Research Article

The Evaluation of Electromyography Biofeedback on Proprioception and Balance in Healthy Young Athletes

Aliyeh Daryabor[1], Javad Naghizad[2], Aliasghar Jamehbozorgi[2*], Khosro Khademi Kalantari[3], Mehdi Rezaei[3]

1. Physiotherapy Research Center, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
2. Department of Occupational Therapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
3. Department of Physiotherapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran. Iran.

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ABSTRACT

Introduction: We evaluated the effect of electromyography biofeedback on proprioception and functional balance in healthy young athletes.

Materials and Methods: In this clinical trial, 24 athletes were randomly divided into two study (n=12) and control (n=12) groups. The study group received rehabilitation exercises, including one-foot standing, squatted standing, and isometric contraction of quadriceps muscle at different knee angles, including 30, 45, and 90 degrees of knee flexion along with electromyography biofeedback. The control group received only rehabilitation exercises without electromyography biofeedback. Exercises were performed by both groups for a 4-week period in three sessions per week. Functional balance and proprioception before and after exercises were measured using the star excursion balance test and a system consisting of digital photography non-reflective markers, respectively. The data of the center of pressure and time of vertical ground reaction force using a force plate was also collected to evaluate static balance and dynamic balance, respectively.

Results: The absolute error in knee joint reconstruction for 30° (P=0.005), 45° (P=0.001), and 90° (P=0.033) angles significantly decreased after the intervention in the study group compared to the control group. Star excursion balance test scores in all directions did not show any significant differences between the two groups (P>0.05), except for the anterior-lateral direction (P=0.03). Moreover, all variables related to static and dynamic balance did not show a significant difference between two the groups after the interventions (P>0.05).

Conclusion: The electromyography biofeedback intervention can probably be used as a rehabilitation protocol in recovering and healing proprioception injuries resulting from sports injuries.

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

1. Introduction

Balance is defined as the integration of sensory information with respect to the body's position in relation to the environment as well as the ability to provide appropriate muscle responses to maintain postural adaptation so that the body's center of gravity is maintained on the base of support. Balance is one of the indicators of functional and fundamental independence for daily activities to enable activities from maintaining static condition to complex dynamic movements. The posture control system adjusts the body position in space for the purpose of positioning and balance [1]. To initiate a movement or maintain the body's posture and balance control, different systems, such as the musculoskeletal or neuromuscular system should be coordinated. The nervous system consists of visual, vestibular, and proprioception parts, which provide information about the body's position in space [2].

Proprioception is defined as a person's ability to feel or perceive the position and movement of body parts, strength, and timing of muscle contraction. Many proprioception receptors transmit useful information through the neuromuscular pathways to control centers of the central nervous system [3, 4]. Proprioception plays an active role in optimizing exercise skills and preventing injuries [5]. The information provided by the sensors of proprioception can contribute to delicate and precise movements [6]. Proprioception also plays a prominent role in individuals' balance. Therefore, the effect of proprioception, in the absence of other balance systems, has been examined in different age groups, which depended on proprioception to maintain balance [7, 8]. It has been suggested that weakness and disturbance in proprioception can significantly increase the risk of injury in athletes [9] and others [10]. Some interventions, including exercises currently used for balance problems, could improve an individual's physical capability [11, 12]. Exercises usually consist of group exercise programs [13], home-based sports programs [14], and recently biofeedback types [15, 16].

Biofeedback is considered a technique utilized to facilitate normal movement patterns after injuries [17]. This can refer to external or completed feedback; thus it provides additional information to the user. This information is available to people online and harmonized with internal sensory feedback, which helps an individual to use different sensory receptors for obtaining information [18]. Research has suggested that using therapeutic biofeedback is feasible and effective in improving functional balance and postural control [19, 20]. Given the importance of balance as a critical factor in individuals' improvement in rehabilitation after injury, numerous techniques have been employed to improve individuals' balance. However, it is necessary to find newer and more effective techniques. Therefore, as most studies have neglected the impact of biofeedback on proprioception, which is one of the important aspects of balance control, this study attempted to consider this issue. Moreover, the impact of biofeedback has been investigated mostly in people with musculoskeletal injuries [21, 22]. We aimed to evaluate the effect of using biofeedback on proprioception and balance performance in healthy young athletes so that in the case of positive results, it can be used by the relevant experts.

2. Materials and Methods

Participants

In this clinical trial, 24 healthy athletes (men: 12, women: 8) aged 18-30 years participated. Regarding the 95% confidence level and 80% power and considering the Mean±SD of the star excursion balance test (SEBT) for the anterior-lateral direction in a previous study [23], the number of subjects was calculated as 11 per group (Equation 1):

$$1.\ n=\frac{(Z_{\alpha}+Z_{\beta})^2(\delta^2_1+\delta^2_2)}{(\mu_1-\mu_2)^2}=\frac{(1.96+1.28)^2(4.8+5.86)^2}{(88.86-85.80)^2}=11$$

Inclusion criteria were as follows: 1) regular activity in the gym and being a member of the student Sports Olympiads in sports focused on the lower limbs, such as football, volleyball, and basketball, 2) the lack of cognitive, visual, and hearing impairments (using glasses and hearing aid was permitted), 3) the lack of any systemic or neuromuscular diseases (such as diabetes and rheumatism), 4) the lack of limb length discrepancy (more than one centimeter), and 5) the absence of neurological diseases or uncontrolled seizures. Exclusion criteria were as follows: 1) undergoing surgery, 2) being absent for more than three sessions in the training, 3) existence of musculoskeletal injury during the study, and 4) using drug or alcoholism and any disorder that disturb balance (vestibular disorders, stroke, etc.). At the beginning of the study, the aim and process of the study were explained to all individuals and they filled out the informed written consent. Then, individuals were randomly divided into the two study (n=12) and control (n=12) groups. Also, the participants were blind to the assignment of groups.

Outcome measures

Outcome measures were the knee reconstruction error for 30, 45, and 90 degrees, the displacement and velocity of the center of pressure using force plate data, and functional balance using SEBT in eight different directions, including anterior, anterior-lateral, lateral, posterior-lateral, lateral, posterior-medial, medial, and posterior-medial.

Proprioception

In both groups, the knee angle reconstruction method in the standing posture was used to evaluate joint proprioception. A system consisting of skin marking and digital photography was utilized to measure the target angle and reconstruction angles. For marking, individuals wore sport short. Each person was placed on a treatment bed in a supine and relaxed position, while three passive colored and circle-shaped markers with a diameter of 2 cm were attached to the lateral part of the individuals' lower extremity as follows: The first marker was located at the upper 1/4 of the line between the large trochanter and the middle part of the lateral articular line of the knee, and the second marker was attached to the upper part of the lateral malleolus. The person was then seated on the bed edge with the flexion position of knees at about 90 °, and the third marker was attached to the upper section of the popliteal line along with the upper edge of the patella. A Samsung model ES95 camera, with a resolution of 20 megapixels, was positioned on a tripod and perpendicular to the knee joint motion plane at 185 cm from the individual and 65 cm from the ground so that the lens was fully aligned with the knee joint. Then, when the person was in the standing position (full extension of the knee joint (0°)), he/she was asked to touch his/her non-dominant leg with the ground (a ball-hit test was used to determine the dominant leg) so that the person could easily maintain his/her balance. The person was also asked to keep his/her head straight (to avoid stimulation of the vestibular system) and not to lean the trunk back. Then, while the individual's eyes were closed, he/she was asked to flex the knee joint. When the knee reached 30, 45, and 90 degrees of flexion, the patient was asked to hold his/her knee at those angles for 5 seconds while remembering those positions. After 10 seconds of rest, the person was asked to reconstruct the angle and announce it. For further measurement accuracy, the angular reconstruction test was repeated three times, and a rest time of ten seconds was considered between each repetition. By an announcement from the participant, the examiner photographed the restored status, and the data were extracted using a system consisting of digital photography, non-reflective markers, and Digitizer software, version 5.3.4. The difference between the test and reconstruction angles considered as the absolute error was recorded.

Static and dynamic balance

For the evaluation of static and dynamic balance, a force plate (Bertec Corporation, Columbus, USA) with dimensions of 60×40 cm was used to collect the data of the center of pressure and ground reaction force. For static balance, participants were assessed on the force plate in four conditions: double-leg standing with eyes open, double-leg standing with eyes closed, single-leg standing with eyes open, and single-leg standing with eyes closed. The order of these conditions was chosen randomly for each subject. To evaluate this type of balance, the displacement and velocity of the center of pressure in the anterior-posterior and medial-lateral directions were measured.

To evaluate the dynamic balance, first individuals were asked to jump the maximum distance on the ground with both feet and the examiner measured this distance. Then, half of this distance was determined, from which individuals jumped on the force plate with both feet. Thus, for the dynamic balance, the time to reach the maximum of the peak vertical ground reaction force was measured. The shorter the time to reach the maximum value, the better the balance.

Functional balance

For evaluation of the functional balance, we used the star excursion balance test (SEBT) with reliable and valid outcomes [24], in which the individual should maintain his/her balance on one leg (dominant) without disrupting the base of support while achieving maximum functional reach in eight directions with another leg (Figure 1).

Procedure

All tests were conducted by another trained examiner (someone other than the researcher). The study group received the rehabilitation exercises, including one-foot standing, squatted standing, and isometric contraction of the quadriceps muscle along with the electromyography biofeedback. The control group received only the rehabilitation exercises without electromyography biofeedback. Both groups were subjected to interventions for a 4-week period and three half-hour sessions per week. Electromyography biofeedback means measur-

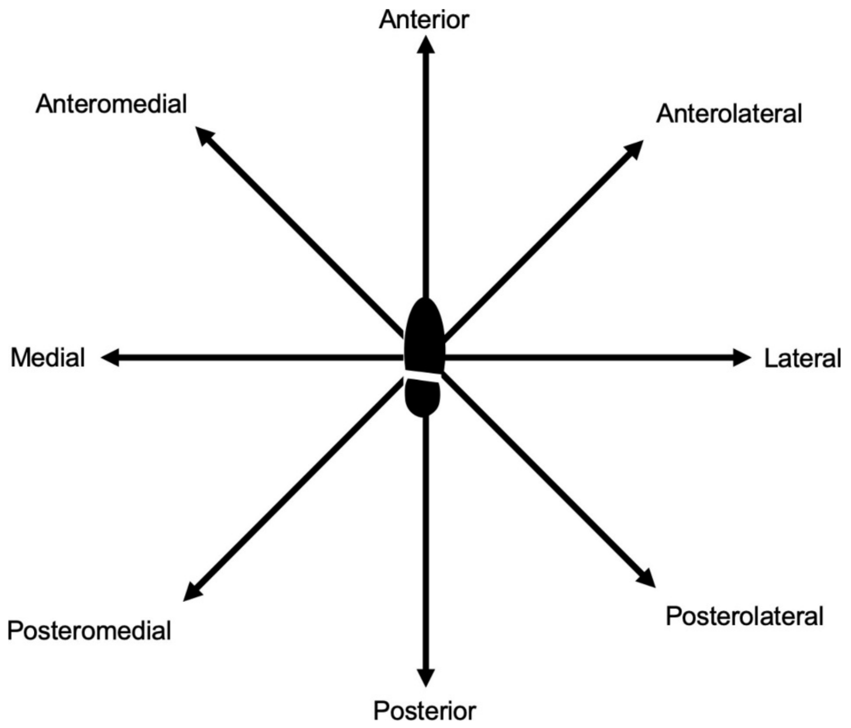

Figure 1. Star excursion balance test

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ing electrical signals associated with muscle activity and displaying these signals for individuals to control muscle activity. The signals were presented as visual feedback. In this study, a 5-channel ProComp5 biofeedback device made by Canada's ThoughtTechnology Company, model SA7525 with serial number CB1825, as well as BioGraph Infiniti Software and EMG MyoScan-Pro™ sensors -T9401M-60 were utilized. The electrodes used were the silver chloride T3402M-Triode electrode with a standard distance of 20 mm. To reduce the impedance, individuals' skin was cleaned with cotton and medical alcohol after thorough shaving of hair. The electrode was obliquely mounted on the vastus medialis obliques (VMO) muscles at a 20 mm distance from each other, at an angle of 55 degrees above the muscle bulk and 4 cm above the patella edge with a distance of 3 cm from the inner part of the upper patella edge. The reference electrode was also placed on the tibia prominence. At first, the maximum isometric contraction was recorded in the knee extension position in a way that the individual performed the contraction four times, each lasting four seconds, and then ten seconds of rest. In the end, the mean of the contraction was calculated by the software. During the intervention, 20% of the mean of these contractions was deducted to prevent muscle fatigue, which was considered as the threshold point. Individuals received feedback only when the immediate contraction of muscle was more than the threshold value. The exercises were performed in three positions, including squat (Figure 2 A), one-leg extension (Figure 2 B), and knee extension (Figure 2 C) each for 10 minutes.

Statistical analysis

The data were analyzed using SPSS software, version 22. In this study, the independent t-test was used for the data with normal distribution and the Mann-Whitney U test for their non-normal data to compare the absolute error of angle reconstruction and balance function between the study and control groups. $P<0.05$ was considered significant.

3. Results

During the study period, all 24 participants were evaluated and followed up with regular and continuous attendance at intervention sessions. Demographic data of the individuals, including age, sex, height, and weight are shown in Table 1. All outcomes are presented as the average of three repetitions for each condition. Data distribution was not normal for some variables, including absolute error at 30, 45, and 90 degrees; therefore, the Mann-Whitney U test was utilized to compare the two groups. There was no statistically significant difference between the two groups in terms of demographic data. Moreover, no significant difference was observed between the two groups before the interventions for knee reconstruction error and SEBT scores (Table 2).

Table 1. Mean±SD of individuals' demographic characteristics

Group (n=12)	Mean±SD			
	Age (y)	Height (cm)	Weight (kg)	BMI (kg/m²)
Study	22.91±2.57	173.75±8.67	65.83±4.54	21.74±2.41
Control	20.91±1.88	173.58±5.63	66.50±6.03	22.02±0.92

BMI: Body mass index.

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Table 2. Mean±SD, and P for knee reconstruction error

Variables (Angle)	Mean±SD				P Between Two Groups	
	Study (n=12)		Control (n=12)			
	Before Intervention	After Intervention	Before Intervention	After Intervention	Before Intervention	After Intervention
30 degrees[a]	10.79±6.61	2.36±0.93	4.95±2.18	6.78±4.79	0.170	0.005*
45 degrees[a]	11.87±8.17	2.17±0.91	8.13±5.94	6.01±3.52	0.213	0.001*
90 degrees[a]	7.68±2.89	2.29±0.82	11.40±6.76	5.08±3.88	0.143	0.033*

*P<0.05, [a]Non-parametric data analyzed by Mann-Whitney U test.

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Table 2 shows that the absolute error rate in knee joint reconstruction at 30° (P=0.005), 45° (P=0.001), and 90° (P=0.033) angles significantly decreased after the interventions in the study group compared to the control group. Table 3 shows that SEBT scores in all directions did not show any significant differences between the two groups after the interventions (P>0.05), except for the anterior-lateral direction (P=0.03), in which there was a significant increase in the study group compared to the control group. Finally, Table 4 indicates that all variables of static balance, including the center of pressure displacement and velocity in four different conditions of the test as well as the variable of dynamic balance did not

Table 3. Mean±SD and P for balance performance

Variables	Mean±SD				P Between Two Groups	
	Study Group (n=12)		Control Group (n=12)			
	Before Intervention	After Intervention	Before Intervention	After Intervention	Before Intervention	After Intervention
Anterior (cm)	101.33±4.96	111.19±6.43	110.67±7.29	107.78±5.99	0.478	0.713
Anterior-lateral (cm)	103.58±6.43	113.72±7.31	93.90±6.96	92.55±6.62	0.198	0.033*
Lateral (cm)	99.35±6.16	110.87±7.24	103.52±6.30	98.11±5.29	0.347	0.319
Posterior-lateral (cm)	93.56±4.29	104.33±5.42	102.56±7.15	96.89±4.98	0.242	0551
Posterior (cm)	93.35±3.84	96.56±4.75	102.28±7.97	97.52±6.00	0.478	0.977
Posterior-medial (cm)	89.61±4.35	91.91±4.07	104.35±9.84	98.34±7.07	0551	0.478
Medial (cm)	76.00±3.93	81.50±4.93	95.15±11.13	94.36±8.86	0.347	0.443
Posterior-medial (cm)	63.66±4.02	66.23±5.50	88.52±13.57	85.10±11.78	0.378	0.219

*P<0.05

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Table 4. Mean±SD, and P for static and dynamic balance, before and after intervention

Balance	Test Conditions	Variables	Mean±SD				P Between Two Groups	
			Study (n=12)		Control (n=12)			
			Before	After	Before	After	Before	After
Static balance	Double-leg standing with eyes open	Anterior/posterior displacement of CoP (cm)	6.24±2.25	5.86±2.14	5.20±1.25	5.54±1.68	0.221	0.690
		Medial/lateral displacement of CoP (cm)[a]	3.27±1.2	4.61±3.54	3.34±1.59	3.27±1.27	0.843	0.410
		Anterior/posterior velocity of CoP (m/s)	30.67±12.42	29.79±1.30	41.71±16.25	36.27±17.71	0.76	0.348
		Medial/lateral velocity of CoP (m/s)	13.87±6.78	14.27±5.02	14.17±1.43	11.47±3.47	0.977	0.128
	Double-leg standing with eyes closed	Anterior/posterior displacement of CoP(cm)	6.57±2.53	6.69±1.92	55.44±1.66	5.80±2.34	0.319	0.324
		Medial/lateral displacement of CoP(cm)[a]	3.61±1.49	4.28±1.57	4.07±2.09	3.72±1.87	0.478	0.242
		Anterior/posterior velocity of CoP (m/s)	30.85±10.77	13.92±6.87	33.81±19.26	32.71±1.87	0.843	0.837
		Medial/lateral velocity of CoP (m/s)a	33.80±10.90	14.12±7.84	13.30±5.39	14.90±4.84	1.000	0.410
	Single-leg standing with eyes open	Anterior/posterior displacement of CoP(cm)	8.63±1.69	8.23±1.90	8.2±1.59	8.03±1.41	0.373	0.777
		Medial/lateral displacement of CoP(cm)	8.97±1.71	8.10±1.71	8.63±1.65	8.62±2.09	0.635	0.381
		Anterior/posterior velocity of CoP (m/s)[a]	38.63±8.37	38.28±12.18	45.95±10.96	36.49±8.69	0.079	0.932
		Medial/lateral velocity of CoP (m/s s)	74.08±21.67	70.72±20.34	72.54±20.10	69.16±24.76	0.859	0.868
	Single-leg standing with eyes closed	Anterior/posterior displacement of CoP(cm)[a]	14.45±6.33	15.56±5.82	17.96±9.94	16.83±11.83	0.590	0.799
		Medial/lateral displacement of CoP (cm)[a]	20.45±16.47	13.22±3.37	20.37±16.98	13.68±6.72	0.977	0.713
		Anterior/posterior velocity of CoP (m/s)[a]	99.92±81.46	103.15±97.58	139.75±129.60	112.96±92.71	0.347	0.977
		Medial/lateral velocity of CoP (m/s)	101.00±25.58	104.10±26.65	109.23±35.62	99.36±31.95	0.523	0.697
Dynamic balance	Jumping	Time of vertical ground reaction force (s)	1.75±0.48	1.59±0.53	1.81±0.79	1.61±0.61	0.819	0.939

[a]Non-parametric data analyzed by Mann-Whitney test, Cop: Center of pressure.

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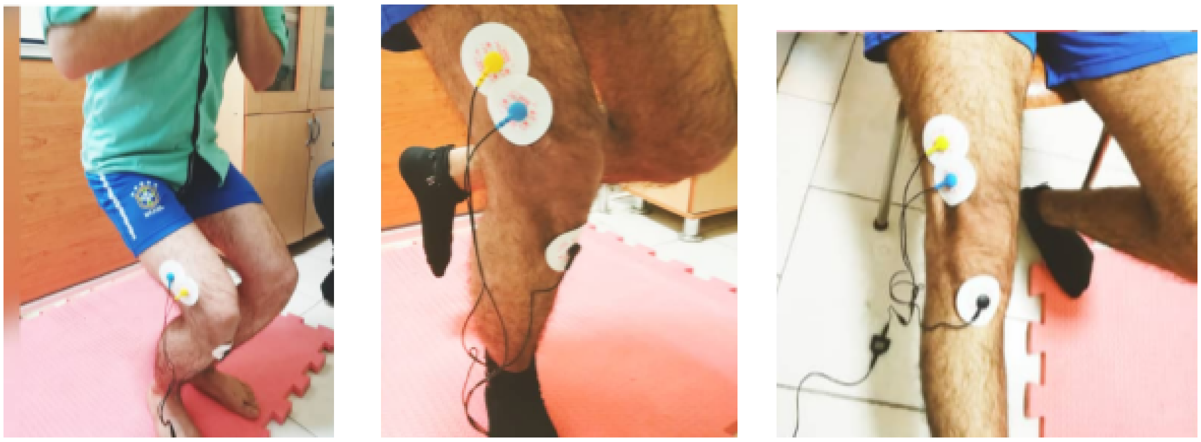

Figure 2. Performing balance exercises including A) Squats, B) One-leg extension, C) knee extension JMR

show any significant differences between the two groups after the interventions (P>0.05).

4. Discussion

In the present study, we investigated the effect of electromyography biofeedback on the accuracy of proprioception and functional balance in healthy athletes. Regarding proprioception, this study showed that the absolute error rate in knee joint reconstruction after the intervention decreased at 30, 45, and 90° angles in the group with the visual feedback compared to the control group without the visual feedback. Thus, the present study confirmed that visual feedback could increase proprioception. Visual feedback helps to learn precise movements by correcting observed errors during exercise. This is in agreement with previous studies that applying visual feedback training could improve proprioception in patients after stroke [21] and total knee arthroplasty [22]. Therefore, these results point to balance improvement through visual information obtained through visual feedback and can be used as a sensory replacement to compensate for the affected proprioception. In other studies by In et al. [25] and Pellegrino et al. [26], it has been suggested that if postural training is accompanied by visual feedback, it can improve a person's ability to maintain a relaxed standing balance on unstable surfaces. However, positive results can be found during training to justify that the integration of technology-based protocols with the current approach of rehabilitation education may result in improved performance. In the present study, we focused on the biofeedback modality in healthy young athletes associated with the improvement of proprioception in these populations. Therefore, as the risk of injuries is high in athletes using their lower limbs, increasing proprioception in sports activities may reduce the risk of injuries, such as ankle sprain [27].

Concerning the functional balance, there was no significant difference between the two groups in all directions of SEBT, except for the anterior-lateral direction. Moreover, no significant difference was found on all force plate data as a static and dynamic balance between the two groups. The present study showed the use of sensory feedback, such as visual sense and its integration with muscle activity can increase proprioception, which is also directly related to balance. Considering that the proprioception exercises of the intervention group were performed at 30, 45, and 90 angles and due to the effect of biofeedback on the motor learning pattern [28, 29], it can be justified that the improvement of proprioception could occur following the training. It seems that because the exercises performed were not specifically balance exercises, it could not create a significant difference in the balance outcomes between the two groups. Dadfar's study also indicated that six weeks of corrective-plyometric exercises without visual feedback could effectively improve dynamic balance in adolescent athletes with dynamic knee valgus [30]. We assume that more treatment sessions using biofeedback while exercising may detect enough change between interventions, as strengthening the muscles around the knee plays an effective role in improving balance [31]. However, this possibility should be studied further.

5. Conclusion

Based on the findings, no changes were found in most results of the balance function of SEBT scores between the two groups, which could be due to appropriate postural control in healthy neuromuscular and musculoskeletal structures of the participants. The findings showed that absolute error in knee reconstruction significantly decreased after the intervention in the study group compared to the control group, which can result from the enhanced sensory information with electromyography biofeedback; thereby increasing the accuracy of proprioception was increased.

One of the limitations of this study was short-term follow-up. Studying individuals with balance disorders, examining the muscle strength of the participants, and recording the electrical activity of the vastus medialis muscle are recommended.

Ethical Considerations

Compliance with ethical guidelines

This research was approved by the Research and Ethics Committee of Shahid Beheshti University of Medical Sciences (Code: IR.SBMU.RETECH.REC.1397.206306).

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Authors' contributions

Conceptualization: Aliasghar Jamehbozorgi; Methodology: Javad Naghizad, Aliyeh Daryabor; Writing the original draft: Khosro Khademi Kalantari; Writing, review, and editing: Aliyeh Daryabor and Mehdi Rezaei.

Conflict of interest

The authors declared no conflict of interest.

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