Research Paper: The Effects of Corrective Exercise With and Without Visual Feedback on Lower Extremity Biomechanics and Dynamic Balance in Adolescent Female Athletes With Dynamic Knee Valgus: A Pilot Study

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ABSTRACT

Introduction: This study aimed to compare the effectiveness of corrective-plyometric training with and without visual feedback on landing biomechanics and dynamic balance in adolescent female athletes with dynamic knee valgus (DKV).

Materials and Methods: A total of 26 adolescent female athletes were randomly divided into feedback (n=10), exercise (n=8), and control (n=8) groups. Six weeks of training with and without visual feedback were prescribed for feedback and exercise groups, respectively. Biomechanical data were measured at initial contact (IC) and maximum knee flexion (MAX) using 8 motion analysis cameras (Vicon) and a Kistler force plate. Y-balance test was employed to evaluate dynamic balance.

Results: Based on the between-group outcomes, knee flexion-extension moment at IC (P=0.026), hip internal rotation angle at IC (P=0.016), and MAX (P=0.028) significantly changed during double-leg landing. Ankle dorsiflexion angle (P=0.05), tibial external rotation angle (P=0.012), and anterior-posterior ground reaction force (P=0.05) at IC, maximum tibial external rotation angle between IC to MAX (P=0.042), and hip internal rotation angle at MAX (P=0.022) significantly changed during single-leg landing test. Y-balance significant improvements were recorded in anterior (P=0.000), posteromedial directions (P=0.000), and composite (P=0.023).

Conclusion: Corrective-plyometric exercises without visual feedback effectively improve landing biomechanics and dynamic balance in adolescent female athletes with DKV.

Keywords: Biomechanics, Sports, Alignment, Therapeutic exercises

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1. Introduction

In recent years, the statistics have shown more tendency in adolescents to participate in sports activities [1]. However, higher participation in the sports fields may come with greater risks of sports-related injuries, especially in sports like handball, gymnastics, and volleyball [2]. Among all those injuries, the anterior cruciate ligament (ACL) strain has been reported as one of the most prevalent noncontact injuries with long rehabilitation duration and high costs on the societies [3]. Imbalanced biomechanical characteristics during physical activities, such as Dynamic Knee Valgus (DKV) and knee hyperextension, are suggested to contribute to ACL injuries [4, 5]. DKV is defined as a combination of excessive knee abduction and external tibial rotation with hip adduction and internal rotation [6]. According to biomechanical studies, female athletes land with greater DKV than male athletes putting them at a higher risk of ACL injury [7].

One of the underlying mechanisms behind this higher risk may be inadequate neuromuscular control in the upper segments, such as the hip [8]. Therefore, increasing neuromuscular control by different exercise protocols may effectively improve biomechanical profiles [9]. Among many exercise protocols offered by the researchers, plyometric exercises are among the effective and frequently used approaches to reduce DKV alignment during the landing phase of unilateral or bilateral jump-landing tasks [9]. Regarding the muscles' contraction mechanisms during a plyometric exercise, first, the elastic energy aggregates in musculotendinous units during the eccentric phase, increasing muscle output and consequently mechanical work in the concentric phase of jumping [10]. Previous studies have found improvements in knee biomechanics in both sagittal and frontal motion planes such as increased knee flexion and decreased knee abduction during and after plyometric exercises interventions [9]. Additionally, combining plyometric exercises with verbal or visual feedback is reported to enhance the lower extremity biomechanical outcomes at greater extents [9]. For instance, it is suggested that visual feedback from mirrors during exercising may positively affect counter-movement jump kinematic and kinetic [11]. Moreover, comparing various types of visual feedback shows that visual feedback from mirrors could be more effective in increasing athletic performance than feedback from videos or their combination [12].

To the best of our knowledge, no study has investigated the effects of corrective-plyometric exercises augmented with visual feedback on lower extremity biomechanics during landing tasks and dynamic balance performance in adolescent female athletes with DKV. Thus, the present study aimed at comparing the effectiveness of 6 weeks of corrective-plyometric training with and without visual feedback on lower extremity kinematic and kinetic during single-leg and double-leg landings. We also examined the dynamic balance performance in adolescent female athletes with DKV.

2. Materials and Methods

Study participants

To determine the study's sample size, we used G*Power software, v. 3.1. Based on a previous study, and considering α=5% and power=80%, six participants were enough for each group. However, due to the possibility of dropouts, ten participants were considered for each group [13]. Thus, 30 adolescent female athletes with DKV were chosen for the present single-blinded randomized clinical trial study. They were randomly divided into 3 groups: feedback (n=10), exercise (n=10), and control (n=10). However, 2 participants dropped out of the trial from each exercise and control group and did not participate in the post-test examinations. So, 26 participants completed the trial: feedback (n=10), exercise (n=8), and control (n=8). The participants were female athletes between 10 to 14 years old and had a minimum of 3 years of participation in a regular volleyball or basketball training program. The exclusion criteria were having pain in the lower extremity while performing any prescribed exercise protocol, taking painkillers or any type of medicine at the time of the study, having a history of lower extremity fracture, surgery or suffering from lower extremity or spine diseases, ankle or knee sprains in the last 6 months, suffering from cardiovascular diseases, observing signs of postural malalignment based on the New York posture assessment tool, and being absent for more than three nonconsecutive or consecutive sessions. The written informed consent form was signed by the legal parents of the participants. All participants were assured that their data would be kept confidential, and they could leave the study at any time.

The Single-Leg Squat (SLS) screening test was used to determine DKV in the participants. In doing so, the participants performed an SLS trial with 45° to 60° of knee flexion and maintained the reached squat position for 5 seconds while keeping the non-weight-bearing leg with knees flexed behind. They were also asked to keep their hands folded on their chest during the test. SLS test was repeated 3 times by both dominant and non-dominant legs. If the participants at least repeated the SLS test twice with noticeable or significant knee valgus in both legs, they were selected for the study (Noticeable: when the patella is pointing toward the second toe; significant valgus: when the pattela is coming completely inside of the 1sth toe). Intra-rater and inter-rater reliabilities of frontal plane knee motion recognized by the SLS test were 0.88-0.98 and 0.97-1.00, respectively [14]. The study protocol was approved by the Ethics Committee of Biomedical Research Center of the University of Social Welfare and Rehabilitation Sciences after obtaining the ethical code of IR.USWR.REC.1398.007 and IRCT registration number of IRCT20180626040244N1.

Study protocols

The exercise protocols with and without visual feedback were applied during participants' warm-up routines. The participants in both exercise and feedback groups were given the same corrective-plyometric exercise program, while the feedback group received additional visual feedback by practicing in front of a fully mirrored wall. The control group did not receive any intervention but continued their usual training routine. The exercise protocol of both experimental groups lasted 30 minutes per session and was repeated 3 times a week for 6 weeks. The corrective-plyometric exercise protocol design in this study was a combination of plyometric, corrective, closed-kinematic chain, and balance-challenging exercises. During each session, the researcher monitored the participants' performance. If any wrong motion pattern was observed, verbal feedback was delivered to the participants by the researcher once. Before each exercise, the researcher performed and explained the correct and ideal movement to the participants. Comments were made about the spine, hip, knee, ankle, and foot alignments during each exercise. The feedback group had a full front view of themselves in a mirror and could observe their motions thoroughly during the exercises. They were warned to pay full attention to their lower body alignment in the mirror, especially the exhibited DKV alignment. For the first two weeks, the participants practiced landing from a 20-cm height box. From the third to sixth week, they landed from a 30-cm height box. To follow the progression principle of training, the repetitions and sets of each exercise increased gradually during 6 weeks of training. The protocol is presented in detail in Table 1.

Biomechanical instrumentation

Lower extremity kinematic and kinetic data were recorded in the motion analysis laboratory, Department of Physiotherapy, Tarbiat Modares University using eight motion capture cameras, set at 120 Hz (2.2 MP Vero model cameras, Vicon Company, Switzerland), and one in-floor embedded force plate set at 1200 Hz (Kistler, model 9286ba, Switzerland, 40 cm×60 cm). Processing and collecting the raw data were done based on the Vicon plug-in-gait recommended model by Vicon and Nexus software, v. 2.9, and the Euler method was used to calculate rotational angles [15]. Woltring filter with a Mean Squared Error (MSE) of 10 was used to smooth data and fill the gaps under 20 frames. MATLAB (version R2017b) was used to analyze the outputs of the Vicon system. A self-made MATLAB code was developed to detect discrete kinematic and kinetic data at Initial Contact (IC) when the ground reaction forces exceeded 10 N, at Maximum Knee Flexion (MAX), and the maximum knee abduction and tibial external rotation values between IC and MAX during both landing tasks. Positive numbers were considered ankle dorsiflexion, knee and hip flexion, adduction, and internal rotation values, while negative numbers were taken as ankle plantar flexion, knee and hip extension, abduction, and external rotation values. Motion capture and force plate cameras were synched and calibrated based on the Vicon system manufacturing recommendation. Twenty retroreflective markers were placed on lower extremity landmarks based on the modified plug-in-gait marker system: laterally on posterior superior iliac spine, anterior superior iliac spine, lateral thigh, lateral and medial femoral epicondyle, lateral shank, lateral and medial malleolus, second metatarsal head, and calcaneus. Anthropometric data extracted in a static position was then applied to dynamic data.

Tests procedure

All participants were aware of the test procedure before the testing sessions. The dominant leg was determined using a shooting questionnaire test [16]. They were tutored on the single-leg and double-leg landing and dynamic balance tests by the examiner and were given a trial before the actual tests. The participants performed both landing tests from a 30-cm height box located 70 cm behind the force plate center. To execute the double-leg landing test, the participants stood on the box and landed on both feet on the center of the force plate surface after the examiner's order while keeping their hands on the waist during the whole test procedure. To perform a single-leg landing test, the participants stood on their dominant leg on top of the box and kept the non-dominant leg flexed from the knees at 90°. After landing on their dominant leg, they were asked to maintain the landing position steadily for 5 seconds while resting

Table 1. Training program (type of exercises, loading, intensity, and complexity of the protocol increased gradually), numbers indicate sets×repetitions of each exercise

Exercise	First Week	Second Week	Third Week	Fourth Week	Fifth Week	Sixth Week
Box double-leg landing	3×4	3×6	3×8	3×8	-	-
Box single-leg landing	3×4	3×4	3×6	3×6	-	-
Semi-squat	3×8	3×8	-	-	-	-
Static lunges	3×6	3×8	-	-	-	-
Double-leg long jump	1×8	1×10	-	-	-	-
Four direction single-leg jump	2×6	3×6	-	-	-	-
Full squat	-	3×8	-	-	-	-
Squat jump	-	-	3×6	3×8	-	-
Walking lunges	-	-	4×4	4×6	-	-
Triple double-leg long jump	-	-	3×3	4×3	-	-
Zigzag single-leg jump	-	-	3×4	3×6	3×8	3×8
Intermittent box double and single landing	-	-	-	-	3×10	3×10
Single-leg squat	-	-	-	-	3×4	3×6
180◦ squat jump	-	-	-	-	3×6	3×8
Static lunges jump	-	-	-	-	4×4	4×6
Triple single-leg long jump	-	-	-	-	3×3	4×3
Zigzag single Leg jump	-	-	-	-	3×6	3×8

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their hands on the waist. A correct trial was recorded following these criteria: to land with knees flexed as much as possible, to hold the forward-looking posture, to perform jump-landing without an upward or forward jumping, to land on the center of force plate, to perform both tests neither with arm swing nor wobbly landing pattern, and to maintain their balanced landing position for 5 seconds. Both landing tests were performed three times.

Dynamic balance test was performed on a Y-balance kit thrice. The participants were asked to complete the balance test barefoot at anterior, posteromedial, and then posterolateral directions while keeping their hands on the waist during the test procedure. A trial was recorded as a correct one following these criteria: to push the reach indicator pad as far as possible without removing the heels from the kit, to complete the test without losing balance or touching the ground, and not to remove their hand to strive for balance. To score participants' dynamic balance performance in each direction, the proximal edge of the reach indicator pad from the center of the kit was measured in centimeters and normalized to leg length. The average of the three trials in each direction was considered for further analysis [17].

Statistical analysis

Statistical analysis was done using IBM SPSS Version 24. The Shapiro-Wilk test of normality was run to examine data distribution. Two-way repeated-measures ANOVA was used to compare time×group effects. P values less than or equal to 0.05 were considered statistically significant ($\alpha \leq 0.05$). A time-progression chart was used to show pre-test and post-test results changes between groups.

3. Results

Demographic data for each group were as follows: the exercise group (n=8, Mean±SD age=12.12±1.246

Table 2. Kinematic and kinetic data at initial contact, before and after 6 weeks of corrective-plyometric exercises with and without visual feedback

Double-Leg Landing Test	Mean±SD						P
	Pre-test			Post-test			
	Feedback Group (n=10)	Exercise Group (n=8)	Control Group (n=8)	Feedback Group (n=10)	Exercise Group (n=8)	Control Group (n=8)	Sig.
Ankle flexion angle ◦	-21.66±5.16	-22.13±17.7	-18.3±11.47	-20.55±8.34	-19.53±15.5	-25.52±5.26	0.242
Ankle flexion moment, N.mm	-0.026±0.019	-0.021±0.025	0.038±0.269	0.088±0.357	-0.011±0.024	-0.023±0.013	0.423
Knee flexion angle ◦	9.32±9.93	9.14±9.58	18.54±16.28	7.04±11.63	12.03±13.01	9.75±3.25	0.409
Knee adduction/abduction angle ◦	0.58±4.13	2.36±5.1	-0.14±5.19	3.5±1.67	0.7±4.33	1.21±3.78	0.318
Knee internal/external rotation angle ◦	-6.47±8	-9.69±11.94	-7.8±10.18	-14.24±13.8	-3.8±7.89	-10.82±15.16	0.313
Knee flexion/extension moment, N.mm	-0.208±0.086	-0.243±0.135	0.069±0.369	-0.113±0.317	-0.262±0.122	-0.25±0.043	0.026*
Knee adduction/abduction moment, N.mm	-0.058±0.055	-0.037±0.045	-0.036±0.079	-0.038±0.057	-0.022±0.06	-0.024±0.051	0.972
Knee internal/external rotation moment, N.mm	-0.02±0.013	-0.02±0.025	-0.021±0.023	-0.014±0.013	-0.01±0.016	-0.017±0.007	0.925
Hip flexion angle ◦	27.73±7.35	27.37±4.43	27.43±11.4	20.15±14.16	27.04±13.66	23.44±3.35	0.584
Hip adduction angle ◦	-4.45±2.81	-5.63±6.21	-5.18±3.56	-6.22±9.31	-9.82±6.38	-6.63±2.99	0.776
Hip internal/external rotation angle ◦	0.37±14.63	7.72±11.08	-1.16±9.83	-1.05±11.01	-7.89±9	3.21±10.65	0.016*
Hip flexion moment, N.mm	0.229±0.113	0.187±0.196	0.081±0.307	0.215±0.146	0.244±0.217	0.189±0.129	0.676
Hip adduction/abduction moment, N.mm	-0.105±0.048	-0.099±0.074	-0.085±0.041	-0.064±0.08	-0.124±0.073	-0.122±0.022	0.187
Hip internal/external rotation moment, N.mm	-0.015±0.021	-0.025±0.026	-0.016±0.016	-0.026±0.027	0.006±0.038	-0.001±0.012	0.120
Anteroposterior ground reaction force, N	-1.030±2.280	-0.082±1.854	-1.683±3.504	-0.112±1.744	-0.043±2.169	-1.314±3.756	0.812
Mediolateral ground reaction force, N	0.296±0.662	0.499±0.583	0.160±0.413	1.346±4.110	0.677±0.895	-0.082±0.391	0.670
Vertical ground reaction force, N	1.615±5.403	0.227±4.591	7.876±26.313	-1.985±2.060	-2.348±3.063	1.396±7.785	0.832

Data are presented as Mean±SD. *P≤0.05.

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years, Mean±SD weight=42.68±12.663 kg, Mean±SD height=1.508±0.104 m, Mean±SD BMI=18.46±3.319 kg/m²), the feedback group (n=10, Mean±SD age= 12±1.333 years, Mean±SD weight= 41.77±10.758 kg, Mean±SD height= 153.03±12.026 cm, Mean±SD BMI= 17.501±2.601 kg/m²), and the control group (n= 8, Mean±SD age=12±1.095 years, Mean±SD weight= 45.46±8.065 kg, Mean±SD height=151.70±9.058 cm, Mean±SD BMI= 19.62±1.469 kg/m²). No statistically significant differences were observed between the study groups. To summarize the data, the results of this study are divided into kinematics, kinetics, and dynamic balance categories. Although 2-way repeated measures showed to be significant in some variables mentioned below, we did not find significant results between groups differences in the post-hoc analysis. Therefore, we used the time-progression charts representing the changes between groups from the baseline to 6 weeks after the intervention.

Kinematics

Double-leg landing

Hip internal rotation angle at both IC (P=0.016) and MAX (P=0.028) changed significantly (Tables 2 and 3). Based on the time-progression charts, the exercise group

Table 3. Kinematic and Kinetic data at maximum knee flexion (MAX), before and after 6 weeks of corrective-plyometric exercises with and without visual feedback

Double-Leg Landing Test	Mean±SD						P
	Pre-test			Post-test			
	Feedback (n=10)	Exercise (n=8)	Control (n=8)	Feedback (n=10)	Exercise (n=8)	Control (n=8)	Sig.
Ankle flexion angle ◦	19.17±26.12	12.46±16.68	28.90±10.01	40.78±23.14	31.02±4.69	34.09±2.56	0.361
Ankle flexion moment, N.mm	1.396±0.797	0.973±0.689	1.529±0.978	1.202±0.592	1.372±1.019	1.880±0.867	0.480
Knee flexion angle	62.29±36.6	53.1±31.18	77.51±25.67	97.17±20.52	90.9±17.4	96.79±5.03	0.624
Knee abduction angl ◦	-6.09±9.91	-0.78±5.59	-5.79±6.82	-0.06±4.74	-5.66±11.95	-4.19±7.8	0.208
Knee external rotation angle ◦	15.81±19.15	13.35±17.1	17.89±20.92	26.85±16.7	26.41±12.04	22.42±14.64	0.770
Max knee abduction angle ◦	5.61±10.9	11.19±11.64	6.26±11.22	14.29±13.79	11.79±14.62	11±10.15	0.476
Max knee external rotation angle ◦	-6.69±9	-9.83±7.7	-15±8.9	-16.51±12.2	-12.79±15	-13.5±15	0.384
Knee flexion/extension moment, N.mm	0.940±0.813	0.743±0.463	1.243±0.892	1.515±0.604	1.864±0.918	1.556±0.651	0.316
Knee abduction moment, N.mm	-0.08±0.058	-0.052±0.097	-0.03±0.207	-0.062±0.043	-0.063±0.046	-0.054±0.048	0.830
Knee external rotation moment, N.mm	-0.083±0.05	-0.047±0.024	-0.095±0.024	-0.199±0.184	-0.213±0.128	-0.085±0.055	0.233
Max knee abduction moment/N.mm	2.262±1.315	2.302±1.207	2.312±0.702	4.369±1.415	4.896±1.401	3.7±0.963	0.437
Max knee external rotation moment, N.mm	0.939±0.453	0.798±0.563	1.007±0.61	1.703±0.469	1.534±0.175	1.548±0.115	0.782
Hip flexion angle ◦	51.3± 19.85	58.96±24.35	63.36±18.4	73.71±13.02	78.27±17.2	82.06±17.23	0.969
Hip adduction angle ◦	-0.1±5.41	-0.79±8.89	-1.93±5.02	-7.07±3.83	-8.5±6.41	-2.45± 6.3	0.295
Hip internal rotation angle ◦	7.56±14.2	15.77±10.71	7.5±9.71	9.85±11.78	5.93±10.33	10.2±9.81	0.028*
Hip flexion moment, N.mm	2.853±1.673	3.815±1.783	1.971±0.778	3.427±1.329	3.638±1.482	3.406±1.218	0.274
Hip adduction/abduction moment, N.mm	1.775±0.721	1.919±1.82	1.674±0.672	2.881±5.98	3.228±0.732	2.323±0.693	0.671
Hip internal/external rotation moment, N.mm	0.232±0.171	0.242±0.134	0.24±0.115	0.604±0.234	0.646±0.058	0.451±0.161	0.285
Anteroposterior ground reaction force, N	14.336±20.982	6.864±12.440	6.350±5.378	9.377±6.230	10.727±7.923	11.193±8.849	0.375
Mediolateral ground reaction force, N	-1.341±21.796	6.137±3.535	6.466±3.997	18.930±24.139	13.149±6.507	6.741±2.882	0.178
Vertical ground reaction force, N	179.467±126.078	183.953±121.038	218.134±72.224	284.610±81.508	329.374±84.493	279.155±55.261	0.583

Data are presented as Mean±SD; * P≤0.05.

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showed less hip internal rotation angle at MAX. In comparison, the feedback group showed a greater produced angle compared to the control group after the intervention. However, the post-test results of both exercise and feedback groups showed reduced hip internal rotation angles at IC (supplementary file).

Single-Leg Landing

Significant changes at IC were observed in ankle dorsiflexion (P=0.05) and tibial external rotation angles (P=0.012) (Table 4). Maximum tibial external rotation angle between IC and MAX (P=0.042) and hip internal rotation angle at MAX (P=0.022) changed significantly (Table 5). The time-progression chart displayed less tibial external rotation angle at both IC, decreased

Table 4. Kinematic and Kinetic Data at Initial Contact (IC), Before and After 6 Weeks of Corrective-Plyometric Exercises With and Without Visual Feedback

Single-Leg Landing Test	Mean±SD						P
	Pre-test			Post-test			
	Feedback (n=10)	Exercise (n=8)	Control (n=8)	Feedback (n=10)	Exercise (n=8)	Control (n=8)	Sig.
Ankle flexion angle ◦	-12.74±12.62	-28.29±6.53	-15.11±18.66	-15.19±12.24	-13.96±14.65	-23.71±9.46	0.050*
Ankle flexion moment, N.mm	-0.052±0.141	-0.024±0.007	0.092±0.183	0.014±0.145	0.019±0.129	-0.022±0.009	0.138
Knee flexion angle ◦	17.9±21.23	4.56±5.43	14.29±14.13	10.52±7.27	12.89±11.18	8.62±3.69	0.153
Knee adduction/abduction angle ◦	3.34±6.1	0.19±2.48	5.23±7.84	0.53±3.14	-1.36±3.78	0.45±3.84	0.683
Knee internal/external rotation angle ◦	-0.5±14.25	-20.64±13.09	-9.44±14.44	-12.74±14.7	-6.25±15	-13.64±13.98	0.012*
Knee flexion/extension moment, N.mm	-0.262±0.263	-0.443±0.137	-0.225±0.216	-0.341±0.128	-0.306±0.208	-0.408±0.076	0.073
Knee adduction/abduction moment, N.mm	0.034±0.16	0.071±0.0167	0.079±0.105	0.062±0.137	0.089±0.146	0.061±0.06	0.884
Knee internal/external rotation moment, N.mm	0.0007±0.081	-0.0008±0.017	-0.009±0.011	-0.009±0.004	0.001±0.02	-0.007±0.009	0.755
Hip flexion angle ◦	24.15±10.37	22.72±6.26	31.65±13.86	19.47±7.21	22.4±8.55	23.82±5.52	0.516
Hip adduction angle ◦	-4.75±3.52	-5.56±4.38	-8.54±1.69	-8.15±3.27	-7.48±6.35	-9.47±5.16	0.724
Hip internal/external rotation angle ◦	16.45±45.47	6.97±12.03	1.23±13.27	-4.85±12.71	-8.07±9.15	0.76±9.44	0.458
Hip flexion moment, N.mm	0.353±0.403	0.718±0.353	0.575±0.271	0.402±0.253	0.6±0.329	0.565±0.114	0.536
Hip adduction/abduction moment, N.mm	-0.148±0.226	-0.218±0.08	-0.085±0.12	-0.042±0.11	-0.052±0.107	-0.118±0.062	0.142
Hip internal/external rotation moment, N.mm	-0.037±0.087	-0.005±0.027	-0.007±0.016	-0.014±0.021	-0.013±0.059	-0.09±0.029	0.677
Anteroposterior ground reaction force, N	-1.03±1.74	-1.04±1.75	-0.43±1.31	-0.4±1.54	-0.16±2.23	0.29±0.73	0.050*
Mediolateral ground reaction force, N	0.06±1.21	1.2±3.2	-0.24±0.5	0.23±0.68	0.26±0.84	0.15±0.41	0.365
Vertical ground reaction force, N	3.56±11.42	4.28±8.6	16.74±28.73	3.27±13.62	4.54±14.26	-1.24±1.76	0.162

Data are presented as Mean±SD. * P≤0.05.

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tibial external rotation maximum value between IC and MAX, and greater rates of produced ankle dorsiflexion angle at IC in the exercise group after 6 weeks of intervention. While the feedback group showed negative changes in the mentioned variables. Both experimental groups showed less hip internal rotation angle at MAX than the control group in the post-test results (supplementary file).

Kinetics

Double-Leg Landing

Knee extension moment changed significantly (P=0.026) at IC (Table 2). Pre-test to post-test changes in time-development chart showed that feedback group experienced more reduction in knee extension moment, while exercise group had a slight increase in knee extension moment.

Single-Leg Landing

Post-test results showed that anterior-posterior ground reaction force (GRF) at IC changed significantly (P=0.05) in the post-test session (Table 4). Based on the results from the time-development chart, both experimental groups showed decreased anterior-posterior GRF at IC compared to the control group in the post-test.

Table 5. Kinematic and Kinetic Data at Maximum Knee Flexion (MAX), Before and After 6 Weeks of Corrective-Plyometric Exercises With and Without Visual Feedback

Single-Leg Landing Test	Mean±SD						P
	Pre-test			Post-test			
	Feedback (n=10)	Exercise (n=8)	Control (n=8)	Feedback (n=10)	Exercise (n=8)	Control (n=8)	Sig.
Ankle flexion angle ◦	25.24±21.08	18.17±14.92	37.91±27.67	33.04±6.59	31.33±9.46	31.91±4.48	0.235
Ankle flexion moment, N.mm	1.924±1.379	1.433±0.456	1.559±0.522	1.925±0.273	1.977±0.507	2.002±0.329	0.573
Knee flexion angle ◦	64.06±28.21	49.91±17.38	70.4±16.37	70.84±13.04	63.72±12.78	72.43±9.42	0.606
Knee adduction angle ◦	-0.22±6.22	-2.47±5.2	2.28±10.07	-2.88±4.26	-4.55±5.72	-2.42±5.87	0.821
Knee external rotation angle ◦	-7.32±11.89	-21.91±12.63	-13.72±16.36	-15.05±13.01	-9.68±14.12	-15.24±14.47	*0.042
Max knee abduction angle ◦	19.27±14.14	17.48±11.92	16.45±10.84	11.88±11.84	13.67±11.28	18.56±10.59	0.437
Max knee external rotation angle ◦	26.3±11.21	18.35±16.57	32.54±32.49	27.28±15.27	24.95±12.69	26.06±15.59	0.529
Knee flexion/extension moment, N.mm	0.794±0.662	0.789±0.675	0.843±0.323	1.041±0.554	0.933±0.392	0.846±0.283	0.651
Knee abduction moment, N.mm	-0.124±0.15	-0.116±0.202	-0.042±0.146	-0.175±0.208	-0.103±0.14	-0.048±0.146	0.855
Knee external rotation moment, N.mm	-0.037±0.059	-0.041±0.054	-0.036±0.032	-0.015±0.01	-0.065±0.064	-0.034±0.05	0.440
Max knee abduction moment, N.mm	1.196±0.643	1.353±0.828	1.318±0.404	1.53±0.342	2.493±0.436	1.242±0.054	0.530
Max knee external rotation moment, N.mm	0.467±0.668	0.277±0.193	0.423±0.242	0.341±0.092	0.34±0.245	0.39±0.09	0.733
Hip flexion angle	45.78±10.29	53±12.02	59.43±7.29	47.69±14.14	50.85±9.94	66.52±12.33	0.484
Hip adduction angle ◦	5.76±7.3	7.19±3.6	2.85±3.93	5.37±2.67	4.06±6.14	11±12.34	0.074
Hip internal rotation angle ◦	32.78±47.64	21.36±11.31	12.95±12.32	9.41±14.54	11.52±13.59	38.19±46.26	*0.022
Hip flexion/extension moment, N.mm	3.32±2.263	4.066±1.432	2.851±1.563	4.017±2.451	3.863±2.063	3.114±2.271	0.274
Hip adduction/abduction moment, N.mm	1.481±0.923	1.593±0.964	1.314±0.537	1.924±0.311	2.060±0.648	1.607±0.503	0.946
Hip internal/external rotation moment/N.mm	0.056±0.052	0.076±0.051	0.047±0.048	0.131±0.112	0.131±0.057	0.09±0.052	0.814
Anteroposterior ground reaction force, N	4.24±3.64	6.74±3.67	4.95±4.64	11.12±5.03	11.04±8.3	6.7±4.17	0.405
Mediolateral ground reaction force, N	8.97±5.75	13.14±12.19	6.9±2.67	11.74±4.49	12.24±3.36	10.78±8.01	0.595
Vertical ground reaction force, N	233.78±108.41	282.52±112.95	239.77±52.92	306.19±32.5	328±56.7	284.15±23.55	0.825

Data are presented as mean±SD. *P≤0.05.

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Y-Balance

The dynamic balance test results showed significant changes at anterior (P=0.000), and posteromedial directions (P=0.000), and composite score (P=0.023) after 6 weeks of exercise programs. The results did not show any significant changes in posterolateral direction in any group (Table 6). The time-progression chart showed that

Table 6. Dynamic balance data, before and after 6 weeks of corrective-plyometric exercises with and without visual feedback

Test	Mean±SD						P
	Pre-test			Post-test			
	Feedback (n=10)	Exercise (n=8)	Control (n=8)	Feedback (n=10)	Exercise (n=8)	Control (n=8)	
Anterior	81.35±8.2	75.58±6.19	78.88±11.08	87.46±7.7	78.58±5.91	78.84±10.93	0.000*
Posteromedial	83.18±4.38	76.66±4.55	76.87±7.63	89.71±4.06	81.36±5.25	77.09±7.73	0.000*
Posterolateral	88.8±6.05	82.93±4.78	83.66±7.2	91.56±6.72	85.97±4.55	83.7±7.24	0.060
Composite	82.41±7.36	77.05±3.8	79.89±8.22	89.58±5.54	81.97±4.48	79.88±7.28	0.023*

Data are presented as Mean±SD; * P≤0.05. Composite, an average of three directions.

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both exercise and feedback groups had improvements in dynamic balance performance at anterior, posteromedial, and composite scores compared to the control group, as shown in the supplementary file.

4. Discussion

The results of the present study showed that 6 weeks of corrective-plyometric training without visual feedback was effective in improving landing biomechanics and dynamic balance performance in adolescent female athletes with DKV. However, receiving visual feedback from a mirror during exercises is not suggested as a corrective program to modify DKV alignment during landing tasks. Moreover, the participants' dynamic balance was enhanced in both experimental groups. The discussion is categorized to present a better perspective.

Kinematics

Double-leg landing

The kinematic analysis indicated that 6 weeks of the corrective-plyometric training with and without visual feedback resulted in a significant decrease in hip internal rotation angle at IC, by a greater reduction observed for the exercise group. However, hip internal rotation results at MAX were reduced only in the exercise group, while the feedback group post-test results increased.

Single-leg landing

The single-leg landing post-test results showed that both exercise and feedback groups had less hip internal rotation angle at MAX. However, greater ankle dorsiflexion angle decreased tibial external rotation angle at both IC, and the maximum value between IC to MAX was observed only in the exercise group, while the feedback group results showed negative changes in those variables.

The results of our study were consistent with other studies that found plyometric training an effective tool for decreasing hip internal rotation and adduction [18] and knee abduction angle during landing tasks [19]. Based on the documented results, plyometric training in adolescent female athletes may decrease DKV [20]. Furthermore, it is shown that the combination of plyometric and strength training could positively affect lower extremity biomechanics in athletes [21], which is reported to be one of the most effective exercise approaches to reduce the risk of ACL noncontact injuries [22]. It is noteworthy to mention that developing the ability to maintain the correct alignment and proper movement control in the lower extremity by reducing DKV may be achieved by different exercise protocols, which effectively minimize the susceptibility to the injuries [23].

Results from the previous studies have found neuromuscular and plyometric exercises effective interventions to decrease excessive DKV and increase knee flexion in adolescent female athletes [11, 24]. It is also suggested that adding visual feedback to the exercises may improve the effectiveness of the exercise protocol on the biomechanical characteristics [12, 25]. However, there is not enough evidence on the effects of augmented mirror visual feedback therapy applied to exercise protocols on DKV alignment and landing biomechanics. Based on the evidence regarding the other feedbacks, adding visual or verbal feedback to exercise protocols may improve knee joint biomechanics [24, 26]. The current study results were in contrast to a previous study which found that receiving real-time visual biofeedback during exercises could be taken as a corrective training protocol in individuals with DKV [27]. Providing athletes with proper feedback on their performance during

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plyometric exercises may also reduce injuries by improving individuals' control on their alignment during different movements [28].

Kinetics

Double-leg landing

The knee flexion-extension moment results at IC significantly decreased in the feedback group, while the exercise group results tend to rise slightly after 6 weeks of the exercise program.

Single-leg landing

Less GRF at the anterior-posterior direction was observed in both exercise and feedback groups during single-leg landing. Nevertheless, no significant changes in GRF at either vertical or medial-lateral motion planes were found during the landing tasks.

In summary, the outcomes of this study showed that the corrective-plyometric training with and without visual feedback only affected the knee flexion-extension moment and GRF in the anterior-posterior direction. In this regard, a previous study found that a 9-week plyometric training was an effective tool in reducing vertical GRF in female participants [29]. However, the current study results were in contrast to another study which found that 8 weeks of plyometric training was ineffective on GRF values [30].

Dynamic balance

In the current study, better Y-balance test performance was achieved in anterior and posteromedial directions and the overall composite score in the exercise and feedback groups.

The results of this study are in line with a recent study that found the effectiveness of 8 weeks of selective plyometric exercises in increasing Y-balance scores in collegiate female athletes with DKV [31].

Possible Underlying Mechanisms Regarding the Effects of Plyometric Exercise Protocols

The plyometric training has been shown to effectively modify landing techniques by improving feedback and feedforward activities through applying fast forces on muscles and joint receptors [32]. However, only a few studies investigated the underlying mechanism for the effectiveness of plyometric training on lower extremity biomechanics. As one of the main mechanisms, it is suggested that biomechanical and neuromuscular adaptations may occur due to the improvements in the skill learning process developed during ACL injury prevention programs such as plyometric exercises [33]. Moreover, compared to single-leg landing, the current exercise intervention is less effective on the lower extremity biomechanics during a double-leg landing task. Biomechanical analysis of single-leg and double-leg landing tasks suggests that one of the probable reasons behind this difference may be fewer movement errors during double-leg landing. Consequently, more significantly improved variables after the intervention were observed during single-leg landing [34]. For instance, a previous study found more erect landing patterns, including lower knee and hip flexion angles and greater vertical GRF during single-leg landing than double-leg landing [35]. Additionally, greater knee valgus was reported during single-leg landing, which may be another reason behind greater significant improvements during single-leg landing [34].

Possible Underlying Mechanisms Regarding the Effects of Visual Feedback Augmented Exercise Protocols

It is suggested that observing the movements during different physical tasks can help the athletes make better biomechanical alternations in their movements [36]. Movement observation also seems to positively impact the motor function by how the learning mechanism works through the visual-motor system [37] and engages in the motor learning process [38]. However, no evidence supports the biomechanical changes after an augmented visual feedback corrective-plyometric training protocol. It is assumed that shifting individuals' focus to observe their body movements in the mirror may increase movement errors [39]. Accordingly, previous studies showed that using internal focus instructions may negatively affect motor learning in children [40]. Thus, applying visual feedback in the corrective exercises to focus on body movements is not recommended as a corrective approach to address DKV alignment in adolescents.

Study limitations

This study has some limitations. One of those is the inclusion of just female athletes between the ages of 10 to 14. So, further studies on male athletes are needed, as lower extremity motion patterns vary between female and male athletes. In the current study, athletes landed from a 30-cm height box that may differ from real situations in the training sessions or games, and we strongly suggest future studies on the in-field evaluations. Another limitation of this study is the small sample size. For example, the Y-balance result P value in the posterolateral direction was close to the significance level of 0.05, which could be related to the study's small sample size. Based on the power analysis by the significant outcomes of our research, we recommend future studies have a sample size greater than 12 participants in each group.

5. Conclusion

Although we did not find any significant differences between the two exercise protocols, significant positive improvements were observed in landing biomechanics and dynamic balance performance after 6 weeks of interventions. With these results, applying corrective and plyometric exercises augmented with visual feedback is not recommended since it may not be effective enough on adolescents, and clinicians may consider corrective and plyometric exercises without any additional visual feedback an effective protocol for improving DKV posture in adolescent female athletes. But, it should be noticed that the current study was a pilot study in the field, so it is suggested that more studies are needed to clarify the issue.

Ethical Considerations

Compliance with ethical guidelines

The study methodology was approved by the Ethics Committee of the University of Social Welfare and Rehabilitation Sciences and registered with the (Code: IR.USWR.REC.1398.007), at National Research Ethics Committee. Moreover, the study was registered by the Iranian Registry of Clinical Trials with the (Code: IRCT20180626040244N1

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Authors' contributions

All authors contributed to preparing the original idea, writing the manuscript, developing the protocol, analyzing and abstracting data analysis, and preparing the manuscript.

Conflict of interest

The authors declared no conflict of interest.

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