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Comparison of gluteus medius and hamstring activation during seven plyometric exercises on three training surfaces

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Abstract

Introduction. Plyometric exercise is known as one of the key components of neuromuscular training programs. It is also possible to obtain higher muscular activity by exercising on tatami and mats. The purpose of the study was to evaluate the activity of hamstring and gluteus medius in 7 typical plyometric exercises on 3 different surfaces and identify the best exercises and surfaces that would further increase hamstring and gluteus medius activity.
Methods. The study involved 20 male athletes. The participants performed 7 plyometric exercises on 3 surfaces: ground, tatami, and mat. The electromyographic activity of muscles was recorded with a ME6000 device in 2 phases: feedforward and feedback. To analyse the data, 2-way ANOVA with repeated measures and a Bonferroni post-hoc test were used.
Results. Gluteus medius was most active in the feedforward phase in single-leg frontal plane hop (SLFPH), and in the feedback phase in SLFPH and single-leg sagittal plane hop (SLSPH) ($p = 0.001$). The medial hamstring and lateral hamstring showed the highest values of activity in the feedforward phase in SLSPH, SLFPH, and double-leg sagittal plane hop (DLSPH) ($p = 0.001$). There was no significant difference between the surfaces ($p > 0.05$).
Conclusions. SLSPH, DLSPH, and SLFPH improve the recruitment and the strength of gluteus medius and hamstrings and should be given considerable attention in training programs. Exercise on the ground, tatami, and mattress is allowed and in terms of the purpose of the research, there is no difference between them.
Key words: knee, muscle activity, hamstring, electromyography

Introduction

The relationship between neuromuscular deficits and the risk of sport injuries has led to the design of neuromuscular training programs to prevent these injuries [1, 2]. Studies investigating the effect of neuromuscular exercises on injury prevention have been focused on a combination of exercises [3, 4], which include plyometric, balance, stability, and agility exercises. Some research has identified plyometrics as one of the key components of sports injury prevention training [5, 6].

Plyometric exercises improve feedforward and feedback activity by applying rapid forces to athletes while adapting to muscular and articular receptors [7, 8]. These exercises are involved in muscle activation through muscle adaptation to tensile and elastic reflexes, as well as Golgi tendon organs [9]. According to studies, plyometrics has the potential to reduce maximum ground reaction force, knee valgus position, and hip joint adhesion during landing, which is crucial to neuromuscular improvement [10, 11].

While the effects of this exercise method are almost clear, information on the best plyometric exercises is limited [6]. Studies investigating plyometrics to improve neuromuscular function to prevent injury have used a combination of plyometric exercises [3, 9, 12], which prevents the detection of the effect of each plyometric exercise on reducing the occurrence of neuromuscular improvement.

Therefore, the evaluation of electromyographic activity during plyometric exercises with the aim to identify those providing higher muscle activity to neuromuscular improvement can help to determine the best plyometric exercises. However, previous studies of plyometric training have been largely limited to investigating the amount of knee muscle activity in jump-landing movements by changing heights [13] or to examining gender differences [14], and very few studies have assessed the activity of the muscles around the thighs and knees in more than 2 movements [15]; so, very few exercises have been analysed so far. Therefore, the first aim of this study was to evaluate the activity of hamstring muscles (medial hamstring, lateral hamstring) and gluteus medius of male collage athletes in 7 plyometric exercises in order to identify the best exercises that would further increase hamstring and gluteus medius activity.

Today, many clinical centres use soft surfaces to rehabilitate athletes. Jumping and landing in sports may also occur on soft and unstable surfaces (such as landing in gymnastics). It has previously been suggested that muscle activity on unstable surfaces increases electromyographic activity in limb and trunk muscles compared with stable surfaces [16], but there are still contradictions in this case [17–21]. Thus, we expected that the muscle activity on different surfaces would change, and higher muscular activity could be obtained by practising on tatami surfaces and wrestling mats. Consequently, the second aim of this study was to investigate the activity of hamstring and gluteus medius muscles on the ground, tatami, and wrestling mats to identify the surface that would provide higher muscular activity.

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Subjects and methods

Participants

A total of 20 male collegiate athletes with a mean height of 182 ± 5.6 cm, a mean weight of 68.9 ± 4.4 kg, and a mean age of 23.1 ± 1.5 years voluntarily participated in the present study of applied and semi-experimental type, conducted in the Physical Education Laboratory of Tehran University. The inclusion criteria were as follows: at least 3 years of experience in one of the volleyball, handball, or basketball teams of Faculty of Physical Education, University of Tehran, having at least 3 practice sessions per week and exercising for at least half an hour in each session, and age of 18–26 years. The exclusion criteria involved dissatisfaction and unwillingness of the subject to continue the research process, chronic pain or injury during the research, and history of anterior cruciate ligament (ACL) injury. The individuals were asked to restrain themselves from performing any sporting activities within 48 hours prior to the testing.

Procedures

Before the study began, the subjects underwent a warm-up and performed stretch movements for 10 minutes. The plyometric exercises used in this study were the most common ones applied in previous research and injury prevention programs [9, 10, 22]. After receiving a complete explanation of particular movements (Table 1), the person performed each movement twice to ensure that it was accomplished correctly. Then, the participants performed each movement 3 times on each surface (e.g., jumping 3 times on the ground, 3 times on the tatami, and 3 times on the mattress); the average electromyographic activity was considered for calculations. The order of the movements was random for each subject (so fatigue did not have a continuous effect on the movement) and after each exercise, the individuals rested for 1 minute.

Skin preparation for electrode placement included removing excess hair and cleaning the area with alcohol to provide a suitable surface for attaching the electrodes and reducing skin resistance. To determine the location of the electrodes, bone landmarks and isometric contraction were used. The electrodes were placed on the muscles in accordance with the surface electromyography for the non-invasive assessment of muscles (SENIAM) recommendations [23], and the reference electrode was then fixed to the patella. The electrodes were tightened with glue to reduce motion artifacts. When the maximum voluntary isometric contraction (MVIC) of the hamstring muscles was assessed, the person was lying on his back and applying his maximum force against the resistance at a 45° flexion angle. The MVIC of the gluteus medius was taken at an angle of 10° to the thigh abduction of the dominant leg (the foot used to hit the ball). Each MVIC situation was repeated 3 times with a 1-minute interval and was held for 3 seconds; the mean values were used for further calculations.

Instrumentation

In this research, a wrestling mattress, model ROO-Y1 with a density of 100 kg/m^3 (Roozbeh Company, Iran) and a tatami with a thickness of 25 mm (Foamiran Company, Iran) were used.

To investigate the electrical activity of the muscles, a 16-channel surface electromyographic device, model ME6000 (Mega Company, New Zealand) and circular silver/silver chloride surface electrodes (Skintact) with a diameter of 2 cm (made in Australia) were applied (input impedance: 1012 Ω, common mode rejection ratio: 120 dB in 60 Hz, gain range: 1000). The reliability (mean intraclass correlation coefficient: 0.91, range: 0.75–0.98; mean percentage standard error of measurement: 4%, range: 1–12%) and validity of surface electromyography during maximum and sub-maximum voluntary isometric contractions is approved [24, 25].

Data extraction

To determine the ground contact time, a foot switch, model DSL (Danesh Salar Iranian Company) connected to one of the electromyographic channels was used. All electromyographic data were collected from the dominant leg of the individuals, with a sampling frequency of 1000 Hz. The data were averaged with the root mean square and analysed in 15-ms windows.

The electromyographic activity of each muscle was calculated in 2 phases (feedforward and feedback) with the use of the Megawin software in each plyometric exercise. The feedforward phase in a time range of 200 ms (from 160 ms

Table 1. Explanation of the plyometric exercises

Practice	Explanation
Single-leg sagittal plane hop	The athlete jumps forward on the dominant leg in the sagittal plane with maximum power and lands on the dominant leg
Double-leg sagittal plane hop	While standing on both feet, the athlete jumps forward with maximum power in the sagittal plane and lands on both feet
Single-leg frontal plane hop	The athlete stands on the dominant foot, jumps toward the non-dominant foot in the frontal plane with maximum power, and lands on the same dominant foot; e.g., if the dominant foot is right, the subject jumps to the left
Double-leg frontal plane hop	While standing on both feet, the athlete jumps in the frontal plane with maximum power and lands on both feet
Tuck jump	With feet hip-distance apart, the athlete jumps upwards and raises the knees as high as possible at the highest point of the jump. At the highest jump point, the athlete's thighs are placed parallel to the ground
Squat jump	While the subject is standing on both feet and the feet are hip-distance apart, the athlete bends the knee to 90° and performs the maximum jump
180° jump	With feet hip-distance apart, the athlete jumps upwards, making a 180° rotation in the transverse plane

before the foot struck the ground to 40 ms after the collision) and the feedback phase in a time frame of 100 ms (from 40 ms after the collision to 140 ms after the collision) were considered. To compare the subjects, the electromyographic values obtained from the calculation of root mean squares were divided by the values obtained from the MVIC of each muscle and the amount of muscle activity was reflected as a percentage of MVIC.

Statistical analysis

In order to evaluate the normality of the variable distribution from the Shapiro-Wilk statistic and compare muscle activity in exercises and on soft and hard surfaces, 2-way repeated measures ANOVA was used with a Bonferroni post-hoc test.

The effect sizes were classified by calculating partial eta-squared. The effect size is a measure of the effectiveness of a treatment and it helps to determine whether a statistically significant difference is a difference of practical concern. Effect sizes can be classified as small ($0.00 \leq f \leq 0.24$), medium ($0.25 \leq f \leq 0.39$), and large ($f \geq 0.40$) [26].

Wilks' lambda is a measure to assess whether the means of 2 or more continuous variables differ across 2 or more groups. Lambda may range in value from 0.0 to 1.0. Zero implies that there is nothing to be gained by using the independent variable to predict the dependent variable and a lambda of 1.0 indicates that the independent variable is a perfect predictor of the dependent variable. All analyses were performed by using the SPSS software, version 20 (SPSS Inc., Chicago, IL, USA). The significance level was 95% in the test and the alpha level was less than or equal to 0.05.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Committee of the Faculty of Physical Education, University of Tehran (approval No.: IR.TU.REC.1393.1147).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The average amount of muscle electromyographic activity in terms of MVIC is presented in Table 2. The results of 2-way repeated measures obtained in the study of the effect of plyometric exercises and surfaces are provided in Table 3. Tables 4 and 5 demonstrate the results of the

Table 2. Muscle electromyographic activity in terms of maximum voluntary isometric contraction

Practice	Surface	Gluteus medius		Lateral hamstring		Medial hamstring	
		Feedforward	Feedback	Feedforward	Feedback	Feedforward	Feedback
SLSPH	Ground	45.55 (10.99)	91.80 (32.35)	35.59 (15.65)	30.41 (16.35)	65.34 (47.80)	58.48 (33.87)
	Tatami	46.50 (12.72)	87.65 (33.35)	37.90 (15.77)	33.90 (26.62)	67.80 (47.49)	60.00 (44.55)
	Mat	43.00 (13.87)	93.50 (28.49)	34.30 (18.95)	27.35 (19.88)	62.40 (26.56)	58.60 (29.11)
DLSPH	Ground	30.61 (9.1)	58.37 (22.48)	26.15 (17.12)	27.68 (11.94)	55.13 (38.66)	52.13 (34.50)
	Tatami	32.0 (9.70)	59.10 (22.92)	25.40 (6.53)	26.25 (6.71)	58.60 (35.01)	51.50 (40.48)
	Mat	28.35 (10.50)	62.65 (22.48)	27.75 (12.27)	26.80 (8.14)	53.05 (26.94)	48.00 (25.69)
SLFPH	Ground	58.38 (22.48)	92.55 (31.61)	25.47 (11.25)	27.48 (16.04)	54.66 (24.60)	54.87 (75.88)
	Tatami	60.65 (27.54)	89.25 (25.27)	24.65 (6.04)	25.40 (6.53)	50.85 (53.22)	51.45 (55.79)
	Mat	62.05 (28.93)	87.05 (33.78)	26.05 (10.39)	24.65 (9.02)	57.45 (67.78)	56.35 (68.05)
DLFPH	Ground	37.44 (14.25)	60.52 (31.39)	15.81 (7.54)	18.56 (7.87)	29.98 (18.63)	44.40 (27.88)
	Tatami	38.15 (16.43)	61.95 (32.98)	16.15 (9.44)	17.60 (7.92)	30.50 (25.81)	46.25 (24.79)
	Mat	38.35 (24.00)	58.45 (33.62)	15.85 (9.84)	16.60 (5.72)	27.30 (20.41)	43.85 (20.20)
Tuck jump	Ground	32.25 (14.29)	50.13 (29.94)	13.00 (8.89)	18.37 (10.63)	25.18 (13.39)	39.11 (28.27)
	Tatami	34.95 (18.71)	49.75 (34.54)	15.45 (13.65)	19.20 (11.81)	26.75 (8.24)	41.45 (15.20)
	Mat	36.25 (15.18)	51.20 (33.06)	15.05 (10.93)	19.50 (9.20)	24.90 (6.93)	37.90 (15.77)
Squat jump	Ground	17.64 (7.70)	44.48 (26.55)	10.09 (8.45)	17.42 (10.24)	18.42 (12.15)	29.65 (23.34)
	Tatami	19.40 (10.31)	46.25 (24.79)	11.90 (10.06)	17.60 (7.92)	19.70 (9.31)	28.35 (17.07)
	Mat	16.25 (8.28)	42.80 (19.46)	9.75 (6.93)	18.40 (6.69)	17.60 (7.92)	31.85 (26.37)
180° jump	Ground	24.12 (9.91)	54.08 (35.35)	11.19 (7.96)	20.39 (16.38)	25.81 (17.75)	37.41 (25.77)
	Tatami	24.55 (7.10)	52.95 (20.95)	11.90 (8.35)	21.30 (14.65)	23.30 (7.23)	38.85 (13.21)
	Mat	23.25 (8.87)	54.90 (23.23)	13.30 (6.98)	21.45 (12.24)	24.55 (7.10)	36.15 (15.60)

Data presented as mean (standard deviation).
SLSPH – single-leg sagittal plane hop, DLSPH – double-leg sagittal plane hop,
SLFPH – single-leg frontal plane hop, DLFPH – double-leg frontal plane hop

Table 3. ANOVA results in examining the effect of exercise and surface on muscle activity

Muscle	Phase	Variable	Wilks' lambda	Df	*F*	Sig.	Partial eta squared
Gluteus medius	Feedforward	Plyometric exercises	0.047	6	47.24	0.001	0.953
		Surfaces	0.912	2	0.871	0.436	0.088
	Feedback	Plyometric exercises	0.070	6	30.91	0.001	0.930
		Surfaces	0.986	2	0.124	0.884	0.014
Lateral hamstring	Feedforward	Plyometric exercises	0.070	6	30.80	0.001	0.930
		Surfaces	0.969	2	0.284	0.756	0.031
	Feedback	Plyometric exercises	0.228	6	7.91	0.001	0.772
		Surfaces	0.919	2	0.793	0.468	0.081
Medial hamstring	Feedforward	Plyometric exercises	0.190	6	9.925	0.001	0.810
		Surfaces	0.968	2	0.295	0.748	0.032
	Feedback	Plyometric exercises	0.360	6	4.153	0.013	0.640
		Surfaces	0.993	2	0.060	0.942	0.007

Table 4. Results of Bonferroni post-hoc test for muscle feedforward activity

		SLSPH	DLSPH	SLFPH	DLFPH	TJ	SJ	180°
SLSPH	Gmed		0.010	0.832	1.00	0.060	0.001	0.001
	LH		0.221	0.223	0.001	0.001	0.001	0.001
	MH		0.599	1.00	0.026	0.005	0.001	0.009
DLSPH	Gmed	0.010		0.001	1.00	1.00	0.001	0.684
	LH	0.221		1.00	0.047	0.001	0.001	0.001
	MH	0.599		1.00	0.026	0.004	0.001	0.006
SLFPH	Gmed	0.832	0.001		0.026	0.005	0.001	0.001
	LH	0.223	1.00		0.027	0.010	0.001	0.001
	MH	1.00	1.00		0.043	0.010	0.001	0.021
DLFPH	Gmed	1.00	1.00	0.026		1.00	0.001	0.002
	LH	0.001	0.047	0.027		1.00	0.058	0.016
	MH	0.026	0.026	0.043		1.00	0.087	1.00
TJ	Gmed	0.060	1.00	0.005	1.00		0.001	1.00
	LH	0.001	0.001	0.010	1.00		1.00	1.00
	MH	0.005	0.004	0.010	1.00		0.388	1.00
SJ	Gmed	0.001	0.001	0.001	0.001	0.001		0.439
	LH	0.001	0.001	0.001	0.058	1.00		1.00
	MH	0.001	0.001	0.001	0.087	0.388		0.869
180°	Gmed	0.001	0.684	0.001	0.002	1.00	0.439	
	LH	0.001	0.001	0.001	0.016	1.00	1.00	
	MH	0.009	0.006	0.021	1.00	1.00	0.869	

SLSPH – single-leg sagittal plane hop, DLSPH – double-leg sagittal plane hop, SLFPH – single-leg frontal plane hop, DLFPH – double-leg frontal plane hop, TJ – tuck jump, SJ – squat jump, 180° – 180° jump, Gmed – gluteus medius, LH – lateral hamstring, MH – medial hamstring

Table 5. Results of Bonferroni post-hoc test for muscle feedback activity

		SLSPH	DLSPH	SLFPH	DLFPH	TJ	SJ	180°
SLSPH	Gmed		0.009	1.00	0.025	0.001	0.001	0.004
	LH		1.00	1.00	0.053	0.051	0.016	0.494
	MH		1.00	1.00	0.427	0.131	0.001	0.313
DLSPH	Gmed	0.009		0.012	1.00	1.00	1.00	1.00
	LH	1.00		1.00	0.110	0.055	0.025	0.831
	MH	1.00		1.00	1.00	1.00	0.156	1.00
SLFPH	Gmed	1.00	0.012		0.001	0.001	0.001	0.001
	LH	1.00	1.00		0.405	0.259	0.194	1.00
	MH	1.00	1.00		1.00	1.00	1.00	1.00
DLFPH	Gmed	0.025	1.00	0.001		1.00	0.021	1.00
	LH	0.053	0.110	0.405		1.00	1.00	1.00
	MH	0.427	1.00	1.00		0.875	0.087	1.00
TJ	Gmed	0.001	1.00	0.001	1.00		1.00	1.00
	LH	0.051	0.055	0.259	1.00		1.00	1.00
	MH	0.131	1.00	1.00	0.875		0.056	1.00
SJ	Gmed	0.001	1.00	0.001	0.021	1.00		1.00
	LH	0.016	0.025	0.194	1.00	1.00		1.00
	MH	0.001	0.156	1.00	0.087	0.056		1.00
180°	Gmed	0.004	1.00	0.001	1.00	1.00	1.00	
	LH	0.494	0.831	1.00	1.00	1.00	1.00	
	MH	0.313	1.00	1.00	1.00	1.00	1.00	

SLSPH – single-leg sagittal plane hop, DLSPH – double-leg sagittal plane hop, SLFPH – single-leg frontal plane hop, DLFPH – double-leg frontal plane hop, TJ – tuck jump, SJ – squat jump, 180° – 180° jump, Gmed – gluteus medius, LH – lateral hamstring, MH – medial hamstring

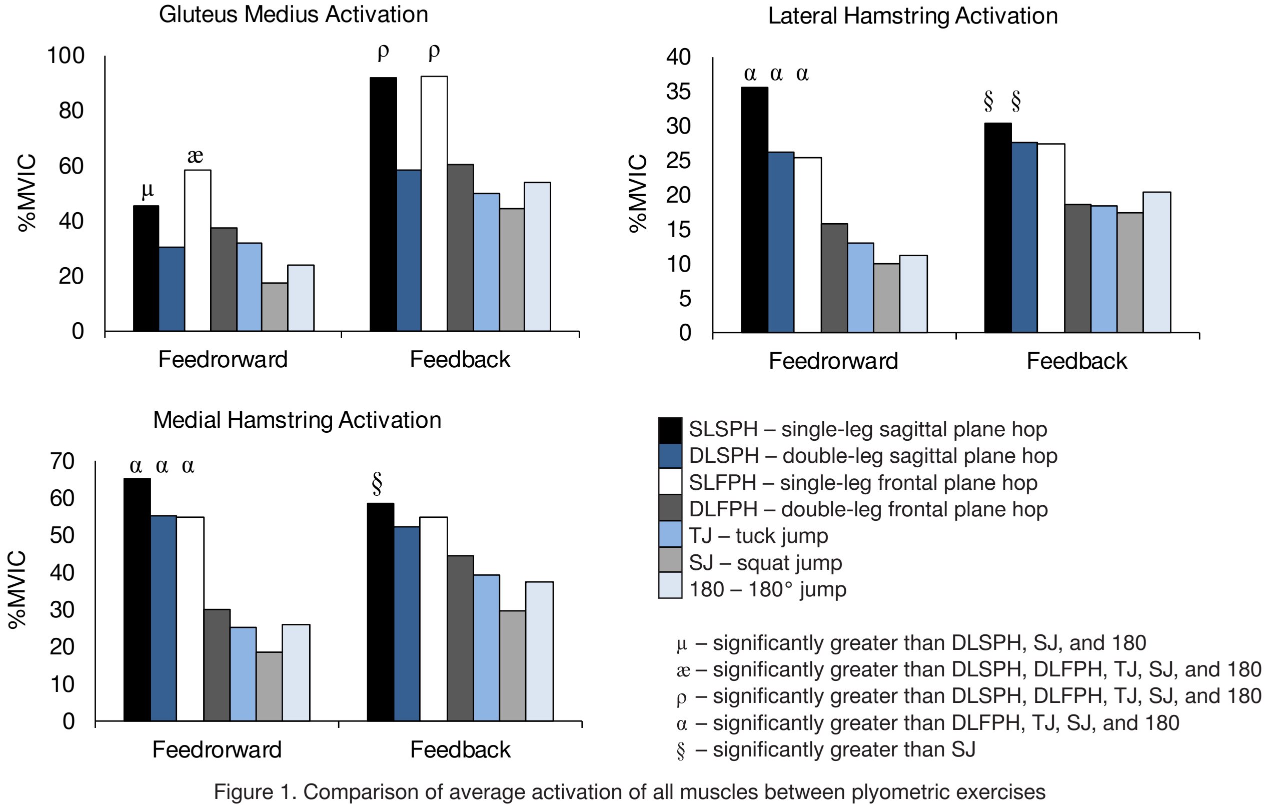

Figure 1. Comparison of average activation of all muscles between plyometric exercises

Bonferroni post-hoc test to compare feedforward and feedback activities of muscles in the exercises.

Surfaces

The results of 2-way repeated measures ANOVA showed that the change in surfaces caused no significant difference ($p < 0.05$) in the feedforward or feedback activity of any of the muscles (Table 3).

Gluteus medius

The results of 2-way repeated measures ANOVA implied that there were significant differences in gluteus medius feedforward activity ($p = 0.001$, $F = 47.24$) and feedback activity ($p = 0.001$, $F = 30.91$) in the 7 plyometric exercises (Table 3). The Bonferroni post-hoc test showed that gluteus medius feedforward activity in single-leg frontal plane hop (SLFPH) was significantly higher than in other exercises ($p < 0.05$) except single-leg sagittal plane hop (SLSPH) (Table 4, Figure 1). In the feedback phase, gluteus medius activity in SLFPH and SLSPH was significantly higher ($p < 0.05$) than in other exercises (Table 5, Figure 1).

Lateral hamstring

There was a significant difference ($p < 0.05$) in the plyometric exercises in both the feedforward ($p = 0.001$, $F = 30.80$) and feedback ($p = 0.001$, $p = 7.91$) phase (Table 3). Subsequent results revealed that the feedforward activity of lateral hamstring in SLSPH, double-leg sagittal plane hop (DLSPH), and SLFPH was significantly higher ($p < 0.05$) than in other plyometric exercises (Table 4, Figure 1). In the feedback phase, the activity in SLSPH and DLSPH was significantly higher ($p < 0.05$) than in squat jump (Table 5, Figure 1).

Medial hamstring

In the study of this muscle, the results of 2-way repeated measures ANOVA indicated a significant difference ($p < 0.05$) in feedforward ($p = 0.001$, $F = 9.925$) and feedback ($p = 0.013$, $F = 4.153$) in the 7 plyometric exercises (Table 3). The Bonferroni post-hoc test showed that the medial hamstring feedforward activity in SLSPH, DLSPH, and SLFPH was significantly higher ($p < 0.05$) than in other exercises (Table 4, Figure 1). In the feedback phase, the activity of the medial hamstring in SLSPH was significantly higher ($p < 0.05$) than in squat jump (Table 5, Figure 1).

Discussion

The preliminary results of the present study showed that gluteus medius was the most active in the feedforward phase in SLFPH and in the feedback phase in SLSPH and SLFPH. Lateral hamstring and medial hamstring feedforward activities were significantly higher in SLSPH, DLSPH, and SLFPH than in other exercises. Also, the activity of these muscles on the 3 surfaces (the ground, the tatami, and the wrestling mat) was almost the same.

Struminger et al. [15] investigated the electromyographic activity of gluteus medius, medial hamstring, and lateral hamstring in single-leg frontal plane hurdle hop, 180° jump, double-leg sagittal plane hurdle hop, single-leg sagittal plane hurdle hop, and squat split jump to identify the best exercise to strengthen these muscles. They reported the highest activity of all these muscles in single-leg sagittal plane hurdle hop and the lowest activity of gluteus medius in single-leg frontal plane hurdle hop. But in the present study, the gluteus medius muscle was the most active in SLFPH. This contradiction can be due to the fact that, first, in the quoted research, the individuals jumped on a force plate that was as high as 50% of their height and they could not jump as high as they could, as well as, second, the participants jumped over a 10-cm hurdle, while there was no hurdle in our study.

Hewett et al. [27] stated that lack of coordination and asymmetry in the activation of proximal muscles such as gluteus medius, which is the main muscle of the femoral abductor and also prevents internal rotation and proximity of the thigh, caused the knee to change its position during landing and shear manoeuvres and ultimately made the individual prone to ACL injury. The findings show that the gluteus medius muscle in SLFPH was actually activated more by predicting movement and could prevent the formation of valgus in the knee. Thus, gluteus medius can prevent ACL injury by controlling the movement in the frontal and horizontal planes and reducing the internal rotation and femoral interaction, and this exercise is the most effective one to strengthen this muscle.

SLFPH makes gluteus medius the most active, followed by SLSPH. In this exercise, because the participants jumped forward with one foot, there was also a tendency to rotate inward; to prevent this movement, gluteus medius contracted sharply [28, 29]. Therefore, SLFPH is the best exercise to strengthen gluteus medius, followed by SLSPH.

The strength of the medial hamstring and lateral hamstring muscles is important to prevent sports injury and obtain better performance in sport [1, 3]. The activity of hamstring muscles was different in various plyometric exercises; SLSPH, DLSPH, and SLFPH provided the highest values of activity in these muscles (although the activity in SLSPH was insignificantly higher than that in SLFPH and DLSPH). This high feedforward activity of hamstring was better for neuromuscular improvement and these exercises should be part of plyometric programs.

Although there was a significant difference between SLSPH, DLSPH, and SLFPH and other exercises in the feedforward phase of lateral hamstring and medial hamstring, in the feedback phase, this difference in their activity was not significant. Thus, lateral hamstrings and medial hamstrings are highly activated in these exercises as feedforward activity to create knee flexion before the foot strikes the ground.

Krosshaug et al. [28] reported that ACL injury happened approximately 17–50 ms after the initial contact of the foot with the ground at the moment of landing. Seegmiller and McCaw [29] stated that in jump landing, the first maximum ground reaction force occurred in the range of 10–18 ms after the first contact of the foot with the ground and with 1–2.4 times the body mass. In this study, up to 40 ms after the moment when the foot struck the ground was considered as part of feedforward activity. Therefore, according to these researchers, the period of feedforward activity is the most dangerous in the context of ACL injury. SLFPH and SLSPH provide the highest activity in the gluteus medius and hamstring muscles during this time. However, it should be noted that DLSPH is very effective to strengthen the hamstring muscles and can also be recommended.

We expected to observe more amounts of hamstring activity to create knee flexion during landing in tuck jump owing to the increased distance of the foot from the ground. However, as Peng et al. [13] stated, as the landing height increases, the hamstring activity remains almost constant. The results of this study also show that the ratio of muscle activity in this exercise is not appropriate. Nevertheless, previous research has implied that this exercise strengthens the deep flexors of the thighs and abdominal muscles and improves the neuromuscular system of the central body [30]. On the basis of the results of the present study alone, this exercise cannot be excluded from plyometric programs but it should not be practised too much.

Gluteus medius, medial hamstring, and lateral hamstring exhibited the least activity in squat jump compared with other exercises. Therefore, this exercise has fewer advantages than other exercises and other plyometric exercises can be used instead in plyometric programs.

Saeterbakken and Fimland [20] compared the activity and force output of leg and trunk muscles in isometric squats on a stable surface (i.e., floor), power board, BOSU ball, and balance cone. They reported some differences in the force output and muscle activity between various surfaces. So, we expected that landing on the mat and the tatami would create different levels of activity in the gluteus medius and hamstring muscles relative to the ground. However, as Wahl and Behm [21] described, in order to create a significant difference in the activity of these muscles by the surface, the degree of softness and instability of the surfaces must differ considerably. In this study, no difference was observed in the activity of these muscles on these 3 surfaces. To change muscle activity, unstable surfaces like power board, BOSU ball, or balance cone should be used; surfaces like tatami and wrestling mat are not unstable enough to provide a change in muscle activity.

Limitations

Because of religious limitations concerning males and females in Iran, this study was conducted among men. Given the high rate of neuromuscular disorders in women, the gap is very obvious.

Conclusions

The results of the present study introduce a strategy to neuromuscular improvement, which is to strengthen the gluteus medius and hamstring muscles through a scientific design of plyometric exercises and the inclusion of SLFPH and SLSPH in training programs. Also, DLSPH creates a high amount of muscle activity after SLSPH and SLFPH and can be involved in programs. Exercises such as squat jump, which have fewer advantages to strengthen the gluteus medius and hamstring muscles and exert fewer effects on the neuromuscular system, can be eliminated.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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