The Effects of Proprioceptive Training on the Incidence of Lateral Ankle Sprains

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THE EFFECTS OF PTR ON LATERAL ANKLE SPRAINS

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Abstract

Lateral ligament ankle sprains are among the most common athletic injuries. Previous research has shown that proprioceptive training is an effective rehabilitation measure for such injuries, as it improves the fine motor control mechanisms of the ankle and assists in functional rehabilitation. However, no recent review of proprioceptive training as a preventative measure is present. This project attempts to fill the void in information into whether or not PTr is an effective tool for prevention of LAS in health adults, and other populations, using various modalities of PTr by summarizing the current research available. This study’s results indicate that preventative proprioceptive training does, in fact, lower the incidence of lateral ankle sprains across most populations. Those with chronic ankle instability benefit especially from proprioceptive training, though benefits exist for those who had never suffered an ankle sprain as well.
Anatomical Analysis

The ankle can be separated into two joints; the talocrural joint, and the subtalar joint. The talocrural joint, made up of the tibia, fibula, and talus, is what most would consider the true ankle joint, and is responsible for dorsiflexion and plantarflexion of the foot. In this joint, the tibia and fibula meet at their distal ends, and form a cup for the talus to sit in. The talus is shaped like a wedge that fits perfectly into this cup, providing support to the joint and limiting the joint in medial and lateral motion (Starkey, Brown & Ryan, 2010). The talus is then free to move in the sagittal plane to perform dorsiflexion and plantarflexion, and is limited in medial and lateral movement due to the medial and lateral malleoli, which are the distal-most ends of the tibia and fibula, respectively. The malleoli give support to the joint on the medial and lateral side. The lateral malleolus extends distally further than the medial malleolus, limiting the ankle range of motion in eversion more so than inversion. The malleoli serve as connection points for the ligaments that connect the lower leg and foot. These ligaments connect the fibula and tibia to the bones of the mid-foot. On the medial side, the deltoid ligament connects the tibia to the talus, calcaneus, and navicular bones. The ligament is made up for four smaller ligaments, called the anterior tibiotalar ligament, the tibiocalcaneal ligament, the posterior tibiotalar ligament, and the tibionavicular ligament, and these ligaments form a web of connective tissue to support the medial aspect of the ankle. The deltoid ligament limits the ankle range of motion in eversion. On the lateral side, three major ligaments provide a majority of the ligamentous support for the foot. The anterior talofibular ligament (ATF), connecting the talus and the fibula, is the primary stabilizer of the ankle joint. This ligament limits motion at the ankle in plantarflexion and inversion, which makes it the most commonly sprained ligament in the ankle. Providing support
are the calcaneofibular ligament (CF), which connects the fibula to the calcaneus and limits inversion, and the posterior talofibular ligament, which connects the fibula and talus posterior to the lateral malleolus, and provides support for the ATF. Primarily, it limits inversion in a dorsiflexed position.

At the subtalar joint, pronation and supination of the foot occur. This joint is the meeting of the talus and the calcaneus, and provides motion as the bones move along an oblique axis. The joint motion is different when weight bearing (WB) as opposed to non-weight bearing (NWB). The talus moves on the calcaneus when WB, and the reverse happens when NWB. This joint does not have well developed muscular support, relying instead on bony articulations and ligamentous support.

The muscles of the ankle serve to move the joint through the motions of dorsiflexion, plantarflexion, eversion, and inversion, and help facilitate pronation and supination of the foot. The muscles responsible for these motions generally originate in the lower leg, and run through the ankle before attaching on the foot. Many muscles operate in more than one motion of the ankle, and the attachment of the muscle is what determines this function. Since the ankle has the most range of motion (ROM) in dorsiflexion and plantarflexion, it is unsurprising that a majority of muscles in the lower leg are responsible for these two motions. The prime mover for dorsiflexion is tibialis anterior, a muscle that originates off the upper half of the lateral tibia, and inserts on the medial and plantar aspects of the first metatarsal. This muscle is assisted in dorsiflexion by extensor digitorum longus and extensor hallucis longus. These two muscles are primarily responsible for extending the toes, but do assist in dorsiflexion. The muscle group involved in plantarflexion has more muscles involved than the group that performs dorsiflexion.
This motion has a greater ROM than dorsiflexion, and the primary movers of the joint have more support than tibialis anterior has in dorsiflexion. The primary movers of plantarflexion are the gastrocnemius and soleus. Both of these muscles attach at the Achilles tendon, which attaches to the posterior calcaneus. The gastrocnemius has two heads, which each attach to the posterior surface of the femoral condyles. This femoral attachment makes the gastrocnemius a two-joint muscle, and because of this attachment the gastrocnemius is also involved with knee flexion. When the knee is extended, the gastrocnemius acts as the primary mover in plantarflexion. When the knee is flexed, the soleus becomes the primary mover, and the gastrocnemius facilitates knee flexion. These two muscles have several muscles that act as assistors, as the peroneals, tibialis posterior, flexor hallucis longus, and flexor digitorum longus muscles all play a part in plantarflexion.

While plantarflexion requires muscles whose only responsibility is performing that motion, inversion and eversion, like dorsiflexion, is performed by muscles that act in multiple directions. The primary muscles involved with inversion are tibialis anterior and tibialis posterior. Both of these muscles sit on the medial aspect of the tibia, and work together to invert the foot. Eversion, in the same way, is controlled by three muscles that all perform other actions. Peroneus longus, peroneus brevis, and peroneus tertius combine to form the peroneal muscle group, and these three muscles evert the foot. It is important to note that while peroneus longus and peroneus brevis plantarflex the foot, peroneus tertius is a dorsiflexor. No muscle works to only invert or evert the foot.

Motor nerve involvement at the ankle is provided by three nerves that course through the ankle and lower leg. The tibial nerve, which runs through the posterior lower leg, is responsible
for innervating the gastrocnemius, soleus, tibialis posterior, and the toe flexors (Starkey, et al, 2010). This nerve is deep in the posterior compartment of the lower leg, but becomes superficial at the posterior medial ankle. This nerve then splits into the medial and lateral plantar nerves at the ankle. The deep peroneal nerve, which innervates the toe extensors and tibialis anterior, runs deep within the anterior compartment (Starkey et al, 2010). The superficial peroneal nerve, which innervates the peroneal muscle group, diverges into the lateral compartment. These two nerves split at the fibular head. Sensory nervous involvement is provided by the sural nerve and saphenous nerve (Starkey et al, 2010). The sural nerve arises from the tibial and common peroneal nerves, and innervates the lateral foot and posterior and lateral lower leg. The saphenous nerve originates from the femoral nerve, and provides sensory information for the medial foot and ankle (Starkey et al, 2010).

The Proprioceptive System

The proprioceptive control mechanism of the ankle relies on several different types of receptors, nerve fibers, and muscle fibers to provide joint stability, position sense, and neuromuscular control to the foot and ankle. Proprioception is extremely important at the ankle, as the ankle proprioceptors play a major role in maintaining balance at the body’s base of support (Lephart & Fu, 2000). Without proper proprioception at the ankles, maintaining balance during such simple tasks as walking and running would be made much more difficult. Proprioceptive mechanisms can be separated into two categories: sensory mechanisms and motor mechanisms. Sensory mechanisms gather information about the ankle’s position in space, stresses on the joint, and movements of the joint, and relay this information back to the spinal cord and then brain, through the use of afferent messaging pathways. Motor mechanisms are responsible for receiving
signals from the brain through the use of efferent pathways, and acting on the muscles of the joint to perform reflexive movements or maintain position. Some proprioceptors work in both ways, as well (Lephart & Fu, 2000).

Ruffini endings, Pacinian corpuscles, and free nerve endings are all types of sensory proprioceptors present in the ankle (Starkey et al, 2010). Each of these works in different aspects of ankle position and motion to provide the central nervous system with joint position sense. Ruffini endings, which can be found throughout the joint capsule, focus on static joint position sense. These fibers generally consist of a cluster of two to six corpuscles with a single parent axon (Lephart & Fu, 2000). These fibers have a slow, continuous response to a stimulus, and have a low threshold to mechanical stress (Lephart & Fu, 2000). They are most active in intermediate joint angles. Pacinian corpuscles are present in the deeper layers of the joint capsule. These have a similar makeup to Ruffini endings, but the corpuscles are smaller (Lephart & Fu, 2000). These corpuscles also have a low stress threshold, but will rapidly adapt to changes in the joint (Lephart & Fu, 2000). Because of this, the corpuscles are active during constant joint motion (Lephart & Fu, 2000). While Ruffini endings are the static mechanoreceptors of the joint, Pacinian corpuscles serve as the dynamic mechanoreceptors. While Pacinian corpuscles fire fairly constantly in response to constant stresses, free nerve endings have a high threshold stimulus, and respond to abnormalities in the joint (Lephart & Fu, 2000). These nerve endings are spread throughout the joint, running through and around the joint capsule. They primarily are triggered when a mechanical deformation occurs to the joint, but can also be triggered by chemical substances, such as serotonin, bradykinin, and histamine, that are involved in the
inflammatory process. These fibers are fairly simple in nature, and essentially send pain signals to the brain (Lephart & Fu, 2000).

Muscle spindle fibers and Golgi tendon organs (GTOs) also play key roles in joint proprioception. These fibers are involved with reflexes, in that they are both triggered by stressors, and perform an action to relieve the stress on a muscle. Muscle spindle fibers are located in the belly of a muscle, and initiate the stretch reflex in a muscle. This occurs when a muscle is stretched to a certain point beyond its normal ROM. These fibers detect this stretch, and cause a contraction in the muscle being stretched. This mechanism guards the joint and muscle against sprains and strains. There are two types of specialized afferent nerve fibers that leave the muscle spindle fibers that act together to accomplish this. Annulospiral endings wrap around the length of an intrafusal muscle fiber, and send afferent signals about sudden stretches or unnatural motions in the fiber, and trigger the stretch reflex (Lephart & Fu, 2000). Flower-spray endings originate at the end of the intrafusal fiber, and spread throughout the fiber. These endings are secondary receptors to the annulospiral endings, and respond only to static stretching. They have a low threshold stimulus (Lephart & Fu, 2000). These fibers send afferent information to the spinal cord and through connector neurons, and the response is sent to the muscle via the alphamotoneurons. The gammamotoneurons adjust the length of the muscle spindle fiber to allow it to accurately interpret the new muscle length. GTOs accomplish the same goal of protection of the joint and muscle, but through an entirely different method. GTOs are located in the musculotendinous junction of a muscle (Lephart & Fu, 2000). When a muscle is put under stress, these organs result in an inhibitory motor response, decreasing neural input to the muscle and allowing it to lengthen. While muscle spindle fibers limit muscle stress by
causing the muscle to contract, GTOs attempt to cease contraction of the muscle. Both of these mechanisms work together to attempt to correct abnormalities in joints and muscles, and offer a form of protection against deformation of a joint or muscle.

Proprioception at the ankle is especially important, as the ankle joint provides the connection between the foot, the body's base of support, and the rest of the lower leg. Therefore, changes are constantly occurring at the ankle joint when a person is weight-bearing. For example, postural sway is something that is completely natural when standing (McKeon et al, 2009). A person will naturally rock back and forth slightly as they stand. This is monitored by the proprioceptive mechanisms in the ankle. Ruffini endings and Pacinian corpuscles monitor the position of the body in relation to the feet, and, along with help from the vestibular and visual systems, attempt to limit the amount of sway that occurs. Without the proprioceptors, a person would be very limited in their ability to stand still in one place (McKeon et al, 2009).

Proprioception is also very valuable to a person when running. The ankle proprioceptors control the foot as it lands, and allow the runner to involuntarily adapt to changes in the surface they are running on. This is particularly important for running on unconventional surfaces, such as a trail or through brush, because the foot is not likely to land in the same position every time (Holme et al, 1999). This mechanism allows the foot to land in a way that prevents stresses on the foot and ankle as much as possible. And since running is an integral part of most athletic events, it is especially important for athletes to have optimal proprioceptive control at the ankle (McKeon et al, 2009).
Ankle Sprain Etiology

Ankle sprains can refer to several different injuries that occur at the ankle. With so many ligaments in the ankle, a sprain can occur to almost any of them. Lateral ankle sprains are by far the most common, with almost 90% of ankle injuries affecting the lateral ligaments, but medial ankle sprains and syndesmotic ankle sprains are also worth noting (Starkey et al, 2010). Medial ankle sprains generally occur due to an eversion mechanism that stresses the deltoid ligament of the medial ankle (Starkey et al, 2010). These are not as common due to the increased stability of the medial ankle due to the thickness of the deltoid ligament and the bony support of the lateral aspect of the ankle, which limits eversion (Starkey et al, 2010). Likewise, syndesmotic ankle sprains are also less common due to the structure of the joint and the rarity of their mechanism. A syndesmotic ankle sprain is commonly caused by forced external rotation of the ankle, which stresses and sprains the anterior tibiofibular ligament. It is extremely rare that this will occur from a non-contact movement, and this type of sprain most commonly occurs in contact sports such as football and wrestling. Lateral ankle sprains are by far the most common due to the lack of medial bony stability to accompany the ligamentous support of the lateral ankle (Starkey et al, 2010). Lateral ankle sprains can occur through contact or from non-contact incidents. The mechanism is usually forced inversion when the foot is plantarflexed, or possible talar rotation. The anterior talofibular ligament is the most commonly sprained ligament in a lateral ankle sprain, but multiple ligaments can be affected (Starkey et al, 2010). Non-contact sprains are more common than contact sprains, but common mechanisms differ from sport to sport. For instance, in basketball, sprains are commonly non-contact, and often result from landing awkwardly from
a jump. In football, sprains are commonly contact injuries, caused by torqueing of the ankle due to a tackle or collision (Starkey et al, 2010).

Research has shown that those who have a previous history of lateral ankle sprains are more susceptible to future sprains than those with no previous history. This can lead to chronic problems with the ankle, which can greatly hinder athletic performance. This condition is referred to as chronic ankle instability (CAI) (McKeon et al, 2009). It has also shown to be very difficult to overcome through conventional rehabilitation tactics. However, preventative techniques such as bracing, strength training, and proprioceptive training are thought to decrease the effects of chronic ankle instability, and limit future sprains (Mohammadi et al, 2007).

Rehabilitation of the Lateral Ankle Sprain

Rehabilitation of an ankle sprain initially focuses on minimizing swelling and scarring, as well as optimizing the time that the joint must be immobilized. At the initial onset of injury, it is important to ice the injury frequently to limit swelling as much as possible. If the joint is allowed to swell excessively, it can lead to a prolonged rehabilitation period, because of excessive scar tissue formation (Houglum, 2010). Compression is also important in the initial phases of the rehabilitation, as this will restrict blood flow and aid in reduction of swelling, as well as help remove swelling from the area. Compression can be performed through use of a compressive bandage or similar wrap, or elastic therapeutic tape (Houglum, 2010). After the initial swelling and inflammation has been controlled, it is important to begin re-mobilization of the joint as soon as possible. Once the blood vessels have healed, and normal blood flow around the joint is reinstated, range of motion will help increase blood flow to the injured structures. While the time frame varies between patients, most individuals can begin rehabilitative exercise between two to
seven days post-injury (Mattacola & Dwyer, 2002). Therapeutic interventions will first focus on regaining any loss of motion seen at the ankle, through the use of stretches and exercises aimed at regaining lost ROM. These exercises, such as ankle pumps, writing the alphabet with the foot, or 4-way ankle Theraband exercises will also help improve ROM, and may improve strength (Mattacola & Dwyer, 2002). As the rehabilitation progresses, strength training exercises can begin. Increasing muscular strength will help the injured person develop better control at the joint, and stronger muscular support will help protect the ligaments from future injury. This will also serve to reverse any atrophy that occurred if the injury is serious enough that immobilization or prolonged removal or weight-bearing activities was required. Strength training also increases blood circulation in the ankle, which will help carry damaged tissue away and provide the damaged cells with oxygen and proteins needed to help repair the damage of the sprain (Mattacola & Dwyer, 2002).

As the patient continues to progress, and ROM and strength return, the next step in the rehabilitative process is to introduce neuromuscular training and functional exercises (Houglum, 2010). Proprioceptive training fits into this category of rehabilitation. Proprioceptive training is progressive, and thus easy to adapt to any individual athlete's needs. Proprioceptive training can begin with something as simple as double-leg standing with eyes closed if an athlete has diminished balance, and it is easy to make this training more difficult as an athlete progresses through their rehab (Baltaci & Kohl, 2003). Proprioceptive rehabilitation can also be multifaceted, as these exercises will also help improve strength of the muscles at the ankle. Proprioceptive exercise forces the muscles around the joint to adapt constantly, and will improve muscle strength and endurance, as well as train the neuromuscular reaction. Proprioceptive
training is a must for functional rehabilitation of a lateral ankle sprain, due to its many benefits and versatility (Baltaci & Kohl, 2003). During the later portion of this phase, the goal is to progressively simulate motions and actions that the injured body part will be required to respond to during normal function with functional exercise (Mattacola & Dwyer, 2002). Functional exercise can have many differing meanings. Functional exercises are defined as exercises that simulate daily activities for the patient (Houglum, 2010). Athletically, this translates to activities that simulate motions the athlete will perform in their specific sport. Choosing functional exercise can be a highly individualized process, and should be based on the nature of the injury as well as the sport and position of the athlete, and the challenges that these bring. For example, a point guard with an ankle sprain will place very different demands on a freshly healed ligament than an offensive lineman will. The point guard will likely be called on to perform lateral motions and cutting movements, while the offensive lineman is going to need more strength at the ankle to brace while they block. Both of these needs should be reflected in their individual rehab. From this stage, the proprioceptive training should continue to escalate in difficulty, and more sport-specific exercise should be incorporated. Once the athlete has demonstrated an ability to complete these exercises without symptoms, the athlete can progress through non-contact drills, then full practice, and then eventual return to play.

Efficacy of Proprioceptive Training in Rehabilitation

Regardless of the sport-specific needs of the athlete in rehabilitation, proprioceptive training (PTr) has been shown to be a very effective rehabilitation tool for a lateral ankle sprain. A 2003 meta-analysis by Baltaci reviewed the use of PTr as a rehabilitation tool for ankle and ACL injuries. This study showed that the concept of a “proprioceptive deficit” resulting from
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ankle injury is widely recognized in the studies that were analyzed. This deficit has shown to decrease balance and coordination, which can lead to chronic ankle instability. The study also showed that PTr will decrease postural sway and improve muscle reaction times, which are key in rehabilitation of the ankle to prevent future sprains. Less recent studies have also supported using PTr as a rehabilitative tool for ankle sprains. One study showed that gymnasts with a previous history of ankle sprain who participated in a PTr program showed a significantly increased passive detection of joint position in the ankle (Bernier & Perrin, 1998). This means that the ability of the mechanoreceptors of the ankle to correct joint position when passively moved is increased after PTr (Bernier & Perrin, 1998). Another study measured the effects of ankle disc training on postural sway and range of motion in soccer players with and without ankle injury, and found that postural sway decreased after disc training on the injured and uninjured ankle, showing that this training improves proprioception in either case (Gauffin et al, 1988). PTr is also shown to improve speed of muscle firing in the anterior tibialis muscle of both trained and untrained extremities, showing a proprioceptive crossover effect (Osborne et al, 2001). Proprioceptive training has been recommended as an advanced rehabilitation technique for years in the athletic training setting, and has been established as an appropriate rehabilitation measure for ankle sprains (Mattacola &Dwyer, 2002). New research on the subject of proprioceptive training as a rehabilitative technique for ankle sprains is not common, perhaps because it is generally accepted as having efficacy in the rehabilitation of ankle sprains.

Proprioceptive Training as a Preventative Tool for Lateral Ankle Sprains

In recent years, a growing research effort has been made into the prevention of lateral ankle sprains. Theoretically, PTr can train the function of the proprioceptive mechanisms of the
foot and ankle which should decrease the incidence of LAS. In the previously mentioned meta-analysis, describing the effects of PTr on ankle and knee rehabilitation, studies that looked into the prospective ability of PTr to positively affect rehabilitation of ankle sprains appeared to be all that was available in the literature (Baltaci & Kohl, 2003). These studies looked at the influence of an ankle sprain on joint proprioception, and used this information to study the effects of an ankle sprain on balance control, and how this affected future ankle sprains (Forkin et al, 1996).

As previously discussed, it has already been shown that postural sway, ankle muscle reaction time, and passive joint position sense are positively affected by the implementation of PTr for injured athletes. Current research appears to be focused on how these effects translate to preventing ankle sprains, rather than rehabilitating them. Past research has covered a wide variety of topics within this subject, but no comprehensive evaluation of the effects of PTr for the prevention of LAS is present in the literature. The rest of this thesis will summarize recent research into the subject of preventative PTr, and discuss the benefits for PTr in various populations, such as those with chronic ankle instability, sport-specific benefits, and the benefits seen with different proprioceptive programs.

Effects of PTr on Chronic Ankle Instability

The research has been very positive behind the use of PTr as a preventative tool for Chronic Ankle Instability (CAI). CAI has been an area of focus in recent years in the proprioceptive research landscape, and many studies have assessed the effects of PTr on ankle sprains. A 2004 study looked at the effects of a proprioceptive balance board training program on the incidence of ankle sprains in volleyball players, many of whom had a previous history of ankle sprains (Verhagen et al, 2004). A significant reduction in occurrence of ankle sprains was
found over one season for athletes that participated in the balance board intervention group and also had a history of previous ankle injury (Verhagen et al, 2004). Over 65% of the participants in the intervention group reported a previous ankle injury, demonstrating that PTr can be an effective measure for preventing LAS in those with a history of this injury. In a 2006 study, it was found that in high school athletes, a previous ankle injury was the largest risk factor for an ankle sprain, and performance of a balance training program was the lowest risk factor among those tested (McGuine & Keene, 2006). This study examined 765 high school basketball and soccer players, and supported the evidence found by the Verhagen study, as well as the prospective studies (McGuine & Keene, 2006). Compliance was measured by the coaches initiating the study. In a 2007 study evaluating the effects of preventative PTr, 11 ankle sprains were seen in 3,860 exposures in players with previous ankle sprains in the pre-intervention period, and 12 sprains were seen in 9,279 exposures in the post-intervention period (McHugh et al, 2007). This indicated a shift from 2.85 sprains/1000 exposures to 1.29 sprains/1000 exposures in these athletes who participated in the PTr program (McHugh et al, 2007). A 2009 study found that an eight-week unsupervised home PTr program significantly decreased the occurrence of recurrent ankle sprains in high school athletes during a one-year follow-up (Hupperets et al, 2009). This study found that those who had participated in the intervention had a 35% risk reduction for suffering a recurrent ankle sprain, which is the biggest risk factor for developing chronic ankle instability (Hupperets et al, 2009). Another study looked at the effects of a PTr program on rear foot inversion and eversion and shank rotation in gait of those with CAI (McKeon et al, 2009). It found that while there was no significant improvement in rear foot inversion/eversion with the implementation of a PTr program, the coupling relationship between
rear foot inversion/eversion and shank rotation was greatly improved for those in the PTr program, indicating that PTr increased stability during gait for patients with CAI (McKeon et al, 2009). This gives insight into why PTr works as a prevention tool for those with CAI, as increasing the stability of the ankle during gait patterns will help protect the weakened lateral ligaments, as well as decrease stresses when moving through a range of motion. In summary, the present research shows that PTr can be an effective prevention tool for those with chronic ankle instability, as it has shown an ability to significantly decrease the risk of future sprains. This may be accomplished by limiting the variability of rear foot/shank coupling during motion, adding stability to the joint.

Effects on Those With No Previous History Of Ankle Sprain

Research into athletes with no previous history of ankle sprains has not been as widely performed as research for those with CAI or at least a previous ankle injury. In the Verhagen study, it was found that while the incidence of ankle sprains in volleyball players was significantly lowered between the intervention group and the control for those with a previous history, those without a history showed no significant difference (Verhagen et al, 2004). In the study, the researchers state that this may indicate that rehabilitative effect of the preventative program, as it could be assumed that for a truly preventative effect, it would show effects for both those who had suffered a previous ankle sprain and those who had not (Verhagen et al, 2004). In the McGuine study regarding high school athletes, researchers found that PTr did not have a statistically significant effect on the incidence of ankle sprains in those without a previous history, but a small change was found, as 4.3% of the athletes without previous injury suffered an ankle sprain during the follow up from the intervention group, as opposed to 7.7% for the control
group (McGuine & Keene, 2006). A third study, concerning high school football players, showed that players without previous injury and at a normal body weight actually saw an increase in injury rate per 1000 exposures over three seasons with a concurrent PTR program than those who were at a higher risk due to their body mass index and previous history (McHugh et al, 2007). This is a very small sample of assessment for the effects of PTR on those with no previous history of ankle sprain, and it shows conflicting data regarding this subgroup. A number of the other studies indirectly assessed this topic, but these were the only ones that showed data for this specific population.

Effects of a Variety of Balance Training Programs

The balance training programs utilized in the research varied greatly in length, type, and style of implementation. This could potentially have an influence on the outcomes of the study. In the Verhagen (2004) study, the program was designed by sports physicians of the Dutch Volleyball Association and the Dutch National Olympic Committee, and consisted of a program of 14 exercises that coaches of the teams participating in the study were in charge of implementing into their training programs on a rotating basis. These exercises were performed during the season, as part of the teams' warm-up during practices (Verhagen et al, 2004). The coaches also reported compliance, and those who did not fully comply with the program were eliminated from the results. The coaches in this study were given four exercises per week from these 14, one involving a ball and a balance board, one involving just a ball, a third involving just a balance board, and a fourth with no material. This program lasted throughout the entire 36-week season. The results of the study showed a significantly decreased number of ankle sprains in the intervention group from the control, from 0.9 injuries/1000 exposures in the control group
to 0.5 injuries/1000 exposures in the intervention group (Verhagen et al, 2004). In the McGuine study, participants completed a five-phase balance training program, with the first four phases being performed five times a week for a week each, and the fifth phase being completed three times a week through the rest of the season (McGuine & Keene, 2006). The program was progressive, and involved the use of a sixteen-inch wooden balance board with a 4-inch sphere, as well as balance activities with eyes open and closed, on the floor and on the board (McGuine & Keene, 2006). This program showed a slightly more significant effect than the Verhagen study, as 1.87 sprains/1000 exposures were seen in the control group, as opposed to only 1.13 in the intervention group (McGuine & Keene, 2006). In the McHugh study, a single-leg balance program was implemented using a foam stability pad for 5-minutes five times a week in the preseason, and twice a week during the season for high school football athletes. This program saw a decrease from 2.2 sprains/1000 exposures pre-intervention to 0.5 sprains/1000 exposures post-intervention (McHugh et al, 2007). In another 2007 study, participants utilized an ankle disc program 30 minutes per day for one year (Mohammadi, 2007). This showed an incidence of 0.13 sprains/1000 exposures, as opposed to 3.33/1000 for the control group (Mohammadi, 2007). The Hupperets study used a home-based program, where athletes were given a balance board and a schedule of exercises they would perform three times a week for 30 minutes over an eight week period (Hupperets et al, 2009). They found that participants in the program had less incidence of ankle sprains in the intervention (1.86/1000 exposures) than the control (2.9/1000 exposures) over the next year (Hupperets et al, 2009). This study also found that there is was a large problem with noncompliance, as only 23% of the athletes reported that they were fully compliant with the home program (Hupperets et al, 2009). Overall, the largest effect was seen in the
Mohammadi study with the ankle disc program. However, this study only included twenty participants, so that number may not be an accurate representation of the effectiveness of this program (Mohammadi, 2007). The most effective program was the one utilized in the McHugh study, which saw a difference of 1.7 sprains/1000 exposures from before the intervention to after (McHugh et al, 2007). All of the programs showed positive results for decreasing the incidence of ankle sprains, but it appeared that the studies that had participants perform the intervention less frequently showed improved results from those that performed the intervention more frequently. The Verhagen and Hupperets studies showed two of the lowest differences in ankle sprain incidence, and those were the only programs that did not reduce frequency during the season. This could be due to fatigue of the proprioceptive mechanisms of the ankle, which would be receiving stress from the program as well as the demands of practice and competition. Between the individual programs themselves, aside from the home program, which showed that noncompliance could be an issue, differences between individual programs did not seem significant. However, no direct comparison of balance board, foam pad, and Dyna-disc® training has been performed. An important area of future research would be to compare these different techniques directly to each other.

Effects of Proprioceptive Training Compared to Alternative Preventative Methods

Traditional methods of ankle sprain prevention have included taping and bracing. Bracing has shown to reduce incidence of ankle sprains in those with previous injury history (Mohammadi, 2007), and taping is one of the most common methods of prevention of ankle sprains. In recent years, strength training of the muscles of the ankle has also shown an ability to decrease the incidence of ankle sprains (Verhagen & Bay, 2010). Certain studies have looked at
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In the Mohammadi study, the effectiveness of PTR compared to these preventative measures. In the Mohammadi study, the effectiveness of PTR, evertor strength training, and bracing were compared over one season in male soccer players. The interventions used in the study included a PTR regimen, a strength training regimen, and a bracing protocol. The PTR program involved the use of an ankle disc for 30 minutes every day (Mohammadi, 2007). The athletes performed weight shifts on the ankle disc, and progressed over the course of a session from eyes open to eyes closed, and from firm surfaces to moving surfaces (Mohammadi, 2007). The strength training program focused on the use of isometric exercise and dynamic resistive exercises for the evertor muscles of the foot (Mohammadi, 2007). Finally, the bracing group used a Sport Stirrup orthosis, and were instructed to wear the brace during all practice and game exposures (Mohammadi, 2007). The study showed that PTR has a significantly lower incidence of ankle sprains (0.13 sprains/1000 exposures) than the control group (3.33 sprains/1000 exposures), while the strength training program (0.5 sprains/1000 exposures) and the bracing program (0.25 sprains/1000 exposures) did not show a significant difference (Mohammadi, 2007). In the McHugh study, it was shown that use of taping or bracing did not have an effect on the incidence of ankle sprains when used in combination with the proprioceptive training program (McHugh et al, 2007). Finally, a 2010 study conducted by Verhagen and Bay looked at comparisons between preventative techniques for ankle sprains, and found that a combination of taping or bracing and PTR will achieve the best preventative effects in athletes, particularly those with chronic ankle instability. Overall, the research shows that PTR is a more effective preventative measure than strength training, and has shown efficacy when used in combination with taping or bracing. The Mohammadi study and McHugh study showed no significant difference was made by using taping or bracing, but the
number of participants that used this measure was very low in both studies, with only 20 participants in the Mohammadi study and 25 participants in the McHugh study, while the Verhagen study utilized a much larger participant pool, so this may have affected the results of these two studies.

Sport-specific Effects

Several sports have been examined in regards to PTR's effectiveness as a prevention tool for ankle sprains. Football, volleyball, soccer, and basketball have all seen specific focus, as these are all sports in which ankle sprains are common. The Verhagen (2004) study showed a significantly lower rate of ankle sprain in professional Dutch volleyball players, both male and female. The study showed a significant effect for reducing ankle sprains in these players, who showed a high frequency of sprains previous to the study, as 65 percent of the athletes in the intervention group had a previous history of ankle sprain (Verhagen et al, 2004). This shows that, while the difference in injury rates between the intervention group and the control group was lower than those seen in some of the other studies, it shows that this can be an important intervention, due to the high number of ankle sprains that can occur in volleyball players (Verhagen et al, 2004). The Mohammadi study focused on Iranian soccer players, and showed that these participants had a significant reduction in ankle sprain incidence as well (Mohammadi, 2007). The McGuine study also studied high school soccer players, as well as basketball players, but made no distinction for which sport then participants competed in (McGuine & Keene, 2006). This study showed the opposite of the Verhagen study, in that only roughly 23 percent of the athletes enrolled in the McGuine study had a previous history, yet the incidence of ankle sprain in the follow-up period was higher across the board (McGuine & Keene, 2006). This is
partly due to the age difference between the two populations, as the McGuine study's average participant age was around 16, while the Verhagen participants had an average age of 24 (Verhagen et al, 2004). This also shows that soccer has a higher incidence of ankle sprains than volleyball, which was seen as well in the Mohammadi study, where the participants had the same average age as the volleyball players (Mohammadi, 2007). As the McGuine study did not differentiate between soccer and basketball players, it is difficult to determine the exact results of the intervention for each sport. However, previous research has shown that the injury rates for basketball and soccer are similar, so it can be assumed that the effects of the intervention for both sports are similar (Handoll, et al, 2001). Finally, the McHugh study analyzed the effects on football players, and saw a significant reduction in those in the intervention group from the pre-intervention period to the post-intervention period (McHugh et al, 2007). The results of this study indicated a fairly large effect of the intervention, especially in those with a previous ankle sprain and a high Body Mass Index (BMI), who saw a reduction from 5.7 sprains/1000 exposures in the pre-intervention period, to 1.2 sprains/1000 exposures post-intervention, which was the largest effect seen in any of the studies (McHugh et al, 2007). While no effect was seen between the different playing positions for football, this distinction shows that PTR is especially helpful for any football player that fits the profile of a high BMI and CAI (McHugh et al, 2007). Based on these results, preventative PTR appears to be most effective for soccer and basketball athletes, though positive effects are seen in all sports that were tested.

**Gender Specific Effects of PTR**

Few studies looked to see if there was a difference in the effects of PTR between men and women. Those studies that did saw no significant differences between the two genders. In the
McGuine study, gender was studied as a potential risk factor for ankle sprains, and it was found that neither gender was associated with a strong risk of ankle sprain (McGuine & Keene, 2006). In the Cumps study, no significant difference was found in incidence rate between the genders of the two groups, although it was found that in both the control and intervention groups that women had slightly lower sprain rates than men (Cumps, 2007). While this shows that not much emphasis has been placed on gender differences, this is understandable, as there are no significant structural differences between the genders at the ankle, much like are seen at the knee and hip (Starkey, et al, 2010).

Future Research Considerations

Current research in preventative PTR has shown that PTR is an effective preventative tool for lateral ankle sprains, especially among those with CAI. It shows effectiveness across all sports, as well as for all ages, from the high school athlete through the professional athlete. However, there are still some areas of PTR research that have remained untouched, that would be helpful to our overall understanding of PTR as a preventative tool. The amount of neglect that has been shown to those with no previous history of ankle sprain in the research is somewhat surprising. While some studies have analyzed this, the effects seen have been inconsistent. A more specific analysis of the effects in these athletes, particularly at the high school level, would be beneficial, as better understanding of these effects could better dictate whether PTR should be implemented across the board as a preventative measure in high school athletics.

Further research into what types of PTR are the most effective would also be helpful. While a full-season program using a foam surface showed the most effectiveness, that study only had a participant population of strictly high school football players (McHugh et al, 2007). There
has been no direct comparison of different PTr programs, and this would further establish what the ideal program would be. A comprehensive study containing athletes of multiple sports would also be suggested, as currently many studies exist testing many different sports and programs, but no study tested a variety of athletes with the same program, outside of the McGuine study, which only studied two different sports (McGuine & Keene, 2006).

Finally, further research regarding the underlying reasons for the effectiveness of PTr as a preventative tool should be conducted. The Verhagen study indicated the possibility of PTr's effectiveness being a rehabilitative effect disguised as a preventative effect, so unearthing the reasons that PTr works preventatively would further our understanding of both PTr and the proprioceptive mechanisms themselves. This appears to be where the research is trending, as studies such as the McKeon study that looked at the biomechanical effects of PTr on chronic ankle instability have started to further our understanding of why PTr improves this function. Discovering underlying causes of the preventative effects of PTr also will further determine whether this effect is directly caused by PTr.

In summary, a review of the current literature suggests that PTr is an effective preventative tool for reducing the incidence of lateral ankle sprains. In particular, those with CAI benefit greatly from preventative PTr. If utilized as a prevention tool in the athletic setting, and compliance was ensured in ways similar to the studies presented, PTr could significantly reduce the incidence of the most common athletic musculoskeletal injury. Specifically, sports that place high demands on the ankle joint through repetitive cutting motions and change of direction, such as basketball, soccer, and volleyball, should attempt to implement a preventative PTr program to reduce the rate of injury. If preventative PTr were implemented throughout the athletic setting,
lateral ankle sprains would easily become less bothersome for players, coaches, and sports medicine staffs everywhere.
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Works Cited


