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# The Effect of Fatigue on the Time to Stability in Jumping and Landing in Football Players Who Have Undergone Anterior Cruciate Ligament Reconstruction

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ABSTRACT

**Background:** Jumping and landing are common activities in soccer that are often reported in connection with anterior cruciate ligament injury. As most injuries occur during fatigue, the present study aimed to investigate the effect of fatigue on the component of time to stability (TTS) during landing between healthy soccer players and soccer players who have undergone anterior cruciate ligament reconstruction.
**Methods:** This quasi-experimental study included 24 professional soccer players who were divided into control and experimental groups. Twelve active professional soccer players (control group) and 12 soccer players with 6-24 months of anterior cruciate ligament reconstruction with hamstring graft (experimental group) participated in this study. Athletes jumped and landed on the obstacle to a height of 7.5 cm. After the fatigue protocol, these movements were repeated. TTS data was collected using force plate. MANOVA test at the significant level of P<0.05 was used to compare pre-test and post-test data between the groups.
**Results:** According to the results of this study, fatigue did not affect the time to stability in any of the anterior-posterior (P=0.104), internal-external (P=0.668), or vertical components (P=0.894) between the two groups, and fatigue could not make a significant difference between the two groups. Moreover, before fatigue, no significant difference was observed between the two groups in any of the components.
**Conclusion:** It seems that a plyometric fatigue training session will not be effective in differentiating between healthy soccer players and soccer players who have had anterior cruciate ligament reconstruction.


## Introduction

The knee joint plays an important role in various movements and interacts with the hip and ankle joints. Impaired posture control is a factor in injury, especially in the lower limbs, in athletes [1]. Rupture of the anterior cruciate ligament (ACL) is a frequently incurred injury by athletes who participate in high intensity and high velocity field and court sports. A high percentage of these injuries are described as non-contact in mechanism [2]. The ACL contributes to knee joint sensorimotor control and mechanical stability. Lower limb ligament injury will produce a number of functional insufficiencies, including deficits in proprioception, postural stability, strength and neuromuscular control [3]. One cause of anterior cruciate ligament reconstruction is functional instability, and because soccer has a lot of rotational movements, anterior cruciate ligament reconstruction is usually suggested after rupture. The primary aim of ACL reconstruction is to restore mechanical and functional joint stability

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to the knee joint such that the athlete can return to full sports participation; however, most athletes are unable to reach pre-injury activity levels after rehabilitation [4]. Walden et al. recently reported that 86% of elite male soccer players are still playing soccer three years after anterior cruciate ligament reconstruction, of which only 65% reach pre-injury levels [5]. Re-rupture rates of 17% for patients younger than 18 years, 7% for patients aged 18 to 25 years, and 4% for patients older than 25 years have been reported [6]. An increasing body of literature suggests that deficiencies in static and dynamic postural stability increase the risk of lower limb injury [7].

Postural control is the basis of the function of body movements and is necessary for most daily activities [8]. It has recently been reported that competitive athletes who have returned to full sports participation after ACL reconstruction still exhibit postural stability deficits [9]. Time to stabilization (TTS) is a functional measurement of neuromuscular control and dynamic postural stability. TTS scores assess an athlete's ability to transfer from a dynamic to a static situation on one leg. Longer TTS values have been reported in athletes with chronic ankle instability as well as athletes who have undergone ACL reconstruction surgery when compared to healthy controls [10]. One way to evaluate dynamic balance is to use the time to stability, which shows the time required to achieve stability after landing [11]. Colby et al. suggested that a static position does not sufficiently challenge the neuromuscular system in recreating athletic activity or even activities of daily living. More dynamic types of activities, such as jump-landing tasks, might be a more accurate tool for assessing the lower extremity neuromuscular system during single-limb activities. The time-to-stabilization (TTS) measurement technique is used to assess the time that participants take to attain a stable position after a jump-landing task, giving an indication of dynamic postural stability [12]. Jump landing is a common athletic activity and a well-known mechanism for injury to the ACL; thus, investigation into stabilization of jump landing might help clinicians and researchers understand more clearly if deficits in dynamic stability might persist even after successful reconstruction and rehabilitation [11].

Fatigue is one of the factors that can affect different movement patterns and change their nature biomechanically. Time to stabilization has also been used to evaluate the effect fatigue has on proprioception and muscular control [13]. Although some studies have increased our knowledge of lower body and ACL injury mechanisms [14], few have elicited fatigue of the lower body similar to what an athlete would experience during competition to observe the effects fatigue has on knee joint stability [15]. Therefore, the present study used the plyometric fatigue protocol to the extent of exhaustion to determine its effect on the time to stability.

## Methods

Data for this quasi-experimental study was collected in Hamadan Azad University in 2020. The research design was approved by the Ethics Committee of the Institute of Sports Sciences (No. IR.SSRI.REC.1399.749). The target population was 30 professional soccer players between the ages of 20 and 30 years, who had at least 8 years of soccer playing experience and three training sessions per week. Exclusion criteria included previous ipsilateral knee injury and/or knee previous surgery, age over 30 years and under 20 years, and reconstruction time of greater than 24 months or less than 6 months [16]. All participants provided written informed consent prior to the start of the study. At the beginning of the study, the demographic form was completed by measuring the height, weight, and leg length of the participants. Other data was supplied by the subjects, including the injured foot and the time elapsed since reconstruction. Prior to the test, subjects performed a ten-minute warm-up to prevent injury, including slow running and stretching movements in the lower extremities [17]. Subjects were then placed on the back of the force plate. From the starting point, the subject was asked to jump from the cone to a height of 7.5 cm, which was located in the middle of the distance between the starting point and the center of the force plate, and after crossing the obstacle, land on the force plate with both feet and then stand still for 15 seconds [18] (Figure 1).

**Figure 1:** Jump and landing method

*Participants*

Based on previous studies that have examined the effect of fatigue on the biomechanics of lower limb landing, it was estimated that a medium to large effect size (F=0.3) should be determined. With statistically significant adjustments at the bilateral level (0.05), power (0.8), and correlation between repeated measures (0.5), at least 10 individuals were required for each group [19].

The study population was divided into two groups, the control group (n=12), which consisted of healthy athletes, and the experimental group (n=12), which consisted of athletes having undergone anterior cruciate ligament reconstruction with a hamstring graft.

### Calculate the Time to Stability

The information obtained from the landing was collected on the force plate. After converting the information to TXT format, the raw data was entered into the Excel program. To equalize the calculations of the test results, a time of 8 seconds was considered as the participants' duration of maintaining balance after the first contact with the force plate. Calculations related to the time to achieve stability were performed using the sequential averaging method for each moment according to Equations 1 to 3 [20]. Because the equilibrium duration was 8 seconds and the sampling frequency of the force plate was 1000 Hz, the averaging process was performed for 8000 moments.

1. $seqavgx(n) = \sum_{i}^{n} fx$

2. $seqavgx(n) = \sum_{i}^{n} fy$

3. $seqavgx(n) = \sum_{i}^{n} fz$

*Fatigue Protocol*

After the pre-test, subjects performed the plyometric fatigue protocol. These exercises included running and jumping, which included running at a high speed of 10 meters, left and right foot hopping, and jumping and landing on both legs, jumping and landing single-legged, vertical jumping, jumping over obstacles, tuck jumping, and one-legged jumping between the lines (Table 1). Subjects performed this protocol to the point of exhaustion. The Borg scale of 6 to 20 was used to determine the degree of fatigue, with 6 indicating fatigue and 17 to 20 indicating exhaustion [21]. Immediately after the fatigue protocol, a post-test was performed, and the obstacle jump was repeated to observe the effect of fatigue. Differences between groups before and after fatigue were analyzed using the MANOVA test. All analyses were performed at a significance level of 0.05 using SPSS software version 25.

**Plyometric Exercises:** (Fatigue exercises are summarized in Table 1).

1. Left foot hopping (10 meter): Hopping forward in two sets with a length of 10 meters.
2. Right foot hopping (10 meter): Hopping forward in two sets with a length of 10 meters.
3. Double leg jump: 10 consecutive forward jumps with both legs.
4. Single leg jump: 10 one-legged jumps forward (one foot in each set).
5. Vertical jump: 10 vertical jumps in two sets.
6. Jumping over obstacles: Side jump in two sets and 10 reps.
7. Tuck jump: Jumping straight up and bending knees.
8. One-legged jump between the lines: Jumping between marked lines (one foot in each set).

### Results

Data concerning the age, weight, height, and body mass index of participants in the two groups is summarized in (Table 2).

Analysis of variance (MANOVA) was used to measure differences between the two groups. No significant difference was found between the two groups in weight indices with (P=0.101), height (P=0.486), age (P=0.284), and body mass index (P=0.107).

The results revealed no significant difference between the components of time to stability in the internal-external direction between the two groups before fatigue (P=0.276). This difference after fatigue was not observed between the two groups (P=0.668). The time to stability in the anterior-posterior direction before fatigue

**Table 1:** Plyometric fatigue protocol

| Task | Left foot hopping (10 meter) | Right foot hopping (10 meter) | Double leg jump | Single leg jump | Vertical jump | Jumping over obstacles | Tuck jump | One-legged jump between the lines |
|---|---|---|---|---|---|---|---|---|
| Stair height 20 cm | 2 | 2 | 2×10 | 2×10 | 2×10 | 2×10 | 2×10 | 2×10 |

**Table 2:** Anthropometric information

| | Control group Mean±Sd | Experimental group Mean±Sd | P value |
|---|---|---|---|
| Age (year) | 23.52±2.50 | 26.41±3.34 | (P=0.284) |
| Weight (kg) | 72.58±9.79 | 81.83±15.97 | (P=0.101) |
| Height (meter) | 1.76±0.07 | 1.78±0.06 | (P=0.486) |
| Body mass index (kg/m$^2$) | 23.24±2.40 | 25.51±3.99 | (P=0.107) |

**Table 3:** Descriptive findings before and after fatigue and results of MANOVA test

| | Component | Control group Sd±mean | Experimental group Sd±mean | F | P value |
|---|---|---|---|---|---|
| Before fatigue | Internal-External | 1.68±0.16 | 1.58±0.25 | 1.247 | 0.276 |
| | Anterior-posterior | 1.63±0.05 | 1.65±0.04 | 0.494 | 0.489 |
| | Vertical | 1.70±0.06 | 1.24±0.12 | 1.457 | 0.240 |
| After fatigue | Internal-External | 1.61±0.14 | 1.58±0.19 | 0.189 | 0.668 |
| | Anterior-posterior | 1.75±0.07 | 1.65±0.04 | 2.868 | 0.104 |
| | Vertical | 1.23±0.12 | 1.24±0.18 | 0.018 | 0.894 |

(P=0.489) and after fatigue (P=0.104) also did not show a significant difference between the two groups. There was no significant difference between the two groups in the time of stability in the vertical direction before fatigue (P=0.240) and after fatigue (P=0.894) (Table 3).

**Discussion**

The aim of this study was investigate the effect of fatigue on the time to stability in jumping and landing tasks in soccer players with ACL ligament reconstruction. Time to stability is a measure of neuromuscular control in which force plate values are used to assess dynamic postural stability in jumping and landing activities. Contrary to the proposed hypothesis, time to stability (TTS) assessments did not show any significant difference in stability time between the injured and healthy participants. Time to stability is also used to assess the effect of fatigue on proprioception and neuromuscular control. Increased time to reach stability indicates the body's delayed response to achieve stability and difficulty in controlling posture during landing.

Brazen et al. examined the effect of fatigue on the biomechanics of single-leg jumping and landing on 24 healthy individuals (12 females and 12 males). Their results showed that during landing after fatigue, participants stabilized their body after landing, and reaching stability, regardless of gender, needed more time [22]. Malmir et al. examined the effect of peroneal muscle fatigue on dynamic stability following axillary jump and landing and stabilization time against dynamic motor stability index in a study of 20 healthy active men with lower limb injuries. They did not use it for the last 6 months. Subjects made a lateral jump on the force plate before and after fatigue, but the time to post-fatigue stability was increased in both internal-external and anterior-posterior levels [23]. Sean Kunugi examined the relationship between the Cumberland Instrument score for ankle instability and stability in 91 college soccer players with and without functional ankle instability and the time to stability at the anterior-posterior and internal-external levels of size. The results showed that the time to stability at the internal-external level in the group with ankle sprain was longer than the control group [24]. In some studies, increased time to stability in the anterior-posterior direction was the most common result [25]; however, some studies have reported increased time to internal-external stability [26].

There is a hypothesis that after damage, the amount of sensory body-environment messages is reduced and consequently neuromuscular control is impaired. If the static and dynamic balance and neuromuscular control in the person do not improve, the person is prone to re-injury and will have difficulty performing his function. On the other hand, increasing postural oscillation is considered a risk factor for injury [27]. Delay in achieving stability indicates that neuromuscular control may be affected by fatigue [28]. The interaction of the central nervous system (CNS) with peripheral dynamics may not be able to neutralize the internal and external disturbances imposed on the body during landing, which would interfere with postural stability. This condition can damage the ankle area if one continues to exercise or compete in matches. Analysis of the kinetic and kinematic variables in individuals with reconstruction of the injured anterior cruciate ligament compared to healthy individuals showed higher ground-reaction forces and a longer time needed to stabilize after the landing jump, which causes movement, force, and speed to occur faster, thus making the anterior cruciate ligament more prone to re-injury. The time to stability requires that the individual control the reaction forces of the earth and achieve rapid stabilization in horizontal and vertical displacement [29].

The ability to stabilize quickly requires good muscle strength and good muscle firing patterns, the lack of which in stabilization as quickly as possible causes problems. Neuromuscular, kinetic, and kinematic differences were seen in individuals with anterior cruciate ligament reconstruction. Specifically, these changes include ground reaction force, maximal hip, knee, and ankle flexion, increased knee valgus, increased posterior shear forces in the tibia, increased tibia rotation, and changes in muscle firing patterns. Rose et al. found that subjects with chronic ankle instability needed a longer time to stability than healthy individuals. Impairment in dynamic posture control should be considered to estimate the degree of re-injury in individuals who have undergone anterior cruciate ligament reconstruction. A longer time to stability indicates that individuals have more difficulty controlling the ground reaction force during landing, which may lead to neuromuscular disorders [30].

In recent years, anterior cruciate ligament injury prevention programs have been implemented that focus on improving neuromuscular control in jump-landing motion. Using the time to stability for the jump-landing study showed that people with anterior cruciate ligament reconstruction needed a longer time to stabilize balance than people with healthy knees. This suggests that these individuals lack dynamic control and have difficulty in controlling the ground reaction force during landing [5]. For example, in a study conducted by Webster et al. on 24 female athletes, 12 of whom were healthy and 12 of whom had a history of anterior cruciate ligament reconstruction, subjects were asked to perform one-legged jumps and landings and to be fixed for 10 seconds after landing. The results showed that the group with anterior cruciate ligament reconstruction needed more time to stabilize, even when 2.5 years had passed since their anterior cruciate ligament reconstruction [29]. The results of these studies were inconsistent with the results of the current study, and therefore experts are recommended to focus more on regaining stability faster after landing to prevent further damage. In general, fatigue clearly affects the biomechanics of the lower body when landing on one leg [31]. In the current study, however, no significant difference in the time to stability after fatigue was observed between the healthy group and the group who had reconstruction of the anterior cruciate ligament. Previous studies have shown that 50% of fatigue results in biomechanical changes in landing, so determining the level of fatigue is not very important [32].

The statement that fatigue affects muscle strength and increases cruciate ligament injury is not always true. Some reports have reported no difference in anterior cruciate ligament injury in the first or second half or first of the season compared to late in the season [33]. For example, in a study conducted by Niu et al. to examine the stability of postural dynamics during bipedal landing on 8 men and 8 women active at the recreational level, subjects descended from three different heights. The results showed no significant difference in the time to stability in any component between the two sexes and two different organs [34]. In another study, the time to stability and ground reaction force after anterior cruciate ligament surgery were examined in 11 men and 6 women who performed the jump and landing movement. Changes in the ground reaction force were observed in the jumps, especially the unpredicted jump, but no change was observed in achieving stability [35].

Based on the current study, it can be stated that plyometric fatigue does not make much difference between healthy and injured soccer players in terms of time to stability, although the intended statistical sample, fatigue protocol, and gender can be effective in this regard.

The current study is not without limitations. Matching the groups in terms of time spent on anterior cruciate ligament reconstruction, different rehabilitation programs in the experimental group, no use of EMG, and no use of female athletes are the limitations of the present study.

## Conclusion

The present study showed that plyometric fatigue did not cause significant changes between the healthy group and the group who had undergone anterior cruciate ligament reconstruction; however, the experimental group had different rehabilitation programs .

**Conflict of Interest:** None declared.

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