

The effect of fatigue on jump height and the risk of knee injury after a volleyball training game: A pilot study

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Abstract

Study aim: To investigate the effect of fatigue, induced by a volleyball training game on the risk of Anterior Cruciate Ligament (ACL) injury.

Material and methods: Thirteen female volleyball college athletes, ages 18 to 21 years old, completed jump landings from a box 30 cm height, prior and post a 60-minute volleyball training game. The clinical tool Landing Error Scoring System (LESS) was employed in order to evaluate the technique of landing prior and post the game. The level of fatigue induced by the volleyball game was assessed by vertical jump test and Borg Rating of Perceived Exertion (RPE) Scale pre and post-game. In order to compare measurements pre and post-game t-tests for dependent samples were used.

Results: Participants performed lower vertical jumps post-game with a Confidence Interval of 26.2 ± 2.3 cm (pre-game) and 24.9 ± 2.2 cm (post game). The difference between pre and post-game was found to be statistically significant with a $t_{12} = 2.55$ and a p-value of 0.026. In the case of assessing fatigue, the Borg RPE scale scores were found to be statistically significant ($t_{12} = 14.05$, $p < 0.001$) higher post-game (10.2 ± 0.6), as compared to pre-game (6.5 ± 0.4). Similarly, LESS scores increased significantly ($t_{12} = 2.21$, $p = 0.047$), post-game (6.3 ± 1.1) compared to pre-game (5.8 ± 1.0) that prove poorer landing ability.

Conclusion: It seems that a short duration volleyball training game induces fatigue and negatively affects the jumping and landing ability.

Keywords: Landing – Injury prevention – Anterior cruciate ligament – Risk factors – Lower extremity

Introduction

Although Anterior Cruciate Ligament (ACL) injuries are not the most common type of injury in volleyball, the effect of an injury is much more severe and often devastating [2]. ACL injury directly affects knee joint stability [5], which is the basis for multiple long-term negative consequences. These include persistent deficits in muscle strength and hop performance [45], as well as increased the risk of early-onset of osteoarthritis [5]. In terms of return-to-sport rates, the results are lower than expected, considering the enhancements in surgical techniques and rehabilitation protocols. Specifically, merely 65% of athletes manage to return to pre-injury levels, while for elite athletes the percentage is even lower

(55%) [1]. One way to reduce the occurrence of ACL injuries and their negative consequences, is through injury prevention programs.

Findings of several studies [2, 18] suggest that injury rates increasing as fatigue accumulates. It has been reported that a significant proportion of non-contact knee injuries occurred at the last 15 minutes of the first half and last 30 minutes of the second half in rugby games [18]. On the other hand some studies [12] did not find any correlation between playing time and injury. In volleyball, most injuries occurred during games rather than training sessions. Injuries also tend to occur during the most demanding phases of training sessions and games, respectively [2]. Additionally, other studies [41] reported that fatigue induced by a volleyball game caused negative alterations in knee proprioception that may predispose an athlete to

injury. These data may highlight the role of fatigue in lower limb injuries [41].

In the last 20 years, the interest of research has been focused on landing biomechanics because of the relationship between landing technique and ACL injury [6, 27, 32]. More analytically, studies based on observational video analysis of injuries have shown that most ACL injuries are non-contact and happen during sudden deceleration before landing or cutting maneuvers in conjunction with specific movement patterns including increased lateral trunk motion [21], knee valgus, tibial rotation, and decreased flexion at the knee, hip and trunk [7, 32]. Similarly, in volleyball, most ACL injuries occur during the landing of a block or spike [2, 23]. Identifying these patterns is considered a crucial first step in formulating injury prevention strategies.

Numerous studies [26, 31, 44, 46] have demonstrated that fatigue alters landing biomechanics. Findings in these studies are conflicting regarding how biomechanical parameters are influenced by fatigue. In the sagittal plane, findings of most studies indicate that participant athletes landed in a more erected posture, with decreased flexion angles in lower limbs and trunk, thus increasing ACL injury risk, something which may be attributed to fatigue [3, 9, 14, 16, 26, 31, 38, 40]. In contrast, some other studies found that participants may adopt a more protective movement pattern increasing the angles of flexion in lower limbs and trunk. This occurred for both men and women in some studies [13, 46] while other studies found this to be relevant for women only [34].

Further, fatigue was found to induce alterations in muscle pattern recruitment [25, 34]. Muscle pattern alterations include increased quadriceps activation and increased quadriceps to hamstrings ratio after fatigue which increases the risk of ACL injury [25, 34]. In addition, however, there are studies, that found no statistical differences between pre and post-fatigue [22, 39]. Furthermore, knee valgus in the frontal plane increased due to fatigue in several studies [9, 14, 30, 38]. On the other hand knee valgus also found to be decreased in other studies while [3]. These discrepancies in results may be due to methodological differences in population, fatigue protocol, and the level of fatigue. It is important to note, that all the aforementioned studies, induced fatigue in an artificially controlled manner that does not incorporate the psychological and physiological effects that occur on an athlete during an actual game [4]. Further, fatigue protocols in some artificially controlled studies [9, 14, 44], had a short duration and comprising of exercises that cause local muscle fatigue, whereas other studies incorporated general fatigue protocols with a long duration. These were imploded in an attempt to incorporate more realism in the studies [42, 43].

Regarding the assessment of landing mechanism, 3 Dimensional (3D) instrumented motion analysis is considered

the gold standard for assessing motion patterns. However, the laboratory environment, the time, and the cost make such an assessment approach very challenging to implement. This situation has led to the development of low cost and easy-to-use tools based on observational analysis that would allow screening of large groups of participants [15]. Such an instrument is the Landing Error Scoring System (LESS). LESS is a valid and reliable clinical tool for the assessment of jump-landing technique. It is demonstrated good-to-excellent interrater and intrarater reliability, and it has been assessed for its validity against 3D kinematic and kinetic analysis in a large study with approximately 2700 volunteers [36]. Furthermore, both novice and expert raters can use LESS effectively due to the proven excellent interrater reliability [33].

Looking at the above literature, it is clear that the influence of fatigue caused by a realistic condition of a sports game has not been investigated. Of special interest would be the game of volleyball as epidemiological data show that it is one of the sports with the highest rate of ACL injuries in female athletes [24]. The most common injuries in volleyball players are ankle sprain, followed by knee tendinitis and anterior cruciate ligament injury [2]. Volleyball athletes are exposed to situations during a volleyball game that involve many jump-landings that can lead to injury [2, 23].

This paper examines the effect of fatigue, induced by a volleyball training game followed by a discussion on the risk of ACL injury. For this purpose, the measurement instruments of Borg RPE scale, jump-landing height and LESS were employed. Data were collected during a 60-minute (3 sets) volleyball game. In this way more realistic findings concerning the effect of fatigue may be derived. Such findings can provide valuable information for formulating better in-game tactics, as well as for devising appropriate injury prevention strategies.

Material and methods

Participants

Fourteen female college volleyball players participated voluntarily in this study. One participant was excluded, because of the invalid performance of the jump landing task. The individual characteristics of the thirteen participants are presented on Table 1.

The athletes that participated in the study were students of the Department of Physical Education and Sports Science of the University of Thessaly and were active in their sport for a minimum of 2 days per week. Athletes, with an injury or surgery in the past six months and severe neurological, respiratory, or cardiological disorder were excluded. Written consent was obtained from all participants before taking part in the study. The study conformed to the

Table 1. Individual characteristics of participants

n = 13	Minimum	Maximum	Mean $\pm$ SD
Age [yrs]	18.0	21.0	19.3 $\pm$ 1.1
mass [kg]	52.3	94.4	67.0 $\pm$ 12.3
Height [m]	1.62	1.76	1.68 $\pm$ 0.04
BMI [kg/m ²]	19.2	31.9	23.6 $\pm$ 3.5
TS/week	2.0	6.0	4.2 $\pm$ 1.1

Abbreviations: TS/W – Training Sessions/Week

guidelines of the Helsinki Declaration and was approved by the Ethical Committee of the Department of Physical Education and Sport Science of the University of Thessaly with protocol number 1226 and the number of decision 2-5/5-4-2017.

Procedure

Pre-exercise evaluation

The study was carried out at a university gymnasium. We instructed participants to abstain from any intense physical activity the previous day. At first, the participants signed the consent form, and instructions were given regarding the procedures as well as the appropriate way of performing the tests. Then their subjective sense of fatigue was rated via the 20-point scale (6 to 20 scale) of the Borg rating of perceived exertion (RPE) instrument [8]. The Borg RPE scale has been used in previous studies evaluating the impact of fatigue on different biomechanical parameters [13, 41]. Furthermore, the RPE scale has been previously proposed as a suitable measure for assessing the subjective sense of exertion during exercise [17]. In this way, the scale provides a subjective sense of central and peripheral fatigue [17]. Moreover, there is evidence to support the association of RPE scores with VO₂ max, as well as with “one repetition maximum” or vertical jump performance [17].

Prior to the evaluation procedure participants completed a survey comprised of questions on demographic characteristics, physical activity level, injury history. Further, baseline measurements of weight and height were performed. After that, athletes performed a 10-minutes warm-up and they were randomly divided into two group. The first group performed the landing task, while the second group performed the vertical jump. Finally, the two groups interchanged the tasks of landing and vertical jump.

Volleyball game

After the pre-exercise testing a training volleyball game was carried out. The athletes performed a more specific warm-up for approximately 20-minutes and then divided

into two groups of seven athletes. For the seven athletes of each team, six were playing the game, with one athlete helped as a substitute. Substitutions were made cyclically for all player participants, so that they had the same active time during the game. Additionally, athletes played in all positions during the game, so that the demands of each position, such as the jumps performed were similar in number. The volleyball game had a duration of 60 minutes (3 sets).

Post-exercise evaluation

After completing the game, we divided the participants again, into two groups. The one group was evaluated for the landing task with the LESS instrument. The other group was evaluated on the vertical jump using the Bosco Ergojump System. Finally, the groups interchanged tasks and the evaluation was repeated. In between playing the game and performing the landing task, we rated the participant's perceived fatigue via Borg's exertion rating scale [8].

Evaluation Instruments

Landing Error Scoring System (LESS)

The LESS evaluation test was performed according to guidelines described by Padua et al. (2009). To perform the test correctly we instructed participants to: a) jump from the box with both limbs, b) jump in a front direction just after the floor sign, c) do a maximum vertical jump after landing, d) do the test with maximum effort without stopping between landing and jumping. At first, we allowed participants to perform 1-2 trial jumps for familiarizing themselves with the procedure and then we video captured three consecutive jumps from a 30 cm height. Participants performed a forward jump from the box at a distance equal to 50% of their height. They also landed with both limbs and immediately jumped vertically as high as they could [36].

To capture the video of the landing tasks, we set up two camera recorders (Panasonic HC-V770 and Sony HDR-CX625). One camera recorder was positioned on the vertical plane to capture the right side of the participants and the other on the frontal plane to capture the landing area. The camera recorders were 3.45 m away from the landing area and were supported on tripods with a height of 1.20, as described in a previous study [36]. Due to the position of the camera recorders, only the right limb was fully visible in the sagittal and frontal planes, and therefore the right limb was selected for assessing all participants.

After the procedure, the lead author analyzed the videos that captured the landing tasks using the kinovea software (0.8.26 experimental version) for 2 Dimensional (2D) video analysis. The landing technique was evaluated via the LESS instrument based on scoring form and

instructions from previous studies [35, 36]. Note that the evaluator (lead author) had clinical experience in sports injury assessment and rehabilitation, as well as in the proper use of the LESS scoring instrument. The evaluator randomly selected and scored each participant's landing technique. This was done regardless of whether the videos were taken before or after the game. This blind procedure on the pre – and post-game data was carried out for avoiding the introduction of bias in the evaluation procedure.

The LESS scoring form provides a total of 17 evaluation items, including items that were evaluated from the sagittal plane, such as trunk, hip, knee, and ankle flexion angles at initial contact, and maximum knee flexion during landing. Additionally, frontal plane 2D kinematics, such as trunk alignment, valgus of the knee, stance width, and foot alignment were also included. Finally, the scoring form included, the joint angles displacement among initial contact and maximum knee flexion, and the overall impression of the landing technique.

Note that a higher score in the LESS scale indicates more landing errors [35, 36]. The total scores for each participant were recorded on the scoring form and subsequently were used for the analysis. The evaluator further analyzed and scored each landing task. Specifically, the mean values of the 3 landing task scores for each participant (pre and post-game) were used for the statistical analysis [36].

Vertical jump

To appraise the level of fatigue, we have used the measurement of the maximum vertical jump. Participants performed three maximum vertical jumps from a squat standing of 90-degree knee flexion using the Bosco Ergojump System [10, 11, 29]. Before any recording taking place participants performed 1-2 attempts for familiarization.

Statistical analysis

Descriptive and inferential statistical analysis was carried out using the IBM SPSS Statistics 21.0 software. First the collected data were tested for normality. Then, demographic data and data from LESS, vertical jump, and Borg

RPE scale were analyzed using descriptive statistics such as means and Standard Deviations. Further, t-tests for dependent variables were performed to compare the mean values between pre and post-game LESS scores, vertical jump height scores, and BORG scale values. The level of significance was set at $p < 0.05$.

Results

Following the statistical analysis, we have found that there were significant differences in the mean values of evaluation scores prior and post-game as shown in Table 2. Specifically, we have found a significant difference ($t_{12} = 2.55$, $p = 0.026$) in the pre and post-game mean values of vertical jump. The scores on the vertical jump after the game were significantly lower with a confidence interval (CI) (24.9 ± 2.2) as compared to (26.2 ± 2.3) before the game.

Further, the LESS t-test also revealed significant differences ($t_{12} = 2.21$, $p = 0.047$) pre and post-game. Participants scored significantly higher post-game (6.3 ± 1.1) than pre-game (5.8 ± 1.0). Moreover, the perceived exertion measured by the Borg RPE instrument showed significant differences ($t_{12} = 14.05$, $p < 0.001$) prior and post-game. Specifically, scores were higher post-game (pre 6.5 ± 0.4 ; post 10.2 ± 0.6). Note that the level of the subjective sense of fatigue after the game was rather low in the scoring scale.

Discussion

This study evaluated the effect of fatigue after a three-set volleyball training game on jumping and landing ability. We hypothesized that a three-set game would induce a fatigue effect that would decrease jump height and impair landing technique, increasing the risk of ACL injury. Indeed, the participants had a statistically significant increase in Borg RPE scale scores. Further their jumping height was significantly reduced post-game. Moreover,

Table 2. Differences between pre and post a volleyball match for Borg exertion rating scale, Vertical Jump and Landing Error Scoring System (LESS)

n = 13	Pre		Post		p-value	Cohen's d
	Mean $\pm$ SD	CI	Mean $\pm$ SD	CI		
BRPE	6.5 $\pm$ 0.8	0.4	10.2 $\pm$ 1.0	0.6	< 0.001	3.9
VJ [cm]	26.2 $\pm$ 3.9	2.3	24.9 $\pm$ 3.7	2.2	0.026	0.6
LESS	5.8 $\pm$ 1.8	1.0	6.3 $\pm$ 1.9	1.1	0.047	0.7

higher scores on the LESS scale were observed post-game, which proven to be of significant difference. This implies that fatigue induces a higher likelihood of injury as a result of movement errors.

Our findings are in agreement with other studies that suggest that fatigue causes adverse changes in movement patterns [3, 9, 14, 16], including a stiffer landing pattern and changes in posture alignment during landing [44]. On the other hand, our findings are in contrast with other studies, which suggest that there is no change in parameters that are associated with the risk of ACL injury, like knee valgus or flexion angles in the trunk, hip, and knee [13, 46].

The findings of the present study support the suggestion that ACL prevention programs should incorporate components to train athletes to resist fatigue sufficiently [5]. A stiffer landing can set more forces on ACL, increasing ACL injury risk [1, 28]. For this reason, the proper technique should emphasized a softer landing for appropriate loading attenuation [27]. Further, movements on the frontal and transverse planes are equally important since ACL injuries mechanism includes a combination of rotation on the knee. The movements that athletes should avoid because they increase directly or indirectly the forces on ACL are lateral trunk flexion, knee valgus, and ankle inward and outward rotations [1]. In our study, most changes on landing technique were observed on the reduction of knee flexion, followed by the presence of knee valgus after the game, both at initial contact of landing. These changes were observed in item 1 and item 5 on the LESS assessment form. A reduction in knee flexion angle indicates more anterior shear forces on ACL, and more quadriceps dominance technique as quadriceps extend the knee. This quadriceps dominance technique on landing contrasts the use of the posterior muscle chain [20]. Furthermore, the presentation of knee valgus post-fatigue may indicate insufficient control of the lower limb by gluteals muscles (both maximus and medius), hamstrings muscles, and gastrocnemius and soleus muscles [20]. The hamstrings are considered as synergists of ACL and can increase knee flexion. Moreover the hamstrings by extension, provide better force attenuation, as well as offer control of frontal plane motion at the knee, which is crucial for ACL injury prevention [20].

In addition, significant changes in the Borg RPE scale and jump height were observed after the volleyball game, indicating the presence of fatigue. We consider that the volleyball game caused both peripheral and central fatigue, which affected the neuromuscular control of landing. Previous studies have shown that repetitive full-body movements and jumps affect both central and peripheral fatigue mechanisms [4]. In all previous studies, the fatigue protocols incorporated exercises that attempted to simulate athletic demands. Local muscle fatigue stimulates the

neuromuscular system intensely, causing adjustments in motor control [9], resulting in possibly increase of ACL injury risk.

The most common instrument used for local muscle fatigue is the isokinetic dynamometer [19]. On the other hand isokinetic dynamometer does not simulate realistically the sporting activity. In contrast, fatigue protocols can cause general fatigue and simulate better the demands of the sporting activity. Protocols cause both general and local fatigue affecting more generally dynamic balance which is dependent on proprioception, visual, vestibular system and mechanoreceptors [37]. However, both local and general types of fatigue protocols cannot simulate the complex psychological and physiological demands that take place during an actual game [4]. For this reason, it is best to go for a field study and evaluate the realistic effect of sporting activity. We have specifically chosen volleyball athletes because it is among the sports with the most ACL injuries [28].

The mean value scores of the Borg RPE (10.2) post-game marked a slight subjective sense of fatigue. Note that values above 15 in the Borg RPE scale have reported in the literature [41]. The mean value scores for jump height showed a significant reduction of 5% post-game. Note that other studies show mean values reduction in jumping height of 10% [44]. The Cohen's *d* (0.7) indicating the standardized difference between two means shown on Table 2 suggests that the risk of ACL injury increased as jump height decreased significantly even though participants only completed part of a normal volleyball game (3 sets and 60 minutes instead of 5 sets and 90 minutes).

To maintain high jumping performance and decrease the likelihood of injury, it appears that coaches need to consider a effective tactics to reduce the demands placed on athletes during the game and increase their resistance to fatigue. In addition, college recreational athletes would benefit from proper injury prevention strategies in order to reduce the risk of injury.

The findings on LESS scores pre and post the volleyball game are similar to a previous study [44], where fatigue is induced by a functional exercise protocol. Wesley et al. [44] found that women scored on LESS significantly higher (mean value 6.9, SD 1.7) post-exercise than pre-exercise (mean value 5.7, SD 1.9). In our study, participants scored in a similar range (mean value 6.3, SD 1.9 post-game and mean value 5.8, SD 1.8 pre-game). The slight differences between our study and the study by Wesley et al. [44] can be explained by the fatigue level. In the study of Wesley et al. [44], the vertical jump difference in mean values decreased by 13%, while in our study the decrease was merely 5%.

LESS scores are divided into four categories that characterize landing technique [36]. A score equal to or below 4 represents excellent landing technique, a score between

4 to 5 represents good technique, a score between 5 to 6 represents moderate technique, while a score above 6 represents poor landing technique [36]. Based on the above criteria, participants in our study were in the moderate category pre-game (5.8 ± 1.0) and in the poor category post-game (6.3 ± 1.1). This provides further evidence of the importance of teaching athletes proper landing techniques. Athletes with excellent landing technique may have a lower risk of fatigue-related injury.

It is important to note that the present study has certain limitations. The game itself chosen for our field study may have an impact on parameters that affect athletes' performance, such as motivation and psychological stress. Further, in-game workload factors, such as how many sprints or landings each player performed, were not evaluated. To reduce the risk of bias we have arranged so that participants played in all positions, so that they are exposed to similar demands during the game.

To the knowledge of the authors, this is the first study that examines the effects of a training volleyball game on landing ability using the LESS scores and jump height pre and post the game. Further, the results cannot really be generalized to other athlete groups in other sports as well as athletes of different ages. On the other hand, the findings of this study may be useful to coaches and health clinicians to better understand the importance of teaching proper landing techniques to both athletes under fatigue or not.

An interesting future study, that could follow our work is to analyze the effect of fatigue on both lower limbs during landing pre and post-game. Moreover, investigating the characteristics of strength, cardiorespiratory endurance, and workload during game, will provide further insight into fatigue mechanisms and other factors that increase the risk of ACL injury. Finally, to generalize the game-induced fatigue in ACL injury risk, further research is needed involving different sports and populations in which there are elevated ACL injury rates.

Conflict of interest: Authors state no conflict of interest.

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