

Functional And Psychological Responses To Acute Fatigue During Single-Leg Hop Testing In Young Professional Soccer Players

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Abstract:

Background: Fatigue has been recognized as a key factor influencing both physical performance and psychological readiness in athletes. However, limited evidence exists regarding its combined effect on single-leg hop performance and psychological readiness in soccer players.

Objective: To investigate the impact of induced fatigue on single-leg hop performance and psychological readiness to return to sport in professional male soccer players.

Methods: A total of 105 professional male soccer players underwent a fatigue protocol, and pre- and post-fatigue assessments included single-leg vertical jump, single-leg hop for distance and single-leg side hop test. Psychological readiness was assessed using the Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) scale. Paired t-tests compared pre- and post-fatigue outcomes, while Spearman's rho examined correlations between fatigue index and outcomes.

Results: All hop performance measures significantly declined post-fatigue ($p < 0.001$), with large effect sizes ($d = 1.08-1.18$). Vertical jump height, power, and RSI-mod decreased, while contact time increased. Single-leg hop for distance and side hop tests also showed significant reductions. ACL-RSI scores decreased modestly post-fatigue ($d = 0.19$). The fatigue index correlated negatively with side hop performance on both limbs (Right: $r = -0.204$, $p = 0.004$; Left: $r = -0.157$, $p = 0.028$) and with ACL-RSI scores ($r = -0.531$, $p = 0.034$), but not with other performance measures.

Conclusion: Fatigue substantially impairs hop performance and moderately reduces psychological readiness in professional soccer players. The observed associations between fatigue, lateral hop ability, and psychological readiness highlight the importance of incorporating fatigue-based assessments into return-to-sport decision making.

Keywords: anterior cruciate ligament, fatigue, hop tests, soccer, return to sport

INTRODUCTION

Soccer is one of the most widely played sports worldwide, exposing players to frequent high-intensity actions such as sprinting, cutting, and jumping, which increase the risk of lower-limb injuries, particularly to the knee.^{1,2} Among these, anterior cruciate ligament (ACL) injuries, though relatively infrequent compared with muscle strains, are considered one of the most severe due to their long rehabilitation periods, high reinjury rates, and risk of early-onset osteoarthritis.^{3,5}

Epidemiological studies in professional leagues highlight the burden of ACL injuries. For instance, the Qatar Stars League reported an incidence of 0.076 per 1,000 hours of exposure, with match injuries occurring nearly ten times more frequently than in training, and an average time-loss of 225 days per injury.⁶ Similarly, previous data also indicate a mean absence of over 220 days following ACL injury, despite relatively low incidence rates.⁷ Video-based analyses further reveal that most ACL injuries are non-contact or indirect-contact, often occurring during single-leg landings or cutting maneuvers under neurocognitive stress.⁸

Return-to-sport (RTS) following ACL reconstruction is complex, with evidence suggesting that only 55-65% of athletes return to pre-injury competitive levels.^{9,10} RTS decisions typically involve objective performance tests, strength assessments, and psychological readiness measures.^{11,12} Among these, functional hop tests are widely used to evaluate limb symmetry, neuromuscular control, and lower-limb power.^{13,14} A battery of hop tests, such as the single-leg hop for distance, vertical jump, and side-hop, has been shown to provide greater reliability and sensitivity compared to individual tests.¹⁵⁻¹⁷

While hop tests effectively assess functional capacity, the influence of fatigue on both hop performance and psychological readiness remains underexplored. Fatigue is inherent to soccer, impairing neuromuscular function, decreasing CMJ height, and reducing reactive strength index (RSI) values post-match.^{18,19} Moreover, psychological readiness, encompassing confidence and fear of injury, is recognized as a crucial factor in safe RTS but is rarely assessed under fatigued conditions.^{20,21}

Previous studies often applied generalized fatigue protocols such as cycling or repeated sprints, which may not reflect the intermittent, soccer-specific demands of competition.²² There is a need to evaluate fatigue using ecologically valid soccer-specific protocols while simultaneously assessing functional performance and psychological readiness. Hence, this study aims to investigate the effects of an acute soccer-specific fatigue protocol on single-leg hop performance and psychological readiness in young male professional soccer players. By integrating both physical and psychological measures pre and post fatigue, this study seeks to provide a comprehensive understanding of performance readiness in a competitive context and to inform evidence-based RTS and injury prevention strategies.

METHODS

Study design: This investigation employed a within-subject, pre-post experimental design. All participants underwent performance testing both before and immediately after a standardized soccer-specific fatigue protocol. The study was conducted in single sessions at training facilities of professional soccer clubs in various metropolitan cities in India. The study protocol was approved by the Institutional Ethics Committee (10/AHS/EC/2024), and the trial was prospectively registered with the Clinical Trials Registry of India (CTRI/2024/08/072445). All participants provided written informed consent prior to participation, in accordance with the Declaration of Helsinki.

Study participants: A convenience sample of professional male soccer players was recruited for the study. Eligible participants were required to be between 18 and 30 years of age, actively engaged in competitive soccer at the district, state, national, or international level, and to have at least one year of competitive playing experience. In addition, participants were expected to be training regularly for a minimum of two hours per day on at least three days per week. Players were excluded if they were collegiate or recreational athletes, had not participated in competitive soccer within the past year, or reported any lower extremity injury in the preceding six months. Individuals presenting with low back pain or lower limb dysfunction at the time of testing, as well as those unwilling to provide informed consent, were also excluded.

Procedure: Eligible players were screened, and demographic and anthropometric characteristics such as body mass index (BMI), leg length, and limb dominance were recorded. A standardized 10 minute warm-up consisted of five minutes of spot jogging followed by one set of ten squats, ten toe raises, and ten submaximal jumps. Test procedures were verbally explained and demonstrated, and participants were allowed two practice trials per limb (not recorded) to ensure familiarization. All testing was performed outdoors on third generation artificial turf, with participants wearing standard soccer apparel including jerseys, shorts, socks, and football boots with studs. The use of studs ensured appropriate traction on the turf surface, replicating match-like conditions and thereby enhancing the ecological validity of the testing protocol.

Fatigue Protocol: Fatigue was induced using a soccer-specific repeated sprint ability (RSA) test, which has been widely employed to replicate the intermittent high-intensity demands of competitive soccer.^{23,24} The protocol consisted of six maximal-effort shuttle sprints over a distance of 15 meters, performed in a sequence of 20 meters out and 20 meters return with a 180 degrees change of direction at each end. Each sprint was interspersed with a passive recovery interval of 20–30 seconds, during which participants remained standing to simulate in-game recovery periods. All sprints were timed using a handheld stopwatch, and both the fastest and mean sprint times were recorded for each player. The Fatigue Index (FI) was then calculated using the formula: $FI = 100 - (\text{mean sprint time}/\text{fastest sprint time} * 100)$. A higher FI value indicated greater performance deterioration, thereby confirming the effectiveness of the fatigue protocol. This RSA protocol has been shown to be reliable and valid, with recent reviews highlighting shuttle-based repeated sprint tests as the most widely used and ecologically relevant methods for assessing fatigue in soccer players.^{25,26}

Single-leg Vertical Jump: A smartphone running the app MyJump2 (iOS v17.1.1) was mounted on a tripod at about 1.5–2.0 meters from the sagittal plane of the test limb at approximate hip height and recorded at high frame rate (≥ 240 frames per second).²⁷ From a quiet single-leg stance with arms crossed over the chest, athletes jumped as high as possible, landing on the same leg. A controlled landing with

balance held for at least two to three seconds, without contralateral foot touch was required for a valid trial. Three valid trials were attempted per limb with thirty seconds between trials and the best value was recorded. In MyJump2, the tester manually identified the take-off and landing frames to compute jump height. Time taken from movement onset to take-off was also obtained to derive the reactive strength index-modified ($RSI\text{-mod} = \text{jump height}/\text{time-to-take-off}$) for each limb. MyJump2 shows excellent validity/reliability for CMJ height in youth and adult athletes, including soccer cohorts.^{27,29}

Single-leg Hop for Distance: A start line was marked with tape. Athletes stood behind the line on the test leg with hands behind the back, the free leg permitted to swing naturally. On the cue, athletes hopped forward maximally and landed on the same leg, attempting to maintain balance for at least two to three seconds. A trial was invalid if the athlete touched the ground with the opposite foot or hand, moved the landing foot, or failed to control the landing. Distance was measured with a steel tape from the toe at take-off to the heel at landing. Three valid trials were attempted per limb with thirty seconds between trials and the best value was recorded. This method aligns with contemporary single-leg hop for distance testing guidelines offering excellent reliability and clinical utility in athletic populations.^{30,31}

Single-leg Side Hop Test: Two parallel tape lines were placed 40 cm apart. Athletes stood on the test leg centered between the lines with hands behind the back. On the cue, athletes hopped laterally back and forth over the lines as many times as possible in 30 seconds, landing on the same leg for every jump and aiming for quick ground contacts with controlled balance. A hop was invalid if the athlete touched a line, failed to clear a line, placed the contralateral foot down, or lost balance. If more than 25 percent of hops in a trial were invalid, the attempt was repeated after three minutes rest. This protocol is consistent with established descriptions of the side hop test and is supported by recent evidence confirming its reliability and measurement quality.^{32,33}

Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) scale: Psychological readiness to return to sport was assessed using a soccer-specific adaptation of the ACL-RSI scale. It comprises 12 items across three domains viz., emotions, confidence in performance, and risk appraisal. Each item is rated on a 0–10 scale, with higher scores indicating greater readiness to return. The total score is calculated by averaging the item scores, yielding a range of 0–100. Lower scores reflect reduced confidence and higher perceived risk of reinjury. The ACL-RSI has demonstrated good reliability and validity in athletic populations.^{34,35}

A five minutes cool-down consisting of two minutes of walking followed by three minutes of seated rest was provided at the end of the testing protocol and participants were monitored for adverse events.

Sample size estimation: A priori power analysis was performed for the primary between-condition comparison (paired pre- vs post-fatigue) using a two-tailed paired t-test. Assuming an effect size of Cohen's $d = 0.33$ (small–moderate), 5% level of significance and 90% power, the required sample size was 99 participants. To allow for potential dropouts or unusable trials, we inflated the sample by approximately 10% and therefore aimed to recruit 110 players. The effect size was chosen based on previously reported changes in single-leg hop performance following fatigue protocols in the sports-fatigue literature.³⁶

Statistical Analysis: The assumption of normality was assessed using the Shapiro-Wilk test. Descriptive statistics are presented as mean and standard deviation (SD) for continuous variables and frequencies for categorical variables. Within-subject differences between pre- and post-fatigue outcomes were analysed using paired-samples t-tests. Effect sizes (Cohen's d) were calculated and interpreted as small (0.2), moderate (0.5), or large (0.8). The association between the RSA fatigue index and changes in hop test performance and psychological readiness were examined using Spearman's rho correlation coefficient. Statistical significance was set a priori at $p < 0.05$. All analyses were performed using IBM SPSS Statistics software (Version 29.0.1.0; IBM Corp., Armonk, NY, USA).

RESULTS

A total of 120 professional soccer players were screened for eligibility. Ten players were excluded: six did not meet the inclusion criteria, two reported recent lower limb injuries, and two declined participation. The remaining 110 players were enrolled, and 105 participants successfully completed the full protocol and were included in the final analysis (Figure 1).

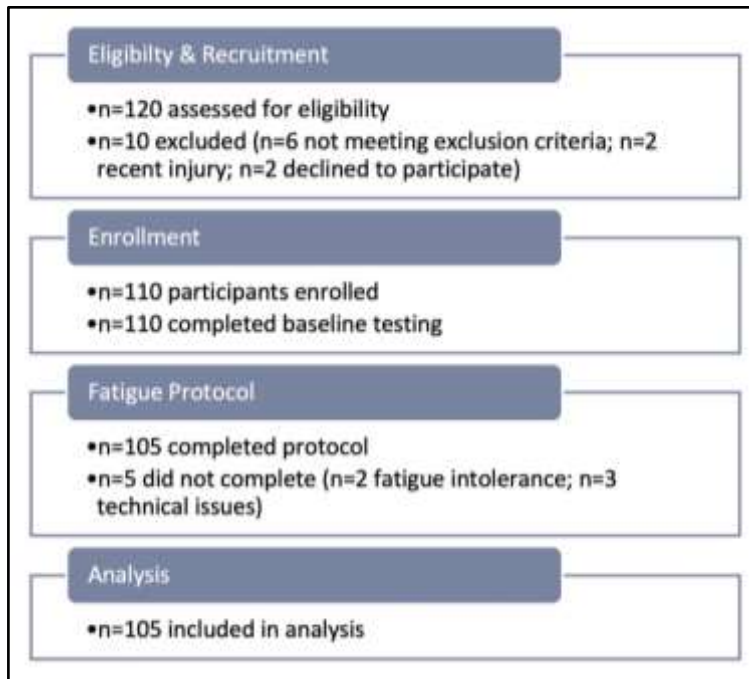


Figure 1: Participant Flow Diagram

The final sample consisted of 105 professional male soccer players with a mean age of 22.2 ± 4.8 years and a mean BMI of 20.4 ± 3.4 kg/m² (Table 1). The majority were right-leg dominant (78.1%), with majority players (54.5%) competing at the state level. Participants reported an average of 3.4 ± 1.3 years of competitive experience and trained approximately 2.3 hours per day for 3–4 days per week. During the fatigue protocol, the mean total sprint time was 16.8 ± 1.0 seconds, with a corresponding fatigue index of -7.1 ± 0.9 , confirming adequate induction of fatigue across participants (Table 1).

Variable	Mean \pm SD / n (%)	Shapiro-Wilk	<i>p</i> value
Age (years)	22.17 \pm 4.79	0.835	0.001
BMI (kg/m ²)	20.38 \pm 3.37	0.753	0.000
Leg Length (cms)	112.79 \pm 15.38	0.825	0.002
Professional experience (years)	3.43 \pm 1.33	0.923	0.000
Practice time (hours/day)	2.33 \pm 0.50	0.612	0.000
Practice time (days/week)	3.60 \pm 0.76	0.739	0.000
Leg dominance:			
Right	82 (78.09%)	-	-
Left	23 (21.91%)		
Playing Level:			
District	32 (33.33%)		
State	53 (54.47%)	-	-
National	12 (11.42%)		
International	8 (8.40%)		
Fatigue:			
Total Sprint Time	16.81 \pm 0.98	0.940	0.000
Ideal Sprint Time	2.41 \pm 0.34	0.972	0.001
Fatigue Index	-7.08 \pm 0.90	0.956	0.000

BMI: Body Mass Index; n: number of participants; *p*: level of significance; SD: Standard deviation

All hop performance measures significantly reduced following the fatigue protocol ($p < 0.001$; Table 2). Vertical jump outcomes were markedly affected, with significant reductions in jump height, power output, and reactive strength index (large effect sizes, Cohen’s $d \approx 1.16$ – 1.18). Contact time increased significantly with a large effect size ($d = 0.89$). Similarly, both single-leg hop for distance and side hop test performance declined significantly post-fatigue, with large effects across right and left limbs ($d = 1.08$ –

1.15). Psychological readiness, assessed with the RSI scale, also decreased significantly after fatigue ($p < 0.001$), though the effect size was small ($d = 0.19$), indicating that while physical performance was substantially impaired, perceived readiness to return to play was only modestly affected (Table 2).

Outcome		Pre-Fatigue (Mean \pm SD)	Post-Fatigue (Mean \pm SD)	Mean Difference (95% CI)	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
Single-leg Vertical Jump	Height (cms)	29.21 \pm 3.862	24.82 \pm 8.2	4.39 (4.07 to 4.72)	12.09	<0.001 ^a	1.181
	Contact time (ms)	253.57 \pm 20.80	265.84 \pm 10.70	-12.27 (-14.55 to -9.99)	9.11	<0.001 ^a	0.889
	Mean power (W)	1765.23 \pm 257.34	1703.73 \pm 198.14	61.50 (45.59 to 77.41)	11.93	<0.001 ^a	1.164
	RSI-mod (m/s)	0.117 \pm 0.022	0.094 \pm 0.012	0.023 (0.021 to 0.025)	12.09	<0.001 ^a	1.181
Single-leg Hop for distance	Right (cm)	220.34 \pm 11.24	212.63 \pm 10.28	7.71 (7.07 to 8.35)	11.74	<0.001 ^a	1.146
	Left (cm)	217.54 \pm 11.57	210.88 \pm 10.43	6.66 (5.96 to 7.37)	11.30	<0.001 ^a	1.103
Single-leg Side hop	Right (number of jumps)	45.96 \pm 5.02	42.04 \pm 4.07	3.93 (3.63 to 4.23)	11.93	<0.001 ^a	1.164
	Left (number of jumps)	43.98 \pm 5.20	40.35 \pm 4.12	3.53 (3.14 to 3.93)	11.04	<0.001 ^a	1.078
ACL-RSI (%)		75.37 \pm 6.49	73.82 \pm 8.93	1.55 (1.03 to 3.10)	1.99	<0.001 ^a	0.190

^a Statistically significant difference
 ACL-RSI: Anterior Cruciate Ligament-Return to Sport after Injury; Cohen's *d*: Effect size; *p*: level of significance; RSI-mod: reactive strength index-modified; SD: Standard deviation

The fatigue index showed no significant associations with vertical jump height, contact time, mean power, or RSI-mod, as well as hop for distance on either limb ($p > 0.05$; Table 3). However, significant negative correlations were observed with side hop performance on both the right ($r = -0.204$, $p = 0.004$) and left limbs ($r = -0.157$, $p = 0.028$), indicating that greater fatigue was associated with fewer lateral hops. Additionally, a negative correlation was found between fatigue index and ACL-RSI scores ($r = -0.531$, $p = 0.034$), suggesting that higher fatigue was linked to reduced psychological readiness to return to sport (Table 3).

Variable Pair		<i>r</i>	<i>p</i> value
Fatigue Index	Single-leg Vertical Jump:		
	Height	-0.055	0.447
	Contact Time	0.071	0.323
	Mean Power	-0.007	0.925
	RSI-mod	-0.072	0.317
	Single-leg Hop for distance:		
	Right	-0.050	0.491
	Left	-0.027	0.721
	Single-leg Side Hop:		
Right	-0.204	0.004*	
Left	-0.157	0.028*	

	ACL-RSI	-0.531	0.034*
*Statistically Significant ($p < 0.05$) ACL-RSI: Anterior Cruciate Ligament-Return to Sport after Injury; p : level of significance; RSI-mod: reactive strength index-modified; r = Spearman's Rho correlation coefficient.			

DISCUSSION

The present study investigated the influence of induced fatigue on single-leg hop performance and psychological readiness in young male professional soccer players. The findings revealed that all hop performance measures declined significantly after the fatigue protocol, with large effect sizes across vertical jump, hop for distance, and side hop tasks, indicating a substantial impairment in lower-limb functional capacity under fatigue. Psychological readiness, as assessed by the ACL-RSI scale, also decreased following fatigue, although the effect size was small, suggesting that while players experienced a marked reduction in physical performance, their self-perceived confidence and readiness to return to play were only modestly influenced. Furthermore, analysis of associations showed that the fatigue index had significant negative correlations with side hop performance on both limbs and with ACL-RSI scores, highlighting that greater fatigue was linked to poorer lateral hopping ability and reduced psychological readiness, whereas no significant relationships were observed with vertical jump, hop for distance, or RSI-mod outcomes.

Our results showed consistent decrements in vertical jump, single-leg hop for distance, and side hop performance following fatigue. These findings are aligned with previous studies demonstrating that high-intensity intermittent exercise induces acute neuromuscular fatigue, reducing explosive power and jump mechanics in soccer players.³⁷⁻³⁹ In particular, the reductions in vertical jump height and power output corroborate earlier reports that countermovement jump performance is highly sensitive to accumulated fatigue and is frequently used as a fatigue monitoring tool in elite soccer.^{40,41} Increased contact time and reduced RSI-mod observed in our study are indicative of impaired stretch-shortening cycle efficiency.⁴² This can be explained by central and peripheral fatigue mechanisms, including reduced motor unit firing rates, impaired neuromuscular transmission, and diminished muscle-tendon stiffness.^{43,44} Such physiological alterations compromise the ability to rapidly generate and transmit force, thereby limiting explosive single-leg movements critical for soccer-specific actions such as sprinting, cutting, and jumping. Both forward hop distance and lateral hop counts declined substantially after fatigue, confirming the sensitivity of unilateral hop tests to neuromuscular impairments.^{15,31} Importantly, the side hop test appeared particularly responsive to fatigue, which may reflect its higher demand on dynamic balance, agility, and mediolateral stability, components frequently stressed during competitive soccer play.⁴⁵ This aligns with prior evidence that lateral hops are more sensitive to fatigue-related reductions in proprioceptive control compared to sagittal-plane hops.⁴⁶

In addition to physical decrements, psychological readiness to return to play also declined post-fatigue, though the effect size was small. While most prior studies have used the ACL-RSI to assess return-to-sport readiness following ACL injury or reconstruction,^{21,47} our findings extend its application to healthy athletes under fatigue conditions. The observed reduction suggests that acute fatigue may transiently affect confidence and perceived control during high-demand movements, consistent with evidence linking fatigue to elevated perceptions of risk and reduced decision-making efficiency in athletes.^{48,49}

The fatigue index was not significantly correlated with vertical jump or hop for distance outcomes, suggesting that fatigue-related declines in these tasks are relatively uniform across players. However, significant negative associations were observed with side hop performance and ACL-RSI scores. This implies that greater levels of fatigue disproportionately impair tasks requiring rapid mediolateral force generation and psychological readiness. These findings are consistent with studies reporting that fatigue alters movement quality, increasing mediolateral knee loading and potentially elevating injury risk in soccer athletes.^{50,51} The negative relationship between fatigue index and ACL-RSI underscores the interplay between physical and psychological domains in sport performance. Athletes experiencing greater physiological fatigue may perceive reduced readiness to perform explosive or high-risk actions, highlighting the importance of integrating psychological monitoring into fatigue management strategies.⁵² This study has several limitations. First, the cross-sectional design prevents causal inference regarding fatigue and injury risk. Second, only young male professional soccer players were included, limiting

generalizability to female athletes or other playing levels. Third, although the RSA protocol replicates soccer-specific demands, real-game fatigue is influenced by additional contextual factors such as tactical load, psychological stress, and environmental conditions, which were not assessed.

Future studies should explore longitudinal monitoring of hop performance and psychological readiness across a competitive season, including female and youth cohorts. Integrating biomechanical analyses (e.g., 3D motion capture) with psychological assessments may also clarify the mechanisms linking fatigue, movement quality, and injury risk. Finally, examining recovery kinetics post-fatigue could provide valuable insights into return-to-play timelines and workload management in elite soccer.

CONCLUSION

This study demonstrated that fatigue significantly impairs single-leg hop performance in professional male soccer players, with large declines observed across vertical jump, hop for distance, and side hop outcomes. While psychological readiness to return to sport was only moderately reduced, greater fatigue was associated with poorer lateral hopping ability and lower psychological readiness. These findings highlight the importance of incorporating fatigue-based assessments into RTS testing protocols, as they may provide a more realistic evaluation of both physical performance and psychological preparedness. Future research should explore similar relationships across different competitive levels, include female athletes, and examine the long-term implications of fatigue on reinjury risk and RTS decisions.

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