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Title: Perturbation Training Enhances Return-to-Sport Criteria in Female Athletes with ACL Injuries (Copers): A Semi-Experimental Study

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Abstract

Purpose: The anterior cruciate ligament (ACL) of the knee is not only a mechanical stabilizer, but it also provides dynamic sensory feedback that acts in a neuromuscular control function. The purpose of this study was to investigate the effect of perturbation training over 8 weeks on return-to-sport (RTS) criteria in female athletes with ACL injuries classified as "copers."

Methods: In the semi-experimental study, thirty female athletes experiencing unilateral ACL rupture (Coper) were allocated to perturbation training (n=15) and control group (n=15). The intervention group received 8 weeks of perturbation training (3×/week, 60 min), while the control group continued daily activity and did not include any additional training. Outcomes measures included maximum isometric strength of hamstrings and quadriceps (Hand-Held dynamometer), three hop performance tests (Side Hop, Figure-Eight Hop, Triple Hop) and the ACL-Return to Sport after Injury (ACL-RSI) questionnaire. Statistical analyses involved paired t-tests and ANCOVA, and effect sizes (Cohen's d) will be provided

Results: The perturbation group displayed significant increases in quadriceps strength (mean change: +4.5 Nm, p=0.003, d=0.78), hamstring strength (+10.0 Nm, p=0.001, d=1.02), and H/Q ratio (+23%). There were significant improvements in hop performance: side hop (−5.89 sec, p=0.002, d=1.65), figure-8 hop (−6.86 sec, p=0.005), and triple hop (+117.92 cm, p=0.001). The Kyoto ACL-RSI score displayed significant increases by 27% for the perturbation group (p=0.001, d=0.93).

Conclusions: the strength factors enhanced of the hamstrings and quadriceps muscles and the ratio of these two muscles and the functional test of these athletes. thus, Perturbation training improves RTS criteria in female ACL copers, improving neuromuscular performance and reducing the fear of reinjury.

Keywords: Perturbation Exercises, neuromuscular control, Functional Test, Anterior Cruciate ligament, Return to Sport

Highlights

- Perturbation training significantly improves return-to-sport criteria in female athletes with ACL injuries.
- Enhanced neuromuscular control and muscle strength ratios (hamstring-to-quadriceps) were observed after 8 weeks of perturbation training.
- Psychological factors, including reduced fear of re-injury, were positively impacted by perturbation training.

Plain Language Summary

This study shows that a specific type of training called "perturbation training" can help female athletes recover from ACL (knee) injuries and return to sports more confidently. After 8 weeks of this training, athletes not only improved their physical strength and balance but also felt less afraid of getting injured again. This type of training could be a valuable addition to rehabilitation programs, helping athletes regain their performance and confidence on the field.

Introduction

The lower body is the most affected in all age groups and functional levels of exercise, with the knee and ankle joints being the most affected (1). Approximately 200,000 to 250,000 ACL injuries occur annually in the United States(2). Approximately half of the people who suffer from ACL rupture develop osteoarthritis after 5 to 12 years, regardless of the type of treatment (surgical or non-surgical). In anterior cruciate ligament injury, the maximum isokinetic strength of the quadriceps and hamstring muscles changes relative to the normal position(3), as well as muscle activity patterns (timing and activity rate) during functional activities such as walking and jumping(4, 5). Knees with ACL defects are prone to recurrent semi-dislocations, which can be a factor in secondary joint injury (6) .These findings imply that anterior cruciate ligament injury of the knee affects neuromuscular function. Functional tests include the jump test and measurement of isokinetic strength of knee flexors and extensors, and are among the methods used to evaluate the effects of anterior cruciate ligament injury and determine the effectiveness of treatment programs on the neuromuscular function of the knee(7, 8). The changes observed in muscle activity patterns in people with ACL injury are strategies that occur to compensate for the decrease in knee stability. It seems that some people with anterior cruciate ligament injury of the knee successfully compensate for the defect that has occurred, which is called the Coper group, while others are unable to compensate for the defect that has occurred, which is called the non-Coper group(9). The Coper group has a physiological response and motor strategy that is closer and similar to healthy people and can return to high-level physical activity, but the non-Coper group may have difficulty even performing low-level activities such as walking (10). This is especially important for female copers, who may return to high-level activity without surgery, but face significant physical and mental barriers. According to previous research, one type of exercise that helps modulate neuromuscular risk factors is Perturbation training, which is designed according to specific training programs to enhance neuromuscular control, thereby helping to reduce the risk of ACL injury by improving the dynamic stability of the knee (11). Perturbation training is a type of neuromuscular intervention that involves applying controlled, unpredictable disturbances to the body's balance and joint stability using tools such as rockerboards or rollerboards. In some studies, following the use of perturbation exercises, an increase in the co-contraction rate of the vastus lateralis muscle and the medial part of the gastrocnemius muscle, as well as no change in the co-contraction rate of the vastus lateralis muscle and the external part of the hamstring, has been reported(12). While ACL injury prevention programs have made progress, ACL ruptures are still common in sports. In populations with ACL injuries, perturbation-based neuromuscular training has been demonstrated to enhance knee mechanics and functional performance(13) . Despite the fact that fear, confidence, and other psychosocial factors are known to have a significant impact on returning to sport, the majority of current research focuses on physical outcomes and hardly ever examines psychological factors. Although no psychological measures were included in the analysis, a recent perturbation-training trial in adolescent females reported that participants felt more confident after training (14). Therefore, this study aimed to evaluate the effectiveness of an 8-week perturbation training protocol on neuromuscular performance and psychological readiness to return to sport in female ACL copers.

Methods

This is a semi-experimental study using the pre-test and post-test design. The goal of this study is to assess the effects of an experimental perturbation-type training intervention. This study was approved by the Ethics Committee of, Khorasgan (Isfahan) Branch Azad University (Code: IR.IAU.KHUISF.REC.1402.361). The sample size was calculated with G*Power 3.1 with alpha =

0.05, power = 0.80, and effect size = 0.8 (using quadriceps strength as a measure). Therefore, a total of 30 participants were needed. No blinding was used for the assessors or the participants. A total of 30 athletes with mild to moderate unilateral anterior cruciate ligament (ACL) injuries were included in the study. All patients were diagnosed and referred by an orthopedic surgeon based on clinical examination and MRI findings. Individuals were excluded if the injury had occurred more than six months prior, if they had concurrent injuries to other ligaments, significant meniscal or articular cartilage damage, a history of knee surgery, or presented with acute pain, swelling, or joint locking.

After familiarizing the participants with the study protocol, the Fitzgerald protocol was used to classify the patients as "copers." Initial assessments included: The rapid successive hop test over a 6-meter distance (timed 6-meter hop test), the score on the activities of daily living scale, the overall knee function score using a visual analog scale for pain, and the number of knee giving-way episodes since the injury(15).

Participants were classified as "copers" if they met the following criteria: a 6-meter hop test score greater than 80%, a daily living activity scale score of at least 80%, an overall knee function score of at least 60%, and no more than one episode of knee giving way since the injury [12].

A group of participants underwent perturbation training (experimental) (Appendix 1), while the control group did not receive any intervention (control). Following pre-test assessments, the experimental group took part in an 8-week program, with three one-hour sessions per week focused on training with non-linear periodization, specific exercises, and adherence monitoring. Both groups completed a post-test after the training. Psychological factors and fear of re-injury were evaluated using the ACL-RSI questionnaire. The ACL-RSI was administered as a self-report measure in Persian, with an ICC of 0.90 (14). Total IL-18 R expression was positively correlated with total IKDC scores, SF-12 scores, and all KOOS subscales ($P < 0.001$), and negatively correlated with TSK scores. These findings suggest that the Persian version of the ACL-RSI is a suitable scale for use in Iran. This 12-item tool includes five items assessing motivation, five items related to perceived self-confidence in performance, and two items concerning perceived risk.

The isometric strength of the quadriceps and hamstrings was measured using a MMT handheld dynamometer (HHD, USA; 90-99% CI). Participants sat without back support, with hips and knees flexed at 90 degrees and feet dangling. They were instructed to actively extend their knees against resistance. A band was secured around the anterior lower leg and attached to a movable base under the chair. Participants were asked to push against the dynamometer pad as hard as possible and attempt full knee extension. Rest periods of 30 seconds were provided between efforts to prevent muscle fatigue. Isometric strength was recorded as the highest force generated during three maximum efforts, and the average of these was used for analysis. The dynamometer was placed 2 cm proximal to the ankle during measurements. Hamstring strength was assessed with participants in a supine position on an examination table, asked to perform knee flexion as quickly and forcefully as possible.

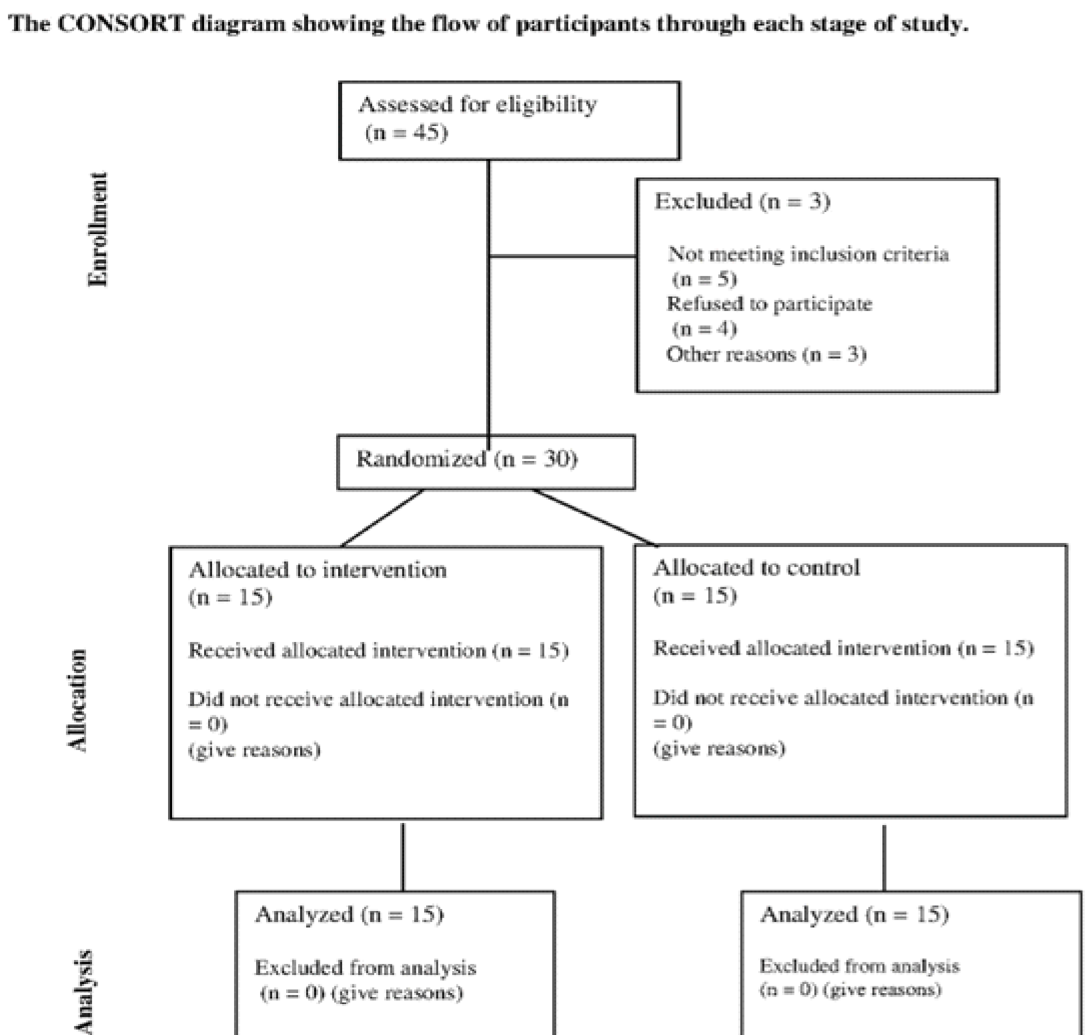
Three-hop tests, previously shown to be reliable predictors of functional performance and readiness to return to sport, were conducted. Each test was performed twice, with the best result recorded.

Side Hop Test: Participants performed a single-leg side hop, timed while completing ten hops on the lower-performing limb, crossing two lines on the floor that indicated hop distance. Any contact with arms or traps for balance resulted in disqualification [15].

Figure-Eight Hop Test: Participants completed a figure-eight hop as fast as possible on one leg, completing two laps around two cones spaced 5 meters apart in a figure-eight pattern.

Triple Hop Test: This test measured the maximum distance of three consecutive hops in a straight line on one leg. A standard cloth tape was placed on the ground opposite a starting line. Participants stood with toes on the starting line and performed three maximal forward hops, arm swing allowed. The distance from the starting line to the heel after the third hop was measured. Participants had two practice trials per leg, followed by three test trials. Practice was limited to prevent fatigue. If a participant couldn't complete three consecutive hops without losing balance or touching the ground with the opposite leg, the trial was repeated. The longest distance across these trials was recorded in centimeters. Participants wore their own athletic footwear during testing [17].

Figure1. The CONSORT chart



Statistics analyses

To analyze the functional performance, psychological factors, and muscle strength data, paired t-tests and one-way ANOVA were employed. Shapiro-Wilk and Levene's tests were used to assess normality and homogeneity of variance, respectively. Effect sizes (Cohen's *d*) were calculated to assess clinical significance. All statistical analyses were conducted using SPSS version 26.

Results

Table 1 presents the mean and standard deviation of the athletes' demographic data, including height, weight, and age.

Table 1: Descriptive Statistics of Participants' Demographic Data

Variable	Group	Mean ± SD	P-value
Age (years)	**Experimental**	23.85 ± 4.10	0.923
	Control	24.72 ± 3.79	
Height (CM)	**Experimental**	162.73 ± 4.87	0.824
	Control	161.82 ± 4.91	
Weight (KG)	**Experimental**	66.36 ± 8.46	0.875
	Control	67.28 ± 7.65	

To assess normality, the Shapiro-Wilk test was employed, and Levene's test was used to evaluate the homogeneity of variances. Given that the significance values were greater than 0.05, the null hypothesis for both normality and homogeneity of variances was not rejected. Therefore, the assumptions of ANCOVA were met.

Table 2. ANCOVA and Paired *t*-test Results for Muscle Strength and H/Q Ratio

Variable	*Group*	*Pre-test mean ± SD (sec/cm)*	*Post-test mean ± SD (sec/cm)*	*95% CI*	*F(1,27)*	*p-value*	*Paired t-test (p)*	*Cohen's d*
Quadriceps Strength (N)	**Experimental**	66.92 ± 9.26	69.97 ± 7.23	69.97 ± 4.00 → (65.97, 73.97)	7.12	.012*	3.63 (.003*)	0.75
	Control	65.65 ± 4.36	66.03 ± 6.63	66.03 ± 3.67 → (62.36, 69.70)			0.71 (.489)	0.10
Hamstring Strength (N)	**Experimental**	34.71 ± 7.14	44.69 ± 6.94	66.03 ± 3.67 → (62.36, 69.70)	16.85	<.001*	6.49 (.001*)	1.42
	Control	34.55 ± 5.53	35.61 ± 6.13	35.61 ± 3.39 → (32.22, 39.00)			1.30 (.213)	0.25
H/Q Ratio	**Experimental**	0.52 ± 0.09	0.64 ± 0.07	0.64 ± 0.039 → (0.60, 0.68)	14.79	<.001*	5.86 (.001*)	1.38
	Control	0.53 ± 0.08	0.54 ± 0.08	0.54 ± 0.044 → (0.50, 0.58)			1.04 (.314)	0.16

Note. ANCOVA controlled for pre-test scores. * $p < .05$ indicates significance. CI = Confidence Interval; H/Q = hamstring-to-quadriceps ratio.

After 8 weeks of perturbation training, the experimental group showed statistically significant improvements in quadriceps strength, hamstring strength, and the hamstring-to-quadriceps (H/Q) ratio compared to the control group. Quadriceps strength increased by an average of approximately 3 Nm (p = 0.012, d = 0.75). Hamstring strength experienced a more substantial improvement of about 10 Nm (p < 0.001, d = 1.42). The H/Q ratio increased from 0.52 to 0.64 (p < 0.001, d = 1.38), indicating improved muscular balance, which is essential for knee stability and injury prevention. No significant changes were observed in the control group.

Table 3. ANCOVA and Paired *t*-test Results for Functional Hop Tests

Test	*Group*	*Pre-test mean ± SD (sec/cm)*	*Post-test mean ± SD (sec/cm)*	*95% CI*	*F(1, 27)*	*p-value*	*Paired t-test (p)*	*Cohen's d*
Side Hop (sec)	**Experimental**	25.34 ± 4.73	19.45 ± 2.41	19.45 ± 1.33 → (18.12, 20.78)	12.34	.002*	4.01 (.002*)	1.46
	Control	24.93 ± 9.30	23.37 ± 3.03	23.37 ± 1.68 → (21.69, 25.05)			1.11 (.294)	0.21
8-Figure Hop (sec)	**Experimental**	27.55 ± 7.12	20.69 ± 6.90	20.69 ± 3.82 → (16.87, 24.51)	9.06	.006*	3.28 (.005*)	0.96
	Control	26.55 ± 5.53	25.21 ± 8.72	25.21 ± 4.85 → (20.36, 30.06)			0.84 (.412)	0.18
Triple Hop Distance (cm)	**Experimental**	305.47 ± 71.30	423.39 ± 32.42	423.39 ± 17.96 → (405.43, 441.35)	22.91	<.001*	8.21 (.001*)	2.15
	Control	306.76 ± 76.30	305.45 ± 43.30	305.45 ± 23.99 → (281.46, 329.44)			0.29 (.776)	0.02

Note. ANCOVA controlled for pre-test performance. Lower times and greater distances indicate better performance. * $p < .05$ = significant**.**CI = Confidence Interval.

The perturbation training group showed significant improvements in all three functional hop tests: Side Hop Test: Completion time decreased notably (−5.89 sec, p = 0.002, d = 1.46), indicating better agility and lateral control. Figure Hop Test: Time improved by approximately 6.86 seconds (p = 0.006, d = 0.96), reflecting improved coordination and neuromuscular response. Triple Hop Distance: Participants in the experimental group jumped about 118 cm farther after training (p < 0.001, d = 2.15), demonstrating increased power and lower limb control. Meanwhile, the control group showed no significant improvements.

Table 4. ANCOVA and Paired *t*-test Results for ACL-RSI Questionnaire Scores

Group	*Pre-test mean ± SD*	*Post-test mean ± SD*	*95% CI*	*F(1,27)*	*p-value*	*Paired t-test (p)*	*Cohen's d*
Experimental	55.28 ± 35.55	70.42 ± 24.70	70.42 ± 13.67 → (56.75, 84.09)	11.72	.002*	4.15 (.001*)	1.06
Control	53.24 ± 28.53	54.29 ± 38.54	54.29 ± 21.33 → (32.96, 75.62)			0.56 (.586)	0.08

Note. ACL-RSI = Anterior Cruciate Ligament Return to Sport after Injury. * $p < .05$ indicates statistical significance. CI = Confidence Interval.

Psychological readiness, measured by the ACL-RSI questionnaire, significantly improved in the perturbation group (from 55.28 to 70.42; p = 0.002, d = 1.06), indicating that perturbation training helped reduce fear of re-injury and increased self-confidence. No significant change was observed in the control group.

Discussions

In the study, the results indicated a significant difference between the muscle strength of the quadriceps and hamstrings in the groups related to perturbation training and those related to the control groups. Following eight weeks of perturbation training, an experimental group showed higher average strength than the control one for those two muscles, as well as a rise in the hamstring to quadriceps ratio, showing ($p < 0.05$).

The findings of this study are consistent with those of previous research conducted by Rahimi et al. (2014) [19] and Ramírez-delaCruz et al. (2022) (16). Our results showed a statistically and clinically significant improvement in H/Q ratio following perturbation training. This is consistent with Letafatkar et al (2015) (17), who observed improved knee flexion angle and co-contraction in female athletes.

A balanced ratio of hamstring to quadriceps strength is essential for reducing lower extremity injuries, particularly those involving the knee. For instance, Kanoos Vargas et al. reported a hamstring-to-quadriceps strength ratio of 0.5 to 0.8 in female athletes(18). Similarly, Van Dyk et al. suggested a minimum hamstring-to-quadriceps ratio of 0.6 to prevent hamstring strains and tears(19). The low pre-test hamstring-to-quadriceps strength ratio in participants may be attributed to the nature of the three sports involved: volleyball, handball, and basketball. It might also be that the repeated jumping and landing characteristic of these sports results in disproportionately stronger quadriceps muscles.

In a similar vein, according to many researchers, the neuromuscular training method is important for enhancing joint stability, determining optimal muscle activation patterns, and correcting muscular imbalances. Perturbation training, as a subcategory of neuromuscular training, especially induces these physiological adaptations(6, 20-22). An increase in the strength ratio of hamstrings to quadriceps increases knee flexion angle and reduces the risks of ACL injuries among athletes. Generally, excessive force exertion on the ACL is due to improper quadriceps activation. Hamstring muscle contraction can counteract this effect (22). Additionally, appropriate co-contraction of the hamstrings can help balance quadriceps activation and thus contribute to controlling excessive valgus moments at the knee (23).

The results of this study indicated a significant difference in return-to-sport performance test scores between the perturbation training group and the control group. Specifically, the experimental group demonstrated significantly better performance on the side-to-side hop, 8-figure one-leg hop, and single-leg triple hop tests compared to the control group. After six weeks of perturbation training, athletes in the experimental group completed the side-to-side hop and 8-figure one-leg hop tests in less time and covered a greater distance in the single-leg triple hop test compared to the control group ($p < 0.05$).

The findings of this study are consistent with previous research conducted by Abbaszadeh et al, (24), Takazouno et al (25), and Lagersted et al (26). Perturbation training, a subset of neuromuscular exercises, can enhance an athlete's biomechanics. These exercises introduce controlled destabilizing forces that challenge balance and stability, compelling the knee to engage compensatory mechanisms at the joints. This process reduces the co-contraction of muscles, facilitates a full range of motion, and improves proprioception, agility, and balance (15). Chamiluski and colleagues reported that perturbation training enhanced the strength of non-coper athletes and improved the activity of muscles around the knee (4).

The mechanism of perturbation training enhancing performance in non-coper athletes may relate to the critical part of the brainstem muscle reflex. Sensory input from joint mechanoreceptor and subsequent balance reflex facilitates co-contraction at around the knee, minimizes excessive stress, and protects joint limiting factors against injury. Such exercises promote this kind of balance reflex involving the brainstem for maintaining posture. Consciously, at the cortical and cerebellar levels, through the efforts of the athlete joint position and balance is restored. Zigzag tests would, therefore, require neuromuscular coordination joint stability, strength, and power at the knee, ankle, and hip, as all these are put together during this test- an extended form of this test is utilized subsequent to rehabilitation in ACL. Also, Zigzag test measures sensitivity up to 88% to predict normal knee functioning. These are the progressions that could result due to removal of constraints in the sensory-motor system. The sensory-motor system involves mechanisms related to the reception of sensory stimuli, conversion of those into afferent neural signals, and generating responses to motor needs for muscular activation to accomplish functional activities and stabilize the joints (27).

Significant differences between ACL-RSI results with the control group and that with perturbation training could be obtained. In our study, the average scores of the athlete members of the perturbation training group were highly different from those athletes constituting the control group. Viewed from a statistical perspective, $p<0.05$ serves as evidence that such is true. Additionally, such findings are in agreement with the results of other studies by Zia et al. (28); Nazari et al. (29); and Karimi et al (30). but disagreed with the results proposed by Gholami et al.(31). These findings of differences may be explained with regard to the study's protocol and age range- enrolled participants aged 18- 45 years. No injured athlete will deny having a fear related to re-injury. Fear can be excessive and irrational and prevents people in general from engaging in exercise altogether (31). The fear of re-injury is considered to be one of the most significant factors in the return of an athlete to sport, hence also forming part of injury prevention and rehabilitation (26). This fear may lead to destitute performance and a decay in specialized aptitudes. It could be a strong factor within the rehabilitation preparation and encompasses a noteworthy impact on the choice of whether an athlete with an ACL tear returns to sport (32). Therefore, psychological aspects need to be addressed in rehabilitation programs, and the mental attitude of the athlete is crucial. The results indicate that the perturbation training may reduce the fear of re-injury in athletes with past ACL tear experiences, due to the fact that unstable conditions in performing the exercises develop an increase in self-confidence of the person and create a full awareness of physical capabilities, and thus they may be ready to feel more comfortable going back into sport (33). While ACL-RSI scores improved, we did not correlate these directly with physical performance. Psychological readiness may have improved due to increased confidence from unstable-task training (34). In light of these findings, perturbation training needs to be considered a useful supplement to ACL rehabilitation regimens, especially for athletes hoping to resume sports. Reducing the fear of reinjury is particularly important for injury prevention and psychological preparedness. Study limitations were small sample size, lack of blinding, no long-term follow-up, and Exclusively female athletes from three certain sports, volleyball, handball, and basketball, had this work executed on them without considering other confounding variables such as extracurricular physical activities, nutrition, sleep patterns, and psychological states. In so doing, generalizing the results may be restricted.

Conclusion

8 weeks of perturbation training improved RTS outcomes in female ACL copers. Athletes showed ~30–40% better hop test performance and a 27% increase in psychological readiness. These findings suggest that incorporating perturbation exercises in rehab may accelerate safe return to sport. As a practical suggestion, rehabilitation specialists and coaches can consider the inclusion of perturbation training into their treatment paradigm.

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Authors' Contributions:

Abouzar Saadatian: Conceptualization, methodology design, data analysis, manuscript drafting.

Elahe Siavashi: Participant recruitment, data collection, and interpretation of results.

Ayoub Hashemi: Supervision, literature review, statistical support, manuscript editing.

Rosul Abdolghader Alhamodi: data collection, Training protocol development, critical revision of the manuscript, and final approval.

Conflict of Interest

The authors declare no financial or personal relationships with other individuals or organizations that could inappropriately influence this work

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Conflict of Interest Statement: The authors declare no financial or personal relationships with other individuals or organizations that could inappropriately influence this work

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Appendix 1. Perturbation Training Protocol

Technique	Sets/Duration	Direction of Board Movement[a]	Application
Rockerboard	3–4 sets/2 min each	A/P, M/L	Begin in bilateral stance for first session; perform in single-leg stance for remaining sessions
Rollerboard/platform	3–4 sets/2 min each, perform bilaterally	Initial: A/P, M/L Progression: diagonal, rotation	Subject force is counter-resistance opposite of rollerboard, matching intensity and speed of application so rollerboard movement is minimal; leg muscles should not be contracted in anticipation of perturbation, nor should response be rigid co-contraction
Rollerboard	3–4 sets/60 s-1 min each	Initial: A/P, M/L Progression: diagonal, rotation	Begin in bilateral stance for first session; perform in single-leg stance for remaining sessions; perturbation distances are 2.54–5.08 cm (1–2 in)
Early Phase [sessions 1–4)			
Treatment goals: • Expose athlete to perturbations in all directions • Elicit an appropriate muscular response to applied perturbations (no rigid co-contraction) • Minimize verbal cues			

Technique	Sets/Duration	Direction of Board Movement[a]	Application
Middle Phase (sessions 5–7)			
Treatment goals: • Add light sport-specific activity during perturbation techniques • Improve athlete accuracy in matching muscle responses to perturbation intensity, direction, and speed			
Late Phase (sessions 8–10)			
Treatment goals: • Increase difficulty of perturbations by using sport-specific stances • Obtain accurate, selective muscular responses to perturbations in any direction and of any intensity, magnitude, or speed			

A/P=anterior/posterior, M/L=medial/lateral.