DOI: 10.22122/jrrs.v16i1.3444 Published by Vesnu Publications

The aim of this study was to investigate the effects Hopping exercises on the feedback and feedforward activity of selected lower limb muscles in single leg jump landing task in athletes with functional ankle inst

Sasan Arjang[1], Farideh Babakhani[2], Ramin Baluchi[3]

Original Article

Abstract

Introduction: The aim of this study was to investigate the effect of hopping exercises on the feedback and feedforward activity of selected lower limb muscles in single leg jump landing task in athletes with functional ankle instability.

Materials and Methods: 24 male athletes (12 in the control group and 12 in the training group) with functional ankle instability participated in this randomized clinical trial. Hopping exercises were given for six weeks, three times a week to the experimental group. The control group continued their routine exercise three sessions per week. The electric activity of Peroneus Longus, Tibialis Anterior, Medial Gastrocnemius, gluteus medius, and gluteus maximus muscles in the jump landing, before and after the hopping exercises were collected.

Results: The results of this study showed that after six weeks of hopping exercises, there was a significant effect on the onset of activity of the Peroneus Longus and gluteus medius muscles ($P \leq 0.001$). There was a significant increase in the activity of Peroneus Longus ($P \leq 0.003$), Medial Gastrocnemius ($P \leq 0.005$), and gluteus medius ($P \leq 0.001$) muscles in 100 milliseconds before the first contact of the foot on the ground. In addition, Peroneus Longus ($P \leq 0.001$) and gluteus medius ($P \leq 0.001$) activity increased significantly between 100-200 milliseconds after the first contact of the foot on the ground. However, no significant difference was observed in muscle activity of the untreated control group ($P > 0.050$). No significant change was recorded in the activity of the Tibialis Anterior, Medial Gastrocnemius, and gluteus maximus muscles ($P > 0.050$).

Conclusion: Six weeks of hopping exercises seem to reduce the time interval before the onset of activity and increase the activity amplitude for aforementioned muscles in single leg jump landing in athletes with functional ankle sprain. Therefore, while planning therapeutic exercise programs for athletes with functional ankle instability, it may be beneficial to have a look at hopping exercises.

Keywords: Electromyography; Ankle joint; Rehabilitation

Citation: Arjang S, Babakhani F, Baluchi R. **The aim of this study was to investigate the effects Hopping exercises on the feedback and feedforward activity of selected lower limb muscles in single leg jump landing task in athletes with functional ankle inst.** J Res Rehabil Sci 2020; 16: 42-50.

Received: 01.02.2020 Accepted: 29.04.2020 Published: 04.05.2020

Introduction

One of the most common injuries among athletes and the general public is ankle sprains that occur not only due to sports activities, but also to recreational activities (1). Among sports injuries, goodbye to the professional level due to ankle sprains is very common and a lot of cost is spent annually on the treatment of ankle injuries by clubs and athletes. 85% of ankle sprains occurs mainly following ankle inversion, which involves the external ligaments of the ankle (2,3). In the etiology of ankle sprain, structural instability is caused by a structural defect in ankle stability agents such as ligaments; while functional instability occurs despite the health of

1- MSc Student, Department of Sport Injury and Corrective Exercises, School of Physical Education and Sports Sciences, Allameh Tabataba'i University, Tehran, Iran
2- Assistant Professor, Department of Sport Injury and Corrective Exercises, School of Physical Education and Sports Sciences, Allameh Tabataba'i University, Tehran, Iran
3- Associate Professor, Department of Sport Injury and Corrective Exercises, School of Physical Education and Sports Sciences, Allameh Tabataba'i University, Tehran, Iran
Corresponding Author: Farideh Babakhani, Email: farideh_babakhani@yahoo.com

ankle structures and due to their dysfunction and has two subsets of open and closed chains (feedback and feedforward). In the open chain, there is a problem with the call pattern in the brain (feedforward phase) and in the closed chain, the problem is in the ankle area, which sends incorrect information to the brain and causes improper messages to be sent from the brain (feedback phase).

Chronic ankle instability can be mechanical or functional. Mechanical instability refers to joint movement beyond the physiological range, weakness of damaged tissues around the joint, and muscle weakness (4); While in functional instability, joint movement is beyond the voluntary control of the individual in the physiological range, and the kinesthetic defect, which affects the dynamic stability during functional movements, is more important (4,5). Mechanical factors affecting chronic ankle instability include pathological laxity, arthrokinematic limitations, and synovial changes. Functional factors affecting chronic ankle instability include impaired proprioception, impaired neuromuscular control, and impaired control of force and strength (6). Functional instability of ankles is also associated with decreased dynamic stability and neuromuscular change in the higher joints (7). Twisting and re-instability are associated with an increased risk of ankle osteoarthritis, and people with instability may not return to their previous levels of activity (8).

Hopping exercises are a set of plyometric exercises (8) and a dynamic training method for the lower limbs that has multiple nature of muscle strength, neuromuscular coordination, joint stability, balance, and joint proprioception (8,9). These exercises can allow the person to have better control over their contractile muscles and synergists by creating changes in the neuromuscular system (10). Muscle strength and balance are two essential components of hopping performance (10). Hopping exercises create neuromuscular adaptations and, as a result, lead to the increased performance and faster and more powerful implementation of the movements (8). It also enhances muscle power, the ability of a muscle to produce maximum force in a short period of time (11). Researchers believe that hopping exercises are a bridge between strength and coordination and increase competitive performance (9).

In a review study, Karimizadeh Ardakani et al. showed that after ankle sprain, the onset time of activity, electromyographic activity, and the level of electrical activity of the distal and proximal muscles of the lower limb decrease and the postural control and movement pattern in these individuals change (8). Based on their study, the results of all studies on individuals with ankle sprains who examined electromyography during perturbation and studies examining dynamic postural control and electromyography during perturbation showed increased reaction time, and delayed onset of activity of peroneal muscles following inversion ankle sprains in individuals with functional ankle instability may be an explanation for recurrent ankle sprains (8). Additionally, changes in the muscular structures controlling the proximal region of the lower limb during closed-chain functional activity were evident in individuals with recurrent ankle sprains. In subjects with ankle instability, the onset of peroneal muscle activity is delayed. Decreased thigh abductor muscle strength was observed on the lesion side compared to the opposite side (8). Injury to the ankle joint reduces the activity of the thigh extensor muscles on both sides. Combined exercises with thigh and ankle muscle activity may lead to a modification of the pattern of muscle utilization; while at the same time stabilizing the ankle. The use of neuromuscular exercises reduces reaction time and dynamic stability (8).

Among the factors that cause impairment in maintaining balance in individuals with ankle functional instability, the decrease in ankle muscle strength and poor coordination of equilibrium movements can be mentioned (12). Information sent from joint and muscle receptors reflexively coordinates muscle activity to achieve the goal. In the feedback process, longer delays occur in transmission (13). The ankle stability can be increased by stimulating the sensory and motor pathways of the muscles in both the feedback and feedforward phases (14). Each time a signal passes through a chain of synapses, they will transmit that signal better than before. When these pathways are facilitated on a regular basis, that signal is stored in memory and is called to plan future movements. Thus, repetitive facilitation of memory required for motor control is planned in advance and reflex pathways improves neuromuscular control (14,15).

The landing movement requires the coordination of the whole body; as the motor control system must properly coordinate the muscles working on different joints. Muscular responses before landing are responsible for controlling acceleration during voluntary landing (16). Feedforward control, this muscle timing is critical to control lower limb stiffness at the moment of foot contact with the ground (17). The time of onset and duration of muscle activity before the foot touches the ground are key variables that ensure the proper level of muscle force created at the moment the foot hits the ground (18). Therefore, any delay in muscle activity and stiffness can allow additional movement in the knee and ankle and lead to injury (19). Hopping exercises are basic motor skills that are low cost and trainable and can be used in a rehabilitation program to prevent injuries (8). However, there are few studies addressing applying only this type of exercise as a non-pharmacological and non-surgical method to prevent injury and rehabilitate people with functional ankle instability. Therefore, the aim of this study is to investigate the effect of hopping exercises on improving muscle activation time in subjects with ankle instability.

Materials and Methods

This study was a randomized controlled clinical trial registered on Iranian Registry of Clinical Trials (IRCT) system with code IRCT20200404046944N1 and included the hopping exercise group and the control group. The statistical population of the study consisted of all male student athletes aged 18 to 25 years active in the sports teams of Allameh Tabataba'i University, Tehran, Tehran, who had regular and at least three sessions of sports activities per week during the last three years. First, the level of activity of individuals and their willingness to participate in the study given the duration of the measurement process was confirmed orally and through interviews. Then, the consent form and personal information questionnaire were presented to the volunteers. Finally, using G*Power software (G*Power, Franz Faul University of Kiel, Germany) and assuming $\alpha = 0.05$ and $1-\beta = 0.80$ and based on the results of previous studies (8), 24 male students (18 to 25 years old) were selected using purposive sampling method. The study inclusion criteria included having at least one experience of internal ankle rotation injury in the past two years, no history of lower limb injury, ability to bear your own weight, normal gait, and full range of motion (ROM) of the ankle joint. The unwillingness to continue the study process, the inability to participate in two consecutive training sessions, and injury and pain during the study process were also considered as the exclusion criteria.

The shoes were the same for all subjects. First, the subjects warmed up for 5 minutes to perform the tests easier. Then, Sargent jump test was taken to obtain 50% of the subject's vertical jump to adjust the jump height on the force plate. The selected muscles were then prepared according to the surface electromyography for non-invasive assessment of muscles (SENIAM) protocol and the maximum isometric contraction was taken from each muscle. To perform the single-leg landing test, an object was hung from the ceiling; so that its height was equal to 50% of the maximum vertical jump (based on the result of the vertical jump test). A 70 cm line was placed before the force plate and a marker was placed in the middle of the distance between the center of the force plate and the 70 cm line before it (35 cm from the force plate and 35 cm to the subject) (20). The participant was instructed to jump from behind the 70 cm line and touch the marker and land on the force plate with the injured foot (Figure 1).

Figure 1. Single-leg landing jump

In order to calculate the time of onset of muscle activity, first, one-way waves and three times the standard deviation (SD) of the electrical activity of the muscles in the baseline were identified as the threshold of onset of activity (21). When the muscle activity reached the threshold and remained above the threshold level for at least 25 milliseconds, this point was considered as the time of onset of activity (21). Then, the electrical activity of the selected muscles was recorded at 100 milliseconds before the first contact and 100 to 200 milliseconds after the first contact and analyzed (22). The test was performed at Allameh Tabataba'i University. To invite the individuals to participate in the study, first people with ankle instability were selected and then, they completed the Ankle Joint Functional Assessment Tool (AJFAT). This questionnaire with the test-retest intraclass correlation coefficient (ICC) reliability of 0.94 and standard error of measurement (SEM) equal to 1.5 was applied to determine the degree of stability and function of the ankle in subjects with functional ankle instability. The AJFAT scale consists of 12 items related to ankle pain, ankle swelling, ability to walk on uneven surfaces, general sense of stability, overall strength of the ankle and the ability to descend stairs, ability to run smoothly, ability to change direction when running, overall level of activity, ability to feel the giving way ankle, the ability to respond to the giving way ankle, and the ability to return to activity after the giving way ankle. For scoring the items, the participant chooses the answer that best describes the condition of his ankle using the options "much less than the other ankle, slightly less than the other ankle, the same as the other ankle, slightly more than the other ankle, and much larger than the other ankle." Each item has a score between 0 and 4. A lower score indicates higher levels of symptoms or more functional instability associated with functional limitations. The total score of the questionnaire is obtained from the sum of scores. The maximum score on this scale is 48 and a score less than or equal to 26 indicates a person with functional ankle instability (23,24).

To evaluate muscle activity, a 16-channel electromyography device (WIRELESS EMG V 4.24 model, Baya Med Company, Iran) was used. The preamplifiers of this device have specifications as a gain of 4000 common-mode rejection ratio (CMRR), 108 dB, which a sampling frequency of 1000 Hz and a bandwidth of 20 to 500 Hz was used in the present study (23). Moreover, disposable surface electrodes (Dormo model) with a 1-cm diameter of the central conductor part were used. Electrodes were placed as the bipolar method and the distance to the center of the electrode was considered to be 20 mm. To reduce the skin resistance, the skin hair was shaved and it was cleaned with cotton soaked with alcohol. In the next step, the electrodes were installed on the Peroneus Longus, Medial Gastrocnemius, Tibialis Anterior, gluteus maximus, and gluteus medius muscles (21). A three-axis force plate (50 × 40 × 8) (Daneshsalar Company, Iran) was used to measure the ground reaction force (GRF) and detect the first contact of the foot with the ground. The GRF was recorded by a force plate with a frequency of 200 Hz (25). Determining the exact moment of foot contact with the force plate was essential to determine 100 milliseconds before and 100 to 200 milliseconds after the first contact. Therefore, the electromyography (EMG) device was matched to the force plate. In processing the EMG signals, muscle activity had to be normalized to a reference value to provide a comparison between different muscles and different subjects (26). For this purpose, the values obtained from the root mean square (RMS) calculation were divided into the values obtained from the maximum voluntary contraction of each muscle and the amount of muscle activity was considered as a percentage of the maximum voluntary contraction. Each maximal contraction position was repeated three times for 10 seconds and then the data mean was used (26).

The hopping group participated in a six-week training program. The control group also did their sports activities, which were the same as regular weekly exercises (three sessions per week). The designed hopping exercise program consisted of three sessions per week as every other day, with a practice range of 90 to 130 foot-to-ground contact per session. The intensity of the exercise increased over the weeks as increase in the number of exercises, as well as by restricting the arms, i.e. from the free position to the arms kept on the chest and then the arms kept behind. The progress of the exercises was such that at first different forms of training were performed on two legs, and in the following weeks by gaining the ability, it was performed on one leg. The subjects performed the exercises sequentially and repetitively, resting for 30 seconds between each set of exercises and 2 minutes between each exercise (27). Furthermore, the intensity of training increased until the fifth week and decreased in the sixth week to avoid fatigue during the post-test phase (18). The training protocol used included side hopping, forward and backward hopping, hopping with forward movement, hopping as a square, zigzag hopping, and 8-shape hopping, the method of implementation of which was determined as previous studies (8,24). Descriptive and inferential statistics were used for statistical analysis. Descriptive statistics and SD were employed to describe the demographic characteristics of the subjects. Given the equality condition of variance by Levene's test and the normal distribution of data using Shapiro-Wilk test, the analysis of covariance (ANCOVA) test was used to analyze the data. Finally, the data were analyzed in SPSS software (version 22, IBM Corporation, Armonk, NY, USA). $P < 0.05$ was considered as the significant level.

Results

The mean weight, height, and body mass index (BMI) of the subjects in the studied groups are presented in table 1. There was no significant difference between the two groups in demographic characteristics.

Table 1. Description of the characteristics of the subjects

Group	Weight (kg)	Height (cm)	BMI (kg/m^2)
Control	78.66 ± 7.66	181.66 ± 6.03	23.82 ± 1.94
Intervention	79.66 ± 8.38	180.41 ± 7.17	24.44 ± 1.85
P value (t-test)	0.763	0.649	0.433

BMI: Body mass index

The mean age of the control and intervention groups was 25.08 ± 4.69 and 24.23 ± 4.16 years, respectively (P = 0.683).

The study process is shown in figure 2.

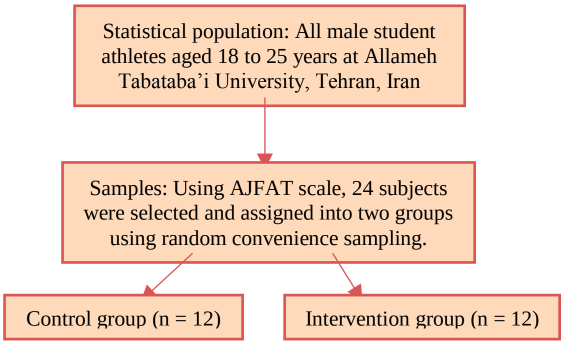

Figure 2. CONSORT diagram

AJFAT: Ankle Joint Functional Assessment Tool

The results of ANCOVA test showed that hopping exercises had a significant effect on the onset of activity of gluteus medius and peroneus longus muscles (P = 0.001), however these exercises did not show a significant effect on the onset of activity of gluteus maximus, internal gastrocnemius, and tibialis anterior muscles (Table 2).

Based on the results of ANCOVA test, 100 milliseconds before the foot hit the ground, hopping exercises had a significant effect on the activity of gluteus medius (P = 0.001), internal gastrocnemius (P = 0.005), and peroneus longus (P = 0.003); However, these exercises did not show a significant effect on the activity of gluteus maximus and tibialis anterior muscles (Table 3). The results of ANCOVA test in table 4 suggested that 100 to 200 milliseconds after the foot hit the ground, hopping exercises had a significant effect on the activity of gluteus medius and peroneus longus muscles (P = 0.001), but no significant effect was observed on the activity of the gluteus maximus, internal gastrocnemius, and tibialis anterior muscles.

Discussion

The aim of this study was to investigate the effect of six weeks of hopping training on the onset time and activity of feedforward and feedback muscles of peroneus longus, tibialis anterior, medial gastrocnemius, gluteus medius, and gluteus maximus of active athletes with functional ankle instability in single-leg landing. The findings revealed that six weeks of hopping exercises resulted in a change in the onset of activity of the muscles of the peroneus longus and gluteus medius. Additionally, at intervals of 100 milliseconds, there was a significant increase in the activity of peroneus longus, gastrocnemius, and gluteus medius muscles, and at intervals of 100 to 200 milliseconds, the activity of gluteus medius and peroneus longus muscles, but there was not a significant difference in muscle activity in the control group. Accordingly, it can be said that the hopping training program may have been effective in accelerating the onset of pre-activity of the mentioned muscles in the training group. In a study, Mamashli et al. concluded that the delay in the onset of peroneal, gluteus medius, and erector spinae muscle activity was longer in the group with functional ankle instability compared to the healthy individuals (28). A movement command is issued to activate the muscles of healthy people, especially the central muscles of the body, before the foot hits the ground. Activation of these muscles before the foot hits the ground is to provide the stability of the motor chain against the perturbation caused by the foot hitting the ground (17). Therefore, perhaps the findings of the present study indicate the return of part of the ability of the movement control system to normal in the exercise group.

Table 2. Results of analysis of covariance (ANCOVA) test to compare groups at the onset of muscle activity

Muscle	Group	Muscle activity start time (milliseconds)		Paired t-test	F statistic	P	Eta coefficient
		Pretest	Posttest				
Gluteus medius	Control	-107.83± 16.23	-106.08 ± 16.90	0.386	44.661	0.001*	0.680
	Intervention	-109.33 ± 17.93	-142.25 ±8.63	2.747			
Gluteus maximus	Control	-75.33 ± 19.71	-76.33 ± 12.19	-1.167	0.799	0.382	0.037
	Intervention	-74.41 ±12.75	-80.33 ± 14.14	3.410			
Peroneus longus	Control	-91.66 ±16.01	-90.16 ± 13.20	-0.814	25.908	0.001*	0.552
	Intervention	-91.58 ± 16.22	-119.25 ± 14.63	2.548			
Internal gastrocnemius	Control	-114.75 ±14.41	-117.50 ± 16.21	-0.255	0.616	0.442	0.028
	Intervention	-116.58 ± 17.99	-124.83 ± 25.46	0.935			
Tibialis anterior	Control	-52.33 ± 11.57	-53.66 ± 10.97	-0.031	0.958	0.339	0.044
	Intervention	-53.75 ± 11.60	-58.58 ± 12.60	0.337			

* Significant difference at the level of 0.05

Table 3. Analysis of covariance (ANCOVA) test results for comparison of groups in muscle activity (feedforward) 100 milliseconds before the foot hits the ground

Muscle	Group	Intensity of muscle activity 100 milliseconds before impact (%)		Paired t-test	F statistic	P	Eta coefficient
		Pretest	Posttest				
Gluteus medius	Control	49.41 ± 10.98	49.15 ± 7.94	0.326	22.656	0.001*	0.519
	Intervention	49.26 ± 8.85	59.21 ± 5.77	-2.352			
Gluteus maximus	Control	47.20 ± 7.78	48.08 ± 7.76	-1.250	3.144	0.091	0.130
	Intervention	47.89 ± 6.83	51.79 ± 6.13	-2.490			
Peroneus longus	Control	39.94 ± 7.15	37.64 ± 6.59	-0.714	11.244	0.003*	0.349
	Intervention	38.48 ± 6.77	48.26 ± 8.45	-2.314			
Internal gastrocnemius	Control	46.88 ± 5.45	47.61 ± 6.61	-0.360	9.660	0.005*	0.315
	Intervention	47.86 ± 7.09	54.32 ± 7.43	-0.510			
Tibialis anterior	Control	36.78 ± 6.09	38.32 ± 5.66	-0.420	0.517	0.480	0.024
	Intervention	33.47 ± 6.37	33.47 ± 5.99	-0.218			

* Significant difference at the level of 0.05

In the study by Keshavarz et al., the effect of jump-landing exercises on some selected muscles of the trunk and lower limbs of women was investigated and it was found that there was a significant difference in the feedback phase of the gluteus medius muscle between the experimental and control groups (26); this was in line with the findings of the present study. Suda and Sacco reported that in the pre-landing stage, subjects with functional ankle instability had lower levels of peroneus longus muscle activity, but it was higher in the post-landing stage. On the other hand, control of the peroneus longus and external gastrocnemius muscles began simultaneously and earlier, followed by the tibialis anterior muscle; while in patients with functional ankle instability, all three muscles were activated simultaneously (29). The results of the study by Samadi et al. showed that the onset time of pre-activity of the muscles of peroneus longus, Tibialis anterior, and Soleus was faster in the training group compared to the control group (18). In the present study, the onset time of feedforward of the peroneus longus and gluteus medius muscles of the training group was increased. It should be noted that the activity of muscles, especially the peroneus longus during landing (before the foot touches the ground), increases the stability of the subtalar joint (18). One of the reasons for not twisting of the ankle is the activation of the peroneus longus muscle, which increases the stability of the subtalar joint and maximizes the torque and velocity of this muscle. Therefore, it protects the joint against the forces applied and the resulting rotations (30). In the present study, after hopping exercises, the sensitivity of the muscle spindles may have increased by the central nervous system (CNS) in athletes with functional ankle instability, causing a change in motor control pattern and a reduction in the feedforward onset delay of the peroneus longus and gluteus medius muscles. This finding was in line with the results of the study by Momeni et al. (14). They concluded that hopping exercises, by modulating and optimizing muscle latency, could possibly play an important role in reducing the recurrence of sprains in people with functional ankle instability (14).

Table 4. Analysis of covariance (ANCOVA) test results for comparison of groups in muscle activity (feedback) 100 to 200 milliseconds after the foot hits the ground

Muscle	Group	Intensity of muscle activity 100 milliseconds after impact (%)		Paired t-test	F statistic	P	Eta coefficient
		Pretest	Posttest				
Gluteus medius	Control	49.61 ± 9.24	50.81 ± 8.82	0.580	15.631	0.001*	0.427
	Intervention	51.12 ± 9.71	62.03 ± 6.56	-2.574			
Gluteus maximus	Control	60.64 ±10.50	61.90 ± 7.41	0.490	3.632	0.070	0.147
	Intervention	61.57 ± 9.21	67.27 ± 7.95	-2.284			
Peroneus longus	Control	40.06 ± 7.19	41.10 ± 6.03	-0.710	14.369	0.001*	0.406
	Intervention	38.60 ± 6.81	50.77 ± 6.69	-2.263			
Internal gastrocnemius	Control	69.73 ±8.07	68.89 ± 5.78	-0.450	2.218	0.151	0.096
	Intervention	69.38 ± 8.78	72.69 ± 7.40	-2.197			
Tibialis anterior	Control	43.87 ± 7.28	42.36 ± 4.22	-0.130	2.485	0.130	0.106
	Intervention	44.64 ± 7.17	45.29 ± 4.95	-0.677			

* Significant difference at the level of 0.05

In the present study, a significant increase was observed in the activity of peroneus longus, gastrocnemius, and gluteus medius muscles in the training group 100 milliseconds before, and for the peroneus longus and gluteus medius muscles in 100 to 200 milliseconds after landing and foot contact with the ground. Decreased muscle activity before foot contact with the ground (feedforward activity) can be attributed to a change in pre-designed programs that are sent to the muscles from the CNS (31). Before the foot hits the ground in the landing movement, the lower limb muscles are activated to absorb the forces exerted during the contact (31). Dynamic neuromuscular limiters for lower limb movement include both feed-forward and feedback control loops. Feedforward neuromuscular control develops in the individual's previous movements and activates the muscles around the joint before a heavy load is applied to the joint (to absorb force and reduce stress on the ligaments) (32,33). Both feedback and feedforward neuromuscular control can increase joint stability by repeatedly stimulating sensory and motor pathways (13). The results of the study by Keshavarz et al. showed that there was a significant difference between the gluteus medius muscle in the feedback stage in the experimental group compared to the control group (26), which is consistent with the findings of the studies. In Momeni et al.'s study, plyometric exercises in active women with functional ankle instability significantly increased the feedback activity of the gluteus medius muscle in the exercise group. However, no significant change was found in the feedback activity of the muscles of the peroneus longus, tibialis anterior, medial gastrocnemius, injury side erector spinae, and opposite side erector spinae (14), which was in line with the results of the present study. Because in the study of Momeni et al., similar training load and variety of training caused more recall of motor units and the training load led to neuromuscular adaptation and recall of motor units (14). The effectiveness of the exercise program used in the present study becomes more evident because it may have been able to improve the feedback activity of the gluteus medius muscle of the exercise group.

Limitations

There was a possibility of signal interference from other muscles on the electromyographic activity of the muscle. Since not all participants in the test were in the same sport or on the same team, it was possible that different levels of fitness due to different training conditions affect muscle activity. The impossibility of examining some other important muscles such as quadratus lumborum (QL) and soleus due to the limitations of the EMG device was another limitation of the present study.

Recommendations

It is recommended to pay more attention to the proximal muscles of the body in designing rehabilitation methods and preventing injury to individuals with ankle instability. In future studiess, it is better to compare the effect of similar exercises in a specific sports group to clarify the difference in the effect of hopping exercises on physical fitness indicators. It is also suggested that future investigations examine the effects of hopping exercises on other joints, such as the knee.

Conclusion

The findings of the present study revealed that hopping exercises lead to improved feedforward control mechanism (faster onset of feedforward time and increased feedforward rate and activation pattern) of the peroneus longus, gluteus medius, and internal gastrocnemius muscles during landing, which is a good exercise to improve the performance of subjects with ankle instability. Taking into account the results of the present study and the review of previous results, it seems that hopping exercises play an important role in controlling the dynamic stability of the ankle joint, and disruption of this mechanism is an important factor in the occurrence of recurrent ankle instability during various functional activities. These exercises improve muscle function and prevent ankle injuries during landing by influencing muscle activation and increasing feed-forward activity.

Acknowledgments

The authors would like to appreciate Mr. Amir Shamlou, PhD student in pathology and corrective exercises, who played an important role in data collection. The Vice Chancellor for Research of Allameh Tabataba'i University and all the athletes who cooperated in the implementation of this research project are also appreciated.

Authors' Contribution

Sasan Arjang: Study design and ideation, attracting financial resources for the study, providing study equipment and samples, manuscript preparation, responsibility to maintain the integrity of the study process from the beginning to the publication, responding to the referees' comments, supportive, executive, and scientific study services, analysis and interpretation of results, specialized statistics services, specialized evaluation of the manuscript in terms of scientific concepts, and final manuscript approval to be submitted to the journal office; Farideh Babakhani: supportive, executive, and scientific study services, analysis and interpretation of results, specialized statistics services, specialized evaluation of the manuscript in terms of scientific concepts, and final manuscript approval to be submitted to the journal office; Ramin Baluchi: supportive, executive, and scientific study services, analysis and interpretation of results, specialized statistics services, specialized evaluation of the manuscript in terms of scientific concepts, and final manuscript approval to be submitted to the journal office.

Funding

The present study was taken from an MSc thesis on pathology and corrective exercises with the code of ethics IR.ATU.REC.1397.096 which was conducted with the financial support of Allameh Tabataba'i University. Allameh Tabataba'i University has not commented on data collection, analysis, and reporting, manuscript preparation, and final approval of the article for publication.

Conflict of Interest

The authors do not have a conflict of interest. Sasan Arjang conducted basic studies related to this article. Dr. Babakhani is an assistant professor and Dr. Baluchi is an associate professor and faculty member of Allameh Tabataba'i University.

References

1. Miklovic TM, Donovan L, Protzuk OA, Kang MS, Feger MA. Acute lateral ankle sprain to chronic ankle instability: A pathway of dysfunction. Phys Sportsmed 2018; 46(1): 116-22.
2. Baroni BM, Generosi RA, Junior ECPL. Incidence and factors related to ankle sprains in athletes of futsal national teams. Fisioter Mov 2008; 21(4): 79-88.
3. Kazemi K, Abdollahi I, Arab A. Evaluation of the electromyographic activity of distal and proximal muscles of the lower extremity after ankle sprain (Review Article). Physical Treatment 2013; 3 (3): 46-52. [In Persian].
4. Salom-Moreno J, Ayuso-Casado B, Tamaral-Costa B, Sanchez-Mila Z, Fernandez-de-las-Penas C, Alburquerque-Sendin F. Trigger point dry needling and proprioceptive exercises for the management of chronic ankle instability: A randomized clinical trial. Evid Based Complement Alternat Med 2015; 2015: 790209.
5. Hubbard TJ, Kramer LC, Denegar CR, Hertel J. Contributing factors to chronic ankle instability. Foot Ankle Int 2007; 28(3): 343-54.
6. Shih YF, Yu HT, Chen WY, Liao KK, Lin HC, Yang YR. The effect of additional joint mobilization on neuromuscular performance in individuals with functional ankle instability. Phys Ther Sport 2018; 30: 22-8.
7. Brown CN, Rosen AB, Ko J. Ankle ligament laxity and stiffness in chronic ankle instability. Foot Ankle Int 2015; 36(5): 565-72.
8. Karimizadeh Ardakani M, Alizadeh Mh, Abrahimi Takamojani E. The effect of barre au sol on the body composition and flexibility of nonathletic women. Management of Sport and Movement Sciences 2012; 2(4): 139-51. [In Persian].
9. Holm LW, Carroll LJ, Cassidy JD, Hogg-Johnson S, Cote P, Guzman J, et al. The burden and determinants of neck pain in whiplash-associated disorders after traffic collisions: Results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. J Manipulative Physiol Ther 2009; 32(2 Suppl): S61-S69.
10. Kuitunen S, Avela J, Kyrolainen H, Nicol C, Komi PV. Acute and prolonged reduction in joint stiffness in humans after exhausting stretch-shortening cycle exercise. Eur J Appl Physiol 2002; 88(1-2): 107-16.
11. Huang PY, Lin CF. Effects of balance training combined with plyometric exercise in postural control: Application in individuals with functional ankle instability. Berlin, Heidelberg: Springer Berlin Heidelberg; 2010 p. 232-5.
12. Kazemi K, Amiri A, Ghotbi N, Jamshidi A A, Razi M. Effects of perturbation training on ground reaction force and function in athletes with anterior cruciate ligament reconstruction. Modern Rehabilitation 2015; 9(3): 27-35. [In Persian].
13. Javdaneh N, Minoonejad H, Shirzad E. Investigating some neuromuscular risk factors of acl injury in athletes with ankle pronation deformity. Journal of Exercise Science and Medicine 2015; 7(2): 221-35. [In Persian].
14. Momeni S, Barati A, Letafatkar A, Jamshidi A, Hovanlo F. The effects of plyometric training on performance and the feed-forward activation of calf muscles in active females with functional ankle instability in single leg drop landing. J Ilam Univ Med Sc 2017; 25(2): 42-54. [In Persian].
15. Prentice WE. Rehabilitation techniques for sports medicine and athletic training. New York, NY: McGraw-Hill; 2004.
16. Hadadnezhad M. Compare the performance and plyometric exercises influence on some parameters of EMG in active females with Trunk Neuromuscular Control Deficit [PhD Thesis] Tehran, Iran: University of Tehran; 2013. [In Persian].
17. Fu SN, Hui-Chan CW. Modulation of prelanding lower-limb muscle responses in athletes with multiple ankle sprains. Med Sci Sports Exerc 2007; 39(10): 1774-83.
18. Samadi H, Rajabi R, Karimizadeh Ardakani M. The effect of six weeks of neuromuscular training on joint position sense and lower extremity function in male athletes with functional ankle instability. Journal of Exercise Science and Medicine 2017; 9(1): 15-33. [In Persian].
19. Wikstrom E. Functional vs isokinetic fatigue protocol: effects on time to stabilization, peak vertical ground reaction forces,

and joint kinematics in jump landing [MSc Thesis]. Gainesville, FL: University of Florida; 2003.
20. Caulfield B, Garrett M. Changes in ground reaction force during jump landing in subjects with functional instability of the ankle joint. Clin Biomech (Bristol, Avon) 2004; 19(6): 617-21.
21. Hodges PW, Bui BH. A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. Electroencephalogr Clin Neurophysiol 1996; 101(6): 511-9.
22. Delahunt E, Monaghan K, Caulfield B. Altered neuromuscular control and ankle joint kinematics during walking in subjects with functional instability of the ankle joint. Am J Sports Med 2006; 34(12): 1970-6.
23. Rose W. Electromyogram analysis [Online]. [cited 2019 Oct 24]; Available from: URL: https://www1.udel.edu/biology/rosewc/kaap686/notes/EMG%20analysis.pdf
24. Caffrey E, Docherty C, Schrader J, Klossner J. The Ability of 4 Single-Limb Hopping Tests to Detect Functional Performance Deficits in Individuals with Functional Ankle Instability. The Journal of orthopaedic and sports physical therapy 2009; 39: 799-806.
25. Gribble P, Robinson R. Differences in spatiotemporal landing variables during a dynamic stability task in subjects with CAI. Scand J Med Sci Sports 2010; 20(1): e63-e71.
26. Keshavarz L, Letafatkar A, Hadadnezhad M. Effect of eight weeks of jump-landing exercise on feedforward and feedback activation of selected trunk and lower extremity muscles andlower extremity performance in active females. Medical Journal of Tabriz University of Medical Sciences 2019; 40(5): 73-82. [In Persian].
27. Caffrey E, Docherty CL, Schrader J, Klossner J. The ability of 4 single-limb hopping tests to detect functional performance deficits in individuals with functional ankle instability. J Orthop Sports Phys Ther 2009; 39(11): 799-806.
28. Mamashli A, Jamshidi AA, Maroufi N, Jafari H. Timing of the core muscles during landing in healthy subjects. Physical Treatment 2013; 2(2): 37-42. [In Persian].
29. Suda EY, Sacco IC. Altered leg muscle activity in volleyball players with functional ankle instability during a sideward lateral cutting movement. Phys Ther Sport 2011; 12(4): 164-70.
30. Abbasi h, Alizadeh MH, Daneshmandi H, Barati AH. Comparing the effect of functional, extra-functional and combined exercises on dynamic balance in athletes with functional ankle instability. Studies in Sport Medicine 2015; 7(17): 15-34. [In Persian].
31. Santello M. Review of motor control mechanisms underlying impact absorption from falls. Gait Posture 2005; 21(1): 85-94.
32. Lephart SM, Abt JP, Ferris CM, Sell TC, Nagai T, Myers JB, et al. Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. Br J Sports Med 2005; 39(12): 932-8.
33. Hadadnezhad M, Rajabi R, Ashraf Jamshidi A, Shirzad E. The effect of plyometric training on trunk muscle pre-activation in active females with trunk neuromuscular control deficit. J Shahid Sadoughi Univ Med Sci 2014; 21(6): 705-15. [In Persian].