Research Paper:
Effects of Hip Muscle Resistance Training With and Without Feedback on Trunk, Pelvis, and Lower Extremity Motions

Malihe Hadadnezhad[1*], **Bahram Sheikhi**[1]

1. Department of Sport Injury and Corrective Exercises, Faculty of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran.

Use your device to scan and read the article online

Citation Hadadnezhad M, Sheikhi B. Effects of Hip Muscle Resistance Training With and Without Feedback on Trunk, Pelvis, and Lower Extremity Motions. Journal of Exercise Science and Medicine. 2020; 12(1):15-24. http://dx.doi.org/10.32598/JESM.12.1.1

doi http://dx.doi.org/10.32598/JESM.12.1.1

Article info:
Received: 15 Jul 2019
Accepted: 20Aug 2019
Available Online: 01 Jan 2020

Keywords:
Anterior cruciate ligament, Resistance training, Feedback, Knee

ABSTRACT

Introduction: The present study aimed to compare hip muscle resistance training with and without feedback on trunk, pelvis, and lower extremity motions in frontal and sagittal planes among active females with dynamic valgus.

Materials and Methods: Twenty-Nine active females (Mean±SD age: 22.8±2.4 years, height: 1.70±0.6 m, weight: 69±7.1 kg) were randomly assigned to a hip muscle resistance training with feedback group (n=15) or a hip muscle resistance training without feedback group (n=14). Both training programs lasted 6 weeks (3 sessions/week). The peak angles of lateral trunk flexion, contralateral pelvic drop, hip flexion, knee flexion, and valgus during single-leg drop landing and single-leg vertical drop jump were assessed in the research participants at baseline and 6 weeks post-training. Unipodal functional screening tests were captured with two standard digital video cameras.

Results: After 6 weeks, significant differences were observed in knee valgus and lateral trunk flexion, contralateral pelvic drop, and knee flexion angles, i.e., compared between hip muscle resistance training with feedback and hip muscle resistance training without feedback ($P<0.05$), except for non-dominant leg hip flexion in single-leg vertical drop jump ($P>0.05$).

Conclusion: In the explored active females with dynamic valgus, hip muscle resistance training with feedback seems to be better at improving trunk, pelvis, and lower extremity motions in frontal and sagittal planes, compared to hip muscle resistance training without feedback; however, no significant difference was observed concerning hip flexion during single-leg vertical drop jump between the study groups.

*** Corresponding Author:**
Malihe Hadadnezhad, PhD.
Address: *Department of Sport Injury and Corrective Exercises, Faculty of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran.*
Tel: *+98 (21) 22228001*
E-mail: *m.hadadnezhad@yahoo.com*

Introduction

Anterior Cruciate Ligament (ACL) injuries are among the most frequent ligament injuries [1]. ACL accounts for 20% of all athletic knee injuries [2-4]. Moreover, female athletes experience ACL injuries 3 to 4 times more frequently, with reportedly 63%-80% of injuries defined as non-contact [4]. Several theories were proposed to explain the prevalence of non-contact ACL injuries, and the higher prevalence of ACL injuries in female athletes [1, 5, 6].

Altered movement patterns that put the knee joint in a vulnerable position expose the individual to a higher risk of the joint moving outside of its normal range of motion. For example, a high knee valgus angle is observed; it is heavily researched as a movement pattern, i.e., strongly associated with ACL injuries. Knee valgus is commonly characterized by knee abduction, hip adduction, and internal hip or knee rotation [1, 2, 4, 7]. It is hypothesized that such altered kinematics during drop landing, and drop vertical jump movements increase the risk of injury during sports and activities that require landing movements. Another potential indicator of ACL injury risk is the control of the knee and hip flexion, contralateral pelvic drop [8], and lateral trunk flexion [9]. These markers are modifiable risk factors in ACL injury. Accordingly, most landing-based ACL injury prevention studies focus on training interventions aimed at reducing these risk factors. This measure is achieved through feedback [10, 11], balance, strength, plyometrics, neuromuscular and technique training [1, 2, 4, 7, 12]. Despite the best efforts of these programs, ACL injuries continue to occur.

Currently, a growing body of evidence suggests hip muscle resistance and movement control training may be effective for preventing ACL injury during athletic participation [4]. The effects of hip muscle resistance training [13] and feedback [10] on lower extremity biomechanics were investigated; however, further investigations are required to explore the relationship between hip muscle resistance training with and without feedback; also their effects should be examined on the trunk and lower extremity motions in active females with dynamic valgus.

Implementing a training program to address the biomechanical risk factors that predispose these athletes to knee injuries should be a component of the overall training regimen. Therefore, this study aimed to compare hip muscle resistance training with and without feedback on the trunk, pelvis, and lower extremity motions in frontal and sagittal planes during unipodal functional screening tests in active females with dynamic valgus. We hypothesized that females with dynamic valgus receiving individualized hip muscle resistance training with feedback would demonstrate better improvement in trunk, pelvis, and lower extremity peak angles in frontal and sagittal planes during landing, compared to those receiving hip muscle resistance training. We further hypothesized that feedback instructions can help reduce knee valgus and lateral trunk flexion, contralateral pelvic drop, increase knee flexion and hip flexion angles during single-leg drop landing, and single-leg vertical drop jump tests in active females with dynamic valgus.

Materials and Methods

Thirty-Two competitive female volleyball and basketball players (age range: 18-28 years) were recruited for this study (Table 1). All study participants provided written informed consent forms. Moreover, the study was approved by the Research Ethics Committee of Tarbiat Modares University of Medical Sciences (code: IR.MODARES.REC.1397.117). The protocol was prospectively registered at the UMIN_RCT website (code: UMIN000035050). The present study was performed per the ethical standards of the World Medical Association Declaration of Helsinki. The research participants were randomly assigned (http://randomizer.org/, Social Psychology Network, USA) into two groups, as follows: hip muscle resistance training with feedback group (n=16) or hip muscle resistance training without feedback (n=16). The randomization was performed by an independent subject who was not involved in other procedural aspects of the study. Another trainer (blinded to the baseline assessment) proceeded with training according to the group assignment.

Three study participants [hip muscle resistance training with feedback (n=1) & hip muscle resistance training group (n=2)] did not complete the assessment protocol. Therefore, the data obtained from 29 participants were analyzed (Figure 1). Twenty-two and seven study participants were left and right limbs dominant, in sequence; the dominant limb was defined as the lower limb preferred for landing.

The inclusion criteria of the study included female gender, the age range of 18-28 years, a healthy Body Mass Index (BMI), no musculoskeletal injuries over the preceding 6 months, no history of non-corrected neurological, vestibular, visual impairments, no musculoskeletal injuries that could interfere with or contraindicate train-

Table 1. Demographic characteristics of the research participants

Variables	Mean±SD		P
	Hip Muscle Resistance Training With Feedback (n=15)	Hip Muscle Resistance Training (n=14)	
Age (y)	23±2.5	22.6±2.3	0.75
Body mass (kg)	68.3±6.1	69.8±8.3	0.69
Height (cm)	170.7±6.7	169.9±6.6	0.59
Body mass index (kg/m^2)	23.4±6.2	24.1±2.1	0.22
Years of experience in thei respective jumping sports (y)	5.7±2	5.6±1.8	0.85
Knee valgus (degree)	12.9±1.4	13.3±2.2	0.61

P-values: based on the independent samples t-test data

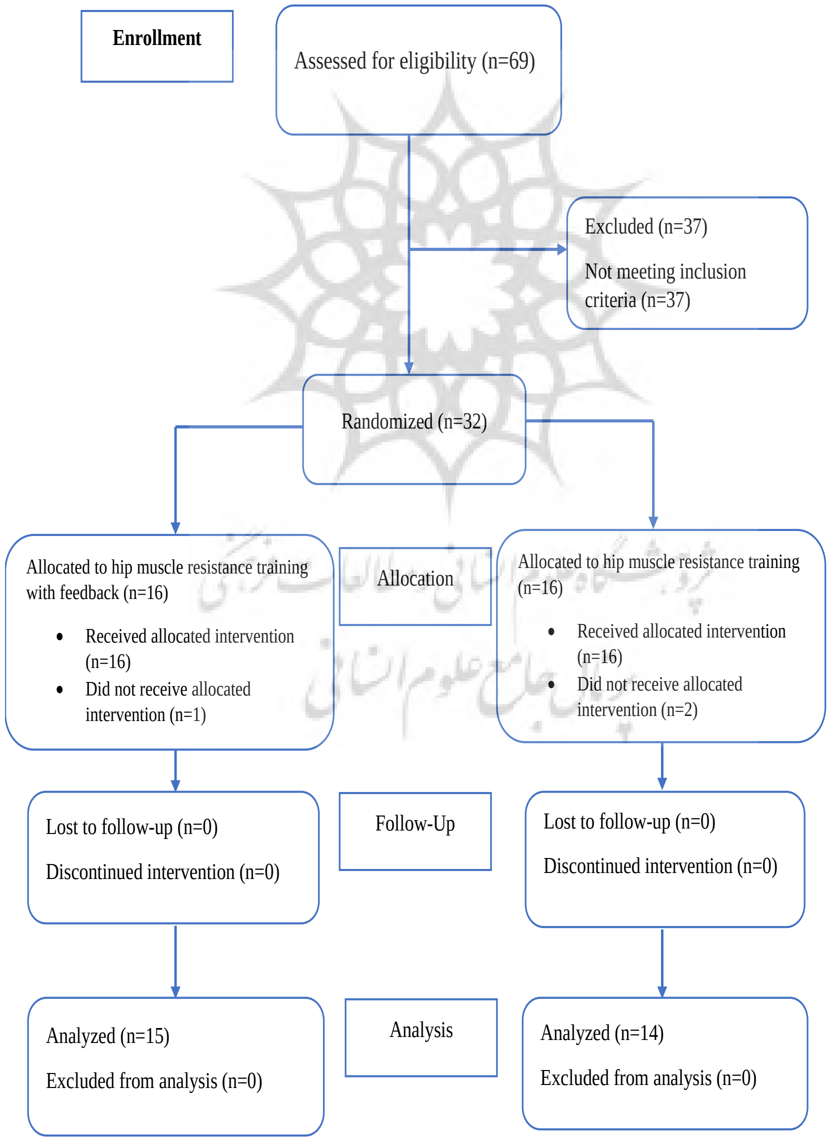

Figure 1. Flow chart of the progress through the phases of the study according to the CONSORT statements

ing and the assessment procedures, and dynamic valgus during the single-leg squat test (knee valgus of >10 degrees). The barefooted participants were requested to place their hands on their hips and stand on one limb and flex the opposing limb to 90°, then return to a fully extended knee position. During the descent phase, observable knee valgus was defined as >10° in frontal plane knee angle. The study sample performed the single-leg squat three times in a row on each leg [14].

Both hip muscle resistance training with feedback and hip muscle resistance training was supervised and conducted by two athletic trainers. Both training programs lasted 6 weeks. Moreover, the experiment comprised 3 training sessions per week with a total of 18 training sessions per intervention group. The hip muscle resistance training with a feedback group received 6 feedback sessions [10], followed by 12 hip muscle resistance training sessions. Each training session lasted 45 min, starting with a brief standardized warm-up program, mainly consisting of low-intensity core strength exercises. This measure aimed to prepare the neuromuscular system for the training loads, ending with a cool-down program.

Hip muscle resistance training includes non-weight-bearing hip exercises, controlled weight-bearing exercises, and functional exercises. In other words, non-weight-bearing hip exercises consist of side-lying hip abduction, side-lying clam with resistance, and unilateral supine bridge, side-bridge (plank). Controlled weight-bearing exercises included single-leg squat, lateral box step-ups, forward box step-down, as well as single-leg deadlift. Functional exercises were lateral resisted band walks, side lunges, forward lunges, and rear cross-over lunges [15].

Feedback exercises included single-leg stance on an unstable platform, single-leg squat, single-leg hop for distance, (walking) lunges, double leg squat, double leg drop jump, countermovement jump, side-step cutting maneuver, and vertical jump with vertec [10].

The performed unipodal functional screening tests included the following:

Single Leg Drop Landing: Each study participant performed a single-leg drop landing from a 30-cm box. After landing, this position was maintained for 5 seconds. A trial was not deemed valid if the other leg touched the ground or if the study participants were clearly out of balance or fell during the test [16].

Single-Leg Vertical Drop Jump: The research participants performed a single-leg vertical drop jump on their dominant leg. A single-leg vertical drop jump consisted of dropping from a 10-cm box, landing on one limb, completing an immediate maximal vertical jump, and re-landing [17]. A trial was deemed invalid if the research participant jumped off the box instead of just dropping, if the other leg touched the ground, or if the examined participant was clearly out of balance or fell during the test.

At least 1 minute of rest was given between each repetition and 2 minutes of rest after each task to minimize fatigue. All measurements were conducted in the Biomechanics Laboratory of Kharazmi University. Before conducting the tests, the explored samples executed a 10-min neuromuscular standardized warm-up protocol. This pattern consisted of a series of double-leg squats (2×8 repetitions) and double-leg maximum jumps (2×5 repetitions), followed by strength and dynamic stretching exercises (5 min) [17].

Unipodal functional screening tests were recorded with two standard digital video cameras (Sony HDR-PJ675). The video cameras were placed on tripods perpendicular to the frontal and sagittal planes, at a height of 60 cm and a distance of 3.5 m from the landing area. Furthermore, retroreflective markers were placed on specific anatomical landmarks [manubrium sterni, bilateral acromioclavicular joint, Anterior Superior Iliac Spine (ASIS), greater trochanter, lateral and medial femoral epicondyles, and lateral and medial malleolus] [18, 19].

In the sagittal plane, the knee flexion angle was defined as the angle formed by a segmented line from the GT to the lateral femoral epicondyle to the lateral malleolus. The hip flexion angle was defined as the angle formed by a segmented line from the lateral femoral epicondyle to the greater trochanter to the acromioclavicular joint. In the frontal plane, lateral trunk lean was defined as the angle formed by vertical and a line from the ipsilateral ASIS to the manubrium sterni. The contralateral pelvic drop angle was calculated as the angle subtended by one line connecting the ASIS with the stance and swing limb and a second line drawn perpendicular to the stance limb ASIS. The measurement was then subtracted from 90° [8]. The knee abduction angle was delimited as the angle formed by a segmented line from the ASIS to the knee joint center to the ankle joint center [9]. The video recordings were analyzed using Kinovea (version 0.8.15). The ankle joint center was defined as the mid-point of the lateral and medial malleolus markers, and the knee joint center was described as the mid-point of the lateral and medial femoral epicondyle markers [9, 20]. Trunk, pelvis, and lower extremity motions in the frontal and sagittal planes were averaged across the three trials and used for statistical analysis.

The Shapiro Wilk's test and Levene's test were conducted to evaluate the normality and homogeneity assumptions. Mean values, effect sizes (f), and frequency changes (%) from pre- to post-training were reported. Effect sizes were determined by calculating partial eta squared (η). According to Cohen [21], 0.00≤f≤0.24 indicates small effects, 0.25≤f≤0.39 signifies medium effects, and f≥0.4 reflects large effects. The study subjects' characteristics were compared using an Independent Samples t-test. Separate two-way repeated-measures Analysis of Variance (ANOVA) were performed to assess differences in kinematic data (trunk, pelvis, & lower extremity motions in frontal & sagittal planes). Moreover, P<0.05 was considered significant. All analyses were performed in SPSS.

Results

Overall, there was no significant difference in baseline values between the intervention groups (P>0.05). Table 2 describes pre- and post-training results for all outcome variables. The data indicated significant main effects of time for all outcomes (P<0.05, effect size: >0.39). Similarly, a significant main effect of the group was obtained (P<0.05). Furthermore, trends towards significant main effects of the group were observed for the hip flexion during single-leg vertical drop jump (dominant leg: P=0.088 effect size=0.21; non-dominant leg: P=0.056, effect size=0.25). However, we detected no significant main effect of group for hip flexion during single-leg vertical drop jump. Moreover, the time x group effect (P<0.05), except for non-dominant leg hip flexion during single-leg vertical drop jump (P>0.05) were significant for all outcomes (Table 2). Thus, the changes in these outcome variables were unequal between the study groups after the training.

Discussion

The current study compared hip muscle resistance training with and without feedback on trunk, pelvis, and lower extremity motions in frontal and sagittal planes during unipodal functional screening tests in active females with dynamic valgus. The primary hypothesis was that the females with dynamic valgus receiving individualized hip muscle resistance training with feedback would demonstrate better improvement in trunk, pelvis, and lower extremity peak angles in frontal and sagittal planes during landing, compared to their counterparts receiving hip muscle resistance training. The collected findings revealed that hip muscle resistance training with feedback and hip muscle resistance training led to significant improvement in knee valgus and lateral trunk flexion, contralateral pelvic drop, increased knee flexion, and hip flexion angles in 6 weeks during single-leg drop landing and single-leg vertical drop jump tests in active females with dynamic valgus. However, hip muscle resistance training with feedback better reduced knee valgus and lateral trunk flexion, contralateral pelvic drop, and increasing knee flexion angles, compared to hip muscle resistance training.

The mechanisms underlying the effectiveness of hip muscle resistance training and feedback as an element of ACL injury prevention programs were identified, including changes in trunk and hip kinematics and kinetics [22-28]. Exclusively, addressing proximal factors with the hip muscle resistance training and feedback programs did, however, result in significant changes in frontal and sagittal plane knee angles. Feedback instruction exercises are a proven modality for the alteration of movement patterns [29]. Feedback resulted in accelerating the learning process or shortening the first stages of learning by facilitating movement automaticity (constrained action hypothesis). According to the constrained action hypothesis, attempting to consciously control one's movements constrains the motor system by interfering with automatic motor control processes that would normally regulate the movement. Furthermore, focusing on the motion effect might allow the motor system to more naturally self-organize, unconstrained by the interference caused by conscious control attempts, resulting in more effective performance and learning [10, 11]. Adding feedback to hip muscle resistance training further improves trunk, pelvis, and lower extremity motions by unconstraining the motor system to optimize movement patterns [10, 11].

The study provided an evidence-based rationale for hip muscle resistance training and feedback programs. Herman et al. reported that lower extremity muscle strength training, when used in conjunction with feedback, may provide an increased capacity for the alteration of knee and hip biomechanics [29]. Programs that include strength training and movement education through feedback may be necessary to increase the effectiveness of ACL prevention programs. Hip muscle resistance training may provide an increased capacity for athletes to respond to other intervention modalities used in ACL injury prevention programs [13, 29].

According to Voight et al., after the elastic-resisted neuromuscular training intervention, knee separation

Table 2. Effects of the two-training group on trunk, pelvis, and lower extremity motions on the study groups

Variables	Tasks	Groups	Landing Leg	Mean±SD		Change Relative to Baseline‡ (%)	P (Effect Size f)		
				Pretest	Posttest		Main Effect, N(%) Time	Main Effect, N(%) Group	Interaction: Time×Group N(%)
Knee valgus	Single Leg Drop Landing	HMRT plus F	Dominant	166.3±3	177.6±1.9	↑ 6.6	<0.001(0.87)	0.043(0.28)	0.003(0.50)
		HMRT		166.9±3.1	173±4.8	↑ 3.7			
		HMRT plus F	Non-dominant	167.3±2.8	178.5±1.5	↑ 6.7	<0.001(0.93)	0.045(0.27)	<0.001(0.86)
		HMRT		167.7±5.1	171.5±4.8	↑ 2.3			
	Single-Leg Vertical Drop Jump	HMRT plus F	Dominant	162.7±3.1	178.1±1.9	↑ 9.5	<0.001(0.94)	0.031(0.31)	<0.001(0.79)
		HMRT		165.7±4.1	171.3±3.3	↑ 3.4			
		HMRT plus F	Non-dominant	166±3.4	178.6±1.3	↑ 7.6	<0.001(0.94)	0.038(0.30)	<0.001(0.78)
		HMRT		167±4.9	171.3±3.4	↑ 2.6			
Knee flexion	Single Leg Drop Landing	HMRT plus F	Dominant	103.1±8.5	90.3±6.3	↓ 12.4	<0.001 (0.66)	0.033 (0.31)	0.06(0.45)
		HMRT		103.5±5.9	101.4±9	↓ 2			
		HMRT plus F	Non-dominant	103.6±4.7	86.7±7.9	↓ 16.3	<0.001(0.85)	0.029(0.88)	<0.001(0.32)
		HMRT		103±10.4	101.7±10.1	↓ 1.3			
	Single-Leg Vertical Drop Jump	HMRT plus F	Dominant	117.8±4.3	92.3±5.2	↓ 21.6	<0.001(0.89)	0.044(0.28)	<0.001(0.90)
		HMRT		112.5±9.4	108.7±6.2	↓ 3.4			
		HMRT plus F	Non-dominant	113.2±7.5	90.1±5.9	↓ 20.4	<0.001(0.79)	0.004(0.49)	<0.001(0.71)
		HMRT		112.9±8.5	109.4±8.9	↓ 3.1			
Hip flexion	Single Leg Drop Landing	HMRT plus F	Dominant	96±12.5	66.3±12	↓ 30.9	<0.001(0.75)	0.039(0.29)	<0.001(0.66)
		HMRT		92.8±9.9	85.6±11.3	↓ 7.8			
		HMRT plus F	Non-dominant	106.9±17	79.6±16.9	↓ 25.5	0.001(0.57)	0.028(0.32)	0.017(0.37)
		HMRT		101.1±6.9	97.5±4	↓ 3.6			
	Single-Leg Vertical Drop Jump	HMRT plus F	Dominant	126.1±15.6	105.1±7.4	↓ 16.7	<0.001(0.75)	0.088(0.21)	0.007(0.44)
		HMRT		125.3±12.3	119.8±5.6	↓ 4.4			
		HMRT plus F	Non-dominant	129.9±10.9	110.5±8	↓ 14.9	0.012(0.39)	0.056(0.25)	0.083(0.21)
		HMRT		128.5±16	125.8±25	↓ 2.3			
Lateral trunk flexion	Single Leg Drop Landing	HMRT plus F	Dominant	12.2±8	2.5±1.8	↓ 79.5	<0.001(0.69)	0.043(0.28)	0.015(0.38)
		HMRT		13.5±6.4	10.9±5.7	↓ 19.3			
		HMRT plus F	Non-dominant	12.5±6.2	1.7±1.1	↓ 86.4	<0.001(0.83)	0.009(0.42)	0.001(0.58)
		HMRT		13.3±5.3	11.7±5.1	↓ 12			
	Single-Leg Vertical Drop Jump	HMRT plus F	Dominant	11.5±4.7	4.1±2.6	↓ 64.3	<0.001(0.68)	0.010(0.41)	0.002(0.53)
		HMRT		11.9±4.3	10.7±5.1	↓ 10.1			
		HMRT plus F	Non-dominant	14.1±3	4.1±1.9	↓ 70.9	<0.001(0.92)	0.020(0.35)	0.001(0.60)
		HMRT		12.7±2.7	8.5±1.8	↓ 33.1			

Variables	Tasks	Groups	Landing Leg	Mean±SD		Change Relative to Baseline‡ (%)	P (Effect Size f)		
				Pretest	Posttest		Main Effect, N(%) Time	Main Effect, N(%) Group	Interaction: Time×Group N(%)
Pelvic drop	Single Leg Drop Landing	HMRT plus F	Dominant	7.5±1.9	2±1.2	↓ 73.3	<0.001(0.88)	0.044(0.28)	<0.001(0.77)
		HMRT		6.9±1.9	4.7±1.7	↓ 31.9			
		HMRT plus F	Non-dominant	8.3±1.8	2.1±1.2	↓ 74.7	<0.001(0.94)	0.002(0.53)	<0.001(0.71)
		HMRT		9±3.1	6.7±1.8	↓ 25.6			
	Single-Leg Vertical Drop Jump	HMRT plus F	Dominant	11.6±4.5	3.9±2.4	↓ 66.4	<0.001(0.92)	0.043(0.28)	0.001(0.74)
		HMRT		11.2±3.6	8.6±2.4	↓ 23.2			
		HMRT plus F	Non-dominant	10.2±3.5	4.2±2.6	↓ 58.8	<0.001(0.94)	0.029(0.31)	0.003(0.50)
		HMRT		11.4±3.3	8.4±2.4	↓ 26.3			

Journal of
Exercise Science and Medicine

HMRT plus F: Hip Muscle Resistance Training with Feedback; HMRT: Hip Muscle Resistance Training; ‡: Percent change relative to baseline (↓=Decrease, ↑=Increase).

distance was reduced and a more neutral limb alignment on landing and takeoff was observed, compared with the control group in female athletes with valgus knee alignment during the drop test [13].

Poor neuromuscular control of the posterior and lateral hip musculature may affect the generation of optimal net hip joint moments required to control pelvic, hip, and knee motion during landing [30, 31]. Therefore, exercises that promote large hip extension and external rotation moments should elicit powerful contractions of the target musculature, including gluteals, internal, and external rotators [30, 31]. The weakness of the hip musculature may not be strongly related to frontal-plane hip and knee mechanics [32]; however, recent evidence links muscle activation deficits to poor control of the lower extremities [30, 31, 33]. Hip muscle resistance training and feedback programs employ equipment that provides an external focus, introducing an advanced challenge to core control, pelvic drop, and lower extremity alignment.

Practicing the hip muscle resistance training and feedback programs are highly beneficial [4, 11, 24, 32, 34, 35]. This is because those who have hip muscles (hip abductor) strength deficit seem more responsive to neuromuscular training. Adaptations from hip muscle resistance training and feedback programs that improve hip abductor strength and recruitment may be protective against high knee abduction or valgus loading during dynamic movements and potentially reduce ACL risk in female athletes. Hip abductor weakness is linked to knee valgus and ACL injury; therefore, hip abductor strength enhancement may potentially help to improve the existing ACL injury condition or provide prophylactic effects for future ACL injury [31, 34].

Trunk displacement in the frontal plane increased the risk of knee ligaments as well as ACL injuries with high sensitivity and specificity in female athletes [31, 35]. The lateral trunk flexion toward the support leg is related to increasing external knee abduction loads. Thus, controlled activities that elicit trunk motion toward the support leg may help female athletes learn better to control these risky knee loads; they may not be completely avoidable during unipodal landing tasks [30, 31]. The hip and knee flexion angles during landing are determinants in the forces resulting from knee overload. Small flexion angles during landing produce high knee impact forces that increase the odds of ACL injury. According to Leetun et al., by strengthening the muscles resisting the moment of dynamic valgus, athletes can decrease the incidence of injury to the ACL [36]. This is because the gluteus maximus and the posterior fibers of the gluteus medius can eccentrically control excessive hip internal rotation [37-39]. Additionally, Powers et al. reported that skill acquisition training was more effective than strength training in improving jump landing strategies. These subjects manifested skill acquisition learning at a 6-month follow-up. Powers et al. suggested that neuroplastic changes in the brain that occur with skill acquisition learning may be used in injury-prevention training [40].

Conclusion

An individualized program involving hip muscle resistance training with feedback is more effective than hip muscle resistance training in active females with dynamic valgus at improving knee valgus, knee flexion, hip flexion, contralateral pelvic drop, and lateral trunk flexion. The changes from baseline to post-intervention were larger in the hip muscle resistance training with feedback group in all outcomes; however, to definitively assert the superiority of this individualized intervention over the hip muscle resistance training, more studies are necessary.

The study was challenged by some limitations. First, kinetics and electromyography data were overlooked. Further studies through which electromyography and kinetics are used to detect changes in muscle excitability and kinetics are required. Second, outcomes were only assessed in the short term; therefore, the long-term effects of the training remain undiscovered. Another study limitation was excluding male participants. Future clinical trials with a male group and larger sample size are recommended to be performed to investigate the effects of hip muscle resistance training with and without feedback on joint kinematics.

Ethical Considerations

Compliance with ethical guidelines

All study participants provided written informed consent forms. Moreover, the study was approved by the Research Ethics Committee of Tarbiat Modares University of Medical Sciences (Code: IR.MODARES.REC.1397.117).

Funding

This work was funded by the faculty of physical education and sports science of the Kharazmi University, Iran (4/36738).

Authors' contributions

All authors contributed to the original idea, study design.

Conflict of interest

The authors declared no conflicts of interest.

Acknowledgments

We would like to express our deepest appreciation for the valuable assistance and contribution of all the participants.

References

[1] Kaeding CC, Léger-St-Jean B, Magnussen RA. Epidemiology and diagnosis of anterior cruciate ligament injuries. Clinics in Sports Medicine. 2017; 36(1):1-8. [DOI:10.1016/j.csm.2016.08.001] [PMID]

[2] Buller LT, Best MJ, Baraga MG, Kaplan LD. Trends in anterior cruciate ligament reconstruction in the united states. Orthopaedic Journal of Sports Medicine. 2015; 3(1):2325967114563664. [DOI:10.1177/2325967114563664] [PMID] [PMCID]

[3] Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: A 10-year study. The Knee. 2006; 13(3):184-8. [DOI:10.1016/j.knee.2006.01.005] [PMID]

[4] Turner C, Crow S, Crowther T, Keating B, Saupan T, Pyfer J, et al. Preventing non-contact ACL injuries in female athletes: What can we learn from dancers? Physical Therapy in Sport. 2018; 31:1-8. [DOI:10.1016/j.ptsp.2017.12.002] [PMID]

[5] Maetzel A, Krahn M, Naglie G. The cost effectiveness of rofecoxib and celecoxib in patients with osteoarthritis or rheumatoid arthritis. Arthritis and Rheumatism. 2003; 49(3):283-92. [DOI:10.1002/art.11121] [PMID]

[6] Heebner NR, Rafferty DM, Wohleber MF, Simonson AJ, Lovalekar M, Reinert A, et al. Landing kinematics and kinetics at the knee during different landing tasks. Journal of Athletic Training. 2017; 52(12):1101-8. [DOI:10.4085/1062-6050-52.11.25] [PMID] [PMCID]

[7] Leroux T, Wasserstein D, Dwyer T, Ogilvie-Harris DJ, Marks PH, Bach Jr BR, et al. The epidemiology of revision anterior cruciate ligament reconstruction in Ontario, Canada. The American Journal of Sports Medicine. 2014; 42(11):2666-72. [DOI:10.1177/0363546514548165] [PMID]

[8] Maykut JN, Taylor-Haas JA, Paterno MV, DiCesare CA, Ford KR. Concurrent validity and reliability of 2d kinematic analysis of frontal plane motion during running. International Journal of Sports Physical Therapy. 2015; 10(2):136-46. [PMID] [PMCID]

[9] Dingenen B, Malfait B, Vanrenterghem J, Verschueren SMP, Staes FF. The reliability and validity of the measurement of lateral trunk motion in two-dimensional video analysis during unipodal functional screening tests in elite female athletes. Physical Therapy in Sport. 2014; 15(2):117-23. [DOI:10.1016/j.ptsp.2013.05.001] [PMID]

[10] Benjaminse A, Gokeler A, Dowling AV, Faigenbaum A, Ford KR, Hewett TE, et al. Optimization of the anterior cruciate ligament injury prevention paradigm: Novel feedback techniques to enhance motor learning and reduce injury risk. The Journal of Orthopaedic and Sports Physical Therapy. 2015; 45(3):170-82. [DOI:10.2519/jospt.2015.4986] [PMID]

[11] Wulf G. Attentional focus and motor learning: A review of 15 years. International Review of sport and Exercise Psychology. 2013; 6(1):77-104. [DOI:10.1080/1750984X.2012.723728]

[12] Lindblom H, Waldén M, Carlfjord S, Hägglund M. Limited positive effects on jump-landing technique in girls but not in boys after 8 weeks of injury prevention exercise training in youth football. Knee Surgery, Sports Traumatology, Arthroscopy. 2020; 28(2):528-37. [DOI:10.1007/s00167-019-05721-x] [PMID] [PMCID]

[13] Voight M, Page P, Chidester M, Hardiek L, Macko S, Sexton Z, et al. The impact of hip abduction elastic-resisted neuromuscular feedback on frontal plane knee kinematics in female volleyball athletes. Journal of Performance Health Research. 2017; 1(2):23-30. [DOI:10.25036/jphr.2017.1.2.voight]

[14] Ugalde V, Brockman C, Bailowitz Z, Pollard CD. Single leg squat test and its relationship to dynamic knee valgus and injury risk screening. PM & R: The Journal of Injury, Function, and Rehabilitation. 2015; 7(3):229-35. [DOI:10.1016/j.pmrj.2014.08.361] [PMID]

[15] Ford KR, Nguyen AD, Dischiavi SL, Hegedus EJ, Zuk EF, Taylor JB. An evidence-based review of hip-focused neuromuscular exercise interventions to address dynamic lower extremity valgus. Open Access Journal of Sports Medicine. 2015; 6:291-303. [DOI:10.2147/OAJSM.S72432] [PMID] [PMCID]

[16] Ward RE, Fong Yan A, Orishimo KF, Kremenic IJ, Hagins M, Liederbach M, et al. Comparison of lower limb stiffness between male and female dancers and athletes during drop jump landings. Scandinavian journal of Medicine & Science in Sports. 2019; 29(1):71-81. [DOI:10.1111/sms.13309] [PMID]

[17] Stensrud S, Myklebust G, Kristianslund E, Bahr R, Krosshaug T. Correlation between two-dimensional video analysis and subjective assessment in evaluating knee control among elite female team handball players. British Journal of Sports Medicine. 2011; 45(7):589-95. [DOI:10.1136/bjsm.2010.078287] [PMID]

[18] Dix J, Marsh S, Dingenen B, Malliaras P. The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: A systematic review. Physical Therapy in Sport. 2019; 37:197-209. [DOI:10.1016/j.ptsp.2018.05.015] [PMID]

[19] Herrington L, Alenezi F, Alzhrani M, Alrayani H, Jones R. The reliability and criterion validity of 2D video assessment of single leg squat and hop landing. Journal of Electromyography and Kinesiology. 2017; 34:80-5. [DOI:10.1016/j.jelekin.2017.04.004] [PMID]

[20] Ageberg E, Bennell KL, Hunt MA, Simic M, Roos EM, Creaby MW. Validity and inter-rater reliability of medio-lateral knee motion observed during a single-limb mini squat. BMC Musculoskeletal Disorders. 2010; 11:265. [DOI:10.1186/1471-2474-11-265] [PMID] [PMCID]

[21] Cohen J. The t test for means. Statistical power analysis for the behavioral sciences. Mahwah: Lawrence Erlbaum Associates; 1987. https://books.google.com/books?id=8wBHAAAAMAAJ&dq

[22] Omi Y, Sugimoto D, Kuriyama S, Kurihara T, Miyamoto K, Yun S, et al. Effect of hip-focused injury prevention training for anterior cruciate ligament injury reduction in female basketball players: A 12-year prospective intervention study. The American Journal of Sports Medicine. 2018; 46(4):852-61. [DOI:10.1177/0363546517749474] [PMID]

[23] Pollard CD, Sigward SM, Powers CM. ACL injury prevention training results in modification of hip and knee mechanics during a drop-landing task. Orthopaedic Journal of Sports Medicine. 2017; 5(9):2325967117726267. [DOI:10.1177/2325967117726267] [PMID] [PMCID]

[24] Taylor JB, Nguyen AD, Shultz SJ, Ford KR. Hip biomechanics differ in responders and non-responders to an ACL injury prevention program. Knee Surgery, Sports Traumatology, Arthroscopy. 2020; 28(4):1236-45. [DOI:10.1007/s00167-018-5158-1] [PMID]

[25] Borin SH, Bueno B, Gonelli PRG, Moreno MA. Effects of hip muscle strengthening program on functional responses of athletes submitted to reconstruction of the anterior cruciate ligament. Journal of Exercise Physiology Online. 2017; 20(3):79-87. https://www.researchgate.netigament

[26] Dos'Santos T, Thomas C, Comfort P, Jones PA. The effect of training interventions on change of direction biomechanics associated with increased anterior cruciate ligament loading: A scoping review. Sports Medicine. 2019; 49(12):1837-59. [DOI:10.1007/s40279-019-01171-0] [PMID] [PMCID]

[27] Neilson V, Ward S, Hume P, Lewis G, McDaid A. Effects of augmented feedback on training jump landing tasks for ACL injury prevention: A systematic review and meta-analysis. Physical Therapy in Sport. 2019; 39:126-35. [DOI:10.1016/j.ptsp.2019.07.004] [PMID]

[28] Haines M, Murray AM, Glaviano NR, Gokeler A, Norte GE. Restricting ankle dorsiflexion does not mitigate the benefits of external focus of attention on landing biomechanics in healthy females. Human Movement Science. 2020; 74:102719. [DOI:10.1016/j.humov.2020.102719] [PMID]

[29] Herman DC, Oñate JA, Weinhold PS, Guskiewicz KM, Garrett WE, Yu B, et al. The effects of feedback with and without strength training on lower extremity biomechanics. The American Journal of Sports Medicine. 2009; 37(7):1301-8. [DOI:10.1177/0363546509332253] [PMID]

[30] Di Stasi S, Myer GD, Hewett TE. Neuromuscular training to target deficits associated with second anterior cruciate ligament injury. Journal of Orthopaedic & Sports Physical Therapy. 2013; 43(11):777-92. [DOI:10.2519/jospt.2013.4693] [PMID] [PMCID]

[31] Hewett TE, Ford KR, Xu YY, Khoury J, Myer GD. Effectiveness of neuromuscular training based on the neuromuscular risk profile. The American Journal of Sports Medicine. 2017; 45(9):2142-7. [DOI:10.1177/0363546517700128] [PMID] [PMCID]

[32] Willson JD, Davis IS. Lower extremity strength and mechanics during jumping in women with patellofemoral pain. Journal of Sport Rehabilitation. 2009; 18(1):76-90. [DOI:10.1123/jsr.18.1.76] [PMID]

[33] Willson JD, Petrowitz I, Butler RJ, Kernozek TW. Male and female gluteal muscle activity and lower extremity kinematics during running. Clinical Biomechanics. 2012; 27(10):1052-7. [DOI:10.1016/j.clinbiomech.2012.08.008] [PMID]

[34] Nunes A, Cattuzzo MT, Faigenbaum AD, Mortatti AL. Effects of integrative neuromuscular training and detraining on countermovement jump performance in youth volleyball players. Journal of Strength and Conditioning Research. 2019; 10:1-6. [DOI:10.1519/JSC.0000000000003092] [PMID]

[35] Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: Prospective biomechanical-epidemiologic study. The American Journal of Sports Medicine. 2007; 35(7):1123-30. [DOI:10.1177/0363546507301585] [PMID]

[36] Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. Medicine & Science in Sports & Exercise. 2004; 36(6):926-34. [DOI:10.1249/01.MSS.0000128145.75199.C3] [PMID]

[37] Zazulak BT, Ponce PL, Straub SJ, Medvecky MJ, Avedisian L, Hewett TE. Gender comparison of hip muscle activity during single-leg landing. Journal of Orthopaedic & Sports Physical Therapy. 2005; 35(5):292-9. [DOI:10.2519/jospt.2005.35.5.292] [PMID]

[38] De Blaiser C, Roosen P, Willems T, De Bleecker C, Vermeulen S, Danneels L, et al. The role of core stability in the development of non-contact acute lower extremity injuries in an athletic population: A prospective study. Physical Therapy in Sport. 2021; 47:165-72. [DOI:10.1016/j.ptsp.2020.11.035] [PMID]

[39] Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. Journal of Orthopaedic & Sports Physical Therapy. 2003; 33(11):671-6. [DOI:10.2519/jospt.2003.33.11.671] [PMID]

[40] Powers CM, Fisher B. Mechanisms underlying ACL injury-prevention training: the brain-behavior relationship. Journal of Athletic Training. 2010; 45(5):513-5. [DOI:10.4085/1062-6050-45.5.513] [PMID] [PMCID]

This Page Intentionally Left Blank