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The acute effect of functional fatigue on knee and trunk kinematics in female soccer players with and without dynamic knee valgus during single-leg landing

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Abstract

Background: Dynamic knee valgus (DKV) is due to the weakness of the thigh abductor muscles and the vastus medialis muscle, which increases the internal rotation of the thigh and increases the possibility of anterior cruciate ligament (ACL) injury. The amount of DKV in women is higher than men, which is one of the reasons for the possibility of more injury in women.

Aim: The aim of the present study was the effect of acute soccer functional fatigue on knee and trunk kinematic factors in female soccer players with and without DKV during single leg landing.

Materials and Methods: The present study is quasi-experimental research conducted on 28 female soccer players who were selected using purposeful and convenience sampling. They were classified into two groups with and without DKV. The subjects performed a single leg soccer landing, and the kinematic changes of the participants' trunk and knees were recorded through high-speed video cameras (SONY camera) in two sagittal and frontal planes and analyzed by Kinovea software. The data were analyzed in SPSS-26 software using a mixed ANOVA statistical test.

Results The results revealed a significant interaction effect between fatigue conditions and groups on knee and trunk joint angles in frontal plane in the initial contact with the ground in single leg landing. The results showed that fatigue significantly reduced knee flexion and increased knee valgus and trunk lateral flexion increased significantly after fatigue.

Conclusion: The results indicated the acute effect of fatigue on knee and trunk kinematics of female soccer players with DKV. Therefore, by increasing the amount of knee and trunk flexion and correcting the landing technique, the possibility of ACL injury in fatigue can be reduced.

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1. Introduction

Soccer is one of the popular sports. The number of its audiences and players is always increasing. Almost 265 million people are active in soccer and 10% of them are female [1]. Thus, increased participation in soccer may increase the risk of injury and makes it among the high-risk injury sports. Rate of injury in soccer has been reported at 12.5 injuries per 1000 hours of activity [2]. About 71.4% of soccer injuries occur in the lower limbs [3]. The knee joint is one of the most injured areas in soccer. Among the knee joint injuries, anterior cruciate ligament (ACL) injury causes high economic, social and psychological damage to players [4, 5]. Conducted studies indicate that the occurrence of ACL injury in soccer is 12% [4] and it is 2-4 times higher in female players than in males. The reason may be related to the different anatomical structural and hormonal differences [5]. If these internal factors are combined with other factors, they may increase the risk of ACL injury [1, 5].

Studies have always indicated that biomechanical changes can be one of the influential factors in the occurrence of injuries [6]. The combination of other factors and biomechanical factors such as the kinematic changes of the trunk, hip, knee, and ankle, and their kinetic changes can significantly expose people to injury [7]. Several factors such as narrow intercondylar width, fatigue, landing in an undesirable body position, muscle imbalance between agonist and antagonist muscles, and dynamic knee valgus (DKV) are involved in the occurrence of ACL injury [7, 8]. DKV is one of the most significant risk factors for ACL injury [4]. It is due to the weakness of the thigh abductor muscles, which increases the internal rotation of the thigh and tibia, and increases the possibility of ACL injury [9, 10]. Females always have more DKV than males due to the anatomical differences between them. So, this injury is more likely to occur in females [4, 11]. Studies have indicated that the activation of the Vastus Medialis (VM) and Gluteus Medius (GM) muscles were delayed in people with DKV. This group of people tends to activate the Vastus Lateralis (VL) muscle faster. This issue causes the knee joint to be in a valgus position, increasing the probability of ACL injury [12, 13].

Studies have indicated that the trunk and knee of people in the injury position are not in their natural and anatomical position in the sagittal and frontal planes, which can be a reason for the occurrence of injury [4].

Some studies have reported that people have less flexion in their trunk and knee during ACL injury, which can cause a harder landing in people and put more force on this ligament [14, 15, 16, 17].

Also, another study has shown that with excessive trunk and knee flexion, the person's center of gravity is outside the range of the support surface, which leads to an increase in the activity of the quadriceps muscles and increases the amount of force exerted on the ACL ligament [18]. Additionally, due to excessive trunk lateral flexion and knee valgus, the center of mass (COM) of the athletes is out of the intended range and affects the activity of the muscles in pelvis and trunk, leading to an increase in the load on this ligament [6].

Landing after a head shot is one of the most dangerous situations in soccer [7, 19] and most ACL injuries occur in landings after a head shot [5, 7]. The risk of ACL injury increases in appropriate conditions during landings and when the receptors have insufficient activity [12].

It seems that the probability of injury in single-leg landing is more than in double-leg landing [20]. However, no study has been conducted on this group of people who are potentially at risk of ACL injury [3]. Single-leg landing requires higher neuromuscular control to maintain balance due to applying more force and a lower level of support, increasing the possibility of injury if any of the knee support components are not working properly [3].

Several studies have been conducted in the area of double-leg and single leg landings, indicating the possibility of injury [21, 22]. However, it is not clear which one the single-leg or double-leg landing along with DKV exposes athletes to more ACL injuries.

Studies have indicated that the probability of injury occurring in the first and last 15 min of the game is higher, which may be related to the effect of fatigue on the occurrence of injury [23, 24]. Fatigue affects joint receptors and nerve pathways and causes them to malfunction. It also causes messages not to be sent correctly and the person is exposed to injury [25, 26]. Due to the disturbance in the function of joint receptors as a result of fatigue, the kinematics and kinetics of the joints change, the amount of force exerted on the joints changes and the probability of injury increases [12, 27]. Therefore, identifying neuromechanical alterations due to fatigue could provide important insight into prevention of and rehabilitation from lower-extremity injury [28].

Fatigue leads to a decrease in the amount of knee flexion and the activity of the gastrocnemius and tibialis anterior muscles, which will increase the probability of injury [28]. Functional fatiguing exercises significantly altered jump landing neuromechanics [28], and due to its greater similarity to specialized sports activities, creates physiological and psychological demands similar to those of competitions for athletes and may provide a more detailed investigation for researchers [1].

Given the 90-min nature of soccer and the involvement of fatigue in neuromuscular activities and having landing and a change in directions in this field, it seems necessary to examine knee and trunk kinematics after functional fatigue in female soccer players with dynamic knee valgus.

2. Materials and Methods

The research presented here is of a semi-experimental nature. The sample size was calculated using the G*Power software with a statistical power of 0.8 and a confidence level of 95% and an effect size of 0.9 [29], resulting in a sample size of 28 participants. They were divided into two groups of 14 participants with DKV and 14 participants without DKV using the single-leg squat test.

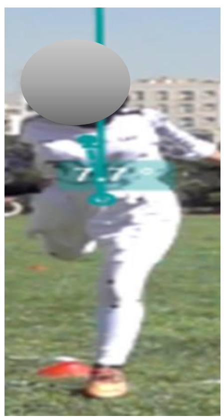
2.1. Participation

The participants were female athletes aged between 18 and 30 years old, with a body mass index ranging from 18-25 [30]. The subjects had a minimum of one year of regular training history (three times a week) [23] and no history of injury to the lower limbs or trunk in the past six months [31]. Exclusion criteria included the observation of knee valgus in a static position [11], any surgical history [32], insufficient sleep within 24 hours prior to the test [33, 34], history of childbirth, women currently in or one week prior to their menstrual periods [35], and hormonal problem of the participants.

The participants performed the single leg squat test (SLS). In this task, participants with bare feet placed their hands on their hips, stood on one leg, and flexed the other leg 90 degrees [36]. The SLS test was considered positive if any abnormal response was observed, including Trendelenburg's sign, arm tremors, and inward rotation of the knee in the supporting leg. If more than four tests out of six tests were positive, the participants were placed in the group with DKV.

2.2. Instrument

To calculate the trunk and knee changes, two high-speed Sony Cyber-shot x10 cameras with a speed of 250 fps were used in the frontal and sagittal planes. Kinovea software (version 0-9-5) was used. The changes of joint angles at the initial contact with the ground is shown in Figure 1.



a) Trunk angle in the frontal plane

b) Knee angle in the frontal plane

c) Trunk angle in the sagittal plane

d) Knee angle in the sagittal plane

Figure 1. The method of calculating the angles

2.3. Procedure

After explaining the goals and procedure of the tests to the participants, the informed consent form was obtained from the subjects. Following the measurement of height and weight, the test subjects engaged in uniform stretching exercises for warming up, including jogging lightly, dynamic stretching movements, squats, lunges, changes of direction, and agility exercises, for a duration of 10 min [36]. The shooting test was used to identify the dominant leg [37], then Sargent's jump test was performed.

The leg that hits the ball was identified as the dominant leg. Markers were placed on anatomical points such as acromion, sternum ridge, anterior superior iliac spine (ASIS), greater trochanter of the femur, lateral femoral condyle, tuberosity of the tibia, lateral malleolus, middle of the patella and navicular bone were placed. Two cameras were placed at a distance of 3 m from the subjects in two sagittal and frontal planes [38], a special soccer landing was performed. In the special soccer landing, the subjects jumped half their height from the 7.5 cm barriers. The ball was hanging half the length of the sergeant, so they could jump and head shooting (Figure 2a) [7]. Kinematic variables related to the knee were measured in two planes by two cameras on the dominant leg of the subjects. The participants performed Bangsbo Fatigue Protocol (Figure 2b) [39].

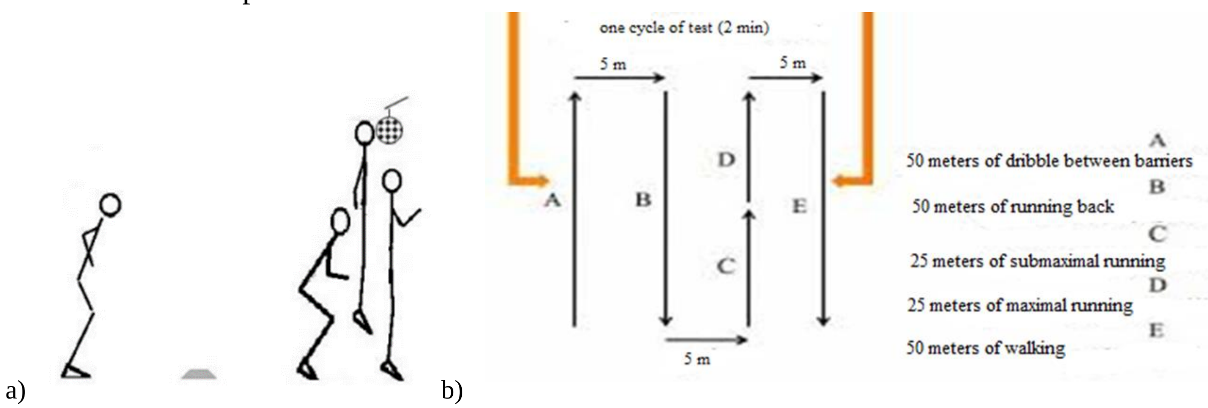


Figure 2. a) Soccer specific landing, b) Bangsbo Fatigue Protocol

In this research, the Bangsbo fatigue protocol was used along with the Burg scale, and when the minimum score of 16 was declared, the fatigue protocol was completed, and landing test was performed to check the kinematic changes of the knee and trunk.

2.4. Statistic

Statistical analysis was done in SPSS-26 software. Descriptive statistics were used to report the mean and standard deviation of the data. After examining the homogeneity of the data, statistical test with mixed ANOVA was used to analyze the data. A significant level of 5% was considered.

3. Results

Table 1 shows the descriptive characteristics of the participants. The statistical results showed that the participants were homogeneous in terms of age, height, weight and body mass index (BMI). There was no significant difference between the two groups.

The results showed that after fatigue, the amount of knee flexion and knee valgus significantly changed in both groups, but these changes were not significantly different between the two groups.

Also, fatigue had a significant effect on the amount of trunk lateral flexion in two groups, but it did not have a significant effect on the amount of trunk flexion. However, a significant difference was found in both flexion and lateral flexion factors between the two groups.

Table 1. Descriptive characteristics of female soccer players with and without dynamic knee valgus

	The group with DKV	p-value	The group without DKV	p-value	Total p-value
Age	19.64±3.20	0.074	20±2.96	0.538	0.152
Height	162.14±4.01	0.638	163±4.09	0.355	0.160
Weight	55.64±4.68	0.478	55.07±4.32	0.440	0.182
BMI	21.52±1.73	0.502	20.92±1.17	0.993	0.922

3.1. Kinematic changes of the knee in the sagittal and frontal planes in single-leg landing

According to the results, a significant interaction effect was observed between the acute effects of soccer functional fatigue (before and after measurement) in two groups on the rate of knee changes in the frontal plane during the initial contact (*P*=0.008 and F=8.36). However, no significant interaction effect was found between the acute effects of functional fatigue and two groups with and without DKV on the rate of knee flexion in initial contact with the ground in single-leg landing (*P*=0.45 and F=0.718). The results revealed the significant acute effect of functional fatigue (before and after measurement) on knee flexion (*P*=0.001 and F=69.08) and knee angle in the frontal plane (*P*=0.02 and F=6.11). The results also revealed a significant intergroup effect in the rate of knee angle in the frontal plane in the initial contact with the ground in single-leg landing (*P*=0.001 and F=199.39). However, no significant intergroup effect was seen in the rate of knee flexion in the initial contact with the ground in single-leg landing (*P*=0.98 and F=0.001; Table 2).

Table 2. Kinematic changes of the knee in the sagittal and frontal planes during single leg landing in female soccer players

Variable	Group with DKV	Group without DKV	The effect of time		The effect of group		The effect of time × group	
			F value	P value	F value	P value	F value	P value
Knee flexion before fatigue	28.4±3.72	28.8±5.87	69.08	0.001	0.001	0.98	0.718	0.405
Knee flexion after fatigue	25.23±1.02	24.9±5.50						
Knee adduction before fatigue	19.78±0.87	5.2±1.80	6.11	0.02	199.39	0.001	8.36	0.008
Knee adduction after fatigue	16.59±5.03	5.45±1.93						

3.2. Kinematic changes of the trunk in the sagittal and frontal planes in single-leg landing

According to the results, a significant interaction effect was observed between the acute effects of functional fatigue (before and after measurement) and two groups with and without DKV on the rate of trunk lateral flexion in the initial contact with the ground in single-leg landing (*P*=0.001 and F=18.33). However, no significant interaction effect was observed between the acute effects of functional fatigue and the two groups with and without DKV on the rate of trunk flexion in the initial contact with the ground in single-leg landing (*P*=0.621 and F=0.251).

The results revealed the significant acute effect of functional fatigue (before and after measurement) on the rate of trunk lateral flexion in the initial contact with the ground in single-leg landing (*P*=0.001 and F=12.96). However, the acute effect of the functional fatigue (before and after measurement) on the rate of trunk lateral flexion in the initial contact with the ground in single-leg landing was not significant (*P*=0.097 and F=2.97).

The results also revealed the significant inter-group effect in the rate of flexion and trunk lateral flexion (*P*=0.001 and F=32.26; *P*=0.002 and F=11.82) in the initial contact with the ground in single-leg landing (Table 3).

Table 3. Trunk kinematic changes in the frontal and sagittal plane in single leg landing in female soccer players

Variable	Group with DKV	Group without DKV	The effect of time		The effect of group		The effect of time × group	
			F value	P value	F value	P value	F value	P value
Displacement of the trunk in the frontal plane before fatigue	4.82±0.60	10.54±1.30	12.96	0.001	32.26	0.001	18.33	0.001
Displacement of the trunk in the frontal plane after fatigue	5.11±1.61	7.23±3.68						
Displacement of the trunk in the sagittal plane before fatigue	5.55±2.84	9.13±1.53	2.97	0.097	11.82	0.002	0.251	0.621
Displacement of the trunk in the sagittal plane after fatigue	5.81±1.05	11.42±7.59						

4. Discussion

The results of this research showed that functional fatigue had effect on knee and trunk kinematics in single leg landing. The amount of knee flexion decreased significantly in individuals with and without DKV and there is no difference between two groups.

Fatigue had an effect on the amount of lateral flexion of the trunk, after fatigue, the amount of lateral flexion in the DKV group increased significantly, while the lateral flexion and the group without DKV decreased after applying the fatigue protocol and a significant difference in the amount of trunk flexion was observed between the two groups.

One of the main factors in ACL injury is a hard landing [14]. Decreased knee flexion results in a harder landing and increased anterior shear force, which may increase the force on the ACL ligament and increase the risk of injury [39, 40].

The results showed that fatigue affects knee flexion and they landed after fatigue with a lower rate of flexion. The reason for these changes may be due to the effect of fatigue on the activity of the quadriceps muscles and the earlier activation of this muscle compared to the hamstring muscle and the change in proprioceptive, which after these changes reduces the knee flexion and makes landing harder [34].

In this regard, a study conducted on female athletes showed that the rate of knee flexion decreased significantly after applying the fatigue protocol [37]. The results of the mentioned study are consistent with those of the present study, the reason for this similarity may be due to the same gender of the subjects. In another study conducted on male soccer players, it was shown that over time, there is more adaptation in knee changes in players, and the degree of knee flexion improves over time [39], the reason for this difference could be the difference in gender and physiological conditions of the subjects.

DKV is another potential factor in the occurrence of ACL injury, which is more common in females [4]. This inconsistency is due to the weakness of the thigh abductor muscles and vastus medialis muscle, dysfunction of joint receptors [26] and physiological conditions related to females that cause increasing the possibility of ACL injury [4]. In single-leg landing, the pressure on the ACL ligament increases non-linearly with the increase in the maximum torque of the knee external rotation, and the possibility of tearing this ligament increases more significantly as knee valgus, knee extension, and fatigue increases [4, 5].

Studies have shown that fatigue alters the eccentric strength of the hamstrings and impairs knee joint stability. Reduced eccentric hamstring strength has been associated with a reduced capacity to control frontal plane knee kinematics in a single leg squat and during single leg landing tasks [41]. But, research has shown that in order to reduce the effect of fatigue in football, fartlek exercises can be done to reduce the possibility of injury [42].

The present study showed that fatigue significantly reduced knee valgus in the DKV group. The main reason of this result may be due the adaptation of neuromuscular, joint and proprioceptive receptors with fatigue in the DKV group [39].

In this regard, Kim et al. (2021) showed that the local fatigue of the abductor muscles had no significant effect on the kinematics of the knee in the frontal plane [8]. The findings of the mentioned study are inconsistent with those of the present study and the reason could be the difference in the type of fatigue protocol used.

Also, Hosseini et al. (2019) showed that fatigue significantly increased the knee valgus [37]. This study was inconsistent with the current study, the reason for this difference could be due to the absence of DKV in athletes and the type of test used (direction change test) in the research.

Stability and proper functioning of trunk muscles improve performance and may prevent injury [40]. Previous researches found women placed their COM in the posterior region at the time of injury and it caused them to have a harder landing, which may increase the activity of the quadriceps muscle and increase the anterior shear force applied to the ACL ligament [4, 13]. Our results revealed that fatigue did not affect the level of trunk flexion.

However, a significant difference in trunk flexion was found between two groups, and the group without DKV landed with more flexion. The reason for this difference may be related to the different function of joint receptors and muscles in the two groups. But in another research, it was shown that the fatigue of the central muscles had an effect on the amount of flexion of the trunk and the participants made a harder landing [40], that may be for the difference in the gender of the participants and the fatigue protocol used.

The angle of trunk lateral flexion can predict the probability of ACL injury [4]. With increasing the inclination of the trunk toward one side, the knee abduction torque and the possibility of ACL injury increase [6]. The results revealed that fatigue has an effect on trunk lateral flexion. The rate of trunk lateral flexion in the two groups was different and participants without DKV had more trunk lateral flexion toward their non-dominant leg. The reason for this could be the reduction of the force exerted on the dominant leg of the participants to prevent the possibility of injury [8].

The researcher did not find a study consistent with the present study. However, one study showed that the rate of trunk displacement toward the dominant leg was higher after applying the thigh abductor muscle fatigue protocol [8]. The mentioned study is inconsistent with the present study, it may be due to the difference in the type of fatigue protocol used and the different structural characteristics of the participants.

The results of this research showed that fatigue may affect the kinematics of the DKV group and expose them to more injury.

Some of the limitations of our study were climate conditions, psychological issues, and participants' anxiety in performing the tests correctly and placing the markers in the desired anatomical points. More realistic results can be obtained using more accurate tools.

5. Conclusions

Based on the finding of present study, it can be concluded that fatigue can affect the knee and trunk kinematics of female soccer players and put them in risky situations. These changes were seen more in the group with DKV in the lower limbs, putting these people more seriously at risk of ACL injury. Therefore, it seems necessary to consider an appropriate physical fitness program for female soccer players with DKV.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design. Conceptualization, N.T., M.H.A, S.H.M; methodology, N.T., M.H.A, S.H.M; investigation, N.T., M.H.A, S.H.M; writing - original draft preparation, N.T; writing - review and editing, N.T., M.H.A, S.H.M; visualization, N.T.; supervision, M.H.A, S.H.M; project administration, N.T., M.H.A, S.H.M. All authors have read and agreed to the published version of the manuscript.

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc. The study was conducted in accordance with the Declaration of Helsinki, and study protocol was approved by the Research Ethics Committees of Faculty of Physical Education and Sport Sciences-Tehran University (IR.UT.SPORT.REC.1402.002). Written informed consent has been obtained from the patient(s) to publish this paper.

Data availability

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

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