Research Article

# Impact of 6 Week Neuromuscular Training on Muscle Strength, Balance, and Proprioception in Males with Lateral Ankle Sprain

Mohammadreza Karami[1], Aliasghar Jamehbozorgi[2*], Parsa Salemi[3], Mehdi Rezaei[4]

1. Department of Health and Sport Medicine, Faculty of Sport Sciences, University of Tehran, Tehran, Iran.
2. Department of Occupational Therapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
3. Department of Physiotherapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
4. Department of Orthotics and Prosthetics, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Use your device to scan and read the article online

**Citation** Karami M, Jamehbozorgi A, Salemi P, Rezaei M. Impact of 6 Week Neuromuscular Training on Muscle Strength, Balance, and Proprioception in Males with Lateral Ankle Sprain. Journal of Modern Rehabilitation. 2025; 19(3):265-277. http://dx.doi.org/10.18502/jmr.v19i3.19088

http://dx.doi.org/10.18502/jmr.v19i3.19088

**Article info:**
**Received:** 10 Jan 2025
**Accepted:** 12 Mar 2025
**Available Online:** 01 Jul 2025

**Keywords:**

Lateral ankle sprain; Muscle strength; Balance; Range of motion; Proprioception

## ABSTRACT

**Introduction:** Ankle sprains are the most common sports injuries. This study aims to assess the effects of six weeks of neuromuscular training on muscle strength, balance, range of motion (ROM), and proprioception in participants with ankle sprains.

**Materials and Methods:** Seventeen semi-professional athletes with ankle sprains were randomly allocated to the intervention group (n=9) and the control group (n=8). The intervention group followed a prescribed neuromuscular training program, while the control group followed their normal training routine.

**Results:** A significant difference was observed in the muscle strength of the invertor muscles before and after the training at an angular velocity of 60 °/s and before and after the training program at an angular velocity of 120 °/s in the intervention group (P<0.05). Also, a significant difference was observed between muscle strength of evertor muscles before and after a training program with an angular velocity of 60 °/s and before and after training, an angular velocity of 120 °/s in the intervention group (P<0.05). A significant difference was observed between the overall balance scores before and after training in the intervention group (P<0.05). A significant difference was observed in proprioception before and after training in the intervention group (P<0.05). No significant difference was observed in the ROM before and after training in the intervention group (P>0.05).

**Conclusion:** Six weeks of neuromuscular training improved muscle strength, balance and proprioception in athletes with lateral ankle sprains (LASs).

*** Corresponding Author:**
***Aliasghar Jamehbozorgi, Associate Professor.***
***Address:*** *Department of Occupational Therapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.*
***Tel:*** *+98 (912) 2081106*
***E-mail:*** *ass.bozorgi@yahoo.com*

## Introduction

Lateral ankle sprain (LAS) is the most common musculoskeletal injury of the lower extremities [1]. Incidence rates are particularly high in sports involving large running volumes, change of direction, and jump-landing [2, 3]. An inversion ankle sprain occurs when the foot rolls inward, the ankle rotates outward, and the lateral ankle muscles, tendons and ligaments are stretched beyond their normal limits [4]. The risk factors for acute LAS are categorized as intrinsic or extrinsic. Intrinsic factors included the history of previous sprains, age, sex, height, weight, and body mass index. Moreover, musculoskeletal characteristics, such as balance, proprioception, range of motion (ROM), strength and anatomic foot type, may affect repeated sprains. Extrinsic risk factors include external bracing, type of sports activity, competition level and neuromuscular training participation [5]. One of the main challenges following LAS is the possibility of reinjury; therefore, decreasing the risk of reinjury is highly important in LAS management [6].

Impaired postural control is common in patients with ankle instability [7-9]. Based on the sensory organization hypothesis, the central nervous system (CNS) can set the appropriate balance mechanism by processing data from the visual, vestibular, and proprioceptive systems [10]. Impaired sensory input from the body position may lead to imbalance and instability. Individuals with a history of ankle sprains often show impaired proprioception and kinesthesia (sense of movement), which can play a crucial role in reduced balance and reinjury [11]. Therefore, such sensorimotor deficits may lead to some degree of limitation in physical activities in patients who experience ankle sprains.

The articular and cutaneous receptors of the foot and ankle are peripheral receptors that provide proprioceptive information to the CNS and are degraded in individuals with ankle instability [12, 13]. Ankle ligament damage dramatically decreases and sometimes completely disrupts the ability of these receptors to function properly as a source of sensory information toward higher centers in the brain. Therefore, if the proprioceptive system remains untreated after an ankle sprain, neuromuscular coordination of the joint can be impaired, possibly leading to frequent episodes of sprains. The high frequency of ankle sprains and the high recurrence rate demonstrate the importance of designing more effective rehabilitative programs [14-16].

Since an ankle sprain can disrupt proprioceptive ability and neuromuscular control in injured individuals, patients will be treated and return to activities faster by improving muscular strength, balance, joint ROM and proprioception [17-19]. Early dynamic training after an ankle sprain has been previously reported to result in a shorter time to return to sport, increased functional performance, and decreased self-reported reinjury compared to passive interventions for returning injured athletes to sports [16]. Neuromuscular training can be defined as multi-intervention programs that combine balance, weight, plyometric, agility and sport-specific exercises [20]. As an active treatment, exercise therapy, including neuromuscular training, may be useful as a cost-effective intervention to decrease reinjury. Numerous rehabilitation protocols to improve the deficits associated with CAI have been studied, ranging from strength [21-24] or balance [25-27] training programs to multicomponent (strength, balance, ROM) rehabilitation [28, 29] approaches. Resistance band and balance training protocols have been previously shown to improve strength [21, 23, 24] and balance [27] variables, respectively. These functional rehabilitation protocols effectively improve strength, balance, and self-reported function [21-24, 26, 29-31]; however, few studies have assessed improvements in proprioception. To the best of our knowledge, there is little evidence regarding the impact of a comprehensive neuromuscular training program on different biomechanical and clinical variables, including proprioception, in athletes with LAS, using suitable, reliable and modern laboratory instruments. Therefore, this study aimed to evaluate the effect of six weeks of neuromuscular training on muscular strength, balance, ROM, and proprioception in male athletes with LAS.

## Materials and Methods

Seventeen semi-professional male athletes with LAS regularly participated in at least three sessions of sports training or competition per week, each lasting at least 2 hours. They were randomly divided into two intervention (n=8) and control (n=9) groups through a simple randomization method using a random number table. Based on previous studies, the sample size was calculated using G*Power software, version 3.1, with a type I error 0.05 and a power of 80% [6]. The participants were selected using a convenient sampling method, as they were called from the people who were referred to five private clinics in Tehran City, Iran and met the inclusion and exclusion criteria. All participants signed a consent form before treatment initiation. Semi-professional athletes were defined as those performing at the national or international level and receiving some salaries as part

**Table 1.** The strength training program

| Week | Repetitions and Sets | Rest Between Sets | Procedure |
|---|---|---|---|
| Week 1 | 3×10 | 60 s | Isometric contraction, each contraction 5-10 s |
| Week 1-2 | 3×8–12 | 90 s | Isotonic contraction, each contraction 5 s, 4 s recovery |
| Week 2-4 | 3×8–12 | 60 s | Isotonic contraction, each contraction 5 s, 4 s recovery |
| Week 4-6 | 3×8–12 | 45 s | Isotonic contraction, each contraction 5 s, 4 s recovery |

JMR

of their sports activities [32]. According to the examination of an orthopedic specialist, individuals aged 18-35 years in 7-14 days post-injury (grade I or II LAS) were included in the study. Volunteers with a history of fracture, casting, syndesmotic ankle injury, inability to bear full weight, diabetes, neurological, and systemic diseases were excluded from the study. The two study groups were matched regarding the proportion of different injury severities (grades I and II) in each group. A single examiner performed all the assessments for all the participants while blinded to the study groups.

## Training program

All the subjects in the experimental group performed the exercises three times a week for six weeks for 45-60 minutes using the specified medical practice protocol in the affected limb. The exercise was progressive; therefore, the number of repetitions increased, or the rest periods decreased per week [33]. (Tables 1, 2, 3 and 4) If the participant could not progress with the exercise program's timeline, he would stay in the previous stage until he could pass the stage. The subjects in the control group were monitored while they performed their routine physical and sports activities during the study period.

## Muscle strength measurement

The parameters, including the strength of the ankle invertor and evertor muscles, were evaluated using isokinetic dynamometers and manual application of the Biodex, according to the protocol in Table 5. In the isokinetic test, the evertor and invertor muscles of the participants were tested at velocities of 60 and 120 °/s. For this purpose, the ankle was fixed at 10° plantar flexion. At the same time, the knee was at 30-45° flexion to prevent the hamstring muscles and other tibia rotators from replacing the muscles under study. The anchor chair was fixed at 70°. To prevent hip and knee movements during the test, the participants were tied to the chair from the chest, pelvis, and upper thigh (Figure 1). The ankle ROM was measured at -5° from both directions up to the maximum active inversion and eversion. The participants repeated the movements at each velocity to perform three maximum eccentric-concentric contractions for inversion and eversion movements at 60 and 120 °/s [34]. Before starting the test, the participant performed five submaximal contractions for warming and orientation of the test procedure. The main test was initiated after one minute of rest. After each trial, a five-minute rest was considered to prevent pain, discomfort, or cramps [34].

## Balance measurement

In this study, the Biodex 300-950 balance gauge was used to measure balance using the postural stability protocol. Each participant's balance was measured after three attempts. Each participant performed three trials of this measurement and the average values were used for statistical analysis. The duration of each test was 20 s, and the stability level was changed from 8 to 2.

**Table 2.** The balance training program

| Week | Repetitions and Sets | Rest Between Sets | Direction | Procedure |
|---|---|---|---|---|
| Week 1-3 | 5×15–30 s | 20 s | Dorsi/plantar flexion | Long sitting and stretching with thera-band |
| Week 4-6 | 5×15–30 s | 20 s | Dorsi/plantar flexion | |
| | 5×15–30 s | 20 s | Inversion/eversion | |

JMR

**Table 3.** The range of motion training program

| Week | Repetitions and Sets | Rest Between Sets | Direction | Procedure |
|---|---|---|---|---|
| Week 1-3 | 2×5–10 | 60 s | Ant/post | 1 set with open eyes, 1 set blindfolded |
| Week 4-6 | 2×5–10 | 60 s | Med/Lat | 1 set with open eyes, 1 set blindfolded |

JMR

**Table 4.** The proprioception training program

| Week | Repetitions and Sets | Rest Between Sets | Procedure |
|---|---|---|---|
| Week 1-2 | 2×5–10 | 60 s | Sitting, the affected leg follows the unaffected leg movement |
| Week 2-4 | 2×5–10 | 60 s | Sitting, moving with the affected leg |
| Week 4-5 | 2×5–10 | 60 s | Standing on both feet, move with the affected leg |
| Week 5-6 | 2×5–10 | 60 s | Standing on one foot, move with the unaffected leg |

JMR

## ROM measurement

The ROM test used a mark on the skin to identify relevant points. During the measurements, the participants sat on the floor with perfectly smooth knees and the goniometer axis was placed on the lateral malleolus. The fixed arm of the goniometer was placed on the midline of the leg, and the head of the fibula was considered the reference. The movable arm was placed parallel to the fifth plantar bone. The examiner held the goniometer and leg with a fixed hand. The examiner held the movable arm and leg with the other hand in the dorsiflexion position and read the goniometer degree at the end of the ROM [35]. Each participant performed three trials of this measurement, and the average values were used for statistical analysis.

## Proprioception

Biodex instrument was used to measure proprioception. For this purpose, the participant's ankle was placed on the device (Figure 2). Proprioception was evaluated in inversion and eversion movements. The target and start angles were 10° and -5° inversion, respectively. The active joint angle reproduction method was used to measure proprioception. The leg was moved to the target angle by the device and remained in this position for 5 s. Then, it was returned to its original angle. The participant was then asked to move his leg towards the target angle felt by the participant and press the key in his hand. This procedure was performed three times, and the average of these three trials (mean difference from the target angle) was recorded as the proprioception accuracy [36].

Both groups measured muscle strength, balance, ROM, and proprioception similarly. The measurement order was the same as the order in which they appeared in the text and was exactly similar for both groups.

**Table 5.** Muscle strength measurement protocol

| Muscle Group | Repetition | Contraction Type | Angular Velocity | Rest Between Contractions |
|---|---|---|---|---|
| Evertors | 3 repetitions | ECC-CON | 60 (deg/sec) | 1 (min) |
| | 3 repetitions | ECC-CON | 120 (deg/sec) | 1 (min) |
| Inverters | 3 repetitions | ECC-CON | 60 (deg/sec) | 1 (min) |
| | 3 repetitions | ECC-CON | 120 (deg/sec) | 1 (min) |

ECC; Eccentric; CON; Concentric.

JMR

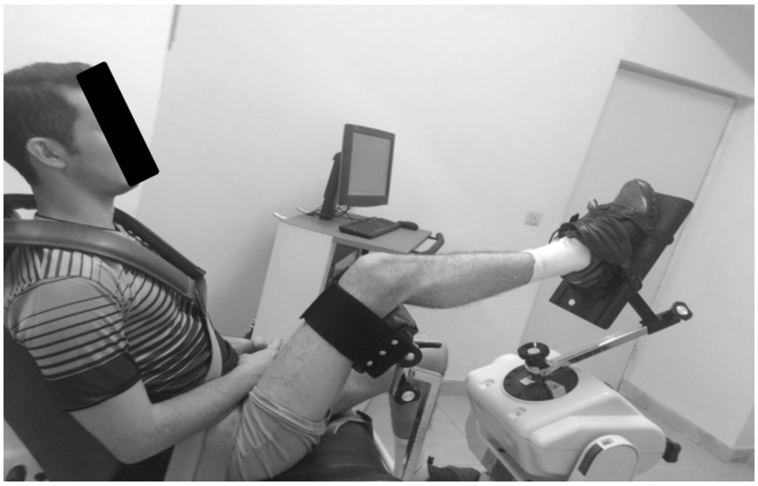

**Figure 1.** Ankle muscle strength testing using biodex isokinetic dynamometer

## Data analysis

The Mean±SD were used for descriptive statistics. The Kolmogorov-Smirnov test was used to ensure data normality. To examine the hypotheses, a paired-samples t-test was used to compare pre-test and post-test data. The independent samples t-test was used to determine the differences between the study variables in the experimental and control groups. It should be noted that the significance level was considered to be 0.05.

## Results

No between-group differences were observed in the anthropometric characteristics (P>0.05) (Table 6).

A significant difference was observed between the mean strength of the evertor and invertor muscles at the angular velocities of 60 and 120 °/s of the ankle before and after the exercise protocol (P<0.05). The maximum torque normalized to body weight in the invertor and evertor muscles at 60 and 120 °/sin the intervention group was significantly different from that in the control group and was 1.03% and 2.18% lower, respectively (Table 7).

According to the results, a significant difference is observed between the overall balance of patients with an ankle sprain before and after the exercise protocol (P<0.05). Also, a significant between-group difference is observed in balance (P<0.5) (Table 8).

The results showed a significant difference in proprioception among participants with ankle sprains before and after the exercise protocol (P<0.05) (Table 9). An independent t-test was used to compare the mean ankle proprioception between the exercise and control

**Figure 2.** Joint position sense testing using biodex isokinetic dynamometer

**Table 6.** Comparison of the anthropometric characteristics between groups

| Characteristics | Group | Mean±SD | T-statistics | P |
|---|---|---|---|---|
| Height (cm) | Intervention | 177.75±7.81 | 0.33 | 0.73 |
| | Control | 179±7.38 | | |
| Weight (kg) | Intervention | 73.68±7.57 | 0.28 | 0.77 |
| | Control | 72.65±6.75 | | |
| Age (y) | Intervention | 22.12±2.9 | 0.48 | 0.63 |
| | Control | 21.44±2.87 | | |
| BMI (Kg/m$^2$) | Intervention | 23.27±1.33 | 0.56 | 0.57 |
| | Control | 22.73±2.36 | | |

BMI: Body mass index.

JMR

groups. The results showed a significant difference in proprioception between the exercise and control groups (P<0.05). The reconstruction error of the joint angle in the intervention group was reduced after exercise.

According to the results, no significant difference was observed between the mean ROM of the ankle in patients with an ankle sprain before and after the exercise protocol (P>0.05). An independent t-test was used to compare the mean ROM of the ankle dorsiflexion between the exercise and control groups. The results showed no significant difference in dorsiflexion ROM between the exercise and control groups (P>0.05). Despite a slight increase in dorsiflexion ROM, this difference was not statistically significant (P>0.05) (Table 10).

## Discussion

This study was conducted to evaluate the impact of a 6-week neuromuscular training protocol on muscular strength, balance, ROM, and proprioception in male athletes with LAS.

The strength of the evertor muscles of the support leg increased significantly after the intervention in both groups; however, this improvement was significantly higher in the intervention group than in the control group. Eversion and dorsiflexion strength are two major factors related to an increased ankle ligament injury rate.

**Table 7.** Muscle strength of the ankle in different groups

| Variables | | | Mean±SD | T-statistics | P |
|---|---|---|---|---|---|
| Intervention group | Evertor 60° (%) | Pre-test<br>Post-test | 40.07±4.89<br>43.66±5.93 | -3.23 | 0.01* |
| | Evertor 120° (%) | Pre-test<br>Post-test | 38.72±6.28<br>40.93±5.77 | -4.62 | P<0.01* |
| | Invertor 60° (%) | Pre-test<br>Post-test | 33.48±4.48<br>36.51±3.97 | -5.95 | P<0.01* |
| | Invertor 120° (%) | Pre-test<br>Post-test | 31.05±3.77<br>33.05±3.45 | -4.29 | P<0.01* |
| Control group | Evertor 60° (%) | Pre-test<br>Post-test | 36.59±5.39<br>37.05±5.75 | -1.02 | 0.33 |
| | Evertor 120° (%) | Pre-test<br>Post-test | 36.03±4.72<br>33.74±5.9 | 1.60 | 0.14 |
| | Invertor 60° (%) | Pre-test<br>Post-test | 32.41±3.99<br>32.32±4.04 | 0.16 | 0.82 |
| | Invertor 120° (%) | Pre-test<br>Post-test | 30.37±2.69<br>29.85±2.23 | 1.08 | 0.33 |

JMR

**Table 8.** Overall balance in different groups

| Overall Balance | | Mean±SD | T-statistics | P |
|---|---|---|---|---|
| Intervention group | Pre-test | 2.92±1.03 | 3.88 | P<0.01* |
| | Post-test | 2.12±0.51 | | |
| Control group | Pre-test | 2.75±0.87 | 3.76 | P<0.01* |
| | Post-test | 2.85±0.78 | | |

JMR

**Table 9.** The ankle proprioception in different groups

| Group | | Mean±SD | T-statistics | P |
|---|---|---|---|---|
| Intervention (degree) | Pre-test | 6.40±1.07 | 2.66 | 0.03* |
| | Post-test | 5.58±0.31 | | |
| Control (degree) | Pre-test | 6.83±0.96 | 1.86 | 0.10 |
| | Post-test | 6.75±0.97 | | |

JMR

Weakness of the evertor muscles decreases their ability to act against inversion torque to return the ankle joint to its optimal condition, which can ultimately lead to ankle sprains. Some of the previous studies indicated that the strength deficiency of evertor muscles does not lead to functional instability of the ankle [37, 38]. In contrast, other researchers have found that defects in the eccentric contraction of evertors in patients are associated with chronic ankle instability [39]. A previous meta-analysis by Arnold et al. showed that participants with ankle instability had weaker ankle evertors than those with stable ankles [40]. Tropp et al. found the long-term weakness of the evertor muscles after an inversion sprain [41]. Baumhauer et al. suggested that evertor muscles' weakness may remain for over ten years after an ankle inversion sprain [42]. If the evertor muscles cannot counteract the external inversion torque, increased ankle inversion may result in a higher risk of inversion sprains [41]. Wilkerson et al. found that the concentric strength of invertor muscles is decreased in patients with ankle sprain [37], which supports a theory presented by Swearingen and Dehne [43] suggesting that decreased stress tolerance of a damaged joint leads to a reflex mechanism that inhibits its muscles which their contraction may increase tensile stress on injured ligaments. Moreover, the results of a study conducted by Hall [44] support the theory of selective reflex inhibition of the ankle invertors immediately following an inversion sprain. The improvements in inversion and eversion strength in the intervention group were consistent with those of several previous studies [23, 24, 45], while some clinical trials found no significant improvement in muscular strength of these muscle groups following a rehabilitation program, including strengthening exercises. The lack of improvement in such studies can be attributed to inadequate resistance in the resistance band protocol [22].

**Table 10.** The dorsiflexion range of motion of the ankle in different groups

| Group | | Mean±SD | T-statistics | P |
|---|---|---|---|---|
| Intervention (degree) | Pre-test | 16.40±3.72 | 1.52 | 0.17 |
| | Post-test | 17.04±4.15 | | |
| Control (degree) | Pre-test | 16.08±2.70 | 0.88 | 0.40 |
| | Post-test | 16.18±2.59 | | |

JMR

The current study found a significant difference between the intervention group's pre-test and post-test balance scores. Our results were consistent with those of Hall et al. [45], Ross and Guskiewicz [46] and Ross et al. [47]. They showed that exercise therapy can improve balance in patients with functional ankle instability. Huang and Lin [48] showed that combined balance and plyometric exercises reduce postural fluctuations in static and dynamic situations and improve energy dissipation patterns in patients with a history of ankle sprain. According to Hale et al. [29], following a comprehensive rehabilitation program of traditional exercises, including balance exercises, the star excursion balance test score improved in the exercise group compared to the control group. They showed that comprehensive rehabilitation exercises may reduce lower-extremity defects. However, it is unclear which component of comprehensive exercises is more effective in minimizing these defects [29].

The balance components of the neuromuscular training protocol follow the dynamic systems theory because it suggests that the sensorimotor system can be developed and strategies can be changed in interaction with the environment [49]. It focuses on dynamic stabilization due to perturbations in different tasks, such as planned and unplanned changes in the direction of movements, landing and dynamic reaching tasks [26].

In the present study, no significant difference was observed between the intervention and control groups regarding the dorsiflexion ROM of the support leg. This result is consistent with that of Beynnon et al. [50], Wiesler et al. [51] and Wester et al. [52]. However, these findings are inconsistent with those of Terada et al. [53], Reid et al. [54] and Vicenzino et al. [55], Goyal et al. [56] and Lazarou et al. [57].

Reduced ankle dorsiflexion ROM is a vital factor that can lead to ankle sprains [58]. According to Bradic et al., the risk of ankle injury in people with poor ankle muscle flexibility increases up to five times [59]. Researchers believe that major sporting activities, such as squatting, running, jumping, and landing, require 20-30° dorsiflexion ROM [60, 61]. Therefore, return to the normal ROM of the ankle and flexibility of the posterior leg structures are vital to carry out various activities, especially in athletes.

Wiesler et al. studied dance students in terms of common lower extremity disorders. According to their results, 83% of students reported lower extremity injuries. Of these, 39% were ankle sprains. A history of previous sprains and low dorsiflexion ROM were significantly associated with ankle sprains. The results of the present study were consistent with this result, such that ROM in patients with ankle sprains was significantly limited [51]. The small number of sessions of the stretching exercises can be considered one of the potential reasons that no changes in ROM were observed following neuromuscular training.

Beynnon et al. conducted a study to determine the factors affecting the incidence of ankle ligament sprain. In their prospective study, hockey, soccer, and lacrosse athletes participated. The possible risk factors in all athletes were measured before the sports season. The athletes were also examined during the sports season in case of injury. According to their results, the injury rates in men and women were 19% and 13%, respectively, and no statistically significant difference was observed. Among men, no correlation was observed between exercise type and ankle injury. The ankle injury factors were different for men and women. Joint laxity, postural stability, and muscle reaction time were not significantly related to injury [50].

This study found a significant difference between the experimental group's pre-test and post-test proprioception scores. The results of the present study were consistent with those of Asadi et al. [62], Lapanantasin et al. [63] and Sarvar et al. [64] found beneficial effects of different exercise types on ankle proprioception in patients with ankle instability. Other investigators have shown no significant effect of therapeutic exercises on ankle proprioception in these subjects [65].

Recognizing and responding to leg motion through postural adaptation is necessary to prevent ankle injuries [66]. Several authors have argued that ankle sprains and subsequent functional ankle instability are related to proprioception defects [67], mechanical instability [68] and fibular muscle weakness [69]. A recent review suggested that patients with ankle instability have proprioception deficits in their injured ankles, especially about joint position sense (JPS) [70, 71]. The JPS allows us to maneuver around obstacles that are out of view. Higher ankle JPS deficits are associated with worse balance impairments and an increased risk of sprain recurrence [72-74]. Several previous studies have shown that people with ankle sprains experience difficulty in the active and passive reconstruction of the joint angle. Boyle and Negus found that individuals with repeated ankle injuries are less precise in active and passive JPS during plantar flexion and dorsiflexion than healthy individuals [75]. Neuromuscular training using a slide board or wobble board is a common rehabilitation method for ankle instability, designed to help retrain the proprioceptive system by improving the performance of joint mechanoreceptors and restoring the normal neuromuscular feedback loop.

Caldemeyer et al. performed a systematic review and demonstrated the positive effect of neuromuscular training in decreasing recurrent sprains in female athletes with ankle instability [76]. Kim et al. reported that an 8-week neuromuscular training program significantly improved ankle dorsiflexion, subjective feeling of instability, functional status, and dynamic balance in patients with CAI [77]. A statistically significant relationship was identified among athletes regarding the preventive impact of training on proprioception through a systematic review by Kalirtahinam et al. They concluded from the meta-analysis that the rate of ankle sprains can be minimized and prevented among athletes through neuromuscular proprioceptive exercise training alone. However, they suggested that a larger sample size should be utilized in future studies to identify more comprehensive outcomes related to ankle injuries [78].

Tao et al. conducted a systematic review and meta-analysis to evaluate the efficacy of current exercise programs to restore the deficits of JPS in patients with chronic ankle instability. They found that existing exercise therapies may positively affect passive JPS during inversion and eversion but do not restore active JPS deficits in injured ankles in patients with CAI compared to non-training controls. They suggested that updated exercise components with a longer duration that focus on active JPS with longer duration are needed to supplement the existing content of exercise therapies [79].

Sekir et al.'s study showed a significant improvement in proprioception after an isokinetic exercise program was implemented. Finally, they concluded that tendon mechanoreceptors and muscles provide active proprioceptive functions [31]. This observation is associated with a physiological understanding of the crucial role of muscle afferents in proprioception [46, 47].

The increase in JPS in this study can be attributed to the improvement in muscle strength by two potential mechanisms. First, the imbalance between the strength of the evertor and inverter muscles may cause mechanical instability of the ankle and subsequently lead to stimulation of the free nerve endings (FNEs). An increase in muscle strength may cause biomechanical balance of the ankle and remove stimulation of FNEs. Subsequently, proprioception is stimulated by the increased transmission of A-beta fibers in the CNS.

Second, according to Docherty et al. it can be due to increased activity of muscle spindles and the Golgi tendon organ (GTO) [24]. When a joint moves, impulses should rise from different levels of the nervous system to provide proprioceptive signals. In addition to increased afferent input from the ligaments and joint capsules, proprioceptive receptors in the skin, muscles (muscle spindles) and tendons GTO provide inputs. After strengthening the muscle structures, the capacity of proprioceptive receptors is improved by stimulating muscle spindles and GTO. Muscle spindles receive static and dynamic stimulation from gamma-efferent nerve fibers. This, in turn, will increase the accuracy of JPS [31]. The results showed that central and peripheral adaptation through wobble board training improved JPS. Peripheral adaptation may be because these exercises frequently stimulate joint mechanoreceptors in the terminal domain of the ankle during exercise [80-82]. According to the literature, joint mechanoreceptors are overstimulated when the ankle moves to the end of its ROM [83, 84]. Furthermore, rapid changes in length and tension when the tendon-muscle structure is loaded during eccentric contractions may facilitate adaptation between the muscle spindle and GTO. Many researchers believe that GTO desensitization increases the stimulation of the muscle spindle stretch toward changes in length [83, 85]. With increasing stimulation of the muscle spindle system, the contribution of muscle spindle afferents to the CNS increases with joint position. This adaptation may increase proprioception in athletes. This new task requires activating muscles in anticipation, balance, weight-bearing in balance, and involuntary contractions for concentric force production while returning to a state of balance after imbalance. JPS is significantly improved when the muscles are stimulated; therefore, these activities improve kinesthesia [86].

## Conclusion

It can be concluded that neuromuscular training can be effectively incorporated into the rehabilitation protocol for athletes with LAS to improve their muscle strength, balance, and proprioception. These results can be crucial for injured people and physiotherapists to achieve good clinical improvements, especially in balance and proprioceptive performance.

## Limitations

The subjects could not be blinded to the study group. Moreover, we did not assess the long-term effects of such a neuromuscular training program in patients with LAS or healthy individuals. We did not follow the participants for a longer period, considering the potential impact of this intervention on decreasing the reinjury risk.

## Ethical Considerations

### Compliance with ethical guidelines

This study was registered with the Iranian Registry of Clinical Trials (IRCT), Tehran, Iran (Code: IRCT2014091619190N1).

### Funding

This paper was extracted from the master's thesis of Mohammadreza Karami, approved by the Department of Health and Sport Medicine, Faculty of Sport Sciences, University of Tehran, Tehran, Iran.

### Authors' contributions

Data analysis, interpretation and writing the original draft: Mohammadreza Karami; Project administration and supervision: Aliasghar Jamehbozorgi; Investigation and data collection: Mehdi Rezaei; Statistical analysis and study design: Parsa Salemi; Final approval: All authors.

### Conflict of interest

The authors declared no conflicts of interest.

### Acknowledgments

The authors acknowledge University of Tehran, Tehran, Iran and the staff of the Biomechanics Center of the Department of Health and Sports Medicine for their support.

## References

[1] Wikstrom EA, Cain MS, Chandran A, Song K, Regan T, Migel K, et al. Lateral ankle sprain and subsequent ankle sprain risk: A systematic review. Journal of Athletic Training. 2021; 56(6):578-85. [DOI:10.4085/1062-6050-168-20] [PMID]

[2] Mason J, Kniewasser C, Hollander K, Zech A. Intrinsic risk factors for ankle sprain differ between male and female athletes: A systematic review and meta-analysis. Sports Medicine. 2022; 8(1):139. [DOI:10.1186/s40798-022-00530-y] [PMID]

[3] Salemi P, Hosseini M, Daryabor A, Fereydounnia S, Smith JH. Trigger point dry needling to reduce pain and improve function and postural control in people with ankle sprain: A systematic review and meta-analysis. Journal of Chiropractic Medicine. 2024; 23(1):23-36. [DOI:10.1016/j.jcm.2024.02.005] [PMID]

[4] Cavazos Jr GJ, Harkless LB. The epidemiology, evaluation, and assessment of lateral ankle sprains in athletes. Journal of Sports Medicine and Therapy. 2021; 6:8-17. [DOI:10.29328/journal.jsmt.1001052]

[5] Martin RL, Davenport TE, Paulseth S, Wukich DK, Godges JJ, Altman RD, et al. Ankle stability and movement coordination impairments: Ankle ligament sprains: clinical practice guidelines linked to the international classification of functioning, disability and health from the orthopaedic section of the American Physical Therapy Association. Journal of Orthopaedic & Sports Physical Therapy. 2013; 43(9):A1-40. [DOI:10.2519/jospt.2013.0305] [PMID]

[6] Sekkehchi S, Tajali SB, Ashnagar Z, Majdi F. Investigating the effects of intrinsic foot muscle exercises on dynamic balance after sub-acute ankle sprain. Journal of Modern Rehabilitation. 2024; 18(4):443-52. [DOI:10.18502/jmr.v18i4.16913]

[7] Arnold BL, De La Motte S, Linens S, Ross SE. Ankle instability is associated with balance impairments: A meta-analysis. Medicine and Science in Sports and Exercise. 2009; 41(5):1048-62. [DOI:10.1249/MSS.0b013e318192d044] [PMID]

[8] Munn J, Sullivan SJ, Schneiders AG. Evidence of sensorimotor deficits in functional ankle instability: A systematic review with meta-analysis. Journal of Science and Medicine in Sport. 2010; 13(1):2-12. [DOI:10.1016/j.jsams.2009.03.004] [PMID]

[9] Wikstrom EA, Naik S, Lodha N, Cauraugh JH. Balance capabilities after lateral ankle trauma and intervention: A meta-analysis. Medicine and Science in Sports and Exercise. 2009; 41(6):1287-95. [DOI:10.1249/MSS.0b013e318196cbc6] [PMID]

[10] Nashner L. A model describing vestibular detection of body sway motion. Acta Oto-Laryngologica. 1971; 72(6):429-36. [DOI:10.3109/00016487109122504] [PMID]

[11] Mahdavi Jafari Z, Mahdavi Nejad R, Zolaktaf V, Sahebozamani M, Mahmodi Najafabadi A. [The comparison of balance between female basketball players with and without a history of lateral ankle sprain (Persian)]. Journal of Exercise Science and Medicine. 2010; 2(1):103-14. [Link]

[12] Freeman M. Instability of the foot affer injuries to the lateral ligament of the ankle. The Journal of Bone & Joint Surgery British Volume. 1965; 47(4):669-77. [DOI:10.1302/0301-620X.47B4.669]

[13] Hoch MC, McKeon PO. Peroneal reaction time after ankle sprain: A systematic review and meta-analysis. Medicine and Science in Sports and Exercise. 2014; 46(3):546-56. [DOI:10.1249/MSS.0b013e3182a6a93b] [PMID]

[14] Hertel J, Corbett RO. An updated model of chronic ankle instability. Journal of Athletic Training. 2019; 54(6):572-88. [DOI:10.4085/1062-6050-344-18] [PMID]

[15] Shah S, Thomas AC, Noone JM, Blanchette CM, Wikstrom EA. Incidence and cost of ankle sprains in United States emergency departments. Sports Health. 2016; 8(6):547-52. [DOI:10.1177/1941738116659639] [PMID]

[16] Tee E, Melbourne J, Sattler L, Hing W. Evidence for rehabilitation interventions after acute lateral ankle sprains in athletes: A scoping review. Journal of Sport Rehabilitation. 2021; 31(4):457-64. [DOI:10.1123/jsr.2021-0244] [PMID]

[17] Hupperets MD, Verhagen EA, Van Mechelen W. Effect of unsupervised home based proprioceptive training on recurrences of ankle sprain: Randomised controlled trial. BMJ. 2009; b2684. [DOI:10.1136/bmj.b2684] [PMID]

[18] Ismail MM, Ibrahim MM, Youssef EF, Shorbagy KME. Plyometric training versus resistive exercises after acute lateral ankle sprain. Foot & Ankle International. 2010; 31(6):523-30. [DOI:10.3113/FAI.2010.0523] [PMID]

[19] Van Der Linde E, Oschman Z. Comparative ultrasound study of acute lateral ankle ligament injuries rehabilitated with conventional and jump stretch flex band programmes s medicine. African Journal for Physical Health Education, Recreation and Dance. 2011; 17(si-1):591-602. [Link]

[20] Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. The American Journal of Sports Medicine. 2008; 36(6):1052-60. [DOI:10.1177/0363546508314432] [PMID]

[21] Hall EA, Docherty CL, Simon J, Kingma JJ, Klossner JC. Strength-training protocols to improve deficits in participants with chronic ankle instability: A randomized controlled trial. Journal of Athletic Training. 2015; 50(1):36-44. [DOI:10.4085/1062-6050-49.3.71] [PMID]

[22] Kaminski T, Buckley B, Powers M, Hubbard TJ, Ortiz C. Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability. British Journal of Sports Medicine. 2003; 37(5):410-5. [DOI:10.1136/bjsm.37.5.410] [PMID]

[23] Smith BI, Docherty CL, Simon J, Klossner J, Schrader J. Ankle strength and force sense after a progressive, 6-week strength-training program in people with functional ankle instability. Journal of Athletic Training. 2012; 47(3):282-8. [DOI:10.4085/1062-6050-47.3.06] [PMID]

[24] Docherty CL, Moore JH, Arnold BL. Effects of strength training on strength development and joint position sense in functionally unstable ankles. Journal of Athletic Training. 1998; 33(4):310. [PMID]

[25] Linens SW, Ross SE, Arnold BL. Wobble board rehabilitation for improving balance in ankles with chronic instability. Clinical Journal of Sport Medicine. 2016; 26(1):76-82. [DOI:10.1097/JSM.0000000000000191] [PMID]

[26] McKeon PO, Ingersoll CD, Kerrigan DC, Saliba E, Bennett BC, Hertel J. Balance training improves function and postural control in those with chronic ankle instability. Medicine & Science in Sports & Exercise. 2008; 40(10):1810-9. [DOI:10.1249/MSS.0b013e31817e0f92] [PMID]

[27] Wright CJ, Linens SW, Cain MS. A randomized controlled trial comparing rehabilitation efficacy in chronic ankle instability. Journal of Sport Rehabilitation. 2017; 26(4):238-49. [DOI:10.1123/jsr.2015-0189] [PMID]

[28] Eils E, Rosenbaum D. A multi-station proprioceptive exercise program in patients with ankle instability. Medicine and Science in Sports and Exercise. 2001; 33(12):1991-8. [DOI:10.1097/00005768-200112000-00003] [PMID]

[29] Hale SA, Hertel J, Olmsted-Kramer LC. The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. Journal of Orthopaedic & Sports Physical Therapy. 2007; 37(6):303-11. [DOI:10.2519/jospt.2007.2322] [PMID]

[30] Mettler A, Chinn L, Saliba SA, McKeon PO, Hertel J. Balance training and center-of-pressure location in participants with chronic ankle instability. Journal of Athletic Training. 2015; 50(4):343-9. [DOI:10.4085/1062-6050-49.3.94] [PMID]

[31] Sekir U, Yildiz Y, Hazneci B, Ors F, Aydin T. Effect of isokinetic training on strength, functionality and proprioception in athletes with functional ankle instability. Knee Surgery, Sports Traumatology, Arthroscopy. 2007; 15(5):654-64. [DOI:10.1007/s00167-006-0108-8] [PMID]

[32] Salemi P, Shadmehr A, Fereydounnia S. The immediate effect of static hamstring stretching on dynamic balance and gait biomechanical variables in athletes with hamstring tightness: A preliminary study. Journal of Modern Rehabilitation. 2021; 15(3):141-50. [DOI:10.18502/jmr.v15i3.7749]

[33] Wolfe MW, Uhl TL, Mattacola CG, McCluskey LC. Management of ankle sprains. American Family Physician. 2001; 63(1):93-105. [Link]

[34] Goharpey S. Comparison of Invertor and Evertor Muscle Strength in Patients with Chronic Functional Ankle Instability. Journal of Medical Sciences. 2007; 7(4):674-7. [DOI:10.3923/jms.2007.674.677]

[35] Venturni C, André A, Aguilar BP, Giacomelli B. Reliability of two evaluation methods of active range of motion in the ankle of healthy individuals. Acta Fisiátrica. 2006; 13(1):39-43. [DOI:10.11606/issn.2317-0190.v13i1a102574]

[36] Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. Journal of Athletic Training. 2002; 37(4):487-93. [PMID]

[37] Wilkerson GB, Pinerola JJ, Caturano RW. Invertor vs. evertor peak torque and power deficiencies associated with lateral ankle ligament injury. Journal of Orthopaedic & Sports Physical Therapy. 1997; 26(2):78-86. [DOI:10.2519/jospt.1997.26.2.78] [PMID]

[38] McKnight CM, Armstrong CW. The role of ankle strength in functional ankle instability. Journal of Sport Rehabilitation. 1997; 6(1):21-9. [DOI:10.1123/jsr.6.1.21]

[39] Hazneci B, Yildiz Y, Sekir U, Aydin T, Kalyon TA. Efficacy of isokinetic exercise on joint position sense and muscle strength in patellofemoral pain syndrome. American Journal of Physical Medicine & Rehabilitation. 2005; 84(7):521-7. [DOI:10.1097/01.phm.0000167682.58210.a7] [PMID]

[40] Arnold BL, Linens SW, De La Motte SJ, Ross SE. Concentric evertor strength differences and functional ankle instability: A meta-analysis. Journal of Athletic Training. 2009; 44(6):653-62. [DOI:10.4085/1062-6050-44.6.653] [PMID]

[41] Tropp H. Commentary: Functional ankle instability revisited. Journal of Athletic Training. 2002; 37(4):512. [PMID]

[42] Baumhauer JF, Alosa DM, Renström AF, Trevino S, Beynnon B. A prospective study of ankle injury risk factors. The American Journal of Sports Medicine. 1995; 23(5):564-70. [DOI:10.1177/036354659502300509] [PMID]

[43] Swearingen R, Dehne E. A study of pathological muscle function following injury to a joint. Journal of Bone and Joint Surgery, American Volume. 1964; 46(6):1364. [Link]

[44] Hall RC. A study of H-reflexes in subjects with acute ankle inversion injuries [Doctoral Dissertation]. Lexington: University of Kentucky. [Link]

[45] Hall EA, Chomistek AK, Kingma JJ, Docherty CL. Balance-and strength-training protocols to improve chronic ankle instability deficits, part I: Assessing clinical outcome measures. Journal of Athletic Training. 2018; 53(6):568-77. [DOI:10.4085/1062-6050-385-16]

[46] Ross SE, Guskiewicz KM. Effect of coordination training with and without stochastic resonance stimulation on dynamic postural stability of subjects with functional ankle instability and subjects with stable ankles. Clinical Journal of Sport Medicine. 2006; 16(4):323-8. [DOI:10.1097/00042752-200607000-00007] [PMID]

[47] Ross SE, Arnold BL, Blackburn JT, Brown CN, Guskiewicz KM. Enhanced balance associated with coordination training with stochastic resonance stimulation in subjects with functional ankle instability: An experimental trial. Journal of Neuroengineering and Rehabilitation. 2007; 4:47. [DOI:10.1186/1743-0003-4-47] [PMID]

[48] Huang P, Lin C. Effects of balance training combined with plyometric exercise in postural control: Application in individuals with functional ankle instability. Paper presented at: 6th World Congress of Biomechanics (WCB 2010). 1 August 2010; Singapore, Singapore. [Link]

[49] Wikstrom EA, Hubbard-Turner T, McKeon PO. Understanding and treating lateral ankle sprains and their consequences: A constraints-based approach. Sports Medicine. 2013; 43(6):385-93. [DOI:10.1007/s40279-013-0043-z] [PMID]

[50] Beynnon BD, Renström PA, Alosa DM, Baumhauer JF, Vacek PM. Ankle ligament injury risk factors: A prospective study of college athletes. Journal of Orthopaedic Research. 2001; 19(2):213-20. [DOI:10.1016/S0736-0266(00)90004-4] [PMID]

[51] Wiesler ER, Hunter DM, Martin DF, Curl WW, Hoen H. Ankle flexibility and injury patterns in dancers. The American Journal of Sports Medicine. 1996; 24(6):754-7. [DOI:10.1177/036354659602400609] [PMID]

[52] Wester JU, Jespersen SM, Nielsen KD, Neumann L. Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. Journal of Orthopaedic & Sports Physical Therapy. 1996; 23(5):332-6. [DOI:10.2519/jospt.1996.23.5.332] [PMID]

[53] Terada M, Pietrosimone BG, Gribble PA. Therapeutic interventions for increasing ankle dorsiflexion after ankle sprain: A systematic review. Journal of Athletic Training. 2013; 48(5):696-709. [DOI:10.4085/1062-6050-48.4.11] [PMID]

[54] Reid A, Birmingham TB, Alcock G. Efficacy of mobilization with movement for patients with limited dorsiflexion after ankle sprain: A crossover trial. Physiotherapy Canada. 2007; 59(3):166-72. [DOI:10.3138/ptc.59.3.166]

[55] Vicenzino B, Branjerdporn M, Teys P, Jordan K. Initial changes in posterior talar glide and dorsiflexion of the ankle after mobilization with movement in individuals with recurrent ankle sprain. Journal of Orthopaedic & Sports Physical Therapy. 2006; 36(7):464-71. [DOI:10.2519/jospt.2006.2265] [PMID]

[56] Goyal M, Kumar A, Singh T. Effect of exercise programme with & without mobilization for the patients with limited dorsiflexion after ankle sprain. International Journal of Health, Physical Education and Computer Science in Sports. 8(1):51-6. [Link]

[57] Lazarou L, Kofotolis N, Pafis G, Kellis E. Effects of two proprioceptive training programs on ankle range of motion, pain, functional and balance performance in individuals with ankle sprain.Journal of Back and Musculoskeletal Rehabilitation. 2018; 31(3):437-46. [DOI:10.3233/BMR-170836] [PMID]

[58] Canavan PK, Roncarati M, Lyles K, Kenney R. Off-season screening of an NCAA division 1 men's basketball team. International Journal of Athletic Therapy & Training. 2012; 17(5):28–32. [DOI:10.1123/ijatt.17.5.28]

[59] Bradić J, Kovačević E, Bradić A. Dorsiflexion range of motion does not significantly influence balance in physically active young women. Homo Sporticus. 2012; 2:19-22. [Link]

[60] Tabrizi P, McIntyre W, Quesnel M, Howard A. Limited dorsiflexion predisposes to injuries of the ankle in children. The Journal of Bone & Joint Surgery British Volume. 2000; 82(8):1103-6. [DOI:10.1302/0301-620X.82B8.0821103]

[61] Youdas JW, McLean TJ, Krause DA, Hollman JH. Changes in active ankle dorsiflexion range of motion after acute inversion ankle sprain. Journal of Sport Rehabilitation. 2009; 18(3):358-74. [DOI:10.1123/jsr.18.3.358] [PMID]

[62] Asadi M, Mino-Nejad H, Alizade MH. Effect of eight weeks of ai chi exercise on balance, proprioception, and performance of elite female athletes with functional ankle instability. The Scientific Journal of Rehabilitation Medicine. 2023; 12(3):504-19. [DOI:10.32598/SJRM.12.3.9]

[63] Lapanantasin S, Thongloy N, Samsee M, Wonghirunsombat N, Nuangpulsarp N, Ua-Areejit C, et al. Comparative effect of walking meditation and rubber-band exercise on ankle proprioception and balance performance among persons with chronic ankle instability: A randomized controlled trial. Complementary Therapies in Medicine. 2022; 65:102807. [DOI:10.1016/j.ctim.2022.102807] [PMID]

[64] Sarvar F, Fallah Mohamadi M, Safari F. [The effect of neuromuscular exercise on balance, functional movement, and knee and ankle proprioception in 15-18-year-old female taekwondo players (Persian)]. Journal of Sport Biomechanics. 2024; 9(4):320-35. [DOI:10.61186/JSportBiomech.9.4.320]

[65] Shepherd J. The effects of an ankle strengthening and proprioception exercise protocol on peak torque and joint position sense [masters thesis]. Bellingham: Western Washington University; 2017. [Link]

[66] Payne KA, Berg K, Latin RW. Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. Journal of Athletic Training. 1997; 32(3):221-5. [PMID]

[67] Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. Journal of Athletic Training. 2002; 37(4):364-375. [PMID]

[68] Wilkerson GB, Nitz AJ. Dynamic ankle stability: Mechanical and neuromuscular interrelationships. Journal of Sport Rehabilitation. 1994; 3(1):43–57. [DOI:10.1123/jsr.3.1.43]

[69] Konradsen L, Magnusson P. Increased inversion angle replication error in functional ankle instability. Knee Surgery, Sports Traumatology, Arthroscopy. 2000; 8(4):246-51. [DOI:10.1007/s001670000124] [PMID]

[70] Han J, Waddington G, Adams R, Anson J, Liu Y. Assessing proprioception: A critical review of methods. Journal of Sport and Health Science. 2016; 5(1):80-90. [DOI:10.1016/j.jshs.2014.10.004] [PMID]

[71] Xue X, Ma T, Li Q, Song Y, Hua Y. Chronic ankle instability is associated with proprioception deficits: A systematic review and meta-analysis. Journal of Sport and Health Science. 2021; 10(2):182-91. [DOI:10.1016/j.jshs.2020.09.014] [PMID]

[72] Kim CY, Choi JD. Comparison between ankle proprioception measurements and postural sway test for evaluating ankle instability in subjects with functional ankle instability. Journal of Back and Musculoskeletal Rehabilitation. 2016; 29(1):97-107. [DOI:10.3233/BMR-150603] [PMID]

[73] Proske U, Gandevia SC. The proprioceptive senses: Their roles in signaling body shape, body position and movement, and muscle force. Physiological Reviews. 2012; 92(4):1651-97. [DOI:10.1152/physrev.00048.2011] [PMID]

[74] Witchalls J, Blanch P, Waddington G, Adams R. Intrinsic functional deficits associated with increased risk of ankle injuries: A systematic review with meta-analysis. British Journal of Sports Medicine. 2012; 46(7):515-23. [DOI:10.1136/bjsports-2011-090137] [PMID]

[75] Boyle J, Negus V. Joint position sense in the recurrently sprained ankle. The Australian Journal of Physiotherapy. 1998; 44(3):159-163. [DOI:10.1016/S0004-9514(14)60375-5] [PMID]

[76] Caldemeyer LE, Brown SM, Mulcahey MK. Neuromuscular training for the prevention of ankle sprains in female athletes: A systematic review. The Physician and Sportsmedicine. 2020; 48(4):363-9. [DOI:10.1080/00913847.2020.1732246] [PMID]

[77] Kim KM, Estepa-Gallego A, Estudillo-Martínez MD, Castellote-Caballero Y, Cruz-Díaz D. Comparative effects of neuromuscular- and strength-training protocols on pathomechanical, sensory-perceptual, and motor-behavioral impairments in patients with chronic ankle instability: Randomized controlled trial. Healthcare. 2022; 10(8):1364. [DOI:10.3390/healthcare10081364] [PMID]

[78] Kalirtahinam D, Ismail MS, Singh TSP, Saha S, Hashim HA. Does neuromuscular exercise training improve proprioception in ankle lateral ligament injury among athletes? Systematic review and meta-analysis. Scientia Medica. 2017; 27(1):3. [DOI:10.15448/1980-6108.2017.1.25082]

[79] Xue X, Tao W, Xu X, Jin Z, Li Q, Wang Y, et al. Do exercise therapies restore the deficits of joint position sense in patients with chronic ankle instability? A systematic review and meta-analysis. Sports Medicine and Health Science. 2023; 5(1):67-73. [DOI:10.1016/j.smhs.2023.01.001] [PMID]

[80] Swanik KA, Lephart SM, Swanik CB, Lephart SP, Stone DA, Fu FH. The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics. Journal of Shoulder and Elbow Surgery. 2002; 11(6):579-86. [DOI:10.1067/mse.2002.127303]

[81] Grigg P. Peripheral Neural Mechanisms in Proprioception. Journal of Sport Rehabilitation. 1994; 3(1):2–17. [DOI:10.1123/jsr.3.1.2]

[82] Clark FJ, Burgess P. Slowly adapting receptors in cat knee joint: Can they signal joint angle? Journal of Neurophysiology. 1975; 38(6):1448-63. [DOI:10.1152/jn.1975.38.6.1448] [PMID]

[83] Lephart SM, Pincivero DM, Giraido JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. The American Journal of Sports Medicine. 1997; 25(1):130-7. [DOI:10.1177/036354659702500126] [PMID]

[84] Lephart SM, Warner JJ, Borsa PA, Fu FH. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. Journal of Shoulder and Elbow Surgery. 1994; 3(6):371-80. [DOI:10.1016/S1058-2746(09)80022-0] [PMID]

[85] Davies GJ, Dickoff-Hoffman S. Neuromuscular testing and rehabilitation of the shoulder complex. Journal of Orthopaedic & Sports Physical Therapy. 1993; 18(2):449-58. [DOI:10.2519/jospt.1993.18.2.449] [PMID]

[86] Chu DA. Jumping into plyometrics. Champaign: Human Kinetics; 1998. [Link]