April 2023, Volume 17, Number 2

Journal of Modern Rehabilitation

Research Article

Postural Stability Changes Following Static Loading in Athletes with and without Anterior Cruciate Ligament Reconstruction

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Citation: Ferdowsi F, Shadmehr A, Mir SM, Olyaie G, Keyhani S. Postural Stability Changes Following Static Loading in Athletes with and without Anterior Cruciate Ligament Reconstruction. Journal of Modern Rehabilitation. 2023; 17(2):172-180. https://doi.org/10.18502/jmr.v17i2.12415

doi **https://doi.org/10.18502/jmr.v17i2.12415**

Article info:
Received: 11 Aug 2021
Accepted: 25 Dec 2021
Available Online: 01 Apr 2023

Keywords:

Anterior cruciate ligament reconstruction; Creep;Integration; Reintegration; Constant load; Postural stability

ABSTRACT

Introduction: This study investigated the effect of change in postural stability after applying static load during internal perturbation among professional athletes with and without anterior cruciate ligament (ACL) surgery.

Materials and Methods: The participants of the present study were 20 athletes with sixteen months post ACL reconstruction surgery and 20 healthy matched athletes. Each participant performed transitional tasks from double limb stance to single leg stance (SLS) and again to double limb stance on the force plate before and after the application of 10 minutes of constant loading. Area, fore-after range (the meaning of fore-after is anterior-posterior and in articles, this term has been used instead of anterior-posterior) range fore-after (Rfa), range sideway (Rsw), mean velocity (Mv) and confidence ellipse (Ce) of the center of pressure were measured.

Results: Rsw ($P=0.009$) and area ($P=0.009$) in response to static loading in the healthy group showed a decrease and an increase of area ($P=0.009$) in response to static loading in the ACLR group was seen on the double limb stance phase. Mv ($P<0.001$) and area ($P<0.001$) were bigger in the ACLR group after static loaded on the integration phase.

Conclusion: Decreased capacity of passive structures to maintain postural stability against perturbation was observed due to positional change among athletes with a history of ACL reconstruction surgery.

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1. Introduction

The anterior cruciate ligament (ACL) is the most common knee injury ligament, especially in sports activities such as jumping- landing, pivoting, and changing directions. A total of 1-2.5% of ACL's volume is enriched from mechanoreceptors and it is known as an important sensory-motor component of the postural control system [1]. Complete rupture of the human ACL occurs in 1725 (N) stress level and causes range of motion limitations, functional and mechanical instability, decreased functional capacity to do activity daily living, sports and recreational activities, and postural control disorder [2]. ACL reconstruction (ACLR) is done to restore the mechanical stability of the knee using the patellar or hamstring tendon [3].

Postural control is the foundation of voluntary motor skills and it is the key structure to perform successful ADL and sports activities which is integrated with sensory input harmony from vestibular, visual, and somatosensory systems. Impaired postural control in ACLR subjects in the operated and non-operated leg has been shown in previous studies [4].

Repetitive or prolonged stresses due to different ADL and sports activities apply cyclic or constant loading on passive structures of joints. If these loadings continue over time, structural elongation occurs which means creep [5]. Creep leads to decreasing ability of the ligament to produce enough tension on initial length, and cartilaginous force distributions are disturbed. A decrease of reflex arc sensitivity initiated from the mechanoreceptor's ligament due to creep causes failure in appropriate and timing feedback reactions on abrupt perturbation situations. Proprioception and kinesthesia functional impairments are other side effects of the creep phenomenon. All of these events lead to postural control impairments and subsequently increase musculoskeletal injuries [6].

The reconstructed tissue has a lower recovery potential from creep than normal tissue because of the structures of reconstructed tissue change in graft materials, an increase of infiltration of scar tissue, and the increase of matrix destruction) [7].

Past studies showed abnormal laxity of the ACLR knee joint after two years of surgery. They stated that unrecovered creep after joint functional activities or overloading rehabilitation processes leads to these phenomena [8].

The literature showed postural control (PC) impairments in ACLR subjects. Previous studies review the effect of constant loading on viscoelastic tissues in the lumbar, ankle, and knee. The result of these studies indicate changes in muscle timing responses, neuromuscular changes as spasms, and changes in the PC system [9]. A single study assumed the effect of applying constant loading on ACL when healthy subjects were done gait initiation and there was no difference in PC behavior [10]. The cause of this result may be related to constant loading or selective tasks that could not challenge the PC system due to constant loading. New approaches to pc evaluation use weight shift tasks from double limb stance (DLS) to single limb stance (SLS). Integration-reintegration of limb subjects exposed to internal perturbation and postural stability is influenced during standing on one leg. The results of these studies showed PC impairments in chronic ankle sprain (CAS) and ACLR subjects [11]. Until now, no study has reviewed the effect of the intervention, for example, constant loading on PC parameters in ACLR subjects. The role of viscoelastic tissues in providing PC changes may be observed clearly in ACLR subjects when the tissues are exposed to constant loading. So, the aim of the present study is the comparison of postural stability changes following static loading in athletes with and without ACLR.

2. Materials and Methods

A total of 40 male soccer players (20 ACLR had undergone reconstruction surgery by a single orthopedic surgeon in a similar fashion hamstring tendon graft and 20 healthy controls) voluntarily participated in this study. The patients were referred from the University Hospital Orthopedic Center, and the controls were the patients' teammates. Age, height, and weight between the groups were not statistically significant (Table 1). In addition, all of the athletes scored 9 physical activity levels according to Tegner's questionnaire. The ACLR group included athletes with a history of unilateral ACLR, at least six months before testing who had returned to their sports activities. If the athletes reported neurological or orthopedic problems and visual and vestibular dysfunctions, they were excluded. All testing procedures were briefed for athletes and asked to read and sign a consent form that was approved by the Ethics Committee of Tehran University of Medical Science (Ethics Code: IR.PUMS.VCR.REC.1395.1551).

Procedure

Each athlete was asked to perform the integration-reintegration dynamic balance task before and after the intervention by the same tester. The result of the reliability of the postural parameters of the present study was published later [12]. All measurement was repeated 3 times before intervention and average scores were used for analysis. All measurements were repeated immediately after intervention only for one repetition (repeated 3 times before the intervention to show the reliability of the test). We matched the affected (operated) legs with non-preferred (so weaker) legs of controls and the

Table 1. Demographic characteristics of subjects in the experimental groups

Variables	Groups		t	P
	Mean±SD			
	ACLR (n=20)	Healthy (n=20)		
Age (y)	27.15±3.75	26.15±3.18	0.9	0.37
Height (cm)	185.00±4.69	183.95±4.12	0.75	0.45
Weight (kg)	84.75±5.47	82.45±4.32	1.47	0.14

ACLR: Anterior cruciate ligament reconstruction.

non-affected (non-operated) legs with preferred (stronger) legs of controls.

Postural task

In this study, the weight shift task procedure was based on a method designed by Dingenen et al. [13]. Each athlete was instructed to stand 25 seconds on double legs with eyes open at a fixed point localized on a facing wall at the center of a single force platform while keeping the arms along the body and barefoot distance from each other as wide as two hip joints (90×90 cm, Bertec Columus, OH, USA). Next, the athletes were asked to do the transition to SLS on their testing leg while they maintained 60^0 hip flexion for 30 seconds. Finally, the athletes transfer to DLS for 5 seconds while they were placed in starting position. It is necessary to mention that the integration phase was considered the first 5 seconds of the SLS phase and the reintegration phase was regarded as the last 5 seconds of the total testing procedure (Figure 1). The transition task from DLS to SLS was performed with the preferred speeds of athletes. The sampling frequency was set at 500 Hz and a low-pass filter with a cut-off frequency of 10 Hz was used to compute the following variables: center of pressure (COP) displacement for range fore-after (Rfa), and range sway (Rsw), mean velocity (Mv) of COP and confidence ellipse (Ce) of COP [14].

Intervention (loading protocol)

Each athlete was seated on a chair. The angle between the lumbar and the joint was fixed on 1350 flexion. The testing leg was placed on 100^0 knee flexion (by handmade goniometer) and fixed in this position for 10 minutes with the strap drawn up from the anterior aspect of the ankle joint to the chair seated. This position was similar to the anterior drawer test and the leg's weight led to getting anterior shear force to the knee joint. During the loading protocol, the athlete was relaxed and avoided muscle activity (Figure 2).

Statistical analysis

SPSS software, version 17 was used for statistical analysis, and 20 athletes were considered in each group based on a pilot study. The level of significance was set at 0.05 and the power was assumed 0.95.

To compare the postural performance before and after intervention in the DLS phase, paired t-test was used. Also, an independent t-test was conducted to determine the difference before and after intervention in ACLR and healthy groups separately. In the following, to evaluate the postural performance in SLS (integration, SLS, and reintegration phase) separate 2×2×2 (group by limb by constant load) mixed model analysis of variance (ANOVA) was used to determine the main effects and interaction of 3 factors for each postural

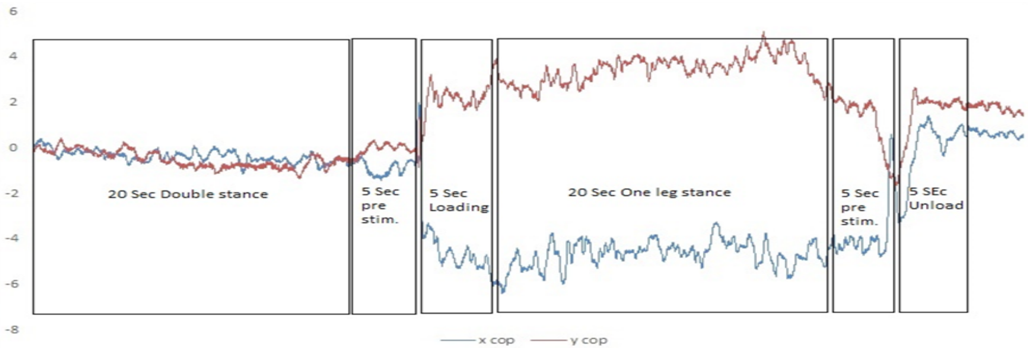

Figure 1. COP displacement in two axis (X/Y COP)

Figure 2. Selective position to apply constant load

variable. An Independent t-test was used to look for comparison after ANOVA.

3. Results

Mean±SD values and results of statistical analysis of the balance measures are represented in Tables 2, 3, and 4.

In DLS, there was no difference between healthy and ACLR groups in response to constant load (P=0.98) but further analysis in DLS revealed decreased postural responses in the healthy group (P<0.001 for Ce, and P=0.03 for Rsw) and an increased this response in ACLR group (for Ce P=0.02) while athletes exposed to the constant load.

In the changing position task (integration-reintegration), in response to the constant load, there was a significant increase in Ce in the ACLR group compared to the healthy group (P=0.01, P<0.001), and no change was seen in SLS (P=0.92).

The main effect of the group in all SLS positions (Mv and Ce for integration, Rsw, and Mv for SLS, Ce for reintegration) was significant (P<0.001, P=0.04, P<0.001) so that this effect in all conditions and legs was the same and greater in ACLR group. During SLS position (integration, SLS, reintegration), there was a significant leg's main effect for Ce (P=0.02, P<0.001, P<0.001). The value greater by the affected leg of the ACLR group and the non-preferred leg of the healthy group was significantly greater than the non-affected leg of the ACLR group, as well as the preferred leg of healthy athletes.

There was no interaction of group×constant load in the SLS phase; but, there was a significant group by constant load interaction found for Ce in the integration phase (P<0.001) and the reintegration phase (P<0.001). Interaction of group×leg for Rsw (P=0.04), Mv (P<0.001), and Ce (P<0.001) was significant in the integration phase, and only Ce (P<0.001) was meaningful for the integration and SLS phase.

Only in the reintegration phase, the interaction of constant load×leg was significant for Ce (P<0.001). There was a three-way interaction (group×constant load×leg) found for the Ce (P<0.001) in all three phases of the SLS position (integration, SLS, reintegration).

4. Discussion

This study indicated five important findings. First, the results show that athletes in both groups responded to the constant load and changed postural control responses in DLS. This finding contradicted to findings of previous studies so that no difference was seen between the two groups in DLS [15, 16]. Possible reasons for the current findings maybe 1) the base of support (BOS) in previous studies was bigger than in the present study. The smaller the DLS BOS, the harder the postural task [17]. Because in past studies, BOS was as wide as the shoulders, while in our study, both legs were concerned as far as the width of the hips. Based on this, with getting a harder postural task, changes appeared. 2) The present study evaluates different postural responses before and after constant load, but previous studies evaluate postural control responses without the effect of any intervention.

Inherently, reconstructed tissue has more inappropriate creep properties than healthy tissue. The reconstructed tissue increases length and laxity two times more than the normal tissue even in low forces [5]. Incremental length can be detected by the nervous system. Reconstructed tissue has a low ability to send joint changes because of proprioception impairments. It will not able to produce appropriate motor responses for keeping the balance, postural control system using hip strategy, and increased postural parameters have responded to this instability [10]. A healthy sensory-motor system responds appropriately to constant load by using the changing strategy in response to a constant load, muscle co-contraction, and activation freezing strategy, which ultimately leads to postural stability in DLS [3].

Table 2. Descriptive statistics for anterior cruciate ligament reconstruction and healthy athletes

Variables	Mean±SD Before Constant Load							
	Healthy Group							
	Preferred leg				Non-Preferred Leg			
	DLS	Int	SLS	Reint	DLS	Int	SLS	Reint
rfa (cm)	2.03±0.50	4.01±0.90	3.54±0.68	4.39±1.03	2.16±0.56	3.97±1.17	3.25±0.77	4.35±1.23
Rsw (cm)	1.31±0.52	19.24±2.76	2.87±0.41	18.63±3.00	1.34±0.54	19.61±3.11	2.58±0.31	20.12±3.69
Mv (cm/s)	0.07±0.02	0.58±0.07	0.18±0.02	0.70±0.10	0.06±0.01	0.57±0.09	0.17±0.02	0.77±0.13
Ce Ce (cm^2)	3.27±1.28	9.57±10.74	6.00±2.49	44.69±11.58	3.38±1.02	31.75±16.25	4.27±1.86	42.58±14.23

Variables	Mean±SD Before Constant Load							
	ACLR Group							
	Operated Leg				Non-Operated Leg			
	DLS	Int	SLS	Reint	DLS	Int	SLS	Reint
rfa (cm)	2.15±0.68	4.07±1.20	3.18±0.87	4.03±0.76	1.97±0.53	4.10±1.02	3.78±1.07	4.14±0.72
Rsw (cm)	1.10±0.40	20.05±3.13	3.07±0.49	19.22±4.14	1.38±0.56	20.30±3.06	2.91±0.59	19.92±4.33
Mv (cm/s)	0.06±0.10	0.62±0.09	0.19±0.03	0.72±0.16	0.06±0.01	0.61±0.10	0.19±0.04	0.74±0.17
Ce Ce (cm^2)	2.51±1.17	34.31±11.72	5.81±2.16	42.66±11.96	1.98±0.89	39.96±10.93	6.24±2.42	41.23±12.29

Variables	Mean±SD After Constant Load							
	Healthy Group							
	Preferred leg				Non-Preferred leg			
	DLS	Int	SLS	Reint	DLS	Int	SLS	Reint
rfa (cm)	2.06±0.55	3.89±1.08	3.59±0.85	4.05±0.79	2.05±0.47	4.14±1.00	3.39±0.70	4.04±1.26
Rsw (cm)	1.31±0.58	19.29±3.07	2.82±0.41	19.08±3.78	1.13±0.44	19.70±2.59	2.80±0.43	20.91±3.50
Mv (cm/s)	0.06±0.01	0.57±0.09	0.17±0.03	0.66±0.20	0.07±0.01	0.55±0.14	0.18±0.03	0.77±0.11
Ce (cm^2)	2.58±1.04	33.42±15.82	8.31±6.58	41.25±18.59	2.76±0.84	33.97±15.01	2.91±1.19	37.12±17.20

Variables	Mean±SD After Constant Load							
	ACLR Group							
	Operated Leg				Non-Operated Leg			
	DLS	Int	SLS	Reint	DLS	Int	SLS	Reint
rfa (cm)	1.99±0.57	4.14±1.14	3.66±0.69	3.93±0.97	1.93±0.64	4.01±0.85	3.10±0.75	4.25±1.02
Rsw (cm)	1.12±0.52	20.36±3.40	2.99±0.59	20.13±4.35	1.09±0.51	20.74±2.91	2.98±0.44	21.16±3.87
Mv (cm/s)	0.05±0.01	0.62±0.09	0.18±0.02	0.74±0.15	0.06±0.01	0.62±0.09	0.18±0.03	0.78±0.13
Ce (cm^2)	3.31±1.41	35.59±12.86	5.63±2.86	278.41±183.76	2.82±1.24	34.13±10.32	5.30±1.93	50.39±12.66

Abbreviations: ACLR: Anterior cruciate ligament reconstruction; Rsw: Range sideway; Rfa: Range fore-after; Mv: Mean velocity; Ce: Confidence ellipse; DLS: Double limb stance; Int: Integration; SLS: Single limb stance; Reint: Reintegration.

Table 3. Result of statistical analysis in double limb stance phase for each variable (n=20)

Variables	Mean±SD			
	Effect of Constant Load		Effect of Group	
	Healthy Group	ACLR Group	Before Load	After Load
Rfa (cm)	0.46±0.06	0.23±0.26	0.97±0.21	0.74±0.13
Rsw (cm)	0.03±0.00*	0.82±0.04	0.11±0.46	0.98±0.35
Mv (cm/s)	0.28±0.65	0.36±0.14	0.91±0.14	0.92±1.03
Ce (cm^2)	0.00±0.61*	0.02±0.63*	0.01±0.64*	0.14±0.6

Abbreviations: Rsw: range sideway; Rfa: Range fore-after; Mv: Mean velocity; Ce: Confidence ellipse. * The P of Paired t-test and independent t-test on the DLS phase of the postural task

Table 4. Result of statistical analysis

Phase Test	Variables	Mean±SD						
		Effect of Group	Effect of Constant Load	Effect of Leg	Effect of Group by Constant Load	Effect of Group by Leg	Effect of Constant Load by Leg	Effect of Group by Constant Load by Leg
Integration	Rfa (cm)	0.63±0.06	0.95±0.012	0.64±0.04	0.90±0.00	0.87±0.06	0.50±0.04	0.85±0.13
	Rsw (cm)	0.06±0.28	0.64±0.02	0.93±0.13	0.75±0.54	0.45±0.28	0.95±0.13	0.92±0.37
	Mv (cm/s)	0.00±0.51*	0.66±0.13	0.66±0.13	0.54±0.51	0.54±0.51	0.85±0.13	0.90±0.51
	Ce (cm^2)	0.00±2.26*	0.01±1.81*	0.02±1.65*	0.00±2.39*	0.00±2.26*	0.08±1.65	0.00±2.25*
SLS	Rfa (cm)	0.05±0.47	0.63±0.07	0.55±0.41	0.22±0.63	0.18±0.47	0.64±0.41	0.95±0.18
	Rsw (cm)	0.04±0.45*	0.72±0.13	0.63±0.82	0.75±0.27	0.49±0.45	0.59±0.82	0.61±0.24
	Mv (cm/s)	0.04±0.4*	0.06±0.04	0.56±0.51	0.46±0.00	0.95±0.40	0.77±0.51	0.37±0.00
	Ce (cm^2)	0.44±0.08	0.92±0.48	0.00±0.81*	0.29±0.32	0.00±0.08*	0.13±0.81	0.00±0.14*
Reintegration	Rfa (cm)	0.46±0.41	0.32±0.38	0.46±0.04	0.31±0.14	0.57±0.41	0.79±0.04	0.71±0.47
	Rsw (cm)	0.49±0.17	0.16±0.14	0.51±0.45	0.71±0.75	0.04±0.17*	0.99±0.45	0.79±0.41
	Mv (cm/s)	0.36±0.15	0.77±0.26	0.19±0.62	0.34±0.71	0.01±0.15*	0.70±0.62	0.54±1.85
	Ce (cm^2)	0.00±0.18*	0.00±0.23*	0.00±0.17*	0.00±0.48*	0.00±0.00*	0.00±0.17*	0.00±1.84*

Abbreviations: Rsw: Range sideway; Rfa: Range fore-after; Mv: Mean velocity; Ce: Confidence ellipse. The P of ANOVA on integration, SLS, and reintegration phases of postural task. *significant (effect size).

Second, results showed that in the changing position phase, in response to the constant load, ACLR subjects changed postural responses. Increased postural parameters in our study were in line with the results of a study by Dingenenin 2015 [11, 18]. Placing subjects under constant load led to changes in kinesthesia and ligament-muscular reflex. On the other hand, ACLR subjects have inherently proprioception impairment. All of these led to instability and the central nervous system (CNS) to deal with this changed strategy and used increased postural parameters to keep stability.

In the present study, no change was seen in postural responses in the SLS phase after the intervention. So, this finding was in conflict with the results by Lysholm (1998) [19] and Henrikson (2001) [20]. The reason for these differences may be the type of perturbation. When an ACLR subject was exposed to external perturbation, the change of center of mass (COM) was bigger and the spatio-temporal characteristics of this perturbation lead to changes in SLS parameters while less disturbance COM and different nature of internal perturbation due to changing position were led subjects to become stable faster.

Indeed, the third important finding was different postural responses between the two groups in all parts of SLS (integration, SLS, and reintegration), so these responses were bigger in the ACLR group.

A previous study done in CAS showed that subjects increased transfer speed when doing weight shift tasks. This speed increase is compensating by enlarging the displacement and area. The causes of these results were used as compensation strategies. So, these strategies can control load transfer along the transition phase of the task and make the least postural challenges in the SLS phase [21]. On the other hand, CNS uses less predictable strategies to decrease the instability effects of weight transfer [22]. It means that unstable subjects have a poor or inefficient ability match to use predictable strategies. So, increased postural parameters indicate decreased ability of subjects to manage perturbations [23].

Therefore, it can be said that CNS adaptations have a key role in the development of effective strategies to provide stability during weight shift tasks in ACLR subjects. Sensory inputs deficiency leads to CNS re-organization and with plasticity changes in CNS, compensate postural instabilities [24].

In the static SLS phase of our postural task, the result was in conflict with the study by Mohammadi (2012) [3]. This study showed no change in the static SLS. The causes of this difference are: 1) selective postural task in the study by Mohammadi was a jump-landing task collecting data after 3s after landing on a single leg while in the present study, 5s after changing position from DLS to SLS, data were collected. Possibly, the time in the previous study was not enough for athletes to reach a steady state position in the SLS phase and could not indicate changes in the static situation. 2) In our study, athletes were tested 16 months after surgery while in the previous study, 8 months after reconstructed surgery, athletes participated in the test. That means, in the present study, chronic changes occurred and could produce challenges in the static postural mechanism and reveal differences between the two groups.

The fourth interesting finding is the importance of the leg postural responses. Postural responses were different between the two legs of each athlete and greater responses were seen in the affected/non-preferred leg than non-affected/preferred leg. If the body is divided into two parts, both sides of the body are not quite symmetrical and most subjects show dominant hands and legs during functional activities. On the other hand, many damaging conditions cause functional asymmetry between lower limbs. Based on this, different balance strategies were seen between the two sides [25]. Previous studies showed that the brain map of the preferred/non-preferred leg was different and pre-programmed and different pathway existence in CNS to do functions of both legs. Furthermore, injuries cause changes in the functional capacity of the injured leg, and changes in central control (called plasticity) lead to transforming the functional deficit of the injured leg into a healthy leg [26].

Findings showed that a clear functional asymmetry exists in subjects with musculoskeletal injuries because of pain and functional deficits but basic low-level functional asymmetry has been seen in healthy subjects because of differences in power, anthropometry, flexibility, and neural control [27]. Paterno in 2007 showed that ACLR subjects with increased displacement area in the reconstructed leg were confronted with perturbations due to jump-landing tasks [28].

Results of the present study showed a different area between affected/non-preferred legs with non-affected/preferred legs. In healthy subjects, because of the difference in the ability of the preferred leg, repeated use of this leg on asymmetry activities, and different neural pathways between two legs, subjects can produce more regular patterns to provide balance and do more skillful and precise ADL and sports activities with preferred leg and finally subjects prefer using this leg. In ACLR subjects, decreased functional capacity, the inappropriate function of the passive element of the reconstructed leg, and plasticity in CNS encountered a problem to keep balance and use a strategy that provided stability with the increased area [29].

Fifth, all these results (postural parameters) suggested that there is some relationship between the ACLR group and the constant load in the integration phase. So, changing postural parameters in response to constant load was seen in both legs of the ACLR group more than in the healthy group.

The kinsiopathologic approach expresses that repetitive movements and static posture can affect musculoskeletal tissues and finally lead to functional deficits. One of the component effects to produce normal movement is the modulator (CNS) component. ACLR subjects may have impaired postural control systems and be susceptible to injury due to changes in passive structures as a result of repetitive movements such as increase-decrease acceleration along exercises and completion or prolonged static postures along ADL [30]. The results of our shows this event so that athletes in response to constant load displayed changing postural behavior and tried to keep balance with changing strategies.

The result of the present study was contrary to Dingenen 2015 [11, 18]. So, no difference was seen between ACLR and healthy subjects in the integration phase but an increased postural parameter between both legs of the ACLR group with the healthy group was seen in the present study. The reasons for these contradictory results include the transfer speed difference from DLS to SLS. In past studies transfer speed was uniform in both groups so that subjects transfer from DLS to SLS along 1s while in the present study, athletes transferred according to preferred speed. Postural responses are affected by the speed of movement along the transition phase. Past studies showed that subjects with musculoskeletal pathologies respond to internal perturbation by increased transfer time, area, and displacement. These behaviors may be used as a protective strategy to decrease the effect of perturbation [11]. Another reason is the effect of the constant load. Past studies evaluated postural responses without any interventions but in the present study, the constant load could challenge central postural control in the integration phase and display differences between groups.

In the static SLS phase, no intra-group difference was seen in the present study which is in line with Dingenen2015 [11] and in contrast with the results by Colby 1999 [31], Patterson 2013 [32], and Webster 2010 [33]. Our results showed increased postural parameters in the static SLS phase. The cause of these results may be related to the kind of selective postural tasks. Previous studies used jump-landing tasks to evaluate postural responses. The result of our study supports this idea that static SLS is not an appropriate test to evaluate the difference between healthy and pathologic subjects so even the effect of the constant load could not display the difference between both groups. Applying greater load and longer time of loading may display intra-group differences.

In the reintegration phase, the increased postural responses were seen only in the reconstructed leg after the constant load. The effect of the constant load was well seen in this phase so mechanoreceptors of the reconstructed leg were influenced by the constant load, failed to send sensory information input, and decreased the ability of the central postural system to produce normal motor responses. The reconstructed leg due to proprioception functional impairment was not able to stay appropriate against perturbation, and with decreased flexibility and subsequently, the increased energy consumption responded to this situation which means the reconstructed leg did not encounter properly with perturbation [11].

This study had some limitations. We tested only soccer players with specific professional levels of activity not generalizable to other populations. We documented postural responses after the effect of the leg weight of each athlete not providing the effect of different loads on postural procedures.

5. Conclusion

In conclusion, the findings showed that even 16 months after ACLR, postural control of athletes was not restored to their affected legs and healthy athletes. The risk of ACLR and other injuries in the lower extremity could be affected by movement patterns, so these important and modifiable factors need attention. The current study demonstrated that the chances of leg asymmetries and differences with healthy athletes may result in an increased risk of re-injury. Identifying possible side-to-side and between-group differences in ACLR and healthy athletes in response to constant load might help us to optimize the postoperative rehabilitation protocols and minimize the risk of future injuries after returning to sports. Based on the results, we suggested that clinicians should use constant load to improve flexibility and extensibility of reconstructed leg and correct postural asymmetries in ACLR athletes before returning to sports.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Tehran University of Medical Science (Ethics approval number: 9323341999).

Funding

This research has been supported by Tehran University of Medical Sciences and Health Services (Code: 96-01-32-34315).

Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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