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The Impact of a Volleyball-Specific Fatigue Protocol on the Balance, Proprioception, and Performance of Volleyball Players at High and Low Risk for ACL Injuries

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ABSTRACT

Background: This study aimed to assess the impact of a volleyball-specific fatigue protocol on balance, proprioception, and performance in volleyball players with differing ACL injury risk levels.
Methods: his semi-experimental research utilized a pre-test-post-test design. Forty volleyball players from Urmia were selected and divided into low- and high-risk groups based on ACL injury potential, assessed using the Landing Error Scoring System (LESS). A LESS score below 6 indicated low risk, while above 6 indicated high risk. Balance was measured using the stork test (static balance) and Y balance test (dynamic balance), knee proprioception was assessed with a goniometer, and performance was evaluated with the Sargent jump test. After baseline assessments, players were subjected to a volleyball-specific fatigue protocol, after which all tests were repeated. Analysis of covariance and dependent t-tests were used to evaluate inter-group and intra-group differences.
Results: The dependent t-tests and analysis of covariance indicated that fatigue significantly decreased static balance (P=0.001, P=0.001), dynamic balance (P=0.001, P=0.001), and performance (P=0.001, P=0.001). Wilcoxon and Mann-Whitney U tests also significantly reduced proprioception post-fatigue (P=0.001, P=0.001). Additionally, significant differences were found between the groups for all variables (P<0.05) except for proprioception (P>0.05).
Conclusion: Overall, the findings suggest that fatigue is a significant factor in reducing balance, proprioception, and explosive power. This decline was greater in the high-risk injury group, likely due to baseline neuromuscular weaknesses in this group.

Introduction

The act of landing after a jump has been frequently cited as a common cause of lower body injuries, especially among athletes engaged in sports involving regular jumping, such as volleyball [1]. Most anterior cruciate ligament (ACL) injuries occur without direct physical contact [2]. Instead, non-contact mechanisms—such as rotational movements and landing from jumps—are prevalent injury triggers for the ACL, particularly among volleyball and soccer players [3]. In volleyball, lower limb injuries represent approximately 60% of all recorded injuries, predominantly affecting the ankle and knee joints [4]. Specifically, landing actions account for 32.4% of all volleyball-related injuries and 23.2% of knee injuries during matches [5].

Jumping movements in volleyball, such as spiking and defensive actions, require the jump itself and an effective

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landing technique that redistributes the kinetic force generated in the jump. Various movement patterns are needed to dissipate the body's energy during landing, which can generate ground reaction forces up to five times the athlete's body weight [6]. Multiple studies have associated high-impact landings with an increased risk of knee injuries, particularly ACL tears [7, 8] and other injuries with both immediate and long-term effects [9].

Research suggests that increasing knee flexion upon initial ground contact during landing can significantly reduce impact forces on the knee joint [10]. Conversely, the presence of a valgus or adducted knee position during landing has been linked to various knee injuries, including ACL [11] and patellofemoral joint injuries [12].

Fatigue results from complex biological processes that occur in both the central nervous system (CNS) and peripheral muscles. It is commonly defined as a diminished ability to produce maximum force, regardless of the required force in a given situation [13]. In sports, athletes frequently experience fatigue, which has been shown to compromise joint stability and increase the risk of injury, especially toward the end of a competition or training session [14]. Various fatigue-induction methods have been used in studies to investigate its effects, including isokinetic contractions [15], repetitive movements [16], and functional activities [17].

Studies have demonstrated that fatigue negatively affects athletic performance. For example, Cooper et al. (2020) examined the impact of lower limb muscle fatigue on vertical jump and balance, showing that fatigue reduced performance levels [18]. Similarly, Lacey and Donne (2019) investigated fatigue's impact on static and dynamic balance in athletes with a history of ankle injuries, revealing a decline in static balance post-fatigue [19]. For fatigue protocols in sports, it is essential that they accurately simulate the physiological and biomechanical changes resulting from real exercises and competitions [20]. Protocols closely replicating the movement patterns specific to sports—particularly those involving closed kinetic chains and submaximal force—are considered superior. These sports-specific protocols provide insights into how fatigue impacts the body in conditions that mirror actual athletic activities, especially for lower-limb movements [17]. Functional fatigue protocols often involve repetitive movements, such as 100 consecutive jumps over low hurdles, 5-6 cm, or 50 maximum vertical jumps. Using this approach, Pappas et al. (2007) found that fatigue had a noticeable if modest, impact on landing biomechanics[21].

Chappell et al. (2005) found that fatigue alters motor control strategies, increasing anterior tibial shear force and, consequently, ACL stress and injury risk in both genders [22]. Dickin et al. (2015) further noted that isolated factors, such as drop height and fatigue, could increase the likelihood of ACL injuries by altering landing biomechanics [23]. Brazen et al. (2010) observed maximum knee and ankle flexion and heightened ground reaction force post-fatigue, suggesting an increased risk of injury [24]. Hosseini et al. (2023) reported similar findings, highlighting that lower-limb fatigue protocols induced kinematic changes associated with heightened ACL injury risk [25].

Fatigue has also been shown to impair stability. For example, Cattoni (2010), in a study entitled "The Effects of Ankle Bracing and Fatigue on Time to Stabilization in Subjects with Chronic Ankle Instability," found that fatigue extended the time needed to stabilize in the anterior-posterior direction in subjects with chronic ankle instability, though this increase was not statistically significant [26]. Despite these findings, results on fatigue's impact on landing mechanics remain mixed. Furthermore, many studies rely on fatigue protocols that do not closely align with sports-specific movement patterns [17, 27], often using single-leg landing tests with force plates or motion analysis systems [27, 28].

To date, no research has specifically examined the effects of fatigue on landing mechanics in volleyball players at varying risk levels for ACL injury. This study aims to fill that gap by investigating how a volleyball-specific fatigue protocol impacts balance, proprioception, and performance in players identified as high-risk versus low-risk for ACL injury.

Methods

This study used a field-based, semi-experimental design with pre-test and post-test measurements to investigate the effects of a volleyball-specific fatigue protocol on balance, proprioception, and performance in volleyball players at high and low risk for ACL injury. Ethical approval was obtained from the Ethics Committee of the Sport Sciences Research Institute of Iran (code: IR.SSRI.REC.1400.1259), and all participants provided informed consent.

The study targeted volleyball players aged 18 to 23 in Urmia. 104 players were initially screened, with 40 athletes meeting the inclusion criteria. They were subsequently and purposefully divided into two groups: 20 high-risk and 20 low-risk for ACL injury [17]. The screening was conducted using the Landing Error Scoring System (LESS) test, where scores above 6 indicated a high risk and below 6 indicated a low risk for ACL injuries [17]. The sample size was determined to ensure a statistical power of 0.8, with a significance level of 0.05 and a beta of 0.2, using G Power software [29].

The inclusion criteria for this study included a minimum of three years of volleyball experience and having a high and low risk of ACL injury. The exclusion criteria included the presence of lower limb injuries that would prevent participation in the fatigue protocol and existing pain in the trunk or lower limbs [25]. Baseline assessments included static balance measured with the Stork Test, dynamic balance assessed using the Y-Balance Test, knee proprioception evaluated with a goniometer, and performance assessed through Sargent's jump Test.

After initial testing, a volleyball-specific fatigue protocol was applied to induce fatigue in participants, followed by post-test assessments on balance, proprioception, and performance. Testing was conducted in a controlled sports hall environment with appropriate ambient conditions, ensuring consistency and accuracy of results. All research protocols adhered strictly to ethical standards.

Assessments were non-invasive, respecting participants' comfort and health. Participation was entirely voluntary, allowing individuals to join or withdraw from the study at any point. To maintain confidentiality, the personal information of participants was securely protected, and only anonymized data was used in analyses and reports, ensuring that no identifying details were disclosed in any published results.

Before the fatigue protocol was applied, descriptive information was collected for each group, including age, weight, height, body mass index (BMI), years of sports experience, and ACL injury risk level as assessed by the Landing Error Scoring System (LESS) test. This information is summarized in Table 1,

The Landing Error Scoring System (LESS) is a reliable tool for assessing participants' jump-landing technique, which is particularly relevant in evaluating ACL injury risk. As shown in Figure 1, the jump-landing task involves jumping from a 30 cm high box to a distance equating to 50% of the participant's height, landing on the floor, and then immediately performing a maximal vertical jump. Participants are encouraged to jump as high as possible after landing but receive feedback only if they perform the task incorrectly. They are allowed unlimited practice attempts to ensure they understand and can perform the task correctly.

Each participant's performance is recorded from two angles (frontal and sagittal), with cameras positioned 4.8 meters and 4 meters away, respectively. The LESS comprises 15 scoring items, with each participant's final score based on the average from three trials [7, 17]. Known for its high sensitivity in detecting high-risk landing techniques, the LESS has demonstrated excellent to good inter-examiner and intra-examiner reliability [17].

This study's functional and volleyball-specific fatigue protocol involved repeated cycles to induce fatigue. Each cycle included three consecutive stations: SEMO agility training, the lunge movement, and a high jump. For the lunge movement, the distance between the participant's legs was based on each individual's lower limb length, providing a personalized range of motion. Additionally, the maximum height achieved in the Sargent jump was used to calculate 50% of each participant's jump height, which was integrated into the fatigue protocol. The SEMO agility exercise, modified for this study, was conducted in a rectangular area measuring 3.6 by 5.7 meters (Figure 2).

Following the SEMO agility training station, participants performed five lunge movements per leg, ensuring equal engagement of both sides. The high jump station followed immediately, requiring participants to complete 10 rapid jumps at 50% of their maximum jump height. A full cycle of the fatigue protocol consisted of these three consecutive stations, after which the participant returned to the starting point to begin a new cycle. The cycles were repeated continuously until fatigue was reached.

To familiarize participants with the protocol, each subject completed a cycle twice at maximum intensity, with the best time recorded as the baseline time for that individual. Fatigue was determined by monitoring the time it took to complete each cycle. Once a participant's cycle duration increased by 50% compared to their baseline time—typically after six cycles—this marked the fatigue threshold. The cycle in which the participant reached this 50% increase was designated as the fatigue point [27].

Table 1: Summary of Research Variable Descriptive Statistics in the pre-test (n=40)

Characteristics	Low-risk injury group M±SD	High-risk injury group M±SD	P value
Age (year)	20.40±1.60	21.15±1.87	0.18
Height (m)	1.80±0.04	1.82±0.06	0.48
Weight (Kg)	72.70±4.73	75.20±5.06	0.11
Body mass index (Kg/M^2)	22.21±0.80	22.66±1.08	0.14
Sport history (year)	5.85±1.26	6.55±2.23	0.23
LESS (Error)	3.85±0.58	7.20±0.69	0.001

LESS: Landing Error Scoring System

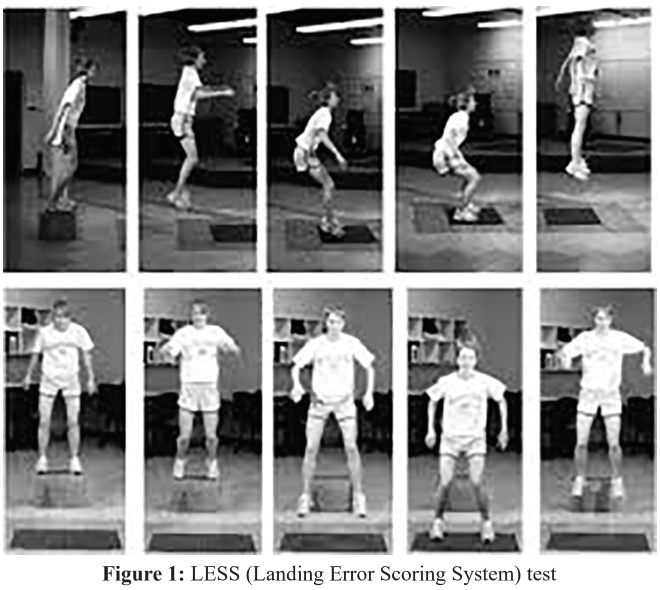

Figure 1: LESS (Landing Error Scoring System) test

Figure 2: SEMO (Southeast Missouri) agility exercise

Figure 3: Static balance evaluation method

For the static balance assessment, the stork test was administered. In this test, participants balanced on their dominant leg, with the toes of the non-dominant foot resting on the knee of the supporting leg and hands placed on their waist (refer to Figure 3). Upon hearing the commands "Ready" and "Go," participants lifted the heel of their dominant leg, aiming to balance on the toes without moving their supporting leg or altering hand placement. Each participant performed the test three times, with the longest successful balance duration recorded as their final score [30]. This test has demonstrated high reliability (0.87) and validity (0.99) in previous research [31].

The Y Balance Test was conducted to measure dynamic balance (Figure 4). Participants positioned themselves at the center of the testing area, standing on their dominant leg and reaching out with the opposite leg to touch a target point in a specified direction. After reaching, they returned to a balanced stance on both legs, maintaining this position for 10 to 15 seconds before the next trial. Trials were completed in one direction first, then switched to another in a clockwise or counter-clockwise order. In each trial, participants aimed to reach the farthest possible distance with their toes in the designated direction, with the reach distance recorded from the center point to the point of contact in centimeters.

To calculate the Y Balance Test scores, the reach distance for each direction was divided by leg length, determined while the participant was in a supine position by measuring from the anterior superior iliac spine to the distal medial malleolus [32]. Each participant's reach was recorded twice per foot, averaged, and used to normalize dynamic balance scores across three directions. The Y Balance Test has a reported validity range of 94% to 96% [33].

To assess knee proprioception, the knee joint active angle reconstruction method was employed, which has a validity of 0.98 to 0.99 [34]. Participants began by sitting on the edge of a bed (Figure 5), with a pad placed under the knee to ensure the femur was nearly horizontal. This setup positioned the knee at approximately 90 degrees of flexion, the ankle at rest, the trunk tilted 30 degrees backward, and the thigh almost level.

A calibrated goniometer was aligned with the femur and lower leg, ensuring the knee's anatomical rotation axis matched the goniometer's mechanical rotation axis. To familiarize participants, they practiced the test with open eyes two to three times by holding a designated angle for 5 seconds. During testing, the examiner moved the participant's knee to a 60-degree flexion angle while the participant's eyes were closed to reduce visual feedback. After a 5-second pause, participants attempted to actively replicate the 60-degree angle by moving their lower leg to the target position, indicating "I've arrived" once they believed they had reached it. This was repeated three times, with each achieved angle recorded. The average of these angles was calculated to determine the joint reconstruction angle at the target of 60 degrees [35].

The Sargent jump test assessed the athletes' performance (Figure 6). In this test, each athlete stood sideways next to a marked wall, reached upward with one hand, and the highest point reached was marked. The athlete then performed a maximal vertical jump, marking the highest point reached during the jump. The distance between the initial and jump

Figure 4: Dynamic balance evaluation method

Figure 5: Knee proprioception evaluation method

Figure 6: Sargent's Jump Evaluation Method

marks represented the athlete's muscular power; a greater distance indicated higher muscle power [36]. Aragon reported the test's validity and reliability as 0.93 [37].

For the statistical analysis, both descriptive and inferential statistics were employed. Initially, the Shapiro-Wilk test was conducted to evaluate the normality of the data distribution. If the data were normally distributed, a dependent t-test was used to assess the effects of fatigue and any intra-group differences. For inter-group comparisons under normal distribution conditions, analysis of covariance (ANCOVA) was applied. In cases where the data did not follow a normal distribution, the Wilcoxon signed-rank test and the Mann-Whitney U test were used for intra-group and inter-group analyses, respectively.

Results

The Shapiro-Wilk test was initially employed to assess the normality of the data in both groups, considering both pre-test and post-test results. The findings from the Shapiro-Wilk test revealed a normal distribution for most variables ($P \geq 0.05$), except for the proprioception variable, which indicated a significant deviation from normality ($P<0.05$). A dependent t-test was conducted to further analyze fatigue's effect on balance and performance metrics and compare pre-fatigue and post-fatigue results within each group. The specific results of this analysis are presented in Table 2.

As shown in Table 2, the results of the dependent t-test indicate that volleyball-specific fatigue ($P=0.001$) significantly impacted balance and performance metrics within each group. Following this, the homogeneity of variances was checked to ensure the data met the assumptions for further comparison. Once verified, inter-group differences were analyzed using analysis of covariance (ANCOVA), as displayed in Table 3.

The covariance analysis results indicated that, after controlling for the pre-test influence, there was a statistically significant difference in balance and performance outcomes following the application of fatigue between the low-risk and high-risk injury groups ($P \leq 0.05$). Specifically, the high-risk group exhibited a more substantial decline in balance and performance metrics than the low-risk group.

Table 2: Average difference of static balance, total score of dynamic balance, and performance of the subjects before and after applying the fatigue protocol

Group	Low-risk injury				High-risk injury			
	Pre-test	Post-test	T	P	Pre-test	Post-test	T	P
Static balance (seconds)	9.43±2.41	7.95±2.38	9.20	0.001**	8.77±2.27	6.81±1.97	8.75	0.001**
Overall score of dynamic balance (cm)	86.74±4.41	82.05±4.63	14.77	0.001**	86.03±4.38	79.50±4.90	14.79	0.001**
Performance (cm)	48.35±4.77	46.30±4.97	5.20	0.001**	46.90±6.34	43.60±5.89	6.24	0.001**

**Sig. at P<0.01 level

Table 3: Findings of covariance analysis to compare the difference inter-group in static balance variables (seconds), total score of dynamic balance (cm), and performance (cm)

Variable	Test stage	Group	Mean ¥	F	df	P	Eta squared
Static balance (seconds)	Post-test	Low-risk injury	7.67	4.79	1	0.03*	0.11
	Post-test	High-risk injury	7.09				
Overall score of dynamic balance (cm)	Post-test	Low-risk injury	81.69	33.06	1	0.002**	0.22
	Post-test	High-risk injury	79.86				
Performance (cm)	Post-test	Low-risk injury	45.64	4.57	1	0.03*	0.11
	Post-test	High-risk injury	44.25				

¥ modified according to initial test results; *Sig. at P<0.05 level

Table 4: The difference in the average knee proprioception in the subjects before and after applying the fatigue protocol

Variable	Group	Pre-test	Post-test	Z	P
Knee proprioception (degree)	Control	1.90±0.91	3.00±0.85	-3.37	0.001**
	Training	2.00±0.91	3.15±0.98	-3.65	0.001**

**Sig. at P<0.01 level

Table 5: Results of the U-Mann-Whitney test to compare the difference inter-group in the knee proprioception variable

Variable	Time	U	W	Z	P
Knee proprioception (degree)	Pre-test	195.00	405.00	-0.14	0.90
	Post-test	184.50	394.50	-0.44	0.67

**Sig. at P<0.01 level

Due to the proprioception variable's non-normal distribution, non-parametric tests were employed. The U-Mann-Whitney and Wilcoxon tests assessed inter-group and intra-group differences, respectively. The results of the Wilcoxon test, comparing pre- and post-fatigue proprioception within each group, are detailed in Table 4.

The Wilcoxon test results indicate that fatigue significantly increased the angle reconstruction error within both groups. The non-parametric U Mann-Whitney test assessed inter-group differences in angle reconstruction error between the high-risk and low-risk groups in both pre-and post-test conditions. The findings of this analysis are summarized in the following Table 5.

The results of the non-parametric U-Mann-Whitney test reveal no significant difference in proprioception between the high-risk and low-risk groups before and after the fatigue protocol. This suggests that the impact of fatigue on proprioception is similar for both groups.

Discussion

The present study's findings highlight the significant impact of fatigue on balance, proprioception, and performance, particularly among athletes at a higher risk of ACL injuries. These results align with previous research by Liederbach et al. [38], Zemková et al. [39], Lacey & Donne [19], and Johnston et al. [40].

Furthermore, the current study's results regarding the differential impact of fatigue on athletes with varying risks of ACL injury are consistent with the work of Tsarbou et al. [41] and Hosseini et al. [25]. One possible explanation for these findings lies in the combined physiological effects of central and environmental fatigue, which can disrupt sensory and motor integration. This disruption may impair an athlete's ability to maintain dynamic balance and control. Supporting this, McLean et al. demonstrated that intermittent high-intensity exercises, which invoke both central and environmental fatigue, significantly affect both static and dynamic postural control [42].

The results of this study indicate that volleyball-specific fatigue significantly reduces knee proprioception, as evidenced by an increase in knee reconstruction errors. However, no significant differences were observed between the two groups. This finding aligns with previous research conducted by Gandevia et al. [43], Abd-Elfattah et al. [44], and Changela et al. [45].

In summary, it appears that fatigue impairs motor control accuracy and diminishes the voluntary stabilizing function of muscles, which ultimately contributes to reduced proprioception and movement control [44]. Fatigue generally leads to decreased muscle strength and slower response times, further compromising proprioceptive abilities and balance [46]. Moreover, studies examining the relationship between proprioception and strength regeneration have shown that muscle fatigue results in increased force production errors [47].

The current study's findings on the effect of fatigue on performance are consistent with prior research by Liederbach et al. [38], Cooper et al. [18], Wong et al. [48], and Watkins et al. [49]. Explosive power, especially as assessed by vertical jump height, is crucial across numerous sports disciplines [50, 51]. For example, Boullosa et al. demonstrated that vertical jump height correlates strongly with running speed in elite runners [50], and explosive vertical strength is vital in team sports like rugby, volleyball, basketball, and soccer [52-54].

The literature indicates immediate and sustained neuromuscular fatigue following exercise weakens vertical jump performance [49]. Fatigue in lower limb muscles, such as the knee extensors, significantly diminishes vertical jump height [55]. As neuromuscular fatigue disrupts the system's ability to maintain expected joint strength [55], Compensatory strategies may lead to reorganizing motor structure, causing new coordination patterns to emerge. Muscle fatigue, particularly in the knee extensor muscles, can significantly reduce jump height [55]. An increase in muscle activation immediately following a set of fatiguing exercises and the recruitment of additional motor units [55] demonstrates how fatigue affects muscle strength and why there is a need to call for more motor units [55]. In this context, fatigue likely reduced explosive power in participants due to diminished muscle strength. This effect was notably more pronounced in the high-risk injury group, potentially reflecting underlying neuromuscular deficiencies that exacerbate performance decline post-fatigue.

The limitations of this study include the challenge of controlling participants' motivation and psychological states, the exclusion of female athletes, and the lack of monitoring for participants' sleep and nutritional habits.

Based on the findings, it is evident that athletes at a higher risk of injury would benefit from a stronger focus on neuromuscular control. Incorporating neuromuscular exercises is especially recommended for injury-prone groups to mitigate the effects of fatigue, which significantly contributes to increased neuromuscular impairments in such athletes. Accordingly, these athletes should minimize jump-landing movements to reduce their risk of injury.

Conclusion

In conclusion, this study demonstrated that fatigue significantly impairs balance, proprioception, and explosive power, with a greater impact observed in athletes at high risk for injury. This heightened vulnerability to fatigue among high-risk individuals may be attributed to pre-existing neuromuscular weaknesses.

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