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EFFECTS OF MUSCLE FATIGUE ON LANDING KINEMATICS IN FEMALES

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SUMMARY
Anterior cruciate ligament (ACL) injury is one of the most common injuries in athletes, especially in females. Alterations on landing strategies can lead to an increased risk of ACL injury. Muscle fatigue is one of the factors that could contribute to alteration in landing kinematics. Thus, the purpose of this study was to evaluate the effects of a fatigue protocol on knee, hip and trunk kinematics during a single-leg drop jump landing in females. Fifteen healthy females performed a single-leg drop jump for kinematic assessment of knee, hip and trunk before and after a fatigue protocol. Female participants showed increased knee abduction, hip adduction and trunk flexion after the fatigue protocol. Therefore, fatigue altered landing biomechanics, possibly increasing the risk of ACL injury in females.

INTRODUCTION
Anterior cruciate ligament (ACL) injury is one of the most common injuries in athletes, predominantly in females [1]. These injuries usually occur during activities that demand a high amount of energy and fatiguing muscular performance [2]. Muscular fatigue occurs during strenuous physical activity and may result in decreased performance and altered hip and knee kinematics [3] on the frontal and sagittal planes [4,5,6].

Excessive knee dynamic valgus has been considered an important mechanism of ACL injury [1]. In addition, abnormal motions in the sagittal plane, such as decreased knee, hip and trunk flexion during jump landing have also been considered risk factors for ACL injury [7]. The cited lower limb biomechanics could predispose female athletes to ACL injury, especially in the end of a sporting activity, when fatigue is most evident [3]. Therefore, the purpose of this study was to evaluate the effects of a fatigue protocol on knee, hip and trunk kinematics during a single-leg drop jump landing in females.

METHODS
Fifteen healthy, physically active females (age 21.1 ± 2 yeas; height 1.64 ± 0.1 m; mass 58.2 ± 7.7 Kg), with no history of lower limb injury or pain, participated in this study.

Three-dimensional kinematic data was collected using a six-camera system (Qualisys Medical AB, Sweden) at 240Hz. Participants performed a single-leg drop jump task with the dominant limb before and after the fatigue protocol. The single-leg drop jump task was performed from a box 31cm height followed immediately by a maximal effort single-leg vertical jump.

Kinematic data were analyzed initially using Visual 3D software (C-Motion, Rockville, MD) and Matlab software (Mathworks, Natick, MA). The variables of interest were knee flexion, knee abduction, hip flexion, hip adduction, trunk flexion and trunk ipsilateral trunk lean during the deceleration phase of the drop jump landing, defined as the interval between initial foot contact and maximal knee flexion. Data were filtered using a second order, zero lag, low-pass Butterworth filter at 10 Hz.

Before the fatigue protocol, participants performed a maximal effort single-leg hop in order to establish their maximum hop distance. Subjects were considered fatigued if their hop distance was reduced to 80% of their pre-fatigue maximum distance. The fatigue protocol included series of 10 squats, 2 vertical jumps and 20 steps. These series were performed until the fatigue was detected.

For statistical analysis paired t-test was used to evaluate the effects of fatigue on knee, hip and trunk. The alpha level was set at $P < 0.05$.

RESULTS AND DISCUSSION
After the fatigue protocol, females presented significant increase in knee abduction and hip adduction. Also, the participants showed greater trunk flexion after the fatigue protocol. No changes were observed in hip and knee kinematics in the sagittal plane.

Fatigue has been shown to affect lower limb biomechanics [3]. The current findings indicate that fatigue altered hip and knee kinematics in ways that could lead to excessive dynamic knee valgus during landing. Previous studies suggested that excessive knee valgus could increase the risk to ACL injury [1].

The effects of muscular fatigue on jump landing kinematics have been previously studied. Corroborating with our results, after the fatigue protocol, females demonstrated greater knee valgus during landing [4,5]. However, Benjaminse and colleagues [6] did not show difference in hip kinematics before and after the fatigue protocol.

Blackburn and Padua [7] demonstrated that trunk flexion during landing reduced quadriceps activity. Since the fatigue protocol of this study focused on the quadriceps muscle, it is possible that the increased trunk flexion performed by the female participants after the fatigue protocol could be the result of decreased quadriceps activation.

CONCLUSIONS

In conclusion, after the fatigue protocol, participant showed increased knee abduction, hip adduction and trunk flexion. Therefore, fatigue increased dynamic valgus position during landing activity. These findings suggest that women may be exposed to increased risk for ACL injury during high demanding physical activities.

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Table 1: Mean ± standard deviation of kinematic data before and after fatigue protocol

	Before fatigue	After fatigue	*P*- value
Knee flexion	57.8° ± 12.1	56.3° ± 10.7	0.277
Knee abduction	5.8° ± 2.3	6.6° ± 2.4	0.048*
Hip flexion	50.2° ± 13.7	51.5° ± 17.1	0.454
Hip adduction	11.6° ± 5.9	9.7° ± 6.1	0.040*
Trunk flexion	8.6° ± 6.6	13.0° ± 9.1	0.001*
Ipsilateral trunk lean	9.6° ± 3.3	9.6° ± 3.9	0.995

* $P < 0.05$