Women. Health. Bull. 2020; 7(2)
Published online 2020 April.

Research Article

Effect of Eight-Week Functional Exercise on Soft Surfaces on the Balance and Electromyographic Activity of the Muscles of Female Taekwondo Athletes

Fatemeh Fallahi Farrash[1], MSc; Rahman Sheikhhoseini[1*], PhD; Farideh Babakhani[1], PhD

[1]Department of Corrective Exercise and Sport Injury, Faculty of Physical Education and Sport Sciences, Allameh Tabataba'i University, Tehran, Iran

Corresponding author: Rahman Sheikhhoseini, PhD; Faculty of Physical Education and Sport Sciences, Allameh Tabataba'i University, Tehran, Iran. **Tel:** +98-21-48394134; **Email:** Rahman.pt82@gmail.com

Received February 28, 2020; **Revised** March 10, 2020; **Accepted** March 15, 2020

Abstract

Background: Ankle sprain is one of the most common injuries in taekwondo fighters. This study aimed to investigate the effect of eight-week functional training on soft surfaces on the balance and electromyographic activity of the muscles of female taekwondo fighters.
Methods: In this randomized field trial study conducted in Tehran, we selected 16 female taekwondo athletes and assigned them to experimental and control groups. The experimental group performed functional exercises on soft surfaces for eight weeks and three sessions per week. We collected the electromyography activity of muscles by a 16-Channel wireless Electromyography Model V 4.24 (Bayamed Company, Iran) in the biomechanics laboratory of the Allameh Tabataba'i University. Before and after the functional training protocol, we recorded the electrical activity of tibialis anterior, medial and lateral gastrocnemius, rectus femoris, and biceps femoris muscles of stance leg while performing Dollyo Chagi. We analyzed the data using ANCOVA at a significant level of $P \leq 0.05$.
Results: Eight-week taekwondo training on soft surfaces was significantly effective in reducing the Center of Pressure displacement (P=0.002 and P=0.045) and standard deviation (P=0.023 and P=0.022) concerning internal-external and anterior-posterior directions, respectively. Moreover, we observed an increase in the electromyographic activity of medial gastrocnemius muscle at 100 ms before foot initial contact (P=0.030).
Conclusions: The results of this study showed that functional taekwondo training on soft surfaces was able to increase the balance of athletes and augment the feed-forward electrical activity of medial gastrocnemius muscle. Therefore, it seems that these exercises can be used to prevent ankle injuries in these athletes.

Keywords: Female, Martial arts, Electromyography, Postural balance, Ankle

How to Cite: Fallahi Farrash F, Sheikhhoseini R, Babakhani F. Effect of Eight-Week Functional Exercise on Soft Surfaces on the Balance and Electromyographic Activity of the Muscles of Female Taekwondo Athletes. Women. Health. Bull. 2020;7(2):19-25.

1. Introduction

Dating back to 1500 years ago, taekwondo is one of the oldest martial arts styles in the world (1). In Iran and the world, taekwondo's popularity is so much that alongside karate and judo, it is considered among the most popular martial arts (2). Despite all the benefits of regular physical activity, the risk of injury in competitive sports is incontrovertible (1). Due to its fighting nature, taekwondo involves intense sparring (heavy training), many impacts, and intense contact characteristics (3). Injuries such as sprains, muscle tensions, and ligament tensions are prevalent in contact sports (2), entailing a great deal more damage compared to non-contact sports (4). It is highly common to use the lower and upper extremities in taekwondo exercises and competitions; however, most techniques are performed by the foot, such that competing taekwondo athletes perform a combination of high-level kicks such as jumping, twisting, and kicking (sliding kicks) during the tournament. Match rules have further permitted the increased use of the lower extremities. Furthermore, approximately 98% of the points in taekwondo competitions are gained from kicking (4).

Most taekwondo injuries occur in the lower extremities due to the sudden changes in direction and powerful rotational strikes, and 45% of athletes have reported sprains and strains (3). Ankle sprains are caused by high-speed jumping sports (5). Therefore, taekwondo athletes are susceptible to ankle sprains because it is fast and involves a great amount of jumping (6). The majority of ankle injuries happen in the lateral ankle side where there are three ligaments, namely calcaneofibular, posterior talofibular, and anterior talofibular ligaments. Excessively supinated foot can hurt these ligaments, particularly the anterior talofibular ligament which bears the greatest strain when the ankle is in plantarflexion (7). Ankle sprains ensue loss of function, pain, swelling (5, 8), functional ankle instability (6), and chronic ankle sprain (5, 9). Functional ankle instability is associated with giving way as well as deficits in neuromuscular control, proprioception, and postural control (10).

Previous studies showed that balance exercises increased the activity of ankle joint receptors, contributing to increased proprioception (11, 12). Mettler and colleagues reported that balance exercises were able to significantly alter the Center of Pressure (COP) displacement (13). Malliou and colleagues observed that soccer players progressively using balance board exercises were less likely to have ankle injuries (14). Existing evidence suggests that training on soft surfaces might enhance ankle stability and reduce injury (15); however, the effects of this training method have yet to be investigated on taekwondo athletes.

On the other hand, most studies have not considered functional exercises; thus, it seems that the presence of functional protocols may have a more effective role in preventing and reducing athletic injuries (16). Based on the findings, there is a need to provide preventive strategies for reducing the incidence of chronic ankle instability in taekwondo athletes. Accordingly, the present study sought to determine whether exercise on soft surfaces affects the balance and electromyographic activity related to the muscles of taekwondo female athletes.

2. Methods

The present randomized field trial (conducted in Tehran, 2018-2019) included all young female taekwondo athletes who had done taekwondo in sports clubs for a minimum of three years and three sessions per week. Based on a previous study (13), we obtained a total sample size of 16 using G*Power ver 3.1 software and considering $\alpha=0.05$ and $\beta=0.20$ for dependent t-test of COP displacement variable in the anterolateral foot region (pretest=231.00±149.6, posttest=118.3±134.4) of the training group. Through a convenience sampling method, we selected 16 female athletes and randomly assigned them to control and experimental groups. Inclusion criteria were 18-25 years of age, more than three years of athletic experience, taekwondo training for at least five days per week, and being a female. We excluded those with a history of surgery, lower extremity fractures and severe lower extremity injuries, feeling of instability over the past six months, other musculoskeletal joint injuries, ankle fractures, ankle ligament rupture and ankle muscular injuries, visual and hearing and nervous system impairments, and any other pathologies that impair motor function and leads to postural disorder. We obtained a written informed consent form from all taekwondo athletes and assured them of the confidentiality of their data. After passing the pre-tests on the studied variables, the experimental group practiced three sessions per week for eight weeks. Engaged in daily activities, the control group did not participate in any rehabilitative exercise activities during this time. After conducting the study protocol, all subjects participated in the post-test, with the test results examined by the same examiner. The Research Ethics Committee of the University of Social Welfare and Rehabilitation Sciences approved all research processes and methods were approved in terms of ethical considerations (coded IR.USWR.REC.1397.123).

Training protocol: Intervention groups underwent specialized training and performed taekwondo techniques under the supervision of the same trainer. Toe training program consisted of warm-up, main exercises, and cool down in each session for 15-20 minutes. Exercises started from a low intensity level (simple) and gradually progressed, with each session having increased number and repetition of movements compared to the previous one.

Experimental group training program: A professional taekwondo trainer designed the protocol which was approved by two other experts in the field of physical education and sport injuries. This protocol was designed as part of a warm-up program which athletes had to perform prior to training sessions. During the first session, they were familiarized with the basics of the exercises, and these principles were followed throughout the sessions. The intervention group performed the exercises on a soft mattress as follows:

First and second weeks:

1. Hopping with the left leg (2 min) and the right leg (2 min)

2. Leg kicks with both legs (2 min) with the legs constantly performing Baal Paco (exchanging legs)

3. Leg kicking and simultaneously performing Ab Dollyo Chagi with the right leg (2 min) and left leg (2 min)

4. Leg kicking and simultaneously performing Ap Dollyo Chagi on the mitt with both right and left legs (2 min)

5. Leg kicking and simultaneously performing double Ap Dollyo Chagi (two consecutive Ap Dollyo kicks) with the right leg (2 min) and the left leg (2 min)

Third-fifth weeks

1. Hopping with the right leg (2 min) and the left leg (2 min)

2. Leg kicking with both legs such that the athlete constantly perform Baal Paco (2 min)

3. Leg kicking and simultaneously performing Ap Dollyo Chagi with the right leg (2 min) and the left leg (2 min)

4. Leg kicking and simultaneously performing double Ap Dollyo Chagi (two consecutive Ab Dollyo kicks) with the right leg (2 min) and the left leg (2 min)

5. Leg kicking and simultaneously performing Ap Dollyo Chagi with the right leg (2 min) and the left leg (2 min)

6. Leg kicking and simultaneously performing Ap Dollyo Chagi on the mitt with both right and left legs (2 min), 30-40 s rest, and the technique is repeated (2 min)

Sixth-eighth weeks

1. Hopping with the left leg (2 min) and the right leg (2 min) with closed eyes

2. Leg kicking with both legs and closed eyes such that the athlete constantly perform Baal Paco (2 min)

3. Leg kicking and simultaneously performing double Ap Dollyo Chagi (two consecutive Ab Dollyo kicks) with the right leg (2 min) and the left leg (2 min)

4. Leg kicking and concurrently performing Ap Dollyo Chagi with the right leg (2 min) and the left leg (2 min) and simultaneously performing Ab Dollyo Chagi on the mitt with both right and left legs (2 min), 30-40 s rest, and the technique is repeated (2 min)

5. Leg kicking and simultaneously performing double Ap Dollyo Chagi (two consecutive Ap Dollyo kicks) with the right leg (2 min) and the left leg (2 min)

6. Leg kicking and simultaneously performing Ap Dollyo Chagi and Dollyo Chagi with the right leg (2 min) and the left leg (2 min)

To assess the muscle electrical activity, we utilized a 16-Channel wireless Electromyography (EMG) Model V 4.24 (Bayamed Company, Iran). Primarily, we recorded maximum voluntary isometric contraction (MVIC) via voluntary contraction of each muscle following skin preparation. Afterwards, we obtained the data related to vertical ground reaction force and COP through force plate apparatus that was synchronized with EMG device; we further collected the data on the electrical activity of the selected muscles of the stance leg (tibialis anterior, medial and lateral gastrocnemius, rectus femoris, and biceps femoris muscles) by an electromyographic device while the subjects performed Dollyo Chagi (a leg technique in Taekwondo). For this purpose, we firstly asked the subjects to stand opposite one another outside of the force plate at a distance of 20 cm, holding the mitt in the preferred position at the height around the head. Next, we asked the subjects to perform Dollyo Chagi on the mitt, with the stance foot touching the force plate after a short jump. Three successful trials were performed and the mean average of these trials was analyzed as study data. We attached the electrodes based on the SENIAM protocol commonly used in recent studies.

After attaching the EMG electrodes on the skin, we examined the MVIC of each muscle as follows: regarding tibialis anterior muscle, we asked the subjects to remain in standing position with the ankle at an angle of 90 ° and then resist against a maximal force tending to plantarflex the joint. Concerning the gastrocnemius muscle, we asked the subjects to perform the maximal plantar flexion while they were in long sitting with fully extended knee, the dominant leg resting on the wall, and ankle-flexion angle of 90. As far as rectus femoris muscle is concerned, we asked the subjects to extend the knee against the maximal resistance in the leg while the dominant leg was placed on the chair in a sitting position, and the knee bent 70-90 degrees. For the biceps femoris muscle, we asked the participants to flex their knees against maximal manual resistance while lying in the prone position, with the knee at a flexion angle of 45 degrees and external tibial rotation. These exercises were performed for three times, each lasting five seconds for each muscle; after that, we employed their Root Mean Square (RMS) as a reference for data normalization. Afterwards, we filtered the data using a 50 Hz notch filter and a 10 to 500 Hz band-path Butterworth filter to remove the noises. To analyze the Dollyo Chagi EMGs, we extracted the RMS of EMG signal in 0-100 ms period before foot initial contacts (as a feedforward electrical activity) and 100-200 ms period after foot initial contact (as a feedback electrical activity). The initial contact time was considered as the first time the force plate vertical output exceeded 10 N. We calculated the average RMS and obtained the percentage of muscle activity through dividing the muscle activity by MVIC. To calculate the COP variables, we used Excel software 2016 and extracted and the variation range and standard deviation of COP displacement using Excel functions.

Statistical Analysis

We analyzed the data at a 95% confidence interval (P<0.05). Independent t-test and analysis of covariance were performed to analyze the data, and the Shapiro-Wilk test was employed to examine data normality in SPSS software Version 22.

3. Results

At the end of the study, 16 female athletes (eight in experimental and eight in control groups) completed the study. There were no statistical differences between the groups in terms of age, weight, height, and Body Mass Index (BMI). Table 1 summarizes the demographic information of subjects.

Analysis of covariance examined the COP displacement in the experimental group; the results showed that the functional training on soft surfaces had a significant positive effect on the balance (Table 2). Furthermore, we used analysis of covariance to assess the electrical activity of the muscles at 100 ms prior to foot initial contact (Table 3) and 100 to 200 ms following the foot initial contact (Table 4). According to the results, functional exercises influenced medial gastrocnemius muscle activity at 100 ms before foot initial contact in female taekwondo athletes; however, these exercises did not change the activity of the selected muscles 100 to 200 ms after the initial contact.

Table 1: Demographic information of subjects and comparison between two groups

Group	Number	Age (year)	Weight (kg)	Height (cm)	BMI
Control	8	22.47±0.42	53.88±6.67	164.58±4.45	19.28±2.06
Experimental	8	23.63±0.91	58.81±4.27	167.43±4.75	20.99±1.53
Independent t-test (P value)		0.321	0.117	0.273	0.099

Table 2: Analysis of covariance results for variable of center of pressure (COP) variations

Variable	Direction	Mean±SD			F	P value	Effect size
		Group	Pre-test	Post-test			
COP displacement	Medial -lateral	Control	14.93±3.45	13.47±2.35	16.125	0.002*	0.594
		Experimental	12.92±2.37	10.27±1.93			
	Anterior- interior	Control	14.84±0.60	14.63±0.74	5.116	0.045*	0.317
		Experimental	14.15±1.20	12.71±0.89			
COP SD	Medial -lateral	Control	7.67±2.02	7.62±1.50	7.001	0.023*	0.389
		Experimental	8.08±1.60	6.40±1.92			
	Anterior- interior	Control	6.29±1.26	6.49±0.90	7.156	0.022*	0.394
		Experimental	6.08±1.44	4.98±1.09			

COP: Center of Pressure, SD: Standard Deviation, *Observation of significant difference

Table 3: Analysis of covariance results for muscle activity variable 100 ms before foot initial contact

Variable		Mean±SD			F	P value	Effect size
		Group	Pre-test	Post-test			
100 ms before contact	Anterior	Control	0.45±0.15	0.44±0.08	0.062	0.809	0.006
		Experimental	0.37±0.12	0.39±0.13			
	Medial gastrocnemius	Control	0.51±0.27	0.49±0.24	2.242	0.030*	0.362
		Experimental	0.53±0.26	0.65±0.18			
	Lateral gastrocnemius	Control	0.43±0.21	0.44±0.20	0.977	0.344	0.082
		Experimental	0.54±0.19	0.62±0.28			
	Rectus femoris	Control	0.45±0.27	0.47±0.23	3.842	0.076	0.259
		Experimental	0.51±0.36	0.59±0.29			
	Biceps femoris	Control	0.74±0.13	0.78±0.15	1.572	0.236	0.125
		Experimental	0.62±0.30	0.75±0.31			

*Observation of significant difference

Table 4: Analysis of covariance results for muscle activity in 100-200 ms before foot initial contact

Variable		Mean±SD			F	P value	Effect size
		Group	Pre-test	Post-test			
100-200 ms after contact	Tibialis Anterior	Control	0.93±0.68	0.109±0.37	0.293	0.599	0.024
		Experimental	0.119±0.46	0.123±0.55			
	Medial gastrocnemius	Control	0.127±0.60	0.132±0.52	0.441	0.520	0.039
		Experimental	0.135±0.35	0.146±0.37			
	Lateral gastrocnemius	Control	0.122±0.63	0.105±0.53	0.087	0.087	0.242
		Experimental	0.123±0.33	0.137±0.38			
	Rectus femoris	Control	0.102±0.27	0.105±0.23	1.504	0.246	0.120
		Experimental	0.98±0.24	0.110±0.25			
	Biceps femoris	Control	0.150±0.57	0.152±0.54	0.428	0.527	0.037
		Experimental	0.138±0.81	0.150±0.83			

4. Discussion

The purpose of the present study was to investigate the effect of eight-week functional exercise on soft surfaces on the balance and electromyographic activity of the muscles of female taekwondo athletes. The results indicated the influence of functional exercises on the COP displacement and feedforward EMG activity of medial gastrocnemius muscle.

Our exercises were able to reduce the center of pressure displacement and improve balance, which is consistent with other research findings (15). Previous studies showed that neuromuscular exercises significantly improved the dynamic postural control of athletes with functional ankle instability (17), enhanced COP displacement in all directions, and might ameliorate balance (18). The increase in COP displacement reflects greater muscle strain and, consequently, less balance, and the reduction in COP displacement means improved muscle function and better balance (19). Balance exercises activate different parts of the nervous system involved in the stability of the joints and ameliorate the function of the motor and neuromuscular sensory system; accordingly, these exercises may further reduce the time required to receive sensory stimulation and motor reactions. It seems that accelerating reflexive muscle contractions reduces joint stresses during daily exercises and movements (20), and exercising on unstable surfaces is a form of neuromuscular exercise. This is in line with the current research findings, based on which COP displacement was reduced in both internal-external and anterior-posterior directions. Thus, balance exercises on unstable surfaces appear to i) increase muscle activity, ii) enhance postural, static, and dynamic postural control, iii) improve postural performance through enhancing proprioception inputs and motor awareness, iv)ameliorate athletic performance, and v) prevent sports injuries (21). Therefore, functional exercises on soft surfaces reduce displacement in both internal-external and anterior-posterior directions, thereby improving balance in taekwondo players.

The results also showed that the feed forward activity of the medial gastrocnemius muscle significantly increased after exercise. Other studies showed that exercise could influence muscle feed forward activity. For instance, the muscle activity of gluteus medius muscle decreased following neuromuscular control exercises (21). This controversy is probably attributed to the type of task and exercises provided by the researcher examining the muscle activity before and after landing; moreover, pre-landing muscle activity is due to predictive contraction and before foot initial contact, where lower extremities are activated and forces are applied during the contact. A previous EMG investigation of single-leg landing motion showed that gastrocnemius muscle activity was higher in the pre-contact phase compared with the contact phase, and it might be that the increased predictive performance of this muscle stabilized the ankle and induced preparation for landing (22). A possible reason for this finding is that training on unstable surfaces may increase the sensitivity of the muscle spindles and the activity of the lower extremity muscles; therefore, increased muscle activity prior to contact might be a factor improving the balance in Taekwondo athletes after functional exercises on soft surfaces (23). The feed forward mechanism, the neuromusculoskeletal system, activates the muscles before they enter the stimulus. In this way, it prevents disrupted balance during landing and keeps the body in a position to maintain balance when exerting large forces such as kicking. This mechanism further provides distal motions that control muscular activity through generating reactive torques, forces, and loads on the joints. Muscle spindles receive static and dynamic stimulation from gamma nerve efferent, and neuromuscular exercise may increase gamma efferent activity (24). Given the role of muscles in controlling body balance, it is recommended that functional exercises be performed to enhance and increase endurance in athletes. , in this study, there were no significant changes in the feedback activity of the selected muscles after functional exercise. It seems that muscle activation may depend on other factors such as landing level or kick severity, which can be investigated by future studies.

The current research encountered certain limitations: first, the small number of participants reduced the effect size. Moreover, there was no follow-up period to evaluate the durability of the effects of exercise. This study also lacked variables for assessing sport-specific performance; thus, the effect of this intervention on taekwondo athletic performance remains unknown. Furthermore, this study investigated the effects of training on young females; therefore, the findings may not be generalized to other ages or sexes. Finally, we did not examine the effects of the training protocol on injury rate and severity of ankle injuries.

5. Conclusions

Based on the results, functional exercises on soft surfaces reduced the center of pressure displacement and changed the EMG activity of the lower extremity muscles. These changes might reduce the likelihood of further injuries. Therefore, this exercise program is recommended for preventing lower extremity injuries in female taekwondo athletes.

Acknowledgment

This research is part of a thesis in Sport Injuries and Corrective Exercises Department of Allameh Tabataba'i University conducted by Fatemeh Fallahi Farrash..

Ethical Approval: The Research Ethics Committee of the University of Social Welfare and Rehabilitation Sciences approved all research processes and methods in terms of ethical considerations (coded IR.USWR.REC.1397.123). Also, written informed consents were obtained from all taekwondo athletes.

Conflict of interest

The authors declared no conflict of interest.

References

1. Lystad RP, Graham PL, Poulos RG. Exposure-adjusted incidence rates and severity of competition injuries in Australian amateur taekwondo athletes: a 2-year prospective study. *Br J Sports Med*. 2013;**47**(7): 441-6. doi: 10.1136/bjsports-2012-091666. [PubMed: 23242960].
2. Atay E. Prevalence of Sport Injuries among Middle School Children and Suggestions for Their Prevention. *J Phys Ther Sci*.. 2014;26(9):1455-57. doi: 10.1589/jpts.26.1455. [PubMed: 25276035]. [PubMed Central: PMC4175256].
3. Varkiani M, Alizadeh M, Kazemi M, Nazari H, Ghafoorian A. Taekwondo competition injuries in Iranian premier league: a prospective study. *International Journal of Sport Studies*. 2013;**3**(5):542-48.
4. Ziaee V, Rahmani S-H, Rostami M. Injury rates in Iranian taekwondo athletes; a prospective study. *Asian j sports med*. 2010;**1**(1):23. doi: 10.5812/asjsm.34877. [PubMed: 22375188]. [PubMed Central: PMC3289167].
5. Delahunt E, Coughlan GF, Caulfield B, Nightingale EJ, Lin CW, Hiller CE. Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Med sci sports exerc*. 2010;**42**(11):2106-21. doi: 10.1249/MSS.0b013e3181de7a8a. [PubMed: 20351590].
6. Naderi A, Baloochi R, Jabbari F, Eslami R. Comparison between the effects of core stability exercises and neuromuscular exercises on dynamic balance and lower limb function of athletes with functional ankle instability. *Scientific Journal of Kurdistan University of Medical Sciences*. 2016;**21**(4):61-72.
7. Ha SC-W, Fong DT-P, Chan K-M. Review of ankle inversion sprain simulators in the biomechanics laboratory. *Asia Pac J Sports Med Arthrosc Rehabil Technol*. 2015;**2**(4):114-21. doi:10.1016/j.asmart.2015.08.002. [PubMed: 29264250]. [PubMed Central: PMC5730649].
8. Hoch MC, Farwell KE, Gaven SL, Weinhandl JT. Weight-Bearing Dorsiflexion Range of Motion and Landing Biomechanics in Individuals With Chronic Ankle Instability. *J Athl Train*.. 2015;**50**(8):833-39. doi: 10.4085/1062-6050-50.5.07. [PubMed: 26067428]. [PubMed Central: PMCPMC4629940].
9. Terada M, Pietrosimone B, Gribble PA. Individuals with chronic ankle instability exhibit altered landing knee kinematics: potential link with the mechanism of loading for the anterior cruciate ligament. *Clin Biomech*. 2014;**29**(10):1125-30. doi: 10.1016/j.clinbiomech.2014.09.014. [PubMed: 25306177].
10. Kazemi K, Arab AM, Abdollahi I, López-López

D, Calvo-Lobo C. Electromiography comparison of distal and proximal lower limb muscle activity patterns during external perturbation in subjects with and without functional ankle instability. *Human mov sci*. 2017;**55**:211-20. doi: 10.1016/j.humov.2017.08.013. [PubMed: 28843163].
11. Roca-Dols A, Losa-Iglesias ME, Sanchez-Gomez R, Lopez-Lopez D, Becerro-de-Bengoa-Vallejo R, Calvo-Lobo C. Electromyography comparison of the effects of various footwear in the activity patterns of the peroneus longus and brevis muscles. *J Mech Behav Biomed Mater*. 2018;**82**:126-32. doi: 10.1016/j.jmbbm.2018.03.003. [PubMed: 29597146].
12. O'Driscoll J, Kerin F, Delahunt E. Effect of a 6-week dynamic neuromuscular training programme on ankle joint function: A Case report. *Sports Med Arthrosc Rehabil Ther Technol.* : SMARTT. 2011;**3**:13. doi: 10.1186/1758-2555-3-13. [PubMed: 21658224]. [PubMed Central: PMCPMC3141569].
13. Mettler A, Chinn L, Saliba SA, McKeon PO, Hertel J. Balance training and center-of-pressure location in participants with chronic ankle instability. *J Athl Train*. 2015;**50**(4):343-9. doi: 10.4085/1062-6050-49.3.94. [PubMed: 25562457]; [PubMed Central: PMCPMC4559992].
14. Malliou P, Gioftsidou A, Pafis G, Beneka A, Godolias G. Proprioceptive training (balance exercises) reduces lower extremity injuries in young soccer players. *Journal of back and musculoskeletal rehabilitation*. 2004;17(3-4):101-04. doi: 10.3233/BMR-2004-173-403.
15. Brachman A, Kamieniarz A, Michalska J, Pawłowski M, Słomka KJ, Juras G. Balance Training Programs in Athletes - a Systematic Review. *J Hum Kinet*. 2017;**58**:45-64. doi: 10.1515/hukin-2017-0088. [PubMed: 28828077]. [Pubmed Central: PMC5548154].
16. Saberian Amirkolaei AA, Balouchy R, Sheikhhoseini R. The Effect of Eight Weeks Swiss Ball Training on Teenage Badminton Players' Functional Movements Integration and Balance. *Journal of Rehabilitation Sciences & Research*. 2019;**6**:153-59. doi: 10.30476/jrsr.2019.81534.1002.
17. 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. doi: 10.1016/j.ptsp.2017.12.001. [PubMed: 29310055].
18. Park S, Ko YM, Park JW. The Correlation between Dynamic Balance Measures and Stance Sub-phase COP Displacement Time in Older Adults during Obstacle Crossing. *J Phys Ther Sci*.. 2013;**25**(9):1193-6. doi: 10.1589/jpts.25.1193. [PubMed: 24259944]. [PubMed Central: PMCPMC3818769].
19. Streich NA, Barie A, Gotterbarm T, Keil M, Schmitt H. Transphyseal reconstruction of the anterior cruciate ligament in prepubescent athletes. *Knee Surg Sports Traumatol Arthrosc*. 2010;**18**(11):1481-6. doi: 10.1007/s00167-010-1057-9.[PubMed: 20130837].
20. Goble DJ, Coxon JP, Wenderoth N, Van Impe A, Swinnen SP. Proprioceptive sensibility in the elderly: degeneration, functional consequences and plastic-adaptive processes. *Neurosci Biobehav Rev*. 2009;**33**(3):271-8. doi: 10.1016/j.neubiorev.2008.08.012. [PubMed: 18793668].
21. Zebis MK, Bencke J, Andersen LL, Dossing S, Alkjaer T, Magnusson SP, et al. The effects of neuromuscular training on knee joint motor control during sidecutting in female elite soccer and handball players. *Clin J Sport Med*. 2008;**18**(4):329-37. doi: 10.1097/JSM.0b013e31817f3e35. [PubMed: 18614884].
22. Santello M. Review of motor control mechanisms underlying impact absorption from falls. *Gait Posture*. 2005;**21**(1):85-94. doi: 10.1016/j.gaitpost.2004.01.005. [PubMed : 15536038].
23. Jafari H, Shah Hosseini GR, Ebrahimi E, Shaterzadeh MJ. Timing and Electrical Activity of Knee Related Muscles in Active and Reactive Movement Patterns in Healty Men. *Razi Journal of Medical Sciences*. 2003;**10**(35):361-70.
24. 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 Surg Sports Traumatol Arthrosc*. 2007;**15**(5):654-64. doi: 10.1007/s00167-006-0108-8. [PubMed: 16770637].