

ORIGINAL ARTICLE

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The Effects of Neuromuscular and Mental Fatigue on Knee Kinematics and Anterior Cruciate Ligament Injury Risk in Male Soccer Players

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How to cite: Khazaei, Z., Gheitasi, M., Barati, A. H., Bagherian Dehkordi, S. The Effects of Neuromuscular and Mental Fatigue on Knee Kinematics and Anterior Cruciate Ligament Injury Risk in Male Soccer Players. *Journal of Advanced Sport Technology*, 2025; 9(1): -. doi: 10.22098/jast.2025.14220.1328

ABSTRACT

Background: The majority of anterior cruciate ligament (ACL) injuries are non-contact, occurring most frequently during landing or changing directions in sports activities. Various factors, such as biomechanical and neuromuscular variables, have been implicated in these injuries. Recent research highlights that both physical and mental fatigue might influence the risk factors for ACL injuries by altering movement patterns during high-risk maneuvers. This study aimed to investigate the effects of neuromuscular and mental fatigue on knee kinematics and potential risk factors for ACL injuries in male soccer players during landing and crossover-cutting maneuvers.

Methods: Thirty professional male soccer players were randomly divided into three groups: physical fatigue (n=10), mental fatigue (n=10), and control (n=10). Experimental groups performed landing and crossover-cutting maneuvers during pre- and post-fatigue states, with kinematic data collected using a seven-camera system and Cortex software. The control group underwent identical maneuvers without fatigue protocols to ensure comparability of conditions across groups. The control group underwent the same tests without implementing fatigue protocols. Statistical analysis was conducted using repeated measures ANOVA to evaluate differences across groups and conditions.

Results: Physical fatigue caused a significant decrease in knee flexion at initial contact ($P = 0.002$), while mental fatigue showed no significant effects on kinematics. Group-by-time interaction effects were observed for knee flexion ($P = 0.05$), with pairwise comparisons revealing significant differences only in the physical fatigue group.

Conclusion: Neuromuscular fatigue alters knee kinematics, increasing ACL injury risk. Coaches should prioritize training programs that enhance fatigue resistance and proper movement mechanics.

KEYWORDS

neuromuscular fatigue, mental fatigue, knee kinematics, soccer players, landing mechanics

Introduction

Knee injuries are a significant concern in sports, accounting for approximately 60% of all sports-related injuries (1). Among these, anterior cruciate ligament (ACL) injuries are particularly debilitating and represent nearly half of all knee injuries (2). Epidemiological studies estimate the prevalence of ACL injuries in males to be approximately 1 in every 3,500 cases (1). These injuries not only diminish athletic performance but also increase the risk of re-injury, leading to psychological distress, reduced participation, and even early retirement from sports (3). Consequently, effective prevention programs are essential to mitigate injury risks, enhance athlete safety, and reduce the associated economic burden (3). However, the development of effective prevention strategies relies on a comprehensive understanding of the mechanisms underlying ACL injuries (4).

Approximately 70% of ACL injuries occur via non-contact mechanisms (5), typically during landing, pivoting, or cutting maneuvers (6). High-risk scenarios include sudden deceleration, directional changes, or evasive maneuvers performed at high speeds to avoid defenders in sports like soccer, basketball, and handball (7). These actions often involve biomechanical factors such as valgus knee alignment, limited knee flexion, and increased ground reaction forces, all of which contribute to ACL injury susceptibility (6). Given the high prevalence of these movements in dynamic sports, cutting maneuvers have been identified as critical for assessing injury mechanisms (8).

Understanding and addressing risk factors is fundamental to injury prevention. Among these factors, fatigue has emerged as a pivotal contributor, encompassing both physical and mental domains (9). Physical fatigue, defined as a decline in muscle performance due to repetitive exertion, has been shown to impair proprioception, neuromuscular control, and coordination (10). In soccer, fatigue frequently occurs during the final 15 minutes of each half, correlating with an increased incidence of injuries (11, 12). Studies have demonstrated that fatigue-induced alterations in muscle activity and joint mechanics, such as reduced knee flexion angles and increased abduction moments, elevate the risk of ACL injuries (13, 14). For instance, McLean et al. reported that fatigue amplifies knee abduction during landing (14), while Kellis et al. observed reduced ground reaction forces and altered knee flexion mechanics due to thigh muscle fatigue (15).

Mental fatigue, characterized as a psychobiological state resulting from prolonged cognitive effort, has also been implicated as a risk factor for non-contact ACL injuries (16, 17). It can impair reaction times, decision-making, and motor coordination, thereby compromising an athlete's ability to perform high-stakes maneuvers (18). Swanik et al. demonstrated that athletes with lower neurocognitive function exhibit slower reaction times and reduced visual-motor coordination, which may predispose them to ACL injuries (18). Furthermore, mental fatigue diminishes focus and agility, exacerbating the risk of errors and missteps during competition (19). Interestingly, ACL injuries are more prevalent during competitive matches (49.2%) compared to practice sessions (34.8%), possibly due to heightened mental stress in competitive scenarios (20).

Despite its critical role, the influence of mental fatigue on ACL injuries remains underexplored, particularly in comparison to physical fatigue. Both neuromuscular and mental fatigue are believed to significantly alter knee kinematics, potentially increasing ACL injury risks (17). Therefore, this study aimed to investigate and compare the effects of neuromuscular and mental fatigue on ACL injury risk factors, focusing on landing and crossover-cutting maneuvers in professional male soccer

players. The findings are expected to provide valuable insights into injury prevention strategies and highlight the need for comprehensive interventions targeting both physical and cognitive domains.

Material and Methods

This semi-experimental study was conducted with 30 healthy male soccer players from the Asia Vision Tournaments (Tehran's Premiere League). Participants were selected based on specific inclusion and exclusion criteria. These criteria ensured the homogeneity of the sample by focusing on experienced athletes without recent injuries or conditions that could confound the results, thereby enhancing the validity and reliability of the study's findings. The inclusion criteria required participants to be professional soccer players with at least two years of experience, with no history of lower-extremity injuries in the past six months, no joint diseases such as osteoarthritis, no physical activity for 48 hours before testing, and abstinence from caffeine or alcohol. Exclusion criteria included the presence of any chronic illness, current or past injuries affecting performance, or failure to comply with pre-test instructions.

To reduce variability, only male athletes were included, as gender-related differences in landing kinematics have been reported. All participants signed a written informed consent form after receiving detailed information about the study objectives and procedures. Participants were then randomly assigned into three groups: physical fatigue (n=10), mental fatigue (n=10), and control (n=10). Randomization was stratified to ensure homogeneity across groups based on height, weight, and years of playing experience.

The sample size was calculated using G*Power software, considering an effect size of 0.3, power of 0.8, and an alpha level of 0.05. The calculated sample size of 30 participants was deemed sufficient to detect differences in kinematic variables across the groups. To simplify data collection, tests were performed based on the right and left legs rather than dominant and non-dominant legs. This limitation was acknowledged in the discussion section, with recommendations for future research to address it. Ethical approval for this study was obtained from the Research Ethics Committee of the Sports Science Research Institute of Iran (Code: IR.SSRC.REC.1398.123)

Participants performed a standardized warm-up protocol, including five minutes of stretching and running. The three-dimensional (3D) kinematic evaluation of landing and crossover-cutting maneuvers was conducted using a calibrated Motion Analysis System. A 40-cm wooden box was used for the landing task. To ensure consistency in landing patterns, participants were explicitly instructed to land on their forefoot and transition to the heel, regardless of the jump height, aligning their movement with a standardized landing strategy. This was confirmed during familiarization trials (2).

Upon jumping, a light box placed three meters away would randomly light up on the left or right side. Participants were instructed to cut in the direction of the light at a 60-degree angle and run three meters at a self-selected speed. Both legs were tested, with three valid trials recorded after familiarization. Landing technique consistency was visually monitored by an experienced researcher to ensure compliance (2).

Regarding the influence of the pelvic girdle, its role as a closed kinematic chain affecting adjacent limbs was acknowledged. Participants were screened for any pelvic or core instabilities during the initial assessment. This ensured minimal compensatory movements from neighboring segments during landing and cutting maneuvers. Participants performed these tasks during pre- and post-fatigue states. The control group underwent the same testing protocol without fatigue induction, with

identical time intervals between pre- and post-tests. No combined fatigue protocol was applied to experimental groups. Figure 2 shows the schematic photo of landing and cutting maneuvers.

The muscle fatigue protocol consisted of sets of 10 single-leg squats (to 90° of knee flexion), two single-leg maximal vertical jumps, and 20 step-ups (31 cm height step, alternating legs for each set). The procedure was repeated until participants reported a score of 10 on the Borg scale, indicating maximal fatigue. No specific limb was targeted for inducing fatigue, as both legs were alternately involved in the protocol to ensure balanced fatigue across both limbs. (21, 22).

Participants continued the protocol if the height of their single-leg maximal vertical jump exceeded 80% of the initial reference value, which was determined by three maximal-effort single-leg hops recorded before the protocol. The average jump height was used as a baseline reference. Fatigue levels were monitored between sets using the Borg scale, with a score of 10 confirming the participant's exhaustion (23).

The mental fatigue protocol involved a 45-minute version of the AX-Continuous Performance Test (AX-CPT), a cognitive task designed to measure alertness, working memory, and rapid response capabilities (24). Participants were required to press one of two buttons in response to a series of letters displayed on a computer screen. Performance metrics included response time, accuracy, and error detection, with auditory feedback (a beep) signaling non-responses or incorrect responses. Upon completing the AX-CPT, participants completed a validated mental fatigue questionnaire to confirm fatigue levels. Scores below 50 on the questionnaire were considered indicative of mental fatigue (17, 25). If a participant did not meet the fatigue criteria, the AX-CPT was repeated to ensure the desired cognitive fatigue level was achieved.

Kinematic data were collected using a seven-camera motion analysis system (Motion Analysis, Santa Rosa, California, USA) and Cortex software (ver. 2.5). The motion capture system was calibrated to the testing range prior to data collection. Data were sampled at a rate of 240 Hz to ensure high-resolution capture of movement.

Reflective markers were applied to the participants based on the Helen Hayes marker set (26). A total of 21 markers were placed on specific anatomical landmarks, including the right and left anterior superior iliac spine, sacrum, right and left greater trochanter, right and left thigh, right and left medial and lateral femoral epicondyles, right and left shank, right and left medial and lateral malleoli, right and left second metatarsal heads, and the right and left heels (26). Figure 1 illustrates the arrangement of the cameras and marker placement in the laboratory setup.

In this study, the KinTools RT section of the Plugin software integrated with the Cortex software was used for segmentation and kinematic data extraction. The landing phase was defined as the interval between initial contact and maximal knee flexion. Initial contact was identified as the moment when the vertical velocity of the marker on the second metatarsal head reached zero (27). To preprocess the data, a low-pass Butterworth filter with a 6 Hz cutoff frequency was applied to reduce noise and improve data accuracy (28). Prior to formal testing, pilot trials were conducted to optimize camera angles and ensure full visibility of the markers throughout the motion range. If a marker became temporarily obscured during data capture, the Cortex software's interpolation functionality was employed to estimate its position.

The location coordinates of the second metatarsal head marker on the Z-axis were used to determine the frame with the smallest spatial distance from the ground, thereby accurately identifying the time of foot strike. This method ensured precise temporal alignment for analyzing kinematic variables during the landing phase.

Upon the completion of the data collection phase, the Shapiro-Wilk test was used to assess the normal distribution of the data, and Levene's test was conducted to evaluate the homogeneity of variances. Variables were averaged across three trials for consistency.

For within-group comparisons (pre-test vs. post-test), paired sample t-tests were employed. This approach provided a clear analysis of the effect of fatigue within each condition, focusing on changes specific to each group.

To evaluate between-group differences and interaction effects (time $\times$ group), a mixed-design repeated measures ANOVA was utilized. This allowed for comprehensive analysis of group and time interactions, while post-hoc pairwise comparisons were performed using Tukey's adjustment to identify specific group differences.

The Mauchly's test of sphericity was applied to ensure the assumption of sphericity, and Greenhouse-Geisser corrections were made when this assumption was violated. The alpha level was set at 0.05 for all statistical tests. Statistical analysis was conducted using SPSS Statistics software (ver. 22) (SPSS Inc., IBM Company, N.Y., USA)

Results

No significant differences in anthropometric characteristics were observed among the groups (Table 1). The Shapiro-Wilk test confirmed the normal distribution of data ($p \geq 0.05$). Kinematic variables are presented in Table 2. Within-group comparisons highlighted a significant change in the physical fatigue group, specifically in the left leg, where the flexion angle at initial contact decreased significantly ($p = 0.002$), indicating the influence of physical fatigue.

Mixed ANOVA analysis (Table 3) demonstrated significant group-by-time interactions for flexion angles at initial contact in both the right ($p = 0.05$) and left ($p = 0.007$) legs, underscoring varying effects across the groups. Post hoc Tukey's analysis revealed that the physical fatigue group exhibited a significant difference compared to the control group ($p = 0.006$). Moreover, the group effect for the left leg's initial contact flexion angle was statistically significant ($p = 0.05$), primarily driven by differences between the physical and mental fatigue groups ($p = 0.05$).

These results emphasize the critical impact of physical fatigue on knee kinematics during high-risk maneuvers, particularly alterations in flexion angles at initial contact. The findings suggest targeted strategies to mitigate fatigue-induced changes in movement patterns to reduce injury risk.

Figure 1. The schematic photo of landing and cutting manoeuvres.

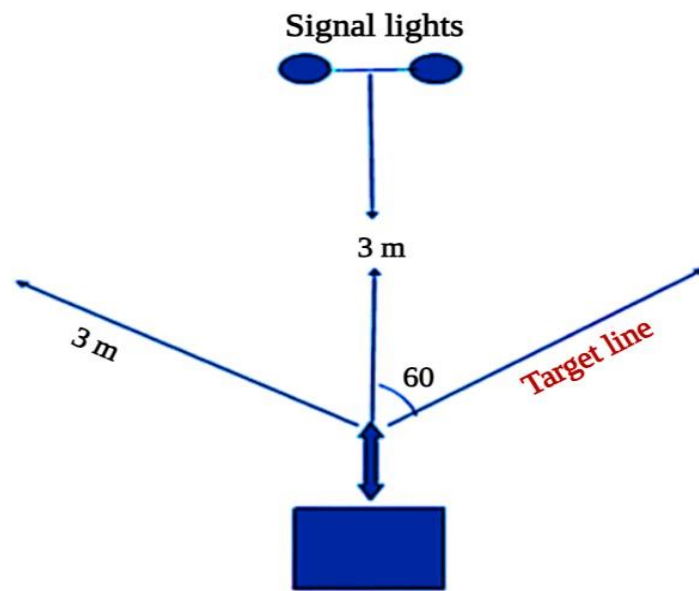


Figure 2. The cameras positions in laboratory.

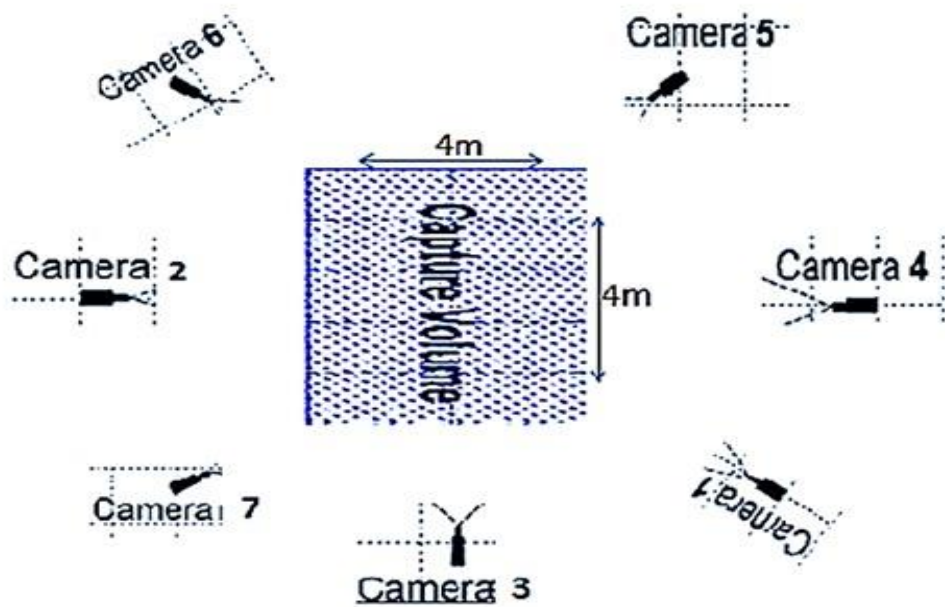


Table 1. Means $\pm$ standard deviations for participants' anthropometric characteristics.

Variable	Physical Fatigue	Mental Fatigue	Control
Age (years)	20.1 $\pm$ 7.05	21.1 $\pm$ 9.59	21 $\pm$ 1.99
Height (cm)	178.4 $\pm$ 9.17	178.7 $\pm$ 5.18	179.5 $\pm$ 8.73
Weight (kg)	71.8 $\pm$ 5.04	71.8 $\pm$ 3.78	73.1 $\pm$ 5.51

Table 2: Kinematic variables.

variables			Control		Sig.	Physical fatigue		Sig.	Mental fatigue		Sig.
			Pre test	Post test		Pre test	Post test		Pre test	Post test	
Flexion(+)/Extension(-)	IC	R	27.71±6.13	32.85±6.45	P=0.054	24.47±5.32	23.98±7.13	P=0.80	28.04±3.60	26.63±5.64	P=0.40
		L	29.47±7.72	32.83±7.13	P=0.80	27.03±5.67	23.70±5.41	*P=0.002	26.49±6.43	26.97±5.30	P=0.75
	Peak	R	59.52±6.72	63.59±13.05	P=0.23	57.19±10.92	53.79±12.12	P=0.36	64.51±14.82	61.74±15.58	P=0.57
		L	57.59±11.11	63.07±13.05	P=0.20	59.36±12.30	50.80±11.58	P=0.18	60.20±14.86	62.38±15.92	P=0.58
Valgus(+)\Varus(-)	IC	R	3.52±8.36	4.32±9.27	P=0.72	0.64±2.83	3.40±6.96	P=0.23	5.84±5.92	5.30±7.24	P=0.78
		L	-0.17±9.59	2.16±8.33	P=0.39	-0.99±6.88	0.55±6.05	P=0.56	7.62±6.63	5.72±8.62	P=0.58
	Peak	R	-7.92±10.26	-5.52±6.94	P=0.51	-9.21±4.19	-7.63±6.78	P=0.46	-5.35±7.42	-10.56±5.16	P=0.07
		L	-6.74±9.54	-6.44±5.00	P=0.92	-10.52±6.43	-8.74±9.84	P=0.40	-8.11±10.97	-6.23±8.32	P=0.72
Rotation Internal(+)/External(-)	Cutting	R	-2.41±8.42	-3.46±9.92	P=0.71	-12.42±8.09	-7.58±18.24	P=0.07	-8.62±8.14	-8.83±5.19	P=0.91
		L	0.56±9.78	-1.95±10.61	P=0.19	-9.10±11.74	-10.32±14.42	P=0.67	-4.30±8.35	-8.62±6.20	P=0.14

Table 3: Result for Analysis of variance with repeated measures test

variables index			df	df error	F	p-value	Effect size
Flexion initial contact	R	time	1	27	0.89	0.35	0.03
		group	2	27	3.80*	0.03	0.22
		time*group	2	27	3.20	0.05	0.19
	L	time	1	27	0.04	0.82	0.002
		group	2	27	2.56	0.09	0.16
		time*group	2	27	6.00*	0.007	0.30
Flexion peak	R	time	1	27	0.09	0.75	0.004
		group	2	27	1.35	0.27	0.09
		time*group	2	27	1.14	0.33	0.07
	L	time	1	27	0.01	0.91	0.00
		group	2	27	0.89	0.42	0.15
		time*group	2	27	2.45	0.10	0.06
Valgus initial contact	R	time	1	27	0.72	0.40	0.02
		group	2	27	0.79	0.46	0.05
		time*group	2	27	0.65	0.52	0.04
	L	time	1	27	0.16	0.69	0.006
		group	2	27	3.35*	0.05	0.19
		time*group	2	27	0.62	0.54	0.04
Valgus Peak	R	time	1	27	0.06	0.80	0.002
		group	2	27	0.25	0.77	0.01
		time*group	2	27	2.23	0.12	0.14
	L	time	1	27	0.40	0.52	0.01
		group	2	27	0.62	0.54	0.04
		time*group	2	27	0.06	0.94	0.004
Cross over Cutting	R	time	1	27	0.99	0.32	0.03
		group	2	27	1.00	0.37	0.06
		time*group	2	27	0.38	0.38	0.06
	L	time	1	27	3.45	0.07	0.11
		group	2	27	1.94	0.16	0.12
		time*group	2	27	0.38	0.68	0.02

Discussion

The current study investigated the effects of neuromuscular and mental fatigue on knee kinematics during landing and crossover-cutting maneuvers in male soccer players. The findings revealed that physical fatigue significantly reduced knee flexion at initial contact, particularly in the left leg, where a 12.3% decrease was observed (from 27.03° to 23.70°, $P = 0.002$). The reduction in the right leg was smaller (2.0%, from 24.47° to 23.98°, $P > 0.05$), indicating that the non-dominant leg might be more susceptible to fatigue-induced changes.

These results underscore the importance of addressing fatigue in injury prevention strategies, as altered knee kinematics under fatigued conditions can increase the risk of ACL injuries.

Reduced knee flexion may increase anterior shear forces on the tibia, heightening the load on the ACL. This biomechanical change is consistent with the study's hypothesis that physical fatigue is a significant risk factor for ACL injuries (29). Previous research has highlighted that diminished knee flexion reduces the efficacy of eccentric muscle control, increasing the reliance on non-contractile tissues such as ligaments. For instance, tightened collateral ligaments under reduced flexion conditions may stabilize the joint but at the cost of increased anterior tibial translation, further escalating ACL injury risk (30)..

The findings align with Benjaminse et al., who reported decreased knee flexion at initial contact and reduced maximal valgus under fatigued conditions during a single-leg stop-jump task (31). Similarly, Lucci et al. observed altered mechanics in the hip and knee after fatigue, particularly in the sagittal and transverse planes. These studies confirm the broader impact of fatigue on lower-extremity kinematics (28).

Thomas et al. expanded on this by examining anticipated and unanticipated single-leg landings in female athletes, finding that fatigue significantly diminished knee flexion and increased knee valgus and hip internal rotation during unanticipated tasks (32). These results emphasize that fatigue can amplify biomechanical risks in unpredictable scenarios. However, discrepancies exist, as highlighted by Allen et al., who found that fatigue protocols resembling neuromuscular warm-ups increased knee flexion and reduced valgus angles (33). Such variations could stem from differences in protocol design, participant demographics, or activity-specific biomechanics. Finally, Abergel et al. demonstrated that fatigue increased hip and knee flexion, further supporting the idea that fatigue-induced kinematic changes are complex and multifaceted (35). Discrepancies between studies may also arise from gender differences, sample characteristics, or variations in fatigue protocols. These findings highlight the importance of considering individual and context-specific factors when interpreting the effects of fatigue on knee kinematics.

Among the key findings of this study was the trend toward increased valgus angles in the physical fatigue group. In the pre-fatigue stage, the left leg exhibited a valgus angle of -0.99° , which increased to 0.55° post-fatigue. Although the right leg showed a larger increase (from 0.64° to 3.40°), these changes were not statistically significant ($P = 0.56$). The lack of significance suggests that while observable trends exist, the magnitude of these changes was insufficient to reach statistical thresholds. This outcome may reflect the complexity of neuromuscular control during unanticipated maneuvers, which require rapid adjustments under fatigue conditions. Despite their non-significance, these trends highlight the potential for fatigue to alter kinematic patterns, which could elevate the risk of ACL injuries under more extreme or prolonged conditions.

Consistent with this, Mejane et al. explored the combined effects of neuromuscular fatigue and perceptual-cognitive tasks on knee biomechanics during landing in female athletes (34). Their study demonstrated significant alterations in knee kinematics, including increased valgus, when fatigue was paired with cognitive challenges. This highlights the amplifying effect of cognitive demands on fatigue-induced biomechanical changes, emphasizing the need to consider both neuromuscular and cognitive factors in injury prevention strategies.

Similarly, Borotikar et al. investigated the effects of fatigue and decision-making on landing mechanics in NCAA athletes, reporting significant increases in knee abduction (valgus), internal hip rotation, and ankle supination angles (35). Their findings further confirm that fatigue exacerbates biomechanical vulnerabilities, particularly during unanticipated or cognitively demanding tasks. However, not all studies align with these observations. Benjaminse et al. found no significant increase in valgus angles after fatigue induced by running during single-leg landings (31). This discrepancy may be attributed to the double-leg landing protocol employed in their study, which distributes mechanical loads across both limbs and reduces the demand on individual neuromuscular systems.

In the current study, the mental fatigue group exhibited some movement changes after performing the AX-CPT protocol. While these changes were not statistically significant, they align with findings from Swanik et al., who reported that impaired cognitive processing can compromise motor behaviors, particularly under

unanticipated conditions. Mental fatigue may reduce visual-spatial orientation and decision-making ability, affecting an athlete's capacity to adapt to conflicting stimuli during gameplay. These subtle effects warrant further investigation to understand how mental fatigue interacts with biomechanical performance over time.

This study has several limitations that should be acknowledged. First, the sample size was relatively small (30 male soccer players), limiting the generalizability of the findings to broader populations, including female athletes and players from different sports or competitive levels. The homogeneity of the sample, while beneficial for controlling variability, reduces the applicability of the results to more diverse groups. Second, the controlled laboratory environment, while ensuring precise data collection, may not fully replicate the dynamic and unpredictable nature of in-game conditions. Real-world factors such as prolonged exertion, psychological pressure, and simultaneous cognitive and physical demands were not fully captured. Additionally, the fatigue protocols used in this study may not encompass all the complexities of fatigue experienced during actual gameplay, potentially limiting the ecological validity of the findings. Third, the tests in this study were conducted and recorded based on the right and left legs, rather than categorizing them as dominant and non-dominant legs. While this approach ensured consistency in data collection, it may have overlooked potential biomechanical differences related to leg dominance, which could influence fatigue responses and kinematic outcomes. Addressing these limitations in future research could enhance the relevance and applicability of the results to diverse athletic populations and real-world scenarios.

Conclusion

The present study highlights the significant role of physical fatigue as a neuromuscular risk factor influencing knee kinematics, particularly in the non-dominant leg. A 12.3% reduction in knee flexion under physical fatigue conditions underscores its potential to elevate ACL injury risk during landing and crossover-cutting maneuvers. Although mental fatigue showed limited direct impact on kinematic variables, its subtle effects on cognitive and motor performance suggest it may play a secondary role in increasing injury susceptibility. Based on these findings, targeted neuromuscular and endurance training programs are recommended to enhance fatigue resistance and improve landing mechanics. Proper coaching of landing and cutting techniques, particularly under fatigue conditions, can reduce biomechanical vulnerabilities. Additionally, integrating visual coordination and cognitive training into athletic programs can prepare athletes for unanticipated movements in high-pressure scenarios, thereby minimizing the risk of injury.

Ethical Considerations:

Compliance with ethical guidelines

Institutional Review Board Statement: The current research protocol was approved by the Iran Sports Science Research Institute (Code: IR.SSRC.REC.1398.123). This work consistently adheres to ethical guidelines, ensuring integrity, transparency, and respect in all my actions and decisions. All participants involved in the research study provided informed consent.

Funding

This research received no external funding.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Acknowledgment

The authors hereby extend their gratitude to the soccer players who participated in this study and the research assistants who contributed to data collection.

References

1. Rishiraj N, Taunton JE, Lloyd-Smith R, Woollard R, Regan W, Clement D. The potential role of prophylactic/functional knee bracing in preventing knee ligament injury. *Sports Med.* 2009;39(11):937-60.

<https://doi.org/10.2165/11317790-000000000-00000>

1. Qu X, Jiang J, Hu X. Effects of subsensory noise and fatigue on knee landing and cross-over cutting biomechanics in male athletes. *Journal of Applied Biomechanics*. 2018;34(3):205-10.

<https://doi.org/10.1123/jab.2017-0180>

2. Zadro JR, Pappas E. Time for a different approach to anterior cruciate ligament injuries: educate and create realistic expectations. *Sports Med*. 2019;49(3):357-63.

<https://doi.org/10.1007/s40279-018-0995-0>

3. Jamison ST, Pan X, Chaudhari AM. Knee moments during run-to-cut maneuvers are associated with lateral trunk positioning. *Journal of biomechanics*. 2012;45(11):1881-5.

<https://doi.org/10.1016/j.jbiomech.2012.05.031>

4. Boden BP, Dean GS, Feagin JA, Garrett WE. Mechanisms of anterior cruciate ligament injury. SLACK Incorporated Thorofare, NJ; 2000. p. 573-8.

<https://doi.org/10.3928/0147-7447-20000601-15>

5. Alentorn-Geli E, Myer GD, Silvers HJ, Samitier G, Romero D, Lázaro-Haro C, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee surgery, sports traumatology, arthroscopy*. 2009;17(7):705-29.

<https://doi.org/10.1007/s00167-009-0823-z>

6. Griffin LY, Agel J, Albohm MJ, Arendt EA, Dick RW, Garrett WE, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *JAAOS-Journal of the American Academy of Orthopaedic Surgeons*. 2000;8(3):141-50.

<https://doi.org/10.5435/00124635-200005000-00001>

7. Stacoff A, Steger J, Stuessi E, Reinschmidt C. Lateral stability in sideward cutting movements. *Med Sci Sports Exerc*. 1996;28(3):350-8.

<https://doi.org/10.1097/00005768-199603000-00010>

8. Benjaminse A, Webster KE, Kimp A, Meijer M, Gokeler A. Revised approach to the role of fatigue in anterior cruciate ligament injury prevention: a systematic review with meta-analyses. *Sports Med*. 2019;49:565-86.

<https://doi.org/10.1007/s40279-019-01052-6>

9. Madigan ML, Pidcoe PE. Changes in landing biomechanics during a fatiguing landing activity. *Journal of electromyography and Kinesiology*. 2003;13(5):491-8.

[https://doi.org/10.1016/s1050-6411\(03\)00037-3](https://doi.org/10.1016/s1050-6411(03)00037-3)

10. García-Luna MA, Cortell-Tormo JM, García-Jaén M, Ortega-Navarro M, Tortosa-Martínez J. Acute effects of ACL injury-prevention warm-up and soccer-specific fatigue protocol on dynamic knee valgus in youth male soccer players. *International Journal of Environmental Research and Public Health*. 2020;17(15):5608.

<https://doi.org/10.3390/ijerph17155608>

11. Zareei M, Rahnama N, Rajabi R. The influence of a positional role of soccer players in Iranian premier league on the sport injuries rates. *HARAKAT*. 2009;-(39).

<https://sid.ir/paper/30329/en>

12. Bagherian S, Rahnama N, Wikstrom EA, Clark MA, Rostami F. Characterizing lower extremity movement scores before and after fatigue in collegiate athletes with chronic ankle instability. *Int J Athl Ther Train*. 2018;23(1):27-32.

<https://doi.org/10.1123/ijatt.2017-0029>

13. McLean SG, Felin RE, Suedekum N, Calabrese G, Passerallo A, Joy S. Impact of fatigue on gender-based high-risk landing strategies. *Med Sci Sports Exerc.* 2007;39(3):502-14.

<https://doi.org/10.1249/mss.0b013e3180d47f0>

14. Kellis E, Kouvelioti V. Agonist versus antagonist muscle fatigue effects on thigh muscle activity and vertical ground reaction during drop landing. *Journal of Electromyography and Kinesiology.* 2009;19(1):55-64.

<https://doi.org/10.1016/j.jelekin.2007.08.002>

15. Van Cutsem J, Marcora S, De Pauw K, Bailey S, Meeusen R, Roelands B. The effects of mental fatigue on physical performance: a systematic review. *Sports Med.* 2017;47(8):1569-88.

<https://doi.org/10.1007/s40279-016-0672-0>

16. Thompson CJ, Noon M, Towlson C, Perry J, Coutts AJ, Harper LD, et al. Understanding the presence of mental fatigue in English academy soccer players. *J Sports Sci.* 2020;38(13):1524-30.

<https://doi.org/>

17. Swanik CB, Covassin T, Stearne DJ, Schatz P. The relationship between neurocognitive function and noncontact anterior cruciate ligament injuries. *Am J Sports Med.* 2007;35(6):943-8.

<https://doi.org/10.1080/02640414.2020.1746597>

18. Xing X, Zhong B, Luo H, Rose T, Li J, Antwi-Afari MF. Effects of physical fatigue on the induction of mental fatigue of construction workers: A pilot study based on a neurophysiological approach. *Automation in Construction.* 2020;120:103381.

<https://doi.org/10.1016/j.autcon.2020.103381>

19. Kobayashi H, Kanamura T, Koshida S, Miyashita K, Okado T, Shimizu T, et al. Mechanisms of the anterior cruciate ligament injury in sports activities: a twenty-year clinical research of 1,700 athletes. *Journal of sports science & medicine.* 2010;9(4):669.

<https://pmc.ncbi.nlm.nih.gov/articles/PMC3761820/>

20. Orishimo KF, Kremenec JJ. Effect of fatigue on single-leg hop landing biomechanics. *Journal of applied biomechanics.* 2006;22(4):245-54.

<https://doi.org/10.1123/jab.22.4.245>

21. Lessi GC, dos Santos AF, Batista LF, de Oliveira GC, Serrao FV. Effects of fatigue on lower limb, pelvis and trunk kinematics and muscle activation: gender differences. *Journal of Electromyography and Kinesiology.* 2017;32:9-14.

<https://doi.org/10.1016/j.jelekin.2016.11.001>

22. Quammen D, Cortes N, Van Lunen BL, Lucci S, Ringleb SI, Onate J. Two different fatigue protocols and lower extremity motion patterns during a stop-jump task. *J Athl Train.* 2012;47(1):32-41.

<https://doi.org/10.4085/1062-6050-47.1.32>

23. Loch F, Hof zum Berge A, Ferrauti A, Meyer T, Pfeiffer M, Kellmann M. Acute effects of mental recovery strategies after a mentally fatiguing task. *Frontiers in Psychology.* 2020;11:558856.

<https://doi.org/10.3389/fpsyg.2020.558856>

24. Smith MR, Marcora SM, Coutts AJ. Mental fatigue impairs intermittent running performance. *Med Sci Sports Exerc.* 2015;47(8):1682-90.

<https://doi.org/10.1249/MSS.0000000000000592>

25. Kadaba MP, Ramakrishnan H, Wootten M. Measurement of lower extremity kinematics during level walking. *Journal of orthopaedic research*. 1990;8(3):383-92.

<https://doi.org/>

26. Orekhov G, Robinson AM, Hazelwood SJ, Klisch SM. Knee joint biomechanics in transtibial amputees in gait, cycling, and elliptical training. *PLoS One*. 2019;14(12):e0226060.

<https://doi.org/10.1002/jor.1100080310>

27. Lucci S, Cortes N, Van Lunen B, Ringleb S, Onate J. Knee and hip sagittal and transverse plane changes after two fatigue protocols. *J Sci Med Sport*. 2011;14(5):453-9.

<https://doi.org/10.1016/j.jsams.2011.05.001>

28. Santamaria LJ, Webster KE. The effect of fatigue on lower-limb biomechanics during single-limb landings: a systematic review. *J Orthop Sports Phys Ther*. 2010;40(8):464-73.

<https://doi.org/10.2519/jospt.2010.3295>

29. Lepers R, Hausswirth C, Maffiuletti N, Brisswalter J, Van Hoecke J. Evidence of neuromuscular fatigue after prolonged cycling exercise. *Med Sci Sports Exerc*. 2000;32(11):1880-6.

<https://doi.org/10.1097/00005768-200011000-00010>

30. Benjaminse A, Habu A, Sell TC, Abt JP, Fu FH, Myers JB, et al. Fatigue alters lower extremity kinematics during a single-leg stop-jump task. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2008;16(4):400-7.

<https://doi.org/10.1007/s00167-007-0432-7>

31. Thomas AC, McLean SG, Palmieri-Smith RM. Quadriceps and hamstrings fatigue alters hip and knee mechanics. *Journal of applied biomechanics*. 2010;26(2):159-70.

<https://doi.org/10.1123/jab.26.2.159>

32. Becker S, Simon S, Dindorf C, Dully J, Bartaguiz E, Schmitz L, et al. Fatigue as a key factor for testing knee stability with single leg drop landing for injury prevention and return to play tests. *Frontiers in sports and active living*. 2023;5:1243732.

<https://doi.org/10.3389/fspor.2023.1243732>

33. Mejane J, Faubert J, Romeas T, Labbe DR. The combined impact of a perceptual–cognitive task and neuromuscular fatigue on knee biomechanics during landing. *The Knee*. 2019;26(1):52-60.

<https://doi.org/10.1016/j.knee.2018.10.017>

34. Borotikar BS, Newcomer R, Koppes R, McLean SG. Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. *Clinical biomechanics*. 2008;23(1):81-92.

<https://doi.org/10.1016/j.clinbiomech.2007.08.008>

تأثیر خستگی عصبی-عضلانی و ذهنی بر کینماتیک زانو و خطر آسیب به رباط صلیبی قدامی در بازیکنان فوتبال مرد

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چکیده

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زمینه و هدف: بیشتر آسیب‌های رباط صلیبی قدامی (ACL) از نوع غیرتماسی بوده و عمدتاً هنگام فرود یا تغییر جهت در فعالیت‌های ورزشی رخ می‌دهند. عوامل مختلفی مانند متغیرهای بیومکانیکی و عصبی-عضلانی در بروز این آسیب‌ها نقش دارند. پژوهش‌های اخیر نشان داده‌اند که خستگی جسمی و ذهنی می‌تواند با تغییر الگوهای حرکتی در مانورهای پرخطر، بر عوامل خطر آسیب ACL تأثیر بگذارد. این مطالعه با هدف بررسی تأثیر خستگی عصبی-عضلانی و ذهنی بر سینماتیک زانو و عوامل بالقوه خطر آسیب به رباط صلیبی قدامی در بازیکنان فوتبال مرد هنگام فرود و مانور تغییر جهت انجام شد.

روش شناسی: سی نفر از بازیکنان حرفه‌ای فوتبال مرد به صورت تصادفی به سه گروه تقسیم شدند: گروه خستگی جسمی (۱۰ نفر)، گروه خستگی ذهنی (۱۰ نفر) و گروه کنترل (۱۰ نفر). گروه‌های تجربی مانورهای فرود و تغییر جهت ضربدری را در دو وضعیت قبل و بعد از اعمال خستگی انجام دادند. داده‌های سینماتیکی با استفاده از یک سیستم هفت‌دوربین و نرم‌افزار Cortex جمع‌آوری شد. گروه کنترل نیز همان مانورها را بدون اجرای پروتکل خستگی انجام داد تا شرایط بین گروه‌ها قابل مقایسه باشد. تحلیل آماری با استفاده از آزمون تحلیل واریانس با اندازه‌گیری‌های مکرر (Repeated Measures ANOVA) برای ارزیابی تفاوت‌ها بین گروه‌ها و شرایط صورت گرفت.

یافته‌ها: خستگی جسمی باعث کاهش معنی‌دار در زاویه فلکشن (خم شدن) زانو در لحظه تماس اولیه شد ($P = 0.002$)، در حالی که خستگی ذهنی تأثیر معنی‌داری بر سینماتیک نداشت. تعامل زمان و گروه برای فلکشن زانو مشاهده شد ($P = 0.05$)، به طوری که مقایسه‌های زوجی تفاوت معنی‌دار را تنها در گروه خستگی جسمی نشان داد.

نتیجه‌گیری: خستگی عصبی-عضلانی موجب تغییر در سینماتیک زانو شده و خطر آسیب ACL را افزایش می‌دهد. مربیان باید برنامه‌های تمرینی را با هدف افزایش مقاومت در برابر خستگی و بهبود الگوهای حرکتی صحیح طراحی و اجرا کنند.

واژه‌های کلیدی

خستگی عصبی-عضلانی، خستگی ذهنی، سینماتیک زانو، بازیکنان فوتبال، مکانیک فرود

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