EXAMINING FATIGUE EFFECTS ON BIOMECHANICAL ACL INJURY RISK FACTORS IN FEMALE ATHLETES DURING SINGLE-LEG DROP VERTICAL JUMP

Raihana Sharir[1,2], Mark A. Robinson[2], Jos Vanrenterghem[3], and Radin Rafeeuddin Radin Dzulfakar[1]

Faculty of Sports Science and Recreation, Universiti Teknologi MARA,Malaysia[1]
Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, UK[2]
Faculty of Kinesiology and Rehabilitation Sciences, KU Leuven, Belgium[3]

This study aimed to examine the impact of fatigue on biomechanical factors associated with ACL injury risk in female athletes during the single-leg drop vertical jump task. Thirty-nine female athletes participated, undergoing a fatigue protocol comprising functional high-intensity exercises. Participants completed five trials before and after the fatigue protocol. Post-fatigue, significant differences were observed, including lower peak knee flexion angle. Notably, while fatigue induced changes in kinematic indicators, kinetics remained unaffected. As conflicting evidence in the role of fatigue is still on-going, this study highlights the influence of fatigue on specific mechanics, providing additional insights into the relationship between fatigue and biomechanical changes.

KEYWORDS: fatigue, single-leg drop vertical jump, ACL, knee

INTRODUCTION: Non-contact anterior cruciate ligament (ACL) injury risk factors are well-known to be multifactorial, with recent attention focusing on fatigue as a significant modifiable risk factor (Barber-Westin & Noyes, 2017). Fatigue weakens muscles and alters movement patterns, contributing to non-contact ACL injuries (Bourne et al., 2019; Cortés et al., 2013). While the workload associated with playing time is a common indicator of fatigue in sports (Benjaminse et al., 2019), it does not precisely quantify fatigue. Athletes undergoing extensive training or competition experience higher workloads, thus more fatigue compared to those with involvement. However, Doyle (2018) challenges the assumption that fatigue significantly contributes to ACL injuries. Their meta-analysis reported no notable difference in ACL injury rates between different game periods or between seasons, suggesting minimal to no impact of fatigue on lower-limb injury likelihood. Few prospective studies have effectively developed consistent fatigue protocols to affect lower limb kinematics or kinetics, leading to insufficient data to ascertain fatigue as a definitive ACL injury risk factor (Barber-Westin et al., 2017, Benjaminse et al., 2019). Despite fatigue's recognized role, the impact of fatigue on single-leg landing kinetics and kinematics remains conflicting (Barber-Westin et al., 2017, Benjaminse et al., 2019). ACL injuries typically occur during single-legged activities, such as landing from a jump, involving knee hyperextension, high ground reaction forces, dynamic valgus collapse, anterior shear force, and tibial rotation (Boden & Sheehan, 2022; Kim et al., 2015). When the knee is minimally flexed, the ACL acts as the sole passive restraint against anterior tibial translation (Markolf et al., 1978). Forceful loads, like a quadriceps pull at a nearly extended knee (20°-30° knee flexion angle), can induce significant anterior tibial translation, increasing ACL loading, especially during landing from a jump (Hashemi et al., 2011). Conflicting evidence emerges regarding fatigue's effect on ACL injuries, particularly in female athletes. While a study on female amateur rugby suggests peripheral fatigue alters landing biomechanics (Yeomans et al., 2021), others find no correlation between fatigue and ACL injury in female footballers (Lucarno et al., 2021; Alsubaie et al., 2021). Despite the debate, our study aims to contribute by examining the impact of fatigue on biomechanical factors associated with ACL injury risk in female athletes during the single-leg drop vertical jump task. We hypothesize that all biomechanical factors of ACL injury will be affected post-fatigue.

METHODS: Thirty-nine female athletes who regularly participated at least twice a week in highly dynamic sports (21.7±3.5 years; 64.6±10.9 kg; 1.6±0.1 m; 7.7±4.8 hours of training/week), free of lower limb injuries for at least 12 months, participated in a controlled cohort repeated-measures experimental design. The study aimed to assess the peripheral fatigue effects on peak knee flexion angle (pKFA), knee abduction angle at initial contact (KAA), peak knee abduction moment (pKAM), and peak vertical ground reaction forces (pVGRF) associated with ACL injury risk. The fatigue protocol, SAFT[5] (Bossuyt et al., 2016) was performed within the laboratory environment, in a circuit composed by functional high intensity movements such as jog, sprint, counter movement jump, agility ladder drill and jump scissors task. Heart rate (HR) and rate of perceived exertion (RPE) (20-point Borg scale) was monitored during the protocol to observe match play exertion.

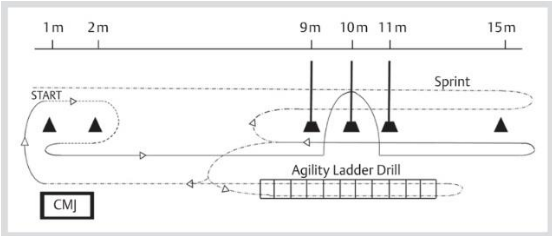

Figure 1: The SAFT[5] course

Only RPE rated between 'hard' and 'very hard' with 87–97 % HR maximum was observed in this protocol as being in the state of fatigue. After warm-up and familiarisation of task and fatigue protocol, participants performed five trials of the single-leg drop vertical jump (SLDVJ) maximally from a 30cm high box following the protocol described in a previous study (Myer et al., 2010). SLDVJ was done before and after the fatigue protocol, on their dominant leg. Motion data were captured at 250 Hz (10 Oqus Cameras and QTM v.2.14 Qualisys AB, Gothenburg, Sweden). Ground reaction forces were measured by two force platforms sampling at 1500 Hz (Kistler InstrumentsLtd., Winterthur, Switzerland). Forty-four spherical markers were used according to the LJMU Lower Limb and Trunk model (Vanrenterghem et al., 2010). Static and functional joint trials were collected prior to testing to define functional hip and knee joint centres. Motion data were modelled and analysed using Butterworth filter with 20 Hz cut-off frequency in Visual 3D (v.5.02.30 C-Motion, Germantown, MD, USA). Touch-down and take-off from the force platform were identified based on a 20 N threshold. The biomechanical variables were compared using paired samples t-tests using the Statistical Package for the Social Sciences (SPSS Statistics v.29, IBM Corporation, Armonk, USA) with a level of significance set at p-value < 0.05.

RESULTS: The paired sample t-test revealed that fatigue altered the knee kinematics during SLDVJ post-fatigue for peak knee flexion angle and knee abduction angle at initial contact (Table 1). Contrary to our hypothesis, no significant differences were observed for kinetic variables.

Table 1: Kinematic and kinetic data during Single-leg Drop Vertical Jump task. Data presented as mean standard±deviation

	Fatigue Protocol		*p-value*	Effect size (Cohen's d)
	Pre	Post		
Peak knee flexion angle (pKFA)(°)	-67.3 ± 8.8	-61.7 ± 8.3	0.000*	-1.13
Knee abduction angle (KAA) (°)	-0.1 ± 2.9	0.4 ± 3.2	0.045*	-0.33
Peak knee abduction moment (pKAM) ($Nm.kg^{-1}$)	0.41 ± 0.19	0.43 ± 0.23	0.489	-0.11
Peak vertical ground reaction force (pVGRF) ($N.kg^{-1}$)	3.47 ± 0.41	3.45 ± 0.38	0.637	0.08

**Significantly different from pre-fatigued (p < 0.05)*

DISCUSSION: The purpose of this study was to compare the biomechanical factors of ACL injury risk during the SLDVJ task before and after a high-intensity exercise fatigue protocol for female athletes. The primary findings indicate that the fatigue protocol influenced the sagittal and frontal plane angles during the task. Similarly to previous studies, knee flexion was reduced post-fatigue (Benjaminse et al.,2019; Chappell et al., 2005; Borotikar et al., 2008). In this current study, we observed the peak knee flexion angle (pKFA), previously found to be significantly associated with new ACL injuries (Leppänen et al., 2016). Additionally, in a further study by Leppänen et al. (2017), the same previous players were found to land with a high peak external knee flexion moment, indicating that athletes who suffered ACL injuries likely experienced increased quadriceps forces. These forces can generate significant ACL loading, particularly at low flexion angles (DeMorat et al., 2004; Markolf et al., 1995). However, it is important to note that the landing strategies observed by Leppänen et al. (2016) were during unfatigued bilateral drop vertical jumps, thus direct comparisons may not be appropriate. Essentially, landing with an increased pKFA allows individuals to disperse impact ground reaction forces across a broader joint range of motion and over an extended period, thereby associated with lower peak impact ground reaction forces which reduces ACL loading (Fisher et al., 2016). No significant differences were observed between pre- and post-fatigue conditions for the pKAM in this current study. This finding contrasts with those of Cortés et al. (2013) and Iguchi et al. (2014), where a decrease in the pKAM was observed after fatigue, typically resulting in a larger pVGRF. Though, it is worth noting that both of these studies examined unanticipated tasks, where movement mechanics changed unfavourably compared to anticipated tasks (Collins et al., 2016; Weinhandl et al., 2013). Additionally, these studies focused on side-cutting tasks, which involve sudden changes of direction. While our study provides insight on the impact of fatigue on ACL injury risk during SLDVJ, it's important to acknowledge limitations. High variability in participant training hours could potentially impact our findings, as training exposure time may increase injury likelihood (Chia et al., 2022).

CONCLUSION: This study highlights the impact of fatigue on particular kinematic and kinetic aspects, offering insights into ACL injury risk during athletic performance in an anticipated task. The findings suggest that fatigue may increase risk of injury through reduced knee flexion in a single-leg drop vertical jump, yet does not increase risk of injury via changed kinetics.

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