercises on joint position sense, ankle strength, or the risk of ankle sprains over a specific period of time, more research could be done to determine if variations to this exercise protocol can have significant benefits in these areas.

Recommendations

There have been numerous studies examining different strength and proprioception training protocols. Some of these protocols have been successful at increasing ankle strength, proprioception, or decreasing the risk of ankle sprains, while others have not had an effect. Observing how the different variations of these strength and proprioception exercises affects JPS error score changes or peak torque improvements over time compared to athletes wearing ankle braces could possibly lead to the development of appropriate injury prevention protocols.

Therefore, alterations to the protocol utilized in this study could ultimately decrease risk factors for ankle sprains. These alterations could include increasing the strength of resistance bands at different intervals throughout the course of the study, increasing the frequency with which exercises are performed, or other methods that increase the intensity of the exercises after a certain period of time. If it is determined that implementing a strength and proprioception protocol can in fact provide the same amount of protection as an ankle brace, it would provide coaches or athletic trainers another method of injury prevention that may be more cost-effective than ankle taping or bracing.

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WESTERN WASHINGTON UNIVERSITY

INSTITUTIONAL REVIEW BOARD

APPROVAL FOR USE OF HUMAN SUBJECTS

TYPE OF REQUEST: ☒ new ☐ continuation ☐ modification

PROTOCOL NUMBER: 17-015

INVESTIGATOR(S): Jayson Shepherd

DEPARTMENT: Health and Human Development

PROJECT TITLE:

Effects of an ankle strengthening and proprioception protocol on strength, joint position sense

APPROVAL PERIOD: 3/12/2017 – 3/11/2018

NUMBER OF SUBJECTS: unknown

APPROVED INFORMED CONSENT FORM ATTACHED: ☒Yes ☐No

Approved by Lara Symons
Institutional Review Board

Date 3/12/2017

Comments:

Note: Approval is for the period specified above. A protocol renewal form will be sent to you prior to the expiration of this approval period. If there are any adverse events or changes in the research procedures affecting the use of human subjects in this project during the current period, the HSRC must be notified immediately.

Western Washington University
Health and Human Development Department

Informed Consent

You are invited to participate in a study investigating the effects of different ankle injury prevention methods on predictors of injury. Specifically we will investigate the differences between a group performing ankle exercises and a group wearing ankle braces. The results of this study will improve our understanding of the effectiveness of ankle exercises on the prevention of ankle sprains.

I UNDERSTAND THAT:

1. The experiment will begin with a measure of height, weight, and ankle motion. Height, weight, and ankle motion will all be measured prior to the testing protocol. The subjects will then undergo a five minute warm-up on an exercise bike at a self-selected pace before testing.

2. After completion of the warm-up, the subjects will perform two tests at the ankle joint. The total time of this testing will be between 30 and 60 minutes, after which further instructions will be given. The subjects will be re-tested after three weeks and six weeks.

3. There may be risks associated with the testing. With the strength testing procedure, there may be some risk of fatigue, though these risks should be minimal. Any fatigue experienced throughout the testing may differ between subjects depending on their prior activity level of the subject, though this should also be minimal in nature. If I do have any problems that are caused by testing or exercise, I can stop at any time without penalty.

4. Possible benefits from the study may include a decreased risk of future ankle sprains for all of the subjects.

5. My participation in this study is voluntary, and I may choose to withdraw my consent to participate at any time I wish with no consequences. I will not receive any financial compensation for my participation in the completed project. However, I may receive extra credit from professors in the kinesiology department.

6. All of my information in this study will be kept confidential. My signed consent form and information sheet will be kept in a locked cabinet separate from data collection forms, and my name will not be associated with any of my data collected during the testing protocols.

7. My signature on this form does not waive my legal rights of protection.

IRB Approved
3/12/17

8. This experiment is conducted under the supervision of Dr. Jun San Juan (Health and Human Development). Any questions that you have about the experiment or your participation may be directed to Dr. Jun San Juan at (360) 650-2336 or Jayson Shepherd at (515) 297-0302.

   If you have any questions about your participation or your rights as a research participant, you can contact Janai Symons, Research Compliance Officer, at Janai.symons@wwu.edu or (360) 650-3082.

   If during or after participation in this study you suffer from any adverse effects as a result of participation, please notify Dr. Jun San Juan (360-650-2336; jun.sanjuan@wwu.edu), or contact Janai Symons, Research Compliance Officer, Janai.symons@wwu.edu and (360) 650-3082.

I have read the above descriptions and agree to participate in this study

Participant's Signature________________________________ Date__________________

Participant's Printed Name____

Circle one:

Participant Copy Investigator Copy

Thesis Checklist

- ☐ Informed Consent
- ☐ Participant Information Sheet
- ☐ Warm-up (5:00 self-selected pace on bike)
- ☐ ROM (inversion, eversion)
    - Three trials each
    - Average recorded
- ☐ Randomized testing order for JPS and torque testing
- ☐ Strength testing (Biodex, plantarflexion and dorsiflexion)
    - Hip and knee flexed to 90 degrees
    - Ankle securely positioned on pedal
    - Record chair position for future testing trials
    - Explain testing procedure
        - Push/pull against pedal as much as possible for five seconds
        - Subject is allowed to grab handrails during testing
        - No thrusting hip during testing
- ☐ JPS testing
    - Subject in prone position with ankle hanging off of table
    - Assure shoe is tight in plantar flexion motion
    - Attach iPod parallel to the base of the shoe
    - Subject maintains slightly dorsiflexed position
    - Explain testing procedure
        - Plantar flex when a low-toned beep is heard
        - Hold in position where no sound is emitted and concentrate on the position of the ankle
        - Return to start position when told to relax
        - Attempt to return to prior position when instructed to find target
        - Relax when instructed and repeat for remainder of the test
    - Complete practice protocol before beginning recorded trial
- ☐ Explanation of responsibilities for protocol
    - Exercise group
        - Return to lab three times per week to complete exercises
        - Instruct subjects to continue normal exercise routine outside of lab
    - Brace group
        - Give subjects ankle brace to use during study
        - Instruct subjects to continue normal exercise routine outside of lab
        - Instruct subjects to wear ankle brace when performing physical activity
    - Both groups
        - Record physical activity in exercise log
        - Submit exercise logs weekly for the duration of the study

Participant Information Sheet

Name_____________________________ Age ___________ Sex M F

Height__________ Weight_________ Subject ID:

Are you physically active? Y N

If yes, what types of activities do you participate in?

____

____

____

Approximately how many hours per week are you active?

____

Ankle being tested? R L

How many sprains have you suffered on this ankle?

____

Have you ever had surgery to repair a structure in your ankle? Y N

If yes, please indicate when and what structure was being repaired

____

____

____

Data Collection List

Subject Number: ____________________ **Ankle Being Tested R L**

Ankle ROM Evaluation

Pre-test

Plantar Flexion: Trial 1_______ Trial 2______ Trial 3_______ Average________

Dorsiflexion: Trial 1_______ Trial 2______ Trial 3_______ Average________

3 Weeks

Plantar Flexion: Trial 1_______ Trial 2______ Trial 3_______ Average________

Dorsiflexion: Trial 1_______ Trial 2______ Trial 3_______ Average________

Post-test

Plantar Flexion: Trial 1_______ Trial 2______ Trial 3_______ Average________

Dorsiflexion: Trial 1_______ Trial 2______ Trial 3_______ Average________

Biodex Testing

Pre-test: PF Peak Torque___________ DF Peak Torque___________

3 Weeks: PF Peak Torque___________ DF Peak Torque___________

Post-test: PF Peak Torque___________ DF Peak Torque___________

Ankle JPS Testing

Average Absolute Error Score

Pre-test: _______________

3 Weeks: _______________

Post-test:________________

Exercise Log

Date	Exercise Type (i.e. basketball, hiking, etc.)	Exercise Duration	Exercise Intensity (low, moderate, or high)