Sport Sciences and Health Research

University of Tehran
Faculty of
Physical Education and Sport Science

Comparison of the effect of acute and delayed fatigue on the time to stability of female gymnasts with and without dynamic knee valgus during drop-landing task

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Article Info

Original Article

Article history:

Received: 19 August 2021

Revised: 25 August 2021

Accepted: 04 October 2021

Published: 07 December 2021

Keywords:
ACL,
fatigue,
knee,
gymnastic,
landing, time to stability,
valgus.

Abstract

Background: Drop landing is one of the tasks performed in many sports skills. Lower limb injuries have the highest prevalence in sports where jump landing is repeated frequently. One of the most common landing injuries is an anterior cruciate ligament (ACL) tear, which increases knee valgus and may contribute to an increased risk of ACL injury in athletes. In this situation, fatigue is one of the components that can affect various parameters of the landing task.

Aim: The purpose of this study was to investigate and compare the acute and delayed effects of fatigue on the time to stability (TTS) of female gymnasts with and without dynamic knee valgus (DKV) during the landing task.

Materials and Methods: In this semi-experimental study with a pretest-posttest design, 42 female gymnasts were selected through purposive and available sampling and divided into two groups of 21: a control group without DKV and an experimental group with DKV. The TTS in these individuals was measured before, after, and 24 hours after the fatigue protocol using the Kistler force plate device. The data was analyzed using SPSS software and statistical methods of analysis of covariance with repeated measures at a significance level of $P \geq 0.05$.

Results: According to the findings of this study, it showed that there is a significant difference in the variable of TTS in three time periods (before, after, 24 hours after fatigue) in the control and experimental groups ($P= 0.026$).

Conclusion: The results of the present study showed that plyometrics on the TTS are significantly different between people with DKV and without DKV, and people with DKV are necessarily at a greater risk of injury during landing tasks.

Cite this article: Akbarieh Kaleybar M, Babakhani F, Balouchi R, Shamlou Kazemi A. "Comparison of the effect of acute and delayed fatigue on the time to stability of female gymnasts with and without dynamic knee valgus during drop-landing task". *Sport Sciences and Health Research*. 2022, 14(2): 265-273. doi: https://doi.org/10.22059/sshr.2023.339435.1047.

EISSN: 2717-2422 | Web site: https://sshr.ut.ac.ir/ | Email: sshr@ut.ac.ir
 Publisher: University of Tehran, Faculty of Sport Sciences and Health

1. Introduction

Anterior cruciate ligament (ACL) injuries are the most common ligament injury of the knee, accounting for between 100,000 and 200,000 injuries among athletes per year [1]. ACL injuries occur via contact and non-contact mechanisms, with the former being more common in males and the latter being more common in females [2].

Numerous studies have attempted to determine risk factors for ACL rupture, including hormonal, biomechanical, and sport- and gender-eeecfifi vvcssss [3]. We investigated the biomechanical mechanisms contributing to ACL injury and considered differences between males and females [2]. Poor core stability, landing with a heel strike, weak hip abduction strength, and increased knee valgus may contribute to an increased risk of ACL injury in athletes [4].

Various factors are thought to contribute to ACL injury incidence. Perhaps the most widely considered risk factor is DKV, which places significant tensile forces on the ACL, especially during landing and cutting [5, 6]. Knee valgus may occur secondary to many factors, including but not limited to weak hip abductor strength, poor hip musculature control, increased femoral anteversion/medial tibial torsion, wider pelvis, increased midfoot mobility, and larger Q-angle. Anatomically speaking, females have wider hips, which predisposes them to larger Q-angles and subsequent higher risk of ACL injury than males [4, 7].

Females who participate in gymnastics, soccer, or basketball appear to be at the highest risk of experiencing a non-contact ACL injury [8]. The subject of landings in gymnastics is important due to the accompanying injuries. Landings in gymnastics are a crucial element that is incorporated in every routine in each artistic gymnastics event. Gymnastics landings should be both proper in terms of judge scores and safe for the athlete [9]. The risks of landing injuries are associated with loads that affect the musculoskeletal system [10]. With regard to landings, the main load is focused on the lower limbs and the trunk. In high-performance sports, where jumping is the primary technique, there is a tendency to transfer larger forces acting on the knee and spine, which can contribute to serious injuries. The higher the ground reaction forces (GRF) during landings, the higher the risk of injury, especially of the ACL [11, 12].

Through previous studies, it has been found that knee ACL injuries mainly occur in the last stage of the game [13, 14]. Fatigue is an important cause of non-contact ACL injury [15]. Fatigue is one of the main factors in increasing the rate of injury in the lower extremities, especially in the knee joint [16]. In this regard, studies have investigated the effect of fatigue on the biomechanics of various sports movements, including landing from a height. Jump-landing movements are performed in many sports [17]. Muscle fatigue would lead to muscle activation delay after fatigue, and this would result in decreased motor control and increased knee laxity [14].

The delay of knee muscle activity has been identified as a major risk factor for knee instability and the risk of cruciate ligament injury [13, 14, 16, 18]. Although previous studies have suggested that lower-extremity muscle fatigue is a risk factor for ACL injury [19, 20, 21, 22, 23], the precise impact of fatigue on injury risk to the ACL is still unknown.

Many sports injuries occur during landing [19]. In fact, the ground reaction force during landing sometimes reaches up to five times the weight of the body, which can be considered a risk factor in this regard [24]. In a study, it was reported that 63% of lower limb injuries were seen in jump-landing competitions. It was finally concluded that successful landing after jumping requires strength, stability, and balance to prevent injury [25].

Preventing joint damage and achieving quick stability after landing is one of the important factors in preventing various injuries. TTS (Time to Stabilization) is the amount of time which takes for a person to return to a stable state after a jump. TTS is an indicator of dynamic stability that measures stability during jump-landing motion. It is defined as the ability of individuals to maintain balance and minimize postural fluctuations during the transition from a dynamic to a static state. Therefore, it is a fully functional test [26]. Increased levels of fatigue with increasing the DKV may put athletes at greater risk for ACL injury [27]. Exercise fatigue increases DKV in young athletes. Female athletes and older individuals also reported the greatest impact [28].

To our knowledge, no study has examined how fatigue affects TTS of female gymnasts with and without DKV during landing, despite its importance for various sports movements. As a result, the aim of the present study was to investigate the acute and delayed effect of fatigue on the TTS during the drop-landing task.

2. Materials and Methods

2.1. Participants

In this study, 42 female gymnasts were divided into two groups, including the control group without DKV (n=21) and the experimental group with DKV (n=21). Participants were physically active females who practiced gymnastics three to five times a week for at least three years. None of the participants had a medical history of injury or neuromuscular disorder within the preceding two years [29]. These individuals participated in this study voluntarily. They were requested to abstain from physical exercises involving the lower limbs 24 hours prior to testing. The number of samples was calculated using G. power and based on Deborah's study [30], considering α= ,,,,,, , = 0.20, SD= 0.80. The subjects also had a dominant right lower limb, which was determined using the selective leg method for shooting the ball [31].

2.2. Design and Procedures

Before performing the fatigue protocol, the subjects performed stretching and warm-up movements for 10 min. They were also asked to perform three repetitions of jump-landing movements as well as landing from a 40 cm platform several times to meet the conditions and method of execution and get acquainted with the test. The landing test from a height of 40 cm on the force plate device was performed by the subjects before performing the fatigue protocol. In this situation, the subject left her bare foot from a 40 cm platform that was placed at a distance of 20 cm from the force plate and landed with a single leg in the center of the force plate. As soon as she sat down, she placed her hands on her hips, held her head up, and looked straight ahead, trying to maintain her balance. The subject maintained this position until complete stability and immobilization of the body.

2.3. Fatigue protocol

For fatigue, the subjects used a plyometric exercise program. These exercises included running and jumping. Running comprised high-speed running at a distance of 10 m in the form of sweeping and jumping, such as double-leg jumping and landing, single-leg jumping and landing, vertical jumping, jumping over obstacles, tuck jumping, and single-leg jumping between lines. The exercises were performed in three sets of 10 m, with 30 sec of rest between each set [32]. This program was performed three times, and there was a two-minute break between each set.

2.4. Measurements

Immediately after the subject reached exhaustion, she performed a descent from a height as a pre-test on the force plate device. Twenty-four hours later, the descent motion on the force plate was measured again. In each measurement of the subject, three landing movements were recorded and analyzed. Component TTS information was measured using a Kistler force plate device made in the Netherlands with a sampling frequency of 1000 Hz. After collecting the data, a low-pass Butterworth filter with zero phase difference of four times and a cut-off frequency of 20 Hz was used to reduce data noise. The force information was normalized to the weight of the subject. Then, the TTS parameter was calculated.

2.5. Data analysis

Descriptive statistics were used to calculate the mean and standard deviation of height, weight, and age. Using the Kolmogorov-Smirnov test, we examined the normality of data distribution. Covariance analysis with repeated measures was used to compare the experimental and control groups. All evaluations were conducted at the significance level of 0.05 in SPSS ver. 25.

3. Results

The study group's information, such as body weight, height, and Body Mass Index (BMI), is summarized in Table 1. The Kolmogorov-Smirnov test was used to check the normality of the data (Table 2). The result of the covariance test with repeated measurements for comparison between variable groups TTS is shown in Table 3.

Based on the findings of the present study, the analysis of the TTS in the post-fatigue state was significantly higher ($P<0.05$) than in the pre-fatigue state (Table 3).

Table 1. Demographic characteristics (age, height, weight, BMI) of the samples

Variable	Group	N	Mean ± SD	p- value
Age (y)	Experimental	21	1.54±23.14	0.09
	Control	21	2.26±22.46	
Height (cm)	Experimental	21	6.10±165.9	0.16
	Control	21	6.37±167.2	
Weight (kg)	Experimental	21	3.44±55.13	0.33
	Control	21	3.18±56.87	
BMI (kg/m^2)	Experimental	21	0.76±20.42	0.25
	Control	21	1.06±21.36	

Table 2. Kolmogorov-Smirnov test to check the normality of the data

Parameter	Component	Statistics	p- value
TTS (s)	Vertical	0.114	0.05

Table 3. Covariance test with repeated measures to compare between groups the variable of TTS

Variable	Total squares	Mean squares	F	p- value
TTS (s)	0.247	0.151	4.195	0.026

4. Discussion

The purpose of this study was to investigate and compare the acute and delayed effects of fatigue on the TTS of female gymnasts with and without DKV during the drop-landing task. According to the results of Table 3, the variable of TTS showed a significant difference in three time periods (before, after, and 24 hours after fatigue) between the two groups (*P*= 0.026). The results of the present study were in line with the results of Nasrabadi et al. (2020) [33]. They showed that the TTS in the post-fatigue state was significantly longer than the pre-fatigue state in active healthy young men during the landing task. Brazen et al. (2010) tested the TTS before and after the fatigue protocol and concluded that there was a significant difference between the mean TTS before and after fatigue. There was an anterior-posterior direction that was consistent with the results of the present study [34].

One of the important points in various studies is the possibility of lower limb injuries during performing landing movements from high altitude or jump-landing due to fatigue [35]. In this context, fatigue has been reported as a risk factor for lower extremity injuries such as ACL injuries [36], and the main reason is probably the biomechanical changes in movement following fatigue or compensatory mechanisms of the central nervous system [37, 38].

For example, in the field of compensatory mechanisms following fatigue, Padua et al. (2006) have pointed out that during maximal quadriceps muscle contraction, hamstring muscle contraction is necessary to maintain dynamic knee stability and prevent shear forces on the ACL. Fatigue causes early activation of the quadriceps muscle and delay in activation of the hamstring muscles. This delay in the recruitment of the hamstring muscles causes anterior displacement of the tibia, resulting in improper and uncontrollable load transfer to the knee joint and exposing the person to ACL damage [39]. In another study, the results showed that when performing the jump-landing movement, people after fatigue tend to use ankle axial strategies more and rely more on the ankle muscles than the knee muscles. This seems to reduce the stability of the knee and increase the risk of ACL injury [40].

Mejane et al. (2019) investigated biomechanical characteristics during landing missions in female recreational athletes and indicated that neuromuscular fatigue may alter knee kinematics during landing, reduce knee buffering capacity during landing, and increase the risk of non-contact cruciate ligament injury [16]. At the same time, knee valgus is one of the main causes of ACL injury during exercise [6]. Kristianslund et al. (2012) reported an increased knee abduction moment in fatigued and injured athletes [41]. After fatigue, the knee buckling torque and valgus moment increased significantly at the moment of contact with the ground, and the horizontal backward maximum GRF also increased significantly [42].

Landing after a jump is a common task in sports activities that requires dynamic stability [31]. Neuromuscular control plays an important role in dynamic joint stability. Neuromuscular control can be defined as the activation of dynamic limitation in the preparation and response to joint movement and loading to maintain and stabilize functional stability of the joints [43]. TTS is a measure of neuromuscular control in which force plate values are used to assess dynamic postural stability in jump-landing activities. TTS is also used to assess the effect of fatigue on proprioception and neuromuscular control. Prolonged TTS indicates that the body's response to stability is delayed and that postural control during landing after the jump is difficult [34, 43]. TTS is the amount of time it takes for a person to bring the ground reaction forces in the vertical, internal-external, and posterior-anterior directions to the normal level of standing. The ability to have a fast TTS is generally seen as a positive and protective trait [44]. Considering that no study has been done in this field so far, further studies in this field seem necessary. According to the findings of this study, it seems that female gymnasts with DKV reach stability later than before fatigue occurs.

5. Conclusions

In conclusion, our study found that greater fatigue levels were correlated with an increase in DKV, which may place athletes at a greater ACL injury risk. Also, fatigue affects the amount of TTS in gymnasts with knee valgus dynamics.

6. Limitations

There are several limitations to this study. First, we attempted to recreate a field-based test with force plate and drop-landing tests. However, this test may not represent the actual landing that occurs in gymnastics. Nonetheless, this testing and grading protocol has been used previously and demonstrated strong accuracy. Second, the fatigue protocol used in this study was not designed for gymnastics, as a valid protocol for this field was not available. Additionally, the interobserver reliability was determined to be fair, and intraobserver reliability was not measured in this study.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc. All study participants provided written informed consent forms. Moreover, the study was approved by the Research Ethics Committee of Allameh Tabataba'i University (Code: IR.ATU.REC.1400.167).

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

Funding

This work was funded by the faculty of physical education and sports science of the of Allameh Tabataba'i University, Iran.

Acknowledgements

We would like to express our deepest appreciation for the valuable assistance and contribution of all the participants.

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