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Research Article

Changes in the Trend of Walking Motor Control in Athletes with Anterior Cruciate Ligament Deficiency in Response to Progressive Perturbation Trainings

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Abstract

Background and Purpose: The beliefs are that sudden and unpredictable balance disturbance by instruments that cause mechanical perturbations can affect individuals with Anterior Cruciate Ligament Deficiency (ACLD) to reach faster and more effective recovery of knee dynamic stabilization strategies to return successfully pre-injury levels. The aim of this study was to investigate the effect of mechanical perturbation training and standard training in the process of changes in motor control during walking task in coper ACLD individuals.

Methods: Thirty athletes with a unilateral rupture of the Anterior Cruciate Ligament (ACL), classified as coper, were randomly assigned to perturbation and standard training groups. Intervention training results based on comparison of scores obtained from functional tests in 4 single-leg jump tests, scores of questioners, and surface Electromyography (sEMG) tests were determined between the two groups as well as between the two healthy and ACLD limbs in each group in the walking task.

Results: The perturbation training group showed a significant increase in muscle activity in both healthy and ACLD limbs with an increase in similarity index (SI) (p=0.08, ES=0.81), while in the standard training group the results were not significant (p=0.39, ES=0.39).

Conclusion: Individuals in the perturbation training group achieved higher scores on all tests compared to the standard training group. This means that the perturbation training group was more mentally and physically prepared in terms of strength, coordination and symmetry between the two limbs to participate in pre-injury sports levels.

Keywords: ACLD; Perturbation training; Walking task; Voluntary response index

Abbreviations

ACLD: Anterior Cruciate Ligament Deficiency; sEMG: surface Electromyography; SI: Similarity Index; CNS: Central Nervous System; ES: Effect Size; VRI: Voluntary Response Index; SENIAM: Surface Electromyography for the Non-Invasive Assessment of Muscles; RVi: Response Vector; PRVi: Prototype Response Vectore

Introduction

Anterior Cruciate Ligament Deficiency (ACLD) is one of the most common knee injuries in sports activities among young athletes [1] in the age group of 16 to 39 years with an estimated incidence of approximately 85 per 100,000 [2]. Commonly the following things have been reported to happen after an ACLD: reduced quadriceps strength [3-7], decreased knee function [4-6], deficits in proprioception and balance [6], abnormal gait patterns [4,5,7-10], asymmetry in both limbs [4,5], knee instability in daily and functional activities [1,4,5,11], reduction in range of motion [5], defective biomechanics [1], secondary knee injury and progression of osteoarthritis in the knee joint [1,4-6,8-10] due to its repetitive dynamic instability [1] all of which have imposed a lot of time,-socio-economic [12], as well as psychological [13] burdens on these patients.

In several studies, persistent abnormal changes in the kinematic and kinetic patterns of the lower limbs in gait activity have been reported following ACLD, which have still existed despite reconstructive surgery compared to healthy individuals [8,9]. Magnitude of shearing forces due to giving way and compressive forces caused by increased co-contractions happen in these individuals on areas of the joint's cartilage that were not previously under load while walking, and the result is the occurrence of early degenerative changes in the knee joint [8-11].

Typically, reconstructive surgery is the selective treatment for athletes who want to return to high levels of sports (including jumping, cutting, and pivoting) to avoid secondary joint damage. However, several recent studies have showed successful non-surgical treatments at higher levels of sports [2,4]. Numerous studies have established documented non-surgical treatment algorithms for perturbation rehabilitation in ACLD patients [1,3-5,12,14], from which long-term success has been reported in patients returning to regular high levels of recreational or sports activities that require jumping, changing direction and rotation [14,15]. Perturbation or

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neuromuscular training improve the dynamic stability of the knee joint and normalize movement patterns of the knee while walking [3-5,12]. Studies on perturbation have shown that by stimulating the visual, vestibular, and proprioceptive systems, body sway increases, and by repetition, the Central Nervous System (CNS) tries to optimally balance mechanisms by reinforcing two feed-forward and feedback control strategies [16]. This model of neuromuscular control training helps to regain the lost coordination, balance, strength and skills by strengthening the joint muscles co-contraction, especially in the stabilizing muscles, to stimulate the stabilization reflex and prepare for the activity while creating functional stability of the joint by stiffening it [17]. In most studies, perturbation trainings have been used manually in different directions [1,11,12,14,15], and in recent studies, mechanical perturbation exercises have been used in limited directions. In the comparison results, it has been reported that mechanical perturbation trainings are preferable to the manual forms [1,4,5].

Surface Electromyography (sEMG) has been commonly used for more than 50 years in research studies of functional activity as well as gait [18,19]. Recording sEMG during voluntary motor work is relatively easy and non-invasive, and provides a quantitative measurement of the output of the CNS to the muscle. It is a reliable method for assessing altered motor control [20], and is commonly used in dynamic tests in ACLD individuals [18]. In most previous studies in the field of sEMG, muscle activity levels have been assessed on a muscle-by-muscle basis in a task, and mainly examined the on-set/off-set of muscle activity and the intensity of activity [21]. Due to the inherent limitations of sEMG recording and measurement during voluntary movement, attempts to quantitatively analyze motor control while walking are still unsuccessful [20]. In recent sEMG studies, instead of measuring the activity of each muscle alone, the EMG activity of all the muscles responsible for the activity as a whole is quantitatively measured in the work pattern. This type of measurement has a more objective evaluation, and it is called the Voluntary Response Index (VRI) [18,20]. All studies in this field have shown that this method has a high sensitivity in detecting altered patterns of muscle activity in people with movement disorders and has a high validity [21]. By studying the available articles, the effectiveness of manual and mechanical perturbation training for non-surgical treatment of ACLD individuals has been determined [1,3-5,11,12,14,15], although issues still exist in the employment of the training protocols regarding the use of specialized personnel, and the timings as well as characteristics of manual and instrumental training [1,4,5].

The aim of this study was to use internal-external mechanical perturbation training with a new training approach in all directions and at relatively high speeds similar to the occurrence of real events under controlled laboratory conditions in ACLD individuals. In this study, we want to compare ACLD individuals in two groups of internal-external mechanical perturbation training and standard training with each other as well as with their healthy limbs. It is hypothesized that with this treatment, the walking patterns of ACLD individuals become more synchronized and we can define a new approach to perturbation training in these individuals.

Methods

Participants

Thirty people (17 men and 13 women in the age range of 18 to 40 years) with complete unilateral rupture of the anterior cruciate ligament of the left knee were selected from the athletes referred to the clinic of the Sports Medicine Federation of the Islamic Republic of Iran (SMFIRI). All participants were first diagnosed by an orthopedic surgeon through clinical tests and MRI images and then referred to a sports physiotherapist to evaluate the inclusion and exclusion criteria. Then, they were randomly assigned to the perturbation training group (15 people) and also to the standard training group (15 people). This study was approved by the ethics committee of the Sports Sciences Research Institute (SSRI), (Approval ID was: IR.SSRC.REC.1399.095) and all participants accepted and signed the consent form to participate in this study before entering the study.

Training interventions

Standard group: The training protocol of this group was cardiovascular, lower extremity muscle strength, balance, core stabilization, agility and sport-specific exercises (according to Table 2). The training program of this group of participants was performed for 3 intermittent sessions at week for a month.

Perturbation group: In the perturbation group, a perturbation plate was used that created movements on all motion plates (angular, horizontal, and vertical), and the simultaneous combination of all horizontal, vertical and angular modes was used.

This device was used in two ways; As a means of dynamic warming up of the muscles of the participants in the closed chain of motion in the front-right and front-left angular movement axes (as an internal-perturbation training), and, as a stimulus to induce unpredictable postural neuromuscular reactions in participants (external-perturbation training or main training). In participants who were randomly assigned to the perturbation group, exercise therapy was performed alternately for one month and three sessions per week as follows (according to Table 3):

(1) Warm-up stage (Internal-perturbation training). In this stage, the participant first rode a stationary bicycle for five minutes, then he/she stood in the functional position on the pre-prepared Exe-balance and tried to apply push on the device in the adjustment directions (in two angles; front-right and front-left), and did this for 15 reps in each direction at the maximum speed and power he/she could create in his/her muscles. This internal-perturbation exercise was repeated immediately for three times in both directions (Figure 1). Therefore, that the participant first did 15 repetitions with maximum speed on the right and immediately did 15 repetitions with maximum speed on the left and did the same thing alternately for the next two repetitions. The time interval between the exercises for each side was considered as the rest time for the other side. Then the participant descended from the device and rested for one minute, during which time the physiotherapist adjusted the device to perform an external-perturbation exercise.

(2) Main exercise stage (External-perturbation training) - At this point, the participant stood on the Exe-Balance device, and the physiotherapist randomly unpredictably disturbed the participant balance, who was trying to maintain his/her postural stability in

Figure 1: The figures show the general panel of the Exe-balance device and the perturbation plate, as well as two protective handles mounted on the wall for the participant to hold if they feel unbalanced. The right shows a participant standing on the perturbation plate while flexing his knees to achieve more stability, and the left shows a standby participant standing with extended knees on the plate.

different directions of the device and the participant's attempt to maintain his/her postural stability was suddenly disturbed. A total of 90 training attempts were considered for each participant at this stage, with a break for one minute between all 30 exercises.

(3) Cool-down stage- After performing the internal-external perturbation exercises, all participants cooled for 10 minutes.

Characteristics of Exe-balance instruments

To perform this study, a device that creates perturbations in all motion plates was designed, built, and nationally registered under the contract name "Exe-balance". The design of the device mechanism, in engineering terms, was the design of a rigid plate with six degrees of freedom of movement in space. Four pneumatic jacks in a special design were used to control and move the plates of the device. Each degree of freedom of movement was controlled separately by special joysticks. The diameter of the circular set was considered to be 65 cm. The degree of freedom of movement of the device was as follows: vertical displacement (up and down): 0-20 cm, angular displacement (sides): 0-20 degrees, translatory displacement (horizontal): 0-10 cm, and rotational displacement around itself: 20-25 degrees. All of these displacements could be adjusted at desired angles and in combination with each other. The values of the given displacements were determined according to the range of normal values of stability in the human body according to Shumway Cook et al. [22], so that the normal limit in front and rear balance was equal to 12.58 degrees and for lateral balance was set as 16.8 degrees. In this design, both values were considered to about 5 degrees higher to apply slightly more pressure to further strengthen the upper, lower limbs and trunk.

In this study, the Exe-balance device was used in two different modes when the person was standing on it: (1) active mode of the device: The device does not provide resistance to the person and the joystick of the device is in the hands of the therapist to create sudden perturbations in the desired directions (used in the practice phase as external-perturbation training), and (2) reinforcement mode or passive mode of device: The device resists at every 6 degrees of freedom of movement of the athlete (i.e. the device tends to return to its original position) (used in the warm-up phase as internal-perturbation training), and in this study only two front-right and front-left angular directions were used.

Testing

Participants received objective assessments in the form of functional tests (hop tests) and sEMG tests of eight muscles in each lower limb, as well as subjective assessments by using the Persian version of the KOS-ADLS, IKDC 2000, and Tegner questionnaires in the form of pre-test (one to two days before starting the intervention training program) and post-test (one week after the end of the intervention training sessions) was performed.

sEMG tests

All sEMG signal recordings were made using the Data LOG, Biometrics Ltd England. Preamplifier bipolar active electrodes (Type NOS. SX230, Biometrics Ltd) with a fixed center-to-center interelectrode distance of 20 mm, recording diameter of 10 mm, with a gain of 1000, the input impedance of 1015 Ω, common-mode rejection ratio of 110 dB at 60 Hz, and bandwidth of 20-450 Hz and ground electrodes were located on the preferred wrist. Participants were asked to shave their lower limbs the day before the test. The sEMG electrodes were placed parallel to the gluteus maximus, gluteus medius, vastus medialis, vastus lateralis, medial hamstring, lateral hamstring, medial and lateral gastrocnemius fibers separately, once on the lower right limb and once again on the left, according to the SENIAM electrode protocol placement (Surface Electromyography for the Non-Invasive Assessment of Muscles) (SENIAM, 1999). Data were taken at 1000 Hz sampling rate for offline analysis.

To perform the gait test, each participant was asked to stand on the marked line and walk the marked path at a normal walking speed with his/her head held high and looking forward. Each participant started walking at the tester's command and walked four steps. The sEMG recording characteristics and the four walking lengths of each participant were stored in 3 walking series to be used in the analysis. The tests were repeated for the opposite limb.

In order to compare the motor control changes of the walking task by using sEMG data between the two study groups (Inter-group) and also to compare between two limbs in each group (Intra-group), the root mean square (RMS) of each muscle was first calculated as the muscle response (R1, R2, R3, R4, R5, R6, R7, and R8). Then, the normalize response was measured by ratio between each response (R1, …R8) to vector of base line correction of each muscle to RMS of rest activity Ri as Equation (1).

Summation of all muscle normalize response (Rnorm) was named as Response Vector (RVi) and average of them was Prototype Response Vector (PRVi). Above calculation for all three groups (healthy, ACLD in two different treatments) were measured. Then the ratio between multiplied of RVi and PRVi (ACLD groups) to RV and PRV of healthy group, separately, indicated SI for each ACLD to healthy, Equation (2). The Voluntary Response Index (VRI) was calculated from multiply of magnitude to SI (RV*SI) for each groups [20].

RVs of all eight muscles in the healthy and ACLD limbs of the participants in the two groups were separately placed in Equation (1), and the PRV for both limbs in the walking task were calculated from the average of three attempts that indicated the magnitude of all muscles used (eight muscles) in walking task. Magnitude is the RV that is equal to the total amount of sEMG recorded from the walking

Table 1: Characteristics of groups in terms of age, weight, height, BMI, pain scale and gender.

	Perturbation group			Standard group			Inter Group
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**P-Value differences**
Age (year)	32.93	5.15	24-39	23.6	2.32	21-29	*0.002
Weight (kg)	69.3	7.51	57-83	76.75	7.03	62-90	0.66
Height (cm)	172	3.25	168-178	180	7.3	170-194	*0.004
BMI	23.38	2.27	26.4-19	23.45	1.65	20.2-26	0.17
Pain scale	5.6	1.5	7-Feb	3.13	1.35	0-5	0.68
Gender	6 female–9 male			7 female–8 male			

Table 2: Guidelines for progression of training in standard group.

Type of training	Activities	Timing	Difficulty progression
Cardiovascular	• Stationary bike • Stepper • Outdoor running	• 10 minutes • 5 minutes • 30 minutes	• 60 to 80 rpm • up to 10 minutes • flat ground to uphill

Lower extremity muscle strength	• NMES
	  • Standing squat (0 to 80 degrees)
	  • Sitting (90 to 35 degrees of knee extension)
	  • SLR (0 to 45 degree of hip flexion)
	• Weight machines
	  • Extension & flexion leg curls
	  • Leg press
	• Elastic bands
	  • Hip movements in four directions
	  • Terminal knee extension
	• Lunges
	  • Forward
	  • Side
		• 10 minutes (10 seconds contraction, 15 seconds rest)
		• 15RM, 5 sets, 10 reps
		• 3 sets, 10 reps
		• 3 sets, 10 reps
			• without to weight cuffs
			• two leg to one leg
			• low to high strength
			• without to elastic bands

Balance	• Circular balance board
	  • Straight knee
	  • Semi squat knee
		3 sets, 30 seconds	eyes open to close eyes

Core stability	• Plank • Crunch • Side planks • Leg scissors crunch • Single leg bridge	• 3 sets, keep within tolerance for seconds • 3 sets, 10 reps	• Increase holding time
Agility	• Running fast in all directions with sudden starts and stops • 8-figure running • side sliding to the right and left with sudden stops • fast forward and backward shuttle run with sudden starts and stops • 45 degree cutting spinning drill	Tolerate speed training without pain or apprehension	To full speed
Sport-specific	• Routine sport form	Tolerate practice without pain or apprehension	Gradually to full sports specific skills

task in microvolts and is equal to the denominator in Equation (2). The SI between two limbs in both groups was calculated by using Equation (2) and its value is a number between zero and one, and the value of one indicates the complete similarity between the two limbs.

In sEMG calculations, healthy limbs in both groups were considered as prototypes for comparisons. Base line correction in the SI equation was calculated based on the average muscle activity at rest, immediately one second before the start of each walking maneuver. Then, the calculated magnitude (microvolts) and SI were plotted in both limbs and in both groups as x and y pairs in a two-dimensional coordinate (VRI) for walking task [18-20].

$$R_{norm} = \frac{(R_1 R_2 R_3 \ldots R_n)}{\sqrt{\sum_i R_i^2}} \quad (1)$$

$$SI = \frac{\sum_i (RViPRV_i)}{|RV||PRV|} \quad (2)$$

Equation (1) quantitatively shows the normalization of the RV of n muscles during motor tasks (Ri: RMS of each muscle, and the magnetite is equal to the denominator of the task in the same equation). Equation (2) shows the SI of the muscle group in a task. RVi: is the RMS equivalent of each muscle, and PRVi is the PRV of each muscle group in the task.

Statistical analysis

To compare the effect of therapeutic intervention inter-groups in the post-test and the studied variables we used independent t-test with Sig 2-tailed acceptance in normal distribution and Mann-Whitney test in abnormal distribution. Paired t-test (in normal

Table 3: Guidelines for progression of training in perturbation group.

Type of training	Activities	Timing	Difficulty progression

Warm-up (Internal-perturbation)	• Stationary bike
	• Internal perturbation
	  ◦ Front-right
	  ◦ Front-left
		• 5 minutes
		• 3 sets, 15 reps alternately for each sides, maximum speed & power
			-

Main exercise (external-perturbation)	• Therapist randomly & unpredictably disturb participant balance in different directions:	Suddenly & randomly, every 30 attempts, 1 minutes rest, low speed of change perturbation, focus with look at the plate (Internal attention), keep handles, eyes open, training without pain or apprehension	• increase speed of perturbation
	◦ Front-right angle ◦ Front-left angle ◦ rear-down angle ◦ antero-posterior horizontal ◦ Medio-lateral horizontal ◦ Up-down ◦ combination of six above modes		• look forward and straight the head (external attention) • release handles • Close eyes

Cool-down	• Static stretching movements
	  ◦ Hamstrings
	  ◦ Quadriceps
	  ◦ Triceps-surae
	• Stationary bike
	• Ice pack for knees
		• 3 sets, 15 seconds for every part
		• 5 minutes
		• 15 minutes
			-

distribution) and Wilcoxon test (in abnormal distribution) were used again for comparing intra-groups pretest-posttest. Then, to evaluate the effectiveness of the therapeutic intervention for the tests that showed a significant difference in their comparison results, effect size Cohen's d test (ES). In statistical analysis, a significance level of 0.05 was selected in all cases. For statistical analysis we used IBM SPSS Statistics Version 22.

Results

Questionnaires

The results of inter-group comparison of questionnaires in the post-test showed a significant difference between the IKDC 2000 questionnaire (p=0.001) and the exercise and recreation section of the KOS-ADLS questionnaire (p=0.04), meaning that the perturbation exercise treatment method significantly improved small ES in IKDC 2000 and a medium ES in exercise and recreation in the perturbation group. Also, according to the results of Table 4, both groups achieved a higher significance status in the intra-group. ES showed a significant increase in intra-group comparison in both groups, which is higher than in the perturbation group.

Functional tests

According to the results of Table 5, the two groups were not homogeneous in comparison with the pre-test and the standard group was in a better status. In the comparison between pre and post-tests intra-groups, the participants in the perturbation group showed significant progress in all four functional tests on the injured leg. Also, significant progress was showed in the healthy leg of the participants in the perturbation group in the tests of "A straight triple hop for distance" and "6-meter timed hop". However, in the standard group, significant improvement was observed only in the healthy leg and only in the "6-meter timed hop". In the intra-group comparison, ES showed medium to large improvement in the perturbation group but did not show improvement in the standard group.

sEMG analysis of walking test

In the comparison inter-groups in the pre-test, there was a significant difference only in the VRI of the healthy leg (p=0.04), which was higher in the standard group and in other items, the two groups did not differ in the pre-test.

In the post-test comparison inter-groups, both groups showed a significant difference in all the studied variables. The perturbation group in the post-test had a higher average SI (0.58 ± 0.18) than the standard group (0.42 ± 0.19). Furthermore, the perturbation group achieved significantly higher VRI in post-test of both legs than the standard group. ES showed a large increase in SI inter-group comparison and a huge effect in VRI in both legs (Table 6).

In the intra-group comparison, the perturbation group in the post-test showed a significant improvement with a huge effect of ES in the VRI variables in both legs.

Discussion

Suitable individuals to participate in this study were copers who were selected by the protocols of previous studies [2,14,15]. In the results of statistical analysis on walking task sEMG variables, the two groups of perturbation and standard were homogeneous in the pre-test comparison and did not differ from each other. However, after therapeutic training interventions, significant differences were found between two groups in SI and VRI in both legs, so that in inter-group comparisons perturbation training in all variables founded large to huge effects in both legs. According to the findings of the present study, the amount of SI in the walking task increased in the perturbation group and the VRI of the injured limb was extended to the PRV of the healthy limb. sEMG patterns increased after intervention in both limbs of the perturbation group, and symmetry was obtained between the two limbs in the walking task. However, in the post-test of the standard group, although the VRI of the injured limb was extended to the PRV of the healthy limb of the same group, the SI in this group showed a small decrease in ES due to a decrease in muscle activity in the healthy limb and an increase in moderate activity of muscles in the injured limbs. As a result, in the perturbation group, the increase in muscle activity in both limbs was associated with an increase in SI, but in the standard group, a small decrease in muscle activity in a healthy limb and a small effect in muscle activity in an injured

Table 4: Comparison of intra-group and inter-group questionnaires of Tegner, IKDC 2000 and KOS-ADLS and interpretation of the effect size of therapeutic interventions on the questionnaires.

			Tegner	IKDC 2000	KOS-ADLS				
					I*	II*	III*	IV*	V*
Perturbation group	Pre-test	M	2.6	51.47	27.9	29.72	51.48	27.33	30.91
		SD	0.63	9.8	17.38	18.11	16.63	7.98	14.93
	Post-test	M	7.6	74.87	68.36	69.64	84.83	65.66	57.33
		SD	1.05	5.2	14.45	12.03	9.11	9.97	10.67
	P-value intra-group		*0.001	*0.000	*0.000	*0.000	*0.000	*0.001	*0.001
	ES Cohen's d		5.94	3.09	2.62	2.69	2.57	4.58	2.05
Standard group	Pre-test	M	4.47	58.16	44.19	44.86	59.63	40.33	43.64
		SD	1.55	11.56	22.24	24.75	20.43	14.81	21.28
	Post-test	M	6.8	66.47	62.5	63.31	83.28	63.26	58.44
		SD	1.2	10.11	16.35	16.7	8.21	17.6	17.11
	P-value intra-group		*0.001	*0.000	*0.000	*0.000	*0.000	*0.001	*0.001
	ES Cohen's d		1.74	0.79	0.97	0.9	1.57	1.36	0.79
Inter Group differences	P-value	Pre-test	*0.000	0.34	0.29	0.36	0.31	*0.02	0.06
		Post-test	0.06	*0.001	0.72	0.24	0.59	*0.04	0.27
	ES Cohen's d		0.73	1.08	0.39	0.77	0.18	0.83	0.29

I* Discomfort and stiffness, II* Pain, III* Daily activities, IV* Exercise and recreation, V* Quality of life, M: Mean, SD: Standard deviation.

Table 5: Comparison of intra-group and inter-group of functional tests and interpretation of the effect size of therapeutic interventions.

			Single-leg hop for distance		A straight triple hop for distance		A triple cross-over hop for distance		6-meter timed hop	
			Right	Left	Right	Left	Right	Left	Right	Left
Perturbation group	Pre-test	M	1.11	1.09	3.35	3.35	3.52	2.98	3.54	4.61
		SD	0.17	0.25	0.97	1.07	0.84	0.87	0.41	0.42
	Post-test	M	1.22	1.29	3.94	4.21	3.82	3.86	2.78	2.82
		SD	0.21	0.39	0.77	1.52	0.91	1.4	0.36	0.72
	P-value intra-group		0.09	*0.05	*0.01	*0.02	0.31	*0.01	*0.001	*0.008
	ES Cohen's d		0.6	0.63	0.7	0.67	0.35	0.79	1.99	3.13
Standard group	Pre-test	M	1.46	1.37	4.69	4.42	4.15	3.76	2.16	2.44
		SD	0.21	0.3	0.61	0.66	0.63	0.33	0.3	0.6
	Post-test	M	1.47	1.39	4.72	4.41	4.48	3.74	2.09	2.34
		SD	0.23	0.32	0.65	0.49	0.61	0.31	0.27	0.53
	P-value intra-group		0.53	0.29	0.51	0.93	0.9	0.31	*0.03	0.08
	ES Cohen's d		0.05	0.07	0.03	0.02	0.02	0.06	0.22	0.24
Inter Group differences	P-value	Pre-test	0.47	0.61	*0.007	*0.01	0.29	*0.002	0.6	0.19
		Post-test	0.06	0.64	0.08	0.77	0.16	0.84	*0.004	0.22
	ES Cohen's d		1.18	0.29	1.13	0.19	0.9	0.13	2.28	0.78

M: Mean, SD: Standard deviation.

limb was associated with a decrease in SI. Thus, although symmetry between the two limbs was obtained in the post-test of both groups, the muscle activity in the walking task in the perturbation group was significantly higher than the standard group.

According to studies, few studies have been conducted in the field of walking activity in ACLD individuals and the calculation of overall muscle activity, and most studies have examined the kinetic and kinematic components in more details. Preliminary studies of perturbation trainings performed on ACLD individuals with the goal of returning to high levels of exercise without surgery by Fitzgerald et al. showed that athletes in 93% of cases reporting no successful GW professionally returned to sport while only 50% of participants in standard training protocols were able to return to previous activity levels [11,14]. So, the documented non-surgical treatment algorithm for ACLD individuals is enhanced perturbation rehabilitation [4,5]. Because by doing perturbation training, the afferent pathways that provide information to the muscle spindles are stimulated, and as a result, joint stability is improved by increasing the activity of gamma-motor neurons and increasing the sensitivity and readiness of the muscle spindles in response to disruptive forces [3,12,14].

Table 6: Intra-group and inter-group comparison of sEMG variables in walking test.

			SI*	M-A*	M-nA*	VRI-A*	VRI-nA*
Perturbation group	Pre-test	M	0.45	10.29	13.21	4.55	5.46
		SD	0.15	2.11	5.75	1.64	2.11
	Post-test	M	0.58	28.53	30.67	18.55	19.24
		SD	0.18	14	14.14	14.18	14.77
	P-value intra-group		0.08	*0.000	*0.000	*0.003	*0.002
	ES Cohen's d		0.81	1.89	1.67	1.43	1.35
Standard group	Pre-test	M	0.48	9.59	16.11	4.9	7.74
		SD	0.18	3.7	4.78	2.78	3.51
	Post-test	M	0.42	12.17	12.7	5.14	5.13
		SD	0.19	4.13	4.61	2.81	2.53
	P-value intra-group		0.39	0.17	*0.02	0.85	*0.05
	ES Cohen's d		0.39	0.68	0.75	0.09	0.89
Inter Group differences	P-value	Pre-test	0.52	0.53	0.14	0.68	*0.04
		Post-test	*0.03	*0.000	*0.000	*0.001	*0.001
	ES Cohen's d		0.89	1.64	1.77	1.36	1.38

SI*: Similarity Index; M-A*: Magnitude of Affected Limb; M-nA*: Magnitude of non-Affected Limb; VRI-A*: Voluntary Response Index Affected Limb, VRI-nA*: Voluntary Response Index Non-Affected Limb; M: Mean; SD: Standard Deviation.

Researchers have shown in previous studies that perturbation training, compared with strength training alone, causes limb symmetry in walking and increases quadriceps strength in both limbs, which is also present in the six-month follow-up after surgery [3]. Studies have also shown that perturbation training improves the gait patterns of potential copers by creating dynamic stability in the knee [1,3-5], and improves the gait deviations in non- copers(3), these results were similar to the results obtained in our study in the form of an increase in the SI of the two limbs in the perturbation group.

Yim et al. showed that ACLD knees in the stance phase of walking shift the tibia more anteriorly with less extension in the sagittal plane [6], and people with ACLD may position their knee into more external rotation to prevent excessive motion into internal rotation in the frontal plane [6,10]. In this study, individuals adopt their gait biomechanics to avoid these anterior and rotational instabilities in turning maneuvers, and reduced the range of motion of ACLD knee by freezing movements in the horizontal plane during the stance phase as an adaptive reaction to prevent further knee vulnerability [6]. In contrast some studies did not exhibited any gait deviations in ACLD knees on the sagittal plane compared with controls [10]. In addition, some studies have shown that ACLD individuals have an increase in the activity of the knee flexors in the stance phase of walking to prevent the tibia from moving forward, causing degenerative shear forces in the knee joint [1,6,23], and adopted a changed gait pattern called quadriceps avoidance associated with decreased quadriceps contraction [8].

With progressive perturbation training, symmetry of both limbs and stability of the knee increased with increasing co-contraction index and the decrease of flexion in the knee joint in the stance phase of gait and the ACLD limb becomes similar to healthy individuals and is a positive adaptation to increase knee joint stability [1,5]. Increased co-contraction is a positive factor and means dynamic stiffness of the knee, which occurs during the functional activities of the normal mechanics of the knee and is associated with a decrease in torque and movement of the knee [1]. In contrast, Chmielewski et al. showed that perturbation training with neuromuscular changes caused the reduction of co-contraction in the muscles around the knee, and in the post-test walking task, knee flexion angles increased in order to adapt to unpredictable surfaces, which was in contrast to the results of other studies that believed that co-contraction would also increase [11].

Another important approach in ACLD individuals is quadriceps muscle strength deficiency [3-5,8], which is one of the main causes of osteoarthritis of the knee and gait disorders and functional defects [1,3]. When the symmetry of the two limbs increases, the injured limb can resist high-risk physical activity and the risk of osteoarthritis is reduced [4]. It has also been reported that by performing perturbation training, in addition to improving neuromuscular control, an increase in strength is observed, especially in the quadriceps muscle [4,11].

In our study, the kinematic components of gait activity were not examined, however, the results of the study showed that mechanical perturbation training increased the overall stability of the knee joint and increased the symmetry between the two limbs by increasing the overall muscle activity. Perhaps the symmetry created in the walking task can be defined as a kind of muscle co-contraction, and the overall increase in muscle activity in the walking task can be considered as an increase in strength and stability in the knee joint. However, due to the lack of information on co-contractile gait in ACLD individuals, judgment is difficult and requires further study.

In several studies, the effects of manual and mechanical perturbation training have been investigated, and all of these studies have confirmed the long-term effectiveness of perturbation trainings [1,3-5,7,11,12,14,15]. The use of manual perturbation training in clinics is done one by one and depends on the presence of a therapist and spending a lot of time for treatment is mandatory. In addition, because these types of manual perturbation training can only be performed on limited motion axes and cannot simulate normal functional movements such as jumping and changing directions, researchers have always been looking for more appropriate mechanical perturbation training substituting manual types in the literature. Usually, these manual types of training are not used or are rarely used in clinics due to their difficult use. On the other hand, mechanical perturbation rehabilitation programs, which are controlled and progressive perturbations, are now included in rehabilitation programs and have better results than manual perturbation trainings [1,4,5]. therefore, in comparative studies between manual and mechanical perturbation trainings, the researchers showed that Both perturbation training modes improved the patients' self-reported of knee functional performance and helped walking with more knee flexion excursion and moment [7]. On the other hand, by performing mechanical perturbation training compared to manual perturbation, gait symmetry is improved in individuals and knee stability is increased by reducing flexion in the knee joint in the stance phase in the ACLD limb similar to healthy individuals [5], and also increasing co-contraction in larger muscles and more muscular forces are produced during walking [1], although it has been pointed out that the benefits of this stability are not clear.

In our study, only the perturbation mechanical machine was used and we did not have a manual perturbation training group to compare. However, the results of our study showed that mechanical perturbation training increases the stability of the knee joint by increasing the distribution of overall muscle activity. The results obtained in this study, in line with previous studies [1], suggest that perturbation training on mechanical plates with the production of greater muscle force while walking can be effective in transferring to other more complex motor activities. Also, one of the advantages of unpredictable mechanical training is achieving dynamic knee stability and functional knee function in less time and less labor force [4,7].

Compared to previous studies, with the present study, it can be said that none of the devices that created mechanical perturbation included all the axes of motion and were often limited to one or two axes of motion. In the present study, however, a device was used that produced unpredictable perturbations in all motion axes that had not been studied in previous studies. However, the perturbation instrument in this study has newer capabilities that can be performed both in the closed movement chain of functional exercises and is effective on all joints of the trunk and lower limbs, as well as rapid motor reactions to provides compensation in maintaining the center of mass at the base of support to maintain balance. Also, studies suggest that it is better to use perturbation tools in training that are both mechanical and not habitual, because habitual phenomena reduce muscle strength. It is thought that by the use of this perturbation training device, the adaptation that typically occurs in the first and second attempts at the use of steady manual and mechanical perturbations [24], does not occur and this requires further study.

Also, in a review of questionnaire studies and functional tests, researchers have shown that ACLD individuals undergoing perturbation treatments show improved limb symmetry in functional activity and improved knee function [4], and these findings were in line with the results of our study. Although the two training groups were not homogeneous in the pre-test questionnaire studies, and the standard group had a higher quality questionnaire, but in the

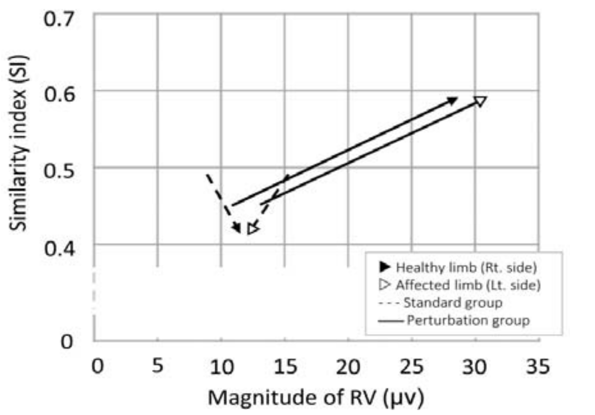

Figure 2: Changes in the VRI in response to walking task in perturbation training group and standard group of both ACLD and healthy limbs. The direction of the arrows shows the trend of changes from the beginning to the end of the sEMG tests. Continuous lines indicate the perturbation training group and dotted lines represent the standard training group. A solid arrow indicates a healthy limb and a hollow arrow indicates an ACLD limb. In the plot, the ACLD limb in the perturbation group is drawn towards the healthy limb response pattern, and both limbs show a similar increase in the size of the response vector. However, the plot clearly shows a negatively decrease in the magnitude of response vector of the ACLD limb towards the healthy limb in the standard group.

post-test comparison of the perturbation training group, there was a moderate increase achieved in the sports and recreation section of the KOS-ADLS questionnaire and a small increase in the IKDC 2000 questionnaire. This means that perturbation trainings were much better than standard trainings in improving a person's mental health to reach previous levels of exercise, and these results were consistent with the results of functional tests in our study.

Moreover, in the evaluation of functional tests, the perturbation group in the ACLD limb showed significant improvement even though no significant improvement was seen in the standard group (Figure 2). These results show that perturbation trainings are preferable to strength, endurance, neuromuscular, balance and agility exercises alone, and perhaps one of the reasons is the presence of cognitive characteristics in this type of exercise and this requires further studies. According to research by Zhang et al. when perturbations are not visually predictable, strong predictive activity occurs and latencies in the tested muscles become shorter, meaning that unexpected postural perturbations with increase in cognition load improves body stability after perturbation [25].

Conclusion

The results of this study showed that the post-test perturbation training group achieved an increase in muscle activity in both ACLD and healthy limbs with huge ES and also showed a significant increase in the amount of SI between the two limbs. The symmetry obtained between the two limbs in the perturbation group occurred with a significantly great increase in muscle activity in both limbs. Perhaps the results of this study can be interpreted to mean that by performing internal-external mechanical perturbation trainings, due to increase of SI and strength due to increase of all RV of all muscles in both limbs, coordination is increased in parallel. In addition, the results of the present study showed that all participants in both perturbation and standard training groups made good progress in terms of questionnaires and functional tests, and this improvement was higher in the perturbation training group. Therefore, participants in the perturbation training group achieved a higher level of mental and objective preparation compared to the standard training group. We think that, training on perturbation devices similar to the present study can help the body adapt more quickly to compensatory motor responses at complex levels and sudden events, and is highly challenging.

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