Research Article

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

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Running title: The Impact of Neuromuscular Training in Lateral Ankle Sprain

Abstract

Background: Ankle sprain is the most common injury among the sport injuries. The purpose of this study was to assess the effects of six weeks neuromuscular training on muscle strength, balance, range of motion and proprioception in subjects with ankle sprain.

Material and Methods: Seventeen semi-professional athletes with ankle sprain were randomly allocated into two groups, intervention group (n=9) and control group (n=8). Intervention group followed a prescribed neuromuscular training program while, control group followed their normal training routine.

Results: There was a significant difference between muscle strength of Invertor muscles before and after a training in angular velocity of 60 degree/second (deg/sec) and before and after a training program in angular velocity of 120 deg/sec in intervention group ($P<0.05$). There was also significant difference between muscle strength of evertor muscles before and after a training program in angular velocity of 60 deg/sec and before and after a training in angular velocity of 120 deg/sec in intervention group ($P<0.05$). There was a significant difference between overall balance score before and after a training in intervention group ($P<0.05$). There was a significant difference between proprioception before and after a training in intervention group ($P<0.05$). There was not a significant difference between ROM before and after a training in intervention group ($P>0.05$).
Conclusions: It can be concluded that six weeks of neuromuscular training improve muscle strength, balance and proprioception in athletes with lateral ankle sprain.
Keywords: Lateral ankle sprain, Muscle strength, Balance, Range of motion, Proprioception

Introduction

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

Impaired postural control is a common finding in patients with ankle instability (7-9). Based on the sensory organization hypothesis, central nervous system (CNS) is able to set the appropriate balance mechanism by processing data taken from the visual, vestibular, and proprioceptive systems (10). Impaired sensory input from the position of the body may lead to imbalance and instability. People with a history of ankle sprain often show impaired proprioception and kinesthesia (sense of movement), so it can play an important role in reduced balance and consequently re-injury (11). Therefore such sensorimotor deficits may lead to some degrees of limitation in physical activities in patients who experienced ankle sprain.

Articular and cutaneous receptors of the foot and ankle are some peripheral receptors that provide proprioceptive information to the CNS and have been found to be degraded in individuals with ankle instability (12, 13). Ankle ligament damage dramatically decreases and sometimes completely disrupts the ability of these receptors to work properly as a source of sensory information toward higher centers in the brain. So, if the proprioceptive system remains untreated after an ankle sprain, the neuromuscular coordination of the joint can be impaired, possibly leads to frequent episodes of sprain. The high frequency of ankle sprains, alongside the high rate of its recurrence, demonstrate the importance for designing more effective rehabilitative programs (14-16).

Since an ankle sprain can disrupt proprioceptive ability and neuromuscular control in injured person, it seems that 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 when compared with passive interventions for returning the injured athletes to sport (16). Neuromuscular training can be defined as multi-intervention programs with a combination of balance, weight, plyometric, agility, and sport-specific exercises (20). Exercise therapy including neuromuscular training, as an active treatment, 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 protocols 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 researchers have assessed the improvements in proprioception. To the extent of our knowledge there is not much 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 the aim of this study was to evaluate the effect of six weeks neuromuscular training on muscular strength, balance, ROM and proprioception in male athletes with LAS.

Material and methods

Population

Seventeen semi-professional male athletes with LAS who regularly taking part in at least 3 sessions of sports training or competition per week each lasting for at least 2 hours, were randomly divided into groups of intervention (n=8) and control (n=9) through a simple randomization method using random number table. The sample size was calculated using G*Power software, version 3.1, a type I error of 0.05, power 80%, and based on previous studies (6). The participants were selected using 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 of the participants signed a consent form before that treatments were started. Semi-professional athletes were defined as those performing at national or international level and receiving some salaries as part of their sport activities (32). This study was registered in Iranian Registry of Clinical Trials (IRCT2014091619190N1). People between the age of 18 and 35 years in 7 to 14 days post-injury (grade I or II of LAS) according to the examination of an orthopedic specialist were included in the study. The volunteers with a history of fracture, casting, syndesmotic ankle injury, inability to full weight bearing, diabetes, neurological, and systemic diseases were excluded from the study. The two study groups were matched regarding the proportion of the different injury severities (grade I or II) included in each group. A single examiner performed all the process of assessments for all of the participants while he was blinded of study groups.

Training Program

All the subject of 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, so the number of repetitions increased or the rest periods decreased per week (33). (Tables 1 - 4) If the participant was unable to progress with the timeline of exercise program, then he would stay in the previous stage until he could pass the stage. The subjects in control group were just monitored while the had their routine physical and sports activities during the study period.

Table 1: The strength training program

	Repetitions and sets	**Rest between Sets**	**Procedure**
Week 1	3× 10	60 s	isometric contraction, each contraction 5-10 seconds
Week 1-2	3×8 – 12	90 s	Isotonic contraction, each contraction 5 seconds, 4 seconds recovery
Week 2-4	3×8 – 12	60 s	Isotonic contraction, each contraction 5 seconds, 4 seconds recovery
Week 4-6	3×8 – 12	45 s	Isotonic contraction, each contraction 5 seconds, 4 seconds recovery

Table 2: The balance training program

	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	

Table 3: The range of motion training program

	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

Table 4: The proprioception training program

	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, move 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

Muscle strength measurement

The parameters including the strength of ankle invertor and evertor muscles were evaluated using the Isokinetic Dynamometers and Manual Application Biodex and according to the protocol in Table 5. In the isokinetic test, the evertor and invertor muscles of the subjects were tested at velocities of 60 and 120 degrees per second. For this purpose, the ankle was fixed at 10° plantar flexion while 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 participant was tied to the chair from the chest, pelvis, and upper thigh (Figure 1). Ankle ROM was measured at -5° from both directions up to the maximum active inversion and eversion. At each velocity, the subjects repeated the movements, so that 3 maximum eccentric-concentric contractions were performed for inversion and eversion movements at 60 and 120 degrees per second (34). Before starting the test, for warming and orientation of the test procedure, 5 submaximal contractions were carried out by the subject. Then, the main test began with 1 minute of rest. After each trial, five-minute rest was considered to prevent pain, discomfort, or cramps (34).

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

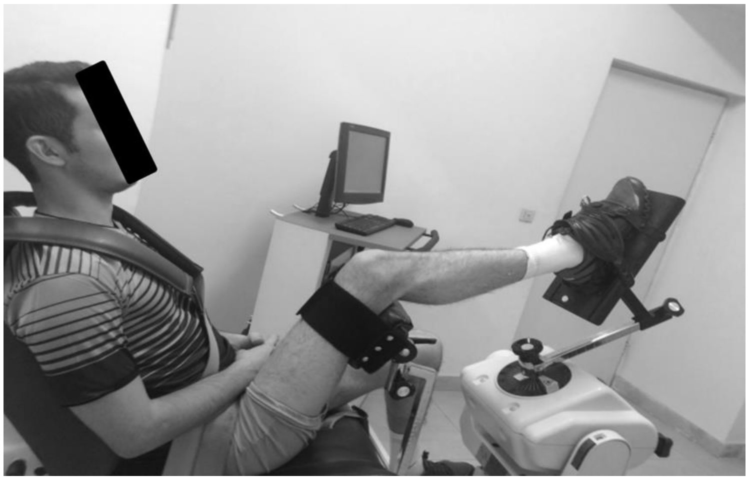

Figure 1. Ankle muscle strength testing using Biodex isokinetic dynamometer

Balance measurement

In this study, Biodex 300-950 balance gauge was used to measure the balance using the postural stability protocol. The balance of each participant was measured after 3 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 seconds and the stability level was changed from 8 to 2.

Range of motion measurement

In the ROM test, a mark was used on the skin to identify the relevant points. During measurements, the subjects 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 as the reference. The movable arm was placed parallel to the fifth plantar bone. The examiner held the goniometer and the leg with a fixed hand. The examiner held the movable arm and the leg with the other hand in the dorsiflexion position and read the goniometer degree at the end of the ROM (35). Each participant perform 3 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 subject'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. 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 seconds. Then, it was returned to the original angle. Then the participant was asked to take his leg towards the target angle felt by the participant and press the key in his hand. This procedure was performed 3 times and then average of these 3 trials (mean difference from the target angle) was recorded as proprioception accuracy (36).

Figure 2. Joint position sense testing using Biodex isokinetic dynamometer

Muscle strength, Balance, ROM and Proprioception were measured respectively and in the same order for both groups. The order of measurement was the same as the order they appeared in the text and it was exactly similar for both groups.

Data Analysis

The mean and standard deviation were used in descriptive statistics. The Kolmogorov-Smirnov test was used to ensure the data normality. To examine the hypotheses, the 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 .05.

Results

There was no between-group differences regarding anthropometric characteristics ($p > .05$) (Table 6).

Table 6: Comparison of the anthropometric characteristics between groups

Characteristics	Group	mean	Standard Deviation	t-statistics	p-value
Height (cm)	Intervention	177.75	7.81	.33	.73
	Control	179.00	7.38		
Weight (kg)	Intervention	73.68	7.57	.28	.77
	Control	72.65	6.75		
Age (year)	Intervention	22.12	2.90	.48	.63
	Control	21.44	2.87		
BMI ($Kg.cm^{-2}$)	Intervention	23.27	1.33	.56	.57
	Control	22.73	2.36		

There is a significant difference between the mean strength of evertor and invertor muscles at the angular velocities of 60 and 120 degrees per second of the ankle before and after the exercise protocol ($p < .05$). The maximum torque normalized to body weight in the invertor and evertor muscles at 60 and 120 degrees per second in the intervention group was significantly different with that in the control group and was 1.03 and 2.18% lower, respectively (Table 7).

Table 7: Muscle strength of the ankle in different groups

Variable			Mean	Standard Deviation	t-statistics	p-value
Intervention group	evertor 60° (%)	Pre-test Post-test	40.07 43.66	4.89 5.93	-3.23	.01*
	evertor 120° (%)	Pre-test Post-test	38.72 40.93	6.28 5.77	-4.62	P < 0.01*
	invertor 60° (%)	Pre-test Post-test	33.48 36.51	4.48 3.97	-5.95	P < 0.01*
	invertor 120° (%)	Pre-test Post-test	31.05 33.05	3.77 3.45	-4.29	P < 0.01*
control group	evertor 60° (%)	Pre-test Post-test	36.59 37.05	5.39 5.75	-1.02	.33
	evertor 120° (%)	Pre-test Post-test	36.03 33.74	4.72 5.90	1.60	.14
	invertor 60° (%)	Pre-test Post-test	32.41 32.32	3.99 4.04	0.16	.82
	invertor 120° (%)	Pre-test Post-test	30.37 29.85	2.69 2.23	1.08	.33

According to the results, there is a significant difference between the overall balance of patients with an ankle sprain before and after the exercise protocol ($p < .05$). There is also a significant between-group difference in balance ($p < . 5$) (Table 8).

Table 8: Overall balance in different groups

Overall balance		Mean	Standard Deviation	t-statistics	p-value
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		

The results showed a significant difference between the proprioception among people with an ankle sprain before and after the exercise protocol ($p < .05$) (Table 9). The independent t-test was used to compare the mean proprioception of the ankle in the exercise and control groups. The results showed a significant difference between the proprioception in the exercise and control groups ($p < .05$). The reconstruction error of the joint angle in the intervention group was reduced after the exercise.

Table 9: The ankle proprioception in different groups

Group		Mean	Standard Deviation	t-statistics	p-value
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		

According to the results, there is no significant difference between the mean ROM of the ankle in the patients with an ankle sprain before and after the exercise protocol ($p > .05$). The independent t-test was used to compare the mean ROM of the ankle dorsiflexion in the exercise and control groups. The results showed no significant difference between the dorsiflexion ROM in the exercise and control groups ($p>0.05$). Despite a slight increase in the dorsiflexion ROM, this difference was not statistically significant ($p > .05$) (Table 10).

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

Group		Mean	Standard Deviation	t-statistics	p-value
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	.88	0.40
	Post-test	16.18	2.59		

Discussion

The aim of this study was to evaluate the impact of a 6-weeks neuromuscular training protocol on muscular strength, balance, ROM and proprioception in male athletes with LAS.

The strength of evertor muscles of the support leg was increased significantly after the intervention in both groups, however this improvement was significantly higher in the intervention group when compared with control group. The eversion and dorsiflexion strength are known as two major factors related to increased ankle ligament injury rate.

The weakness of evertor muscles decreases their ability to act against inversion torque in order to return the ankle joint into its optimal condition and ultimately can lead to ankle sprain. 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 found that defects in the eccentric contraction of evertors in patients is associated with chronic ankle instability (39). Previous meta-analysis by Arnold et al., showed that subjects with ankle instability have weaker ankle evertors than those with stable ankles (40). Tropp et al. found long-term weakness of evertor muscles after inversion sprain (41). Baumhauer et al. suggested that evertor muscles' weakness may remain for more than ten years after an ankle inversion sprain (42). If the evertor muscles cannot counteract the external inversion torque, increased ankle inversion may result in higher risk of inversion sprain (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 which inhibits muscles which their contraction may increase tensile stress on injured ligaments. Moreover, the results of a study conducted by Hall (44), supports 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 was in line with a number of previous studies (23, 24, 45), while some of the 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 protocols (22).

In current study, a significant difference was found between the pretest and post-test balance scores in the intervention group. 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 lead to improved balance in patients with functional ankle instability. Huang and Lin (48) showed that combined balance and plyometric exercises reduce postural fluctuations both in static and dynamic situations, and improve energy dissipation pattern in patient 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 (SEBT) score was improved in the exercise group compared to the control group. They showed that comprehensive rehabilitation exercises may reduce defects in the lower extremities. However, it is not clear which component of the comprehensive exercises is more effective in minimizing these defects (29).

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

In the present study, no significant difference was observed between the intervention and control groups in terms of the dorsiflexion ROM of the support leg. This finding is consistent with the results of Beynnon et al. (50), Wiesler et al. (51), and Wester et al. (52). However , these findings are in contradiction with the findings 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 among the most important factors which can lead to ankle sprains (58). According to Bradic et al., the risk of ankle injury in people with poor flexibility of the ankle muscles increases up to five times (59). The researchers believe that the major sporting activities such as squatting, running, jumping, and landing require 20 to 30 degrees of dorsiflexion ROM (60, 61). Therefore, the return to the normal ROM of the ankle and the 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 disorders of the lower extremities. According to their results, 83% of students reported lower extremity injuries. Of this, 39% of injuries were ankle sprains. The history of previous sprain and low dorsiflexion ROM had a significant relationship with the occurrence of ankle sprain. The results of the present study were consistent with this finding, so that the ROM in patients with an ankle sprain was significantly limited (51). The few number of sessions of the stretching exercises can be considered as one of the potential reasons that no changes in ROM was 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 sports season. The athletes were also examined in the sports season to be re-examined in the case of injury. According to their results, the injury in men and in women was 19% and 13%, respectively, and there was no statistically significant difference. Among men, there was no correlation between the exercise type and ankle injury. The ankle injury factors were different in men and women. In general, joint laxity, postural stability, and muscle reaction time had no significant relationship with injury (50).

In this study, a significant difference was found between the pre-test and post-test scores of proprioception in the experimental group. The results of the present study were consistent with those of Asadi et al. (62), Lapanantasin et al. (63) and Sarvar et al. (64) who found beneficial effects of different exercise types on ankle proprioception in patients with ankle instability. Other investigators failed to show any significant effect of therapeutic exercises on ankle proprioception in these subjects (65).

The ability to recognize and respond to the motion in the leg by postural adaption is necessary to prevent ankle injury (66). A number of authors have argued that an ankle sprain and subsequent functional ankle instability are related to defects in proprioception (67), mechanical instability (68), and fibular muscle weakness (69). A recent review suggested that patients with ankle instability have deficits of proprioception in their injured ankle, especially with regard to their JPS (70, 71). It is JPS that allows us to maneuver our way around obstacles out of view. Higher ankle JPS deficits are associated with worse balance impairments and an increased risk of sprain recurrence (72-74). A number of previous studies have shown that people with ankle sprains suffer from difficulty in active and passive reconstruction of the joint angle. Boyle and Negus found that people with repeated ankle injuries are less precise in the active and passive JPS in plantar flexion and dorsiflexion than healthy individuals (75). Neuromuscular training using slide board or wobble board is a common rehabilitation methods for ankle instabilities, designed to help retraining of the proprioceptive system by improving the performance of joint mechanoreceptors and restoring the normal neuromuscular feedback loop.

Caldemeyer et al. performing a systematic review demonstrated positive effect of neuromuscular training for decreasing the recurrent sprains in female athletes with ankle instability (76). Kim et al. reported that an 8-week neuromuscular training program can significantly improve 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 impacts 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. However, they declared that a larger sample size can be utilized in future studies to identify more comprehensive outcomes related to ankle injuries (78).

A systematic review and meta-analysis was performed by Tao et al. 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 have a positive effect on passive JPS during inversion and eversion, but do not restore the active JPS deficits of injured ankles in patients with CAI when compared with 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).

In a study by Skir et al., the results showed a significant improvement in proprioception after an isokinetic exercise program. Finally, they concluded that tendon mechanoreceptors and muscles provide active proprioceptive function (31). This observation is associated with physiological understanding of the important role muscle afferents in proprioception (46, 47).

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

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

Conclusions

It can be concluded that neuromuscular training is can be effectively incorporated in the rehabilitation protocol for the athletes with LAS aiming to improve their muscle strength, balance, and proprioception. These findings can be highly important both for injured people and the physiotherapists, so that they can achieve good clinical improvements specially in balance and proprioceptive performance.

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Authors' contribution:

MK analyzed and interpreted the data and wrote the manuscript. AJ participated in the planning and supervised all stages of the study. MR participated in the literature search and data collection. PS participated in statistical analysis and study design. All of the authors have reviewed and approved the final manuscript.

Conflict of interest:

The authors declare that they have no competing interests.

Limitations:

We could not blind the subjects regarding the study group. Moreover we did not assessed the long-term effect of such neuromuscular training program in patients with LAS or healthy individuals. We did not follow the participants for longer period considering potential impact of this intervention for decreasing the re-injury risk.

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