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MINIREVIEWS

# Neuromuscular control and rehabilitation of the unstable ankle

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## Abstract

Lateral ankle sprain is a common orthopedic injury with a very high recurrence rate in athletes. After decades of research, it is still unclear what contributes to the high recurrence rate of ankle sprain, and what is the most effective intervention to reduce the incident of initial and recurrent injuries. In addition, clinicians often implement balance training as part of the rehabilitation protocol in hopes of enhancing the neuromuscular control and proprioception of the ankle joint. However, there is no consensus on whether the neuromuscular control and proprioception are compromised in unstable ankles. To reduce the prevalence of ankle sprains, the effectiveness of engaging balance training to enhance the neuromuscular control and proprioception of the ankle joint is also questionable.

**Key words:** Ankle; Proprioception; Neuromuscular control; Physical therapy; Rehabilitation



**Core tip:** Lateral ankle sprain is a common orthopedic injury with a high recurrence rate. However, there is no consensus on whether neuromuscular control and proprioception are compromised in unstable ankles, and whether proprioception training can reduce initial and recurrent ankle injuries. The purpose of this review is to discuss the etiology and intervention of initial and recurrent ankle sprains, focusing on the role of neuromuscular control and proprioception at the ankle joint. This review can provide clinicians the knowledge of constructing better examination protocols and rehabilitation programs for individuals with the unstable ankle.

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## INTRODUCTION

Ankle sprains are among the most common musculoskeletal injuries with an estimated 23000 accidents occur daily in the United States[1]. Ankle sprains constitute up to 45% in sports related injuries[2],and basketball players are more vulnerable to ankle sprains (41.1% prevalence) than other athletes[3]. The

terminology of "sprain" indicates that the structural integrity of the ligament, which functions as a joint stabilizer, has been compromised. For the ankle joint, the ligaments on the lateral portion of the ankle (especially the anterior talo-fibular ligament) are most vulnerable to injuries. Lateral ankle sprains are likely the result of a fast combined motion of ankle plantar flexion and inversion, and such motion can occur when an individual lands on an uneven surface with a single limb[4]. It was reported that lateral ankle sprain comprises up to 83% of ankle injuries[5].

After the initial ankle sprain, mechanical restraints (*e.g.,* injured ligaments, joint capsule), muscle strength, and/or neuromuscular control (*e.g.,* proprioception deficits) may be compromised at the ankle joint[6-18]. As the result, 73% of the individuals who had sprained their ankles before are likely to experience recurrent injuries[19]. Despite decades of research on ankle sprain, is it unclear if compromised neuromuscular control and proprioception of the ankle joint contributes to initial and/or recurrent ankle sprains. Moreover, it is also unclear if neuromuscular training is effective in reducing the incidents of initial and/or recurrent ankle injuries.

Proprioception is an important element of the neuromuscular control. With proper proprioception, one may be able to timely detect the speed and magnitude of perturbation and react with proper muscle activation and joint motion. It is inconclusive if subjects with ankle instability experience proprioception deficits, and there is no standard testing and training protocols for ankle proprioception. The aim of this review is to discuss neuromuscular control and proprioception of the ankle joint, their potential deficits in unstable ankles, and the effectiveness of incorporating neuromuscular control training as part of the rehabilitation program.

## INITIAL ANKLE SPRAIN

The ankle (talocrural) joint stability is achieved by weight loading on the bony structures (osseous congruity), proper activation of active stabilizers (muscles and their tendons), and maintaining the integrity of passive stabilizers (ligaments and joint capsule). The ankle joint reaches a stable position (closed packed position) with maximal dorsiflexion, and it becomes more unstable (subject to greater inversion) with plantar flexion. At its most vulnerable position (plantar flexion with inversion) for lateral ankle sprain, the 3 lateral ligaments (anterior talo-fibular ligament, calcaneo-fibular ligament, and posterior talo-fibular ligament) play the primary stabilization role at the ankle joint[20]. As a passive stabilizer, one cannot voluntarily tighten the ligament. Although ligament strength could be enhanced through proper loading and exercise, strength improvement in ligaments is very limited[21].

Neuromuscular control encompasses both reflexes and voluntary muscle responses. For reflex responses, sudden muscle length changes and the speed of changes would be detected by the muscle spindles of those stretched muscles (*e.g.,* peroneal muscles) during a sudden ankle inversion perturbation. A short latency/loop response (spinal reflex) would be elicited with a result of muscle activation at the stretched muscle. Meanwhile, information from the muscle spindles would also travel up to the supraspinal center, processed, and then the action potential would travel back to the stretched muscles (*e.g.,* peroneal muscles, tibialis anterior) to elicit a long latency response. The short latency response is typically fast enough but not powerful enough to correct a fast and large perturbation. In contrast, the long latency response could be powerful enough but is too slow to prevent injuries. The differences between short and long latency responses was demonstrated by Konradsen *et al*[22] with 10 healthy volunteers participated in their study. Standing on a custom platform with a secret trap door underneath the examined ankle, the trap door was able to tilt 30° in the frontal plane and provide a sudden ankle inversion perturbation to the subject. They found the initial peroneal muscle reflex response started around 54 ms post stretch (short latency response), but the muscle activation was too week to correct the perturbation[22]. The subject was not able to generate enough peroneal force to evert the ankle back until 176 ms after stretch (long latency response), which is significantly later than the estimated time frame (less than 100 ms post stretch) when a ligament injury would occur.

Proprioceptive information includes the position sense and movement sense (kinesthesia) of a joint. The ascending information from muscles (muscle spindles), tendons (Golgi Tendon Organs), and other mechanoreceptors located in skin, capsule, and ligaments can be used by the central nervous system to construct meaningful voluntary movements or to correct perturbations[23]. However, the reaction time of the voluntary movement is similar or larger than the long latency reflex[23], therefore too slow to prevent ankle sprains. In summary, interventions (*e.g.,* balance training) aim to enhance neuromuscular control and proprioception of an intact ankle may not reduce the incidents of future ankle injuries.

## RECURRENT ANKLE SPRAIN

Because lateral ligaments (especially the anterior talo-fibular ligament) of the ankle joint play the primary role in ankle stability[20], compromised ligaments integrity after the initial injury (*e.g.,* ligament sprain, tear) can contribute to recurrent injuries. After the initial injury, the reparative phase may last for 3-6 wk and the remodel phase may last for more than a year after the injury. Moreover, only 50% to 85% of subjects with a prior ankle sprain reported full recovery 3 years after the initial injury[24]. If an individual returns to the same activity level or sports prior to a full recovery, recurrent ankle sprains are almost

inevitable.

It is suggested that altered neuromuscular control due to peripheral proprioception changes of the ankle joint may contribute to the high recurrence rate of lateral ankle sprain[8,11,12,14-18,25]. After the initial injury, overstretched/loosened ligaments and joint capsule may hamper the function of those mechanoreceptors in those structures. Some researchers reported prolonged peroneal muscle reflex latency in injured ankles[26-28], and others reported ankle position sense deficits in passive testing[8,12,29,30] and active testing protocols[12,15,29]. Moreover, it is indicated that the result of position sense testing (active matching of passive positioning) can be used to predict future ankle injuries[14,31].

Despite the previously described evidence that indicates proprioception changes in unstable ankles, there are also many studies that contradict those findings. No peroneal reflex latency difference[32-34], no position sense difference[35-37], and no movement sense (kinesthesia) difference[10] was found between healthy and unstable ankles. In addition, some studies indicate that the condition of ankle position sense is not a good predictor for future ankle sprains[13,38]. Moreover, Witchalls *et al*[39] used the Active Movement Extent Discrimination Apparatus (AMEDA) to compare ankle position sense and its improvement potential between healthy subjects and individuals with chronic ankle instability. With the AMEDA, their subjects were tested in a standing position with normal weight bearing and active control of their ankle joints, therefore with a better clinical and functional significance. They found no position sense difference between the two groups at their initial testing, but the individuals with ankle instability improved their scores less than healthy controls after repeated testing. Although it is unclear if subjects with unstable ankles exhibit position sense or movement sense deficits after the initial injury, as discussion in the prior section, the integrity of ankle proprioception may not play an important role in ankle stability against large and fast perturbations. Even with intact ankle proprioception, the short latency response (stretch reflex) would be too weak and the long latency reflex and voluntary muscle activation would be too slow to combat large and fast perturbations.

## REHABILITATION FOR ANKLE SPRAIN

After decades of research, it is still unclear on what training technique/rehabilitation protocol is most effective in reducing the incidents of initial ankle sprains and recurrent injuries. Because proper proprioceptive information is an important part of the overall neuromuscular control, one might consider restoring the compromised proprioception may improve ankle stability. In order to improve ankle proprioception, it is essential to increase the sensitivity of mechanoreceptors by tightening up ligaments and joint capsules (enhance joint proprioceptors) and/or increase muscle activation (enhance muscle spindles). Without surgically tightening up the stretched/loosened ligaments and joint capsule, increasing muscle activation to sensitize muscle spindles through alpha-gamma co-activation could be a reasonable approach. However, even with better/intact proprioception at the ankle joint, one still cannot generate enough muscle strength that is fast enough to combat large and fast perturbations such as landing on an uneven surface.

The impact of muscle strength on ankle stability is unclear. Muscle weakness was reported in peroneal muscles[15,40,41], ankle dorsiflexors[38], and hip abductors[42] in individuals with ankle instability. However, other studies found no association between muscle weakness and ankle instability[14,37,43,44]. Although larger muscle activation can enhance the sensitivity of muscle spindles, strength training is not likely to reduce the incidents of initial and recurrent ankle sprains through enhancing neuromuscular control of the ankle joint. Instead, strength training may restore ankle muscle balance, position the ankle in more stable position (*e.g.,* more dorsiflexion with a stronger tibialis anterior), increase the strength of ligaments, and a larger/stronger muscle can also provide additional passive restraints to the ankle joint. Further research is needed to examine the impact of strength training on ankle stability.

Balance/postural training is the most commonly employed rehabilitation treatment for individuals with ankle instability. The majority of the literature reports positive therapeutic effects of balance training (*e.g.,* single limb standing, standing on an ankle disc/wobble board)[29,45-55]. However, there are a few studies that disagree with its treatment effect[56,57]. In the "Clinical Practice Guidelines" published in the *Journal of Orthopaedic and Sports Physical Therapy*, a panel of experts also concluded that the evidence is weak (grade of recommendation "C") on implementing weight-bearing functional exercises and balance activities on unstable surfaces[18]. If balance training is beneficial in reducing the incidents of ankle sprains, it is not likely due to enhanced neuromuscular control, but due to enhanced strength and stiffness in both muscles and ligaments at the ankle joint.

## CONCLUSION

Initial and recurrent ankle sprains are a serious problem for athletes. After decades of research, there is still no consensus on the most effect intervention to reduce the incidents of initial and recurrent ankle sprains. Although passive ankle stabilizers such as ligaments provide the primary stability to the ankle joint, one cannot actively control the ligaments and their strength increment potential is limited. On the other hand, neuromuscular training has the potential to improve the latency and magnitude of muscle response of the long latency reflex and voluntary muscle activation. Such "reactive" responses can be

sped up slightly through neuromuscular training, but it is very unlikely to be fast enough to prevent injuries caused by a fast and large perturbation such as landing on an uneven surface with a single limb.

Balance training, neuromuscular training, and proprioception training are just a few terminologies that clinicians often use interchangeably to describe balance activities such as single leg standing and standing on an uneven surface such as a wobble board. It is important to know that improving neuromuscular control and proprioception of an ankle joint may yield little benefits in improving ankle stability against large and fast perturbations. However, balance training can also increase the strength of muscles and ligaments around the ankle joint. Since ligaments are the primary stabilizer of the ankle joint, treatment protocols with a balance training component may benefit the subjects with unstable ankles.

If a healthy ankle could not resist the fast and large perturbation during the initial injury, those compromised structures after an ankle sprain certainly would not be able to resist the same amount of stress without a full recovery. Most athletes did not wait for a year or longer (towards the end of the remodeling phase) before returning to their prior sports/activities. Therefore, it would be extremely difficult to reduce the incidents of recurrent ankle sprains in athletes.

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