SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(2), 1026.
https://doi.org/10.62617/mcb1026

Article

The impact of fatigue on the jumping mechanics and injury risk of basketball players

Tianci Zhao

Department of Physical Education, Zhengzhou University of Economic and Business, Zhengzhou 451191, China; zhaotiancikg@163.com

CITATION

Zhao T. The impact of fatigue on the jumping mechanics and injury risk of basketball players. Molecular & Cellular Biomechanics. 2025; 22(2): 1026. https://doi.org/10.62617/mcb1026

ARTICLE INFO

Received: 6 December 2024
Accepted: 23 December 2024
Available online: 16 January 2025

Abstract: Fatigue can significantly alter an athlete's biomechanics and performance, which can increase their risk of injury. Important basketball moves like jump shots (JS) and countermovement jumps (CMJ) primarily use the muscles in the lower back and lower limbs. Basketball players' jumping mechanics, performance, and risk of injury during CMJ, JS, and ankle sprains were all examined. A total of 415 male collegiate basketball players participated in the league, this season representing varying levels of jumping mechanics. Surface electromyography, a force plate, and a 3D motion analysis system were used to gather data. Field-goal percentage, the center of mass's (CM) lowest point, joint angles during takeoff and landing, and Electromyography data from the lower leg muscles, erector spinae limbal, and rectus femoris were among the parameters that were recorded. Lower back muscle tiredness was created, and performance was evaluated after the fatigue. Data was analyzed using SPSS, with paired-sample *t*-tests, logistic, and Multiple Regression tests employed to examine the impact of fatigue on performance and injury risk. These tests assessed how fatigue affects shooting accuracy and joint angles, and increases the chance of injuries in basketball players. Following a period of tiredness, athletes' field-goal percentages significantly decreased, whereas their CM lowest point increased on jump shots. In both CMJ and JS, fatigue leads to reduced knee flexion angles and increased ankle plantar flexion during landing, changing the contribution ratio of both legs. Due to impaired mechanics, these biomechanical changes suggest an increased probability of ankle sprains and an elevated risk of damage, especially during landing. The risk of lower back, knee, and ankle injuries increased due to major athletic impairments and altered landing mechanics caused by lower back muscular fatigue. To reduce basketball players' risk of injury, these data highlight how crucial it is to address fatigue in training and recovery plans.

Keywords: injury risk; basketball players; fatigue; jumping mechanics; countermovement jumps (CMJ); jump shots (JS); ankle sprains

1. Introduction

Fatigue is a normal part of any activity and may be a serious problem that can impact an athlete's performance and raise their risk of injury [1]. In basketball, where leaping for shots, rebounds, and blocks requires rapid, explosive movements, it is a fact [2]. These movements create a lot of pressure on the body, especially on the lower limbs, and with the players' fatigue, the technique could deteriorate into altered movement patterns, increasing the chances of injury [3]. Fatigue alters basketball players' jumping mechanics, such as jump height, timing, posture, and landing. Such small alterations can impact performance and result in more probable injuries, like sprains, strains, and joint problems [4]. It is one of the sports with the highest injury rates compared to other sports, so it is essential to understand how fatigue affects movement and injury risk [5]. The main focus is on how fatigue influences basketball players' jump mechanics, and how changes induced by fatigue increase the risks for injuries [6]. It particularly addresses the effects of tiredness on jump height, posture, timing, and landing mechanics—all of which were important factors in the development of basketball-related injuries [7]. The research would contribute to future understanding of these concerns by shedding light on how fatigue affects performance and safety on the court as well as the game [8]. Fatigue can have different forms, such as neuromuscular, which influences lower limb injury risk. The power output of a muscle is diminished by fatigue and is classified into two types: Central and peripheral. Central fatigue happens in the nervous system before the neuromuscular junction, while peripheral fatigue occurs mainly through metabolic mechanisms after the neuromuscular junction [9]. The changes may result in faulty functioning of the muscles. Neuromuscular control may be affected, which may increase the risk of injury. **Figure 1** demonstrates the impact of fatigue on basketball performance. Jumping mechanisms are altered by fatigue, which results in decreased control and accuracy. These changes include jump height, timing, posture, and landing. Injuries including sprains, strains, and joint issues are also more likely to occur. All of these elements have an effect on overall performance and greatly increase the risk of gaming-related injuries. The interconnected elements show how important fatigue management is for enhancing sports performance and reducing injury risk.

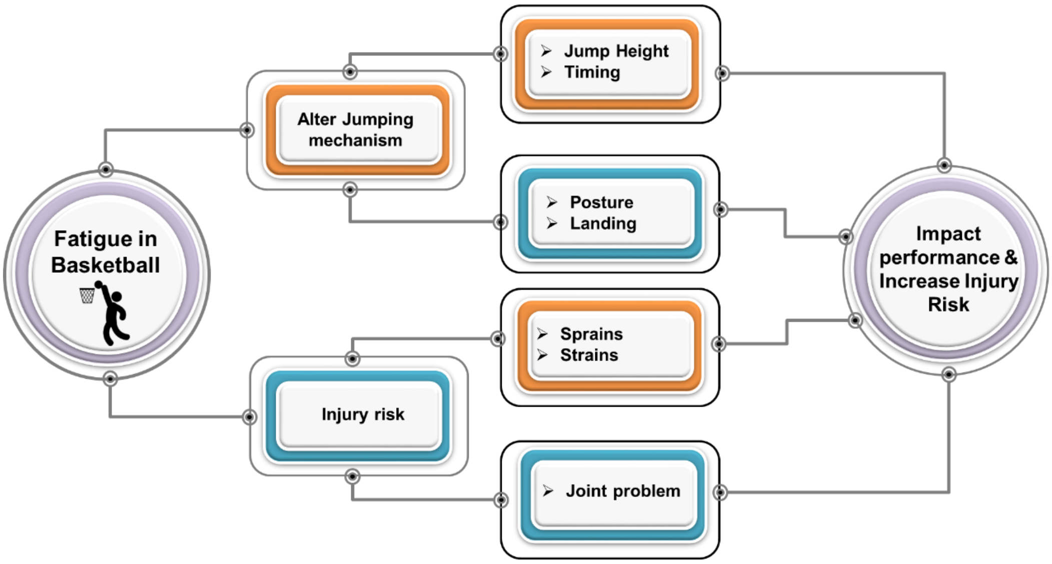

Figure 1. Fatigue's effect on basketball performance.

Aim: Examining how fatigue affects basketball players' biomechanics, performance, and risk of harm while jumping is the goal of the research. It evaluates the risk of lower back, knees, and ankle issues and emphasizes how lower back fatigue impacts the jump mechanism.

Section 2 provides the literature review. Section 3 included the effect of fatigue on basketball players' jumping mechanics and injury risk. Section 4 demonstrates the methodology flow and statistical analysis explanations. Section 5 illustrates the result and discussion. Section 6 finally conclusions.

2. Literature review

Anterior Cruciate Ligament (ACL) injury risk was investigated in volleyball training. Before and during a 60-min match, thirteen female collegiate volleyball players, ages 18 to 21, executed jump landings. Following the game, participants' vertical jumps were smaller and their ratings on the Borg Rate of Perceived Exertion (RPE) scale were significantly higher [10]. Fewer scores sharply designed after the game, suggesting a worse landing ability. It found that short-term volleyball training impairs one's capacity for landings and leaps. Regarding the risk factors for ACLs [11] aimed to assess how tiredness affected joint kinetics and kinematics during repeated changes of direction (CoDs). All twenty female athletes who took a standard shuttle run test displayed changes in their lower-body kinetics and kinematics. Players' diverse coping strategies for frequent CoDs ranged from protective to damaging behaviours, underscoring the importance of an individual biomechanical assessment in fatigue management.

To investigate how a particular sports fatigue treatment affects lower limb kinetic stability and visually show (2-dimensional) mechanical execution of multiple tuck leaps [12]. Before and following a particular sport fatigue regimen, participants completed one set of Tuck Jump Assessment (TJA). The degree of variation in TJA scoring criteria, motion, and kinematic stabilization from pre-fatigue to post-fatigue was assessed using paired *t*-tests and impact sizes. Following a fatigue experiment, a kinematic assessment of repeated tuck leaps revealed a modified jumping technique that was not discernible by visual 2-dimensional structure evaluation. Using a video-based drop-jump test and a standardized training regimen [13] sought to ascertain if exhaustion causes an increase in dynamic knee valgus in teenage athletes. Out of 85 athletes between the ages of 14 and 18, 49% complained that after exercise, their kinetic swelling increased. After training, a greater proportion of participants had leaps categorized as moderate or severe risk. Fatigue was more prevalent in female athletes and those aged ≥ 15. The dynamic knee valgus increases with feeling tired levels, which might raise the risk of the ligament's damage.

In comparison female collegiate athletes [14] looked at how tiredness and recovery affected the knee biomechanics of drop vertical jumps (DVJ) in female leisure athletes. The findings demonstrated that in female amateur athletes, tiredness significantly increased the thigh abducted angle at the first impact and peak abducted values around 40 ms from Initial Contact (IC), but no changes were seen in female university athletes. Furthermore, throughout the post-fatigue third DVJ, female recreational athletes showed lower knee flexion moments and a slower rate of fatigue healing. The effect of tiredness and load on drop leap landing pressures and biomechanics was investigated [15]. Thirteen special agents used body weight or a 15 kg weight vest to make drop leaps from 30 cm. The findings revealed decreased jumping height and reaction strength indices and a higher landing impulse. In both loaded and unloaded settings, it also discovered a correlation between impulse variations and relative aerobic fitness. The results imply that training regimens ought to increase lower-limb power and endurance.

A standard training session [16] evaluated male skilled volleyball players' vertical leaping mechanics before and after a predetermined load. They hired 12 players from the same Brazilian premier league squad. A 10% reduction in vertical ground reaction force following training was found by kinematic evaluation of the horizontal bilateral countermovement jump (CMJ) and bilateral CMJ tests; however, no discernible changes were seen in other results. The results indicated that professional volleyball players do not experience any weariness following frequent in-season training sessions. Recreational tennis players' reported weariness and their jump and sprint abilities were examined [17], after participating in a standardized tennis match. The findings indicated that compared to the beforehand condition, tiredness was greater in the instant and 24-hour post-match situations. It implies that being tired during a competition could impair efficiency and hinder recuperation, which could have an impact on efficiency and injury prevention. Tennis players can use effective recovery techniques by recognizing changes in tiredness.

The effect of an intensive, periodic exhaustion program on changes in the tendon's pressure during the sport of volleyball spiking jump was investigated [18]. Research results demonstrated that tiredness causes longer pelvis-trunk flexion and stiffer landing techniques in the lower extremities, which reduces divergent knee joint activity and patellar tendon forces. The hypothesis is that athletes may be more susceptible to acquiring patellar tendinopathy (PT) if concentric patellar tendon pressures were significant in the non-fatigued phase. It also indicates that preventative techniques were implemented in a fatigued condition to minimize extra tensile pressures on the patellar tendon. It is investigated how lower-body muscular fatigue affected the ability to balance and perform vertical jumps [19]. Twenty-four recreationally trained people participated, becoming acquainted with a static vertical leap, countermovement horizontal jump, and balance. The findings indicated that the pre/post measurements for CMVJ-H (Countermovement Vertical Jump Height), SVJ-H (Static Vertical Jump Height), and CMVJ peak power (PP) differed significantly. Due to a reduction in muscular control, collaboration, and force-generating ability following exhaustion, The Bosco technique decreased VJ altitude and Peak Force (PF), Initial Force (IF), maximal velocity, and PP in CMVJ and VJ height and PF in SVJ. Although it appears that exhaustion has little influence on balance, it advises practitioners to take into account the exhausting effects on those who undertake leaping motions.

The impact of fatigue in the muscles that stabilize the core on the flexibility of the lower limbs during leaping was investigated [20]. The jumping test was administered both before and after the exhaustion treatment to thirty basketball players who were actively participating. The findings indicated that in all three hopping-test circumstances, lower extremity stiffness decreased by 15.3%–15.9% as a result of core muscular exhaustion. It implies that lower extremity stiffness was influenced by core muscle function, which might serve as an indicator of an athlete's performance. It emphasizes the requirement for further exploration of the impact of core muscle exhaustion on performance and stresses the need for interleaved endurance training utilizing various body components of the kinetic network for injury prevention. Comparing how fatigue affects athletes' electromechanical reaction times with and without persistent low back pain [21]. Electromechanical delay (EMD), premotor time (PMT), and total response time (TRT) were measured before and post fatigue in twenty-four male basketball players. The EMD in the huge

Lateralis, Vastus Medialis Oblique, and Semitendinosus muscles was lower after fatigue, however the EMD in the Med gastrocnemius and Tibialis anterior muscles were much longer in the chronic low back pain (CLBP) group. In greater cognitive load scenarios, the impact of axial damage on lower limb injury risk variables might be reflected in the various implications of fatigue on knees and ankles electrophysiological response times.

Using the hamstring test (HT), CMJ, and autonomous repeated sprint ability (RSA) test, it is intended to evaluate neurological fatigue in competitive female football players. The research [22] involved 24 players and comprised CMJ and hamstring testing before and after the RSA test. The findings revealed an important variation in the maximal orientation and acceleration of the legs, a decrease in the height of the CMJ following RSA, and an increase in the sprint total duration and percentage difference. Performance factors taken from the RSA and the reduction of CMJ elevation can be used to measure the tiredness brought on by RSA testing. These results may help female soccer players regulate their abilities better and avoid injuries. Twenty female handball players participated and were examined [23], who looked at how a handball exhaustion regimen affected their knee and hip kinematics. Before and after the exhaustion regimen, they conducted three repetitions of the drop vertical jump, sidestep cutting maneuver, and single-leg landing. The findings demonstrated that tiredness decreased hip flexion during the detour-reducing maneuver, increased leg abduction during the drop vertical leap, and increased hip extension and thigh flexion during the single-leg landing. Lower limb kinematics were similarly changed by the exhaustion treatment, which increased thigh bending throughout both single-leg landing activities and decreased hip and knee flexions throughout the Single-Leg Countermovement (SCM) and Drop Vertical Jump (DVJ) tasks.

The impact of ankle braces on participants with functional ankle instability (FAI) following special-induced tiredness was examined [24]. The mechanics and kinetics data were gathered during single-leg drop landings from 18 adult volleyball players with FAI. Soft and semi-rigid splints decreased heel invert and horizontal range of motion before fatigue, according to the results. To ensure neutral ankle posture during landings and lower the danger of excessive inversion, semi-rigid bracing improved dynamic stability and decreased the forward ground response force and ankle inversion angle after fatigue. With the use of tri-axial acceleration factors, jumping evaluations, and an emotional well-being questionnaire, it sought to evaluate the validity of tiredness measurements in young, competitive soccer players. 17 male gamers participated [25], and their performance was evaluated twice. In contrast to DJ-JH, the results showed that CMJ, Squat Jump (SJ), Drop Jump Contact Time (DJ-CT), and Drop Jump Reactive Strength Index (DJ-RSI) exhibited good test-retest reliability. Except for PlayerLoad anterior-posterior, both tri-axial sensor parameters demonstrated good reliability during a 3-min submaximal flyer sprint. The results provide professionals with significant data to help users decide how much tiredness evaluations have changed.

3. The effect of fatigue on basketball players' jumping mechanics and injury risk

After prolonged exertion, fatigue is the sensation of being exhausted, either physically or mentally. In sports, it is said to be developed when the body's energy sources have been depleted and it cannot continue at its former pace. In basketball, it may develop easily due to the fast movements such as running, jumping, and changing direction in quick turns. The players tend to tire out, and then their muscles do not work properly. Their coordination, timing, and reaction speeds start slowing down, which makes it a bit tough for them to shoot well or land safely. Thus, they become more prone to injuries.

4. Methodology

In the section, provide brief explanation of the research steps such as research design, participants, data collection and apparatus, gathering data using apparatus, research procedures, and statistical analysis.

4.1. Research design

An experimental design was used in the research to explore how fatigue impacts the performance and injury risk of basketball players. Through the simulation of fatigue states, it assessed the two most critical movements:

- Jump Shot (JS), and
- Countermovement Jump (CMJ),

To comprehend how those physical conditions change jumping capacity, landing mechanics, and injury risk. Fatigue impacts these factors through alterations in biomechanics and performance. The design included multiple critical parameters, such as field goal percentage, center of mass during jumps, angles for joints during takeoff and landing, and muscle activation levels. Changes in these parameters were investigated both pre- and post-induction of fatigue to the variations in performance and risk of injury.

4.2. Participants

This season, 415 male collegiate basketball players from college teams took part with a range of leaping mechanic skill levels competed in the competition. Data was collected using a force plate, surface electromyography, and a 3D motion analysis system. The age of the subjects was divided into three age groups: 18–22 years, 23–26 years, and 27+ years. This group of athletes was chosen based on their active participation in collegiate basketball and represents a wide range of experience and skill levels. Such an age distribution provided an opportunity for a more detailed analysis of how fatigue can affect performance and injury risk at various stages of a basketball player's career. **Table 1** shows the demographics of basketball participants.

Table 1. The demographics of participants.

Demographic Variable	Category	Frequency (*n*)	Percentage (%)
Age	18–22 years	250	60%
	23–26 years	120	29%
	27+ years	45	11%
Sport Experience	1–2 years	80	19%
	3–4 years	200	48%
	5+ years	135	33%
BMI (Body Mass Index)	Underweight	40	10%
	Normal weight	310	75%
	Overweight	65	15%
Training Hours per Week	1–5 h	50	12%
	6–10 h	240	58%
	11+ h	125	30%
Total Sample Size		415	100%

4.3. Data collection and apparatus

To investigate how basketball players' fatigue affects their jumping technique and risk of injury, the researchers used three main tools, such as surface electromyography (EMG), a force plate (FP), and a 3D motion (3D-M).

- EMG: It is a technique that detects and records the electrical activity in muscles to track the extent of their contraction during movement. Therefore, it helps identify how fatigue affects muscle activity in the lower back and legs. Changes in muscle activation will alter jumping mechanics and thus increase injury risk.
- FP: It is the force platform that measures the amount of force involved in a jump, especially during landing and takeoff. It calculates the vertical force (how forcefully the players press down on the ground) and it can measure the ground reaction forces (how the body is pushed back by the ground). This device tracks the effects of fatigue on performance and also the forces encountered at impact. Excessive force from landing can increase the risk of ankle sprains.
- 3D-M: A system with cameras and sensors that record three-dimensional joint angles and body movements. It shows how the angles of knees and ankles change during jumps and after landing following fatigue, hence increasing the risk of injury by improper mechanics. It monitors changes in knee and ankle angles during jumps and landings after going tired, demonstrating how such changes may elevate the risk of injury by inefficient mechanics.

Gathering data using apparatus

Four major parameters were recorded field goal (FG) %, the center of mass's (CM) lowest point, joint angles (JA) during takeoff and landing, and electromyography (EMG) data (The measurement of muscle activation during the jumps). The EMG data were further divided into muscle activity from rectus femoris, erector spinae lumbalis, and lower limb muscles. The following key variables were measured and included:

Field goal (FG) percentage: Measure Shooting accuracy

- The ratio of players attempting shots compared to the actual number of shots. The shooting performance of players was evaluated before and after fatigue. After fatigue, the field-goal percentage decreased players were missing more shots when fatigued.

Centre of mass (CM) Lowest Point: Indicate the height of the jump

- The player's lowest body position during jumps. Tracking the lowest point of CM during JS and CMJ. In this case, after the fatigue condition, the CM's lowest point increased. So, the players are jumping down after fatigue.

Joint angles (JA): Measures angles at knees joint angle (Knee JA), ankles joint angle (Ankle JK), and hips joint angle (Hip JA) in the takeoff and landing cycle.

- The degree of bending of knees and other joints during landing and take-off. Measurements of angles of key joints at takeoff and landing were also made. After fatigue, knee flexion angles were decreased (less bending at the knees during landing), and ankle plantar flexion was increased (greater pointing of the toes downward during landing), demonstrating a change in movement mechanics.

Rectus Femoris EMG (RF EMG): Muscle activity in thighs

- Basketball players need strong leg muscles to perform all of the jumping, running, and landing. One such thigh muscle is the rectus femoris, which contributes to these actions. As this muscle becomes fatigued, it performs these functions poorly and puts the athlete at increased risk for knee and thigh injuries.

Erector spinae lumbalis EMG (ESL EMG): Muscle activity in the lower back

- The lower back muscles help to stabilize the body during jump actions and landings. Once these muscles fatigue, it alters posture and control, raising the risk for back injuries and complicating jumping ability.

Lower limb muscles EMG (LLM EMG): Muscle activity in the legs

- The power and balance associated with jumping and landing are provided by the lower leg muscles (like calves, hamstrings, and glutes). Fatigue, which affects the weakening of these muscles, causes bad landing forms and injuries, especially at the knees, ankles, and legs.

4.4. Procedure

The test is designed to assess the change in jump height, landing stability, and strain on muscles and joints, with an emphasis on how fatigue influences injury-prone areas, such as the ankles, knees, and lower back.

- *Countermovement jumps (CMJ)*: The person started in an upright position with his hands on his hips. To jump, the person bent his knees and jumped as high as possible using the power from the legs and hips. The jump is made on two force plates; the left foot touches the first force surface, and the right foot lands on the second force plate such that, at the point of takeoff and landing, the two feet are located on the two force plates at the same time. The player comes to a standing position from there. This test helps show how fatigue affects jump height, landing, and risk of injuries like ankle or knee strains.

- *Jump Shorts (JS)*: Each subject began in a designated position on the court, poised to catch the ball. After receiving the ball, the player stepped forward two steps, placing the left foot on the axial leg, the initial force plate, and the right foot onto the second force plate (the hopping leg). This is followed by performing a jump shot by using the impetus from both legs to propel himself forward into the air. The test evaluates how fatigue influences the balance and power between the legs during the jump and landing. This is essential in understanding how fatigue increases the chances of injuries, especially to the knees, ankles, and lower back, because of changes in jumping mechanics.
- *Ankle Pain*: It refers to pain or tenderness in the ankle, which may be due to overuse injury or poor movement. This is often experienced during sports, such as twisting or landing awkwardly, or simply pushing too hard. Mild discomfort to severe strains, where the ligaments in the ankle are stretched or torn. In the case of fatigue, the control over movements is lost and leads to a higher risk of developing ankle pain or injury, especially when jumping and landing.

4.5. Statistical analysis

For analyzing data, SPSS can be used to run paired-sample *t*-tests, and logistic and multiple regression tests to determine how fatigue impacts different biomechanical parameters. These tools can accommodate a variety of formats of data and can compare the performance metrics before and after the fatigue, like field-goal percentage, joint angles, and muscle activation levels.

5. Result

5.1. Paired sample *t*-test

The paired sample *t*-test would be employed to compare players' jumping mechanics, like height or force, before and after they have experienced fatigue. This can state if the factors have changed significantly, which may influence the course of injury prevention strategies.

Table 2 shows that after fatigue, basketball players show significant performance degradation and modification of their jumping pattern. Their FG (%) decreased from 80.3% to 72.1% ($P < 0.001$), meaning they are shooting lesser accuracy percentages when tired. Likewise, the lowest position of their CM decreases at 5.5 cm ($P < 0.001$), indicating they were shorter to jump. The knee JA decreased by 6.6° ($p = 0.001$) and the Ankle JA by 4.3° ($p = 0.003$). Players seemed to bend less at the knees and ankles in jump landing, potentially leading to inappropriate landing techniques. The Hip JA was also lower, by 3.5° ($P = 0.044$), meaning that less motion occurred at the hips. Muscle activity increased after fatigue, with the RF EMG rising by 6.8 µV ($p < 0.001$), the ESL EMG increasing by 7.1 µV ($P < 0.001$), and the LLM EMG increasing by 7.1 µV ($P = 0.004$). This means that muscle fatigue, and higher muscle tension, especially in the legs and the back, increase the incidence of injury to the lower back, knees, and ankles.

Table 2. Pre and post fatigue comparison of jumping mechanism and risk injury in basketball players.

Parameter	Mean (Pre-Fatigue)	Mean (Post-Fatigue)	Difference (Post − Pre)	Standard Deviation (Pre)	Standard Deviation (Post)	t-value	Degrees of Freedom (df)	*p*-value
FG (%)	80.3	72.1	−8.2	6.3	7.5	4.55	29	< 0.001
(CM)	34.2	28.7	−5.5	3.2	3.8	5.23	29	< 0.001
Knee JA (°)	135.2	128.6	−6.6	4.8	5.7	3.72	29	0.001
Ankle JA (°)	22.5	18.2	−4.3	3.4	3.5	3.18	29	0.003
Hip JA (°)	110.3	106.8	−3.5	4.6	5	2.1	29	0.044
RFEMG (µV)	18.4	25.2	6.8	6.1	8.4	−3.92	29	< 0.001
ESL EMG (µV)	12.7	19.8	7.1	4.3	6	−4.75	29	< 0.001
LLMEMG (µV)	45.3	52.4	7.1	8	9.1	−3.1	29	0.004

Figure 2 demonstrates the outcome of the paired sample *t*-test. RFEMG = 18.4 µV, ESL EMG = 12.7 µV, LLMEMG = 45.3 µV, Knee JA = 135.2°, Ankle JA = 22.5°, Hip JA = 110.3°, and FG (%) = 80.3 were the pre-fatigue values **(a)**. The following were the post-fatigue findings of **(b)** FG (%) = 72.1, CM = 28.7, Knee JA = 128.6°, Ankle JA = 18.2°, Hip JA = 106.8°, RFEMG = 25.2 µV, ESL EMG = 19.8 µV, and LLMEMG = 52.4 µV. Joint angles decreased and muscle activity increased with fatigue.

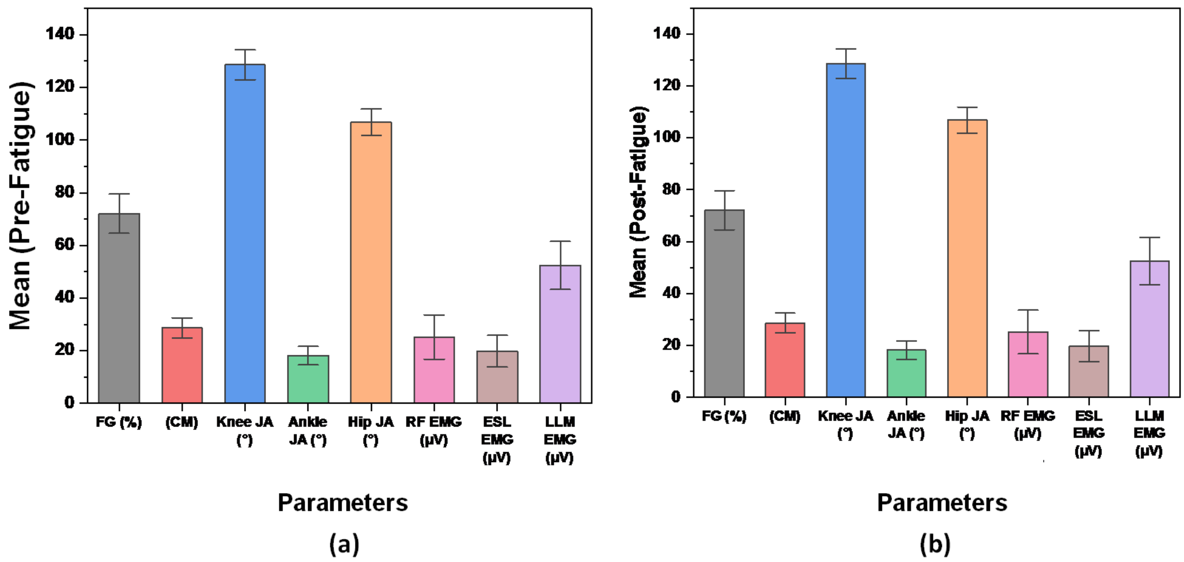

Figure 2. Outcome of paired sample *t*-test for **(a)** Pre; **(b)** Post fatigue.

5.2. Logistic regression test

Logistic regression can be used to determine whether fatigue significantly increases the injury risk based on the jumping mechanics of the players by modeling the probability of injury occurrence as a function of fatigue and other relevant factors. **Table 3** shows the effect of fatigue and jumping mechanisms on basketball players.

Table 3. Analysis of jumping mechanism and fatigue on injury risk levels in basketball players.

Parameter	Coefficient (*β*)	Standard Error (SE)	*z*-value	*p*-value	95% Confidence Interval
FG (%)	0.12	0.05	2.4	0.016	(0.03, 0.21)
(CM)	0.10	0.04	2.5	0.012	(0.02, 0.18)
Knee JA (°)	0.12	0.05	2.4	0.016	(0.02, 0.22)
Ankle JA (°)	0.08	0.04	2.0	0.046	(0.01, 0.15)
Hip JA (°)	0.18	0.07	2.57	0.01	(0.05, 0.31)
RF EMG (µV)	0.03	0.02	1.5	0.134	(−0.01, 0.07)
ESL EMG (µV)	0.05	0.02	2.3	0.021	(0.01, 0.09)
LLM EMG (µV)	0.06	0.03	2	0.046	(0.01, 0.11)

Table 3 indicates the effect of fatigue on basketball players' injury risk. As players become more tired, their shooting accuracy worsens FG (%), increasing injury risk by 0.12. It also makes the body change its shape: A Lower (CM) is poor body positioning and a higher injury risk by 0.10. For the Knee JA (°), lower flexion (0.12) increases the possibility of knee injuries, the Ankle JA (°) (0.08) indicates less optimal positioning of the ankle joints, which further increases their susceptibility to injury due to fatigue, and lower Hip JA (°) extension (0.18) raises the risk of poor landings and injury. Muscle activity is also a factor: Increased RF EMG (0.03) indicates more muscle strain due to fatigue, though it does not significantly affect injury risk, greater activation in the ESL EMG (0.05) indicates strain and greater LLM EMG (0.06) indicates that the body is overcompensating, increasing the risk of injury in the legs. In short, words, when players get tired, their performance decreases, their jumping mechanics become worse, and the chances of injuries especially to the knees, back, and ankles-rise.

Figure 3 shows the result coefficient of logistic regression. The outcomes are logistic regression analysis, displaying the coefficients (*β*) for different parameters. FG (%) and Knee JA (°) are important predictors, both of which had coefficients of 0.12; Hip JA (°) has the most influence, at 0.18. The coefficient for ankle JA (°) is 0.08, and the EMG values that follow are RF EMG (0.03), ESL EMG (0.05), and LLM EMG (0.06). These coefficients emphasize each parameter's importance in the study by showing how much of an impact each one has on the model's output.

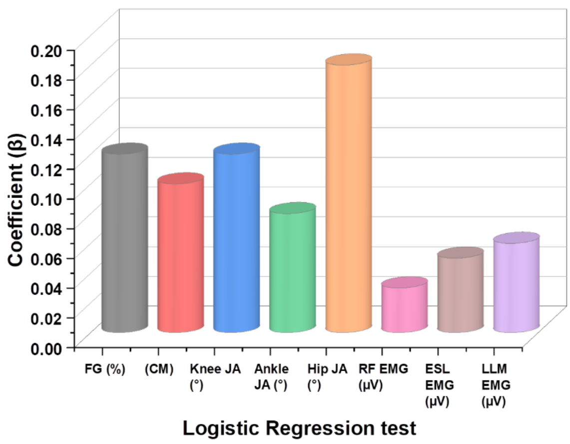

Figure 3. Result of logistic regression test.

5.3. Multiple regression test

It is a statistical technique in multiple regression, which aims at assessing the relationship between two or more independent variables with one dependent variable. It assesses how fatigue, as an independent variable, influences jumping mechanics and injury risk as a dependent variable by controlling other factors such as the player's experience or intensity of training.

Table 4 shows fatigue depresses the performance of basketball players and increases injury risk. As players' fatigue increases, FG (%) accuracy of shots decreases (B = −0.02), they miss more shots, and their jumping movements are altered: They depress their (CM) ($B = -0.08$) and bend their Knee JA (°) less ($B = -0.03$), leading to poor jump technique that might increase the risk for knee injuries. Fatigue also forces them to lower Ankle JA (°) ($B = -0.05$) and Hip JA (°) ($B = -0.02$); there is reduced movement about those areas when jumping. They are susceptible to injuries on the ankles and hips. Muscle activity also shifts as players tire out: Their RF EMG (μV) (thigh muscle) ($B = -0.005$) and their ESL EMG (μV) (lower back muscle) ($B = -0.003$) were significantly less active, showing weak engagement by the muscles that might contribute to possible muscle strain or even a backache. Last, LLM EMG (μV) ($B = -0.002$) experiences a minimal decline in activity, which will eventually result in overuse injuries. In short, fatigue lowers the players' performance and changes their jumping mechanics which increases their chance of getting injured, mainly in the knees, ankles, and lower back.

Table 4. Multiple regression results of fatigue impact of jump mechanism and injury.

Parameter	Unstandardized Coefficients (*B*)	Standard Error (SE)	Standardized Coefficients (*β*)	t-value	*p*-value	95% Confidence Interval (Lower)	95% Confidence Interval (Upper)
FG (%)	−0.02	0.0037	−0.35	−5.4	0.001	−0.03	−0.01
(CM)	−0.08	0.0163	−0.45	−4.9	0.001	−0.11	−0.05
Knee JA (°)	−0.03	0.0143	−0.18	−2.1	0.039	−0.06	−0.01
Ankle JA (°)	−0.05	0.0161	−0.23	−3.1	0.004	−0.08	−0.02
Hip JA (°)	−0.02	0.0083	−0.12	−2.4	0.023	−0.04	−0.01
RF EMG (μV)	−0.005	0.0018	−0.12	−2.8	0.009	−0.009	−0.001
ESL EMG (μV)	−0.003	0.0012	−0.1	−2.5	0.015	−0.006	−0.0002
LLM EMG (μV)	−0.002	0.0011	−0.08	−1.9	0.06	−0.004	−0.0001

Figure 4 displays the result of the performance of basketball players. The effects of tiredness and injury on jump mechanics were evaluated using multiple regression, using Standard Error (SE) values for each variable. The following SE values are found: RF EMG (μV) = 0.0018, ESL EMG (μV) = 0.0012, Knee JA (°) = 0.0143, Ankle JA (°) = 0.0161, Hip JA (°) = 0.0083, and FG (%) = 0.0037. To evaluate the impact of tiredness and injury on the jump mechanism, these SE values that are accurate the regression estimations were for each variable.

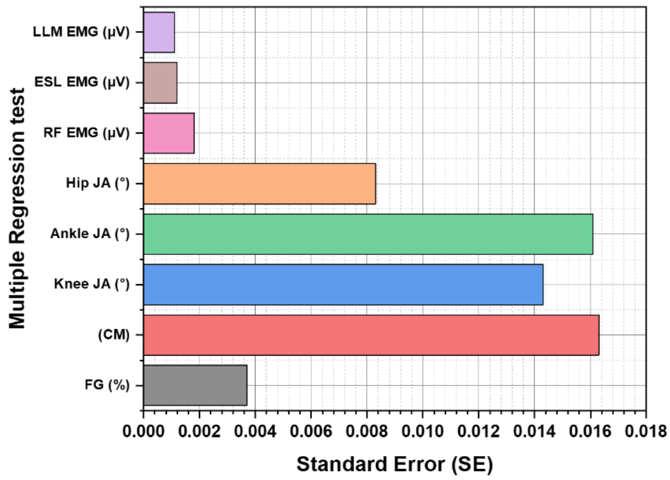

Figure 4. Multiple regression evaluations of injury and fatigue influence on the jump mechanism.

6. Discussion

In this research, statistical techniques such as multiple regression testing, logistic regression, and paired sample *t*-tests were used to investigate how basketball players' leaping mechanics and injury risk were affected by tiredness. The findings of the paired sample *t*-test showed that leaping mechanics changed significantly after tiredness. Players showed a decrease in maximum height (CM) of 5.5 cm ($p < 0.001$) and a drop in shooting accuracy (FG %) from 80.3% to 72.1%, indicating worse performance following tiredness. Furthermore, there was a reduction in knee, ankle, and hip joint angles, suggesting less ideal landing postures that would put athletes at risk for harm. After exhaustion, muscle activity, as determined by electromyography, increased, indicating greater muscular tension, especially in the back and legs, which may result in injuries. Fatigue increases the risk of injury by impairing leaping mechanics, including knee, ankle, and hip joint angles, and shot accuracy. Even though it was a sign of exhaustion, the rise in muscle activation occasionally did not correspond with the danger of injury but added to the total physical strain. Multiple regression analysis supported the findings, demonstrating that tiredness increased the risk of injury by lowering jump height, improving shot accuracy, and compromising joint angles, especially in the knees and ankles. Fatigue significantly impairs performance, changes the way one jumps, and raises the risk of injury, particularly to the lower back, knees, and ankles. These results highlight how crucial it is to consider fatigue management in athlete injury prevention techniques.

7. Conclusion

Fatigue greatly influences the biomechanics of basketball players, their performance, and their injury risk, especially in key movements, such as jump shots (JS) and countermovement jumps (CMJ). After fatigue, shooting performances were significantly affected, showing a decrease in field-goal percentages and the highest point reached by the center of mass when performing jump shots. The impact of fatigue resulted in decreased knee flexion during landing and increased ankle plantar flexion, which was associated with altered contribution from both legs and improper jumping mechanics. The biomechanical changes thus increased the chance of ankle sprains and made the injury risk higher at the lower back, knees, and ankles. The elevated muscle activity was an additional cause of strain due to fatigue, making overuse injuries more probable. The findings emphasize the significance of managing fatigue in the training and recovery plans by highlighting how important it is to control fatigue levels to preserve performance and reduce the risk of injury. Effective strategies for managing fatigue can help to prevent injuries, especially with high-impact movements, and enhance athletic performance.

Limitation and Future Scope:

The fact that the participants were all male collegiate basketball players is a drawback that could restrict the findings' applicability to other groups, such female athletes or people with varying skill levels. Future research could explore the effects of fatigue on a more diverse group of athletes and incorporate additional performance metrics and the long-term fatigue management strategy to reduce injury risk.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

References

1. Cabarkapa, D., Cabarkapa, D.V., Nagy, D., Szabo, K., Balogh, L., Safar, S. and Ratgeber, L., 2024. Differences in anthropometric and vertical jump force-time characteristics between U16 and U18 female basketball players. Frontiers in Sports and Active Living, 6, p.1425475.Doi: https://doi.org/10.3389/fspor.2024.1425475
2. He, M., Li, Y. and Li, Z., 2024. Study on the injury of anterior cruciate ligament of knee joint caused by stop-jump in basketball and its treatment and rehabilitation. International Journal of COMADEM, 27(1).
3. Alimoradi, M., Hosseini, E., Sahebozamani, M., Dos' Santos, T., Sheikhbahaie, S., Bigtashkhani, R. and Kabiri, A., 2024. The effects of two different fatigue protocols on movement quality during anticipated and unanticipated change of directions in female soccer players. Plos one, 19(5), p. e0302144. Doi: https://doi.org/10.1371/journal.pone.0302144
4. Yu, P., Gong, Z., Meng, Y., Baker, J.S., István, B. and Gu, Y., 2020. The acute influence of running-induced fatigue on the performance and biomechanics of a countermovement jump. Applied Sciences, 10(12), p.4319. Doi: https://doi.org/10.3390/app10124319
5. Li, F., Knjaz, D. and Rupčić, T., 2021. Influence of fatigue on some kinematic parameters of basketball passing. International Journal of environmental research and Public Health, 18(2), p.700. Doi: https://doi.org/10.3390/ijerph18020700
6. Aquino, M., Petrizzo, J., Otto, R.M. and Wygand, J., 2022. The impact of fatigue on performance and biomechanical variables—A narrative review with prospective methodology. Biomechanics, 2(4), pp.513–524. Doi: https://doi.org/10.3390/biomechanics2040040
7. Wang, W., 2024. Numerical simulation of lower limb forces during basketball pivot movements investigating injury prevention strategies. Molecular & Cellular Biomechanics, 21(3), pp.576–576. Doi: https://doi.org/10.62617/mcb576
8. Maestroni, L., Turner, A., Papadopoulos, K., Pedley, J., Sideris, V. and Read, P., 2024. Single-leg drop jump is affected by physical capacities in male soccer players following ACL reconstruction. Science and Medicine in Football, 8(3), pp.201–211. Doi: https://doi.org/10.1080/24733938.2023.2225481
9. Asadpour, R. and Norasteh, A.A., 2024. The Effect of a Fatigue Program on the Kinematics of Lower Limb Joints in Basketball Players with Dynamic Knee Valgus Pattern in Various Positions. Journal of Advanced Sport Technology, 8(2), pp.27–44.
10. Tsarbou, C., Liveris, N.I., Tsimeas, P.D., Papageorgiou, G., Xergia, S.A. and Tsiokanos, A., 2021. The effect of fatigue on jump height and the risk of a knee injury after a volleyball training game: A pilot study. Biomedical Human Kinetics, 13(1), pp.197–204. Doi: 10.2478/bhk-2021-0024

11. Zago, M., David, S., Bertozzi, F., Brunetti, C., Gatti, A., Salaorni, F., Tarabini, M., Galvani, C., Sforza, C. and Galli, M., 2021. Fatigue induced by repeated changes of direction in élite female football (soccer) players: impact on lower limb biomechanics and implications for ACL injury prevention. Frontiers in bioengineering and biotechnology, 9, p.666841. Doi: https://doi.org/10.3389/fbioe.2021.666841
12. Kember, L.S., Myer, G.D., Moore, I.S. and Lloyd, R.S., 2024. Effects of Fatigue on Lower Limb Biomechanics and Kinetic Stabilization During the Tuck-Jump Assessment. Journal of Athletic Training, 59(7), pp.705–712. Doi: https://doi.org/10.4085/1062-6050-0252.23
13. Fidai, M.S., Okoroha, K.R., Meldau, J., Meta, F., Lizzio, V.A., Borowsky, P., Redler, L.H., Moutzouros, V. and Makhni, E.C., 2020. Fatigue increases dynamic knee valgus in youth athletes: Results from a field-based drop-jump test. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 36(1), pp.214–222. Doi: https://doi.org/10.1016/j.arthro.2019.07.018
14. Harato, K., Morishige, Y., Niki, Y., Kobayashi, S. and Nagura, T., 2021. Fatigue and recovery have different effects on knee biomechanics of drop vertical jump between female collegiate and recreational athletes. Journal of Orthopaedic Surgery and Research, 16, pp.1–7. https://doi.org/10.1186/s13018-021-02893-6
15. Merrigan, J.J., 2021. Effects of maximal effort running on special agents' loaded and unloaded drop jump performance and mechanics. International Journal of Environmental Research and Public Health, 18(19), p.10090. Doi: https://doi.org/10.3390/ijerph181910090
16. Setuain, I., Berriel, G.P., Lanz, D., Schons, P., Oliveira, H.B., Grazioli, R., Peyré-Tartaruga, L.A., Garcia-Tabar, I. and Cadore, E.L., 2021. Jump performance and mechanics after a regular training bout in elite volleyball players. The Journal of Sports Medicine and Physical Fitness, 62(5), pp.633–640. Doi: https://doi.org/10.23736/s0022-4707.21.12734-3
17. Amatori, S., Gobbi, E., Moriondo, G., Gervasi, M., Sisti, D., Rocchi, M.B. and Perroni, F., 2020. Effects of a Tennis Match on Perceived Fatigue, Jump and Sprint Performances on Recreational Players. The Open Sports Sciences Journal, 13(1). Doi: http://dx.doi.org/10.2174/1875399X02013010054
18. Vermeulen, S., De Bleecker, C., Spanhove, V., Segers, V., Willems, T., Roosen, P., Vanrenterghem, J. and De Ridder, R., 2023. The effect of fatigue on spike jump biomechanics given patellar tendon loading in volleyball. Scandinavian Journal of Medicine & Science in Sports, 33(11), pp.2208–2218. Doi: https://doi.org/10.1111/sms.14458
19. Cooper, C.N., Dabbs, N.C., Davis, J. and Sauls, N.M., 2020. Effects of lower-body muscular fatigue on vertical jump and balance performance. The Journal of Strength & Conditioning Research, 34(10), pp.2903–2910. Doi: 10.1519/JSC.0000000000002882
20. Tazji, M.K., Sadeghi, H., Abbasi, A., Aziminia, M., Shahhosseini, A., Marjani, M.E. and Koumantakis, G.A., 2023. The effects of core stabilization trunk muscle fatigue on lower limb stiffness of basketball players. Sports, 11(10), p.200. Doi: https://doi.org/10.3390/sports11100200
21. Abdollahi, S., Sheikhhoseini, R., Roostayi, M.M. and Huddleston, W.E., 2022. The effect of fatigue on electromechanical response times in basketball players with and without persistent low back pain. Scientific Reports, 12(1), p.17849. Doi: https://doi.org/10.1038/s41598-022-21940-8
22. Armada-Cortés, E., Benítez-Muñoz, J.A., San Juan, A.F. and Sánchez-Sánchez, J., 2022. Evaluation of neuromuscular fatigue in a repeat sprint ability, countermovement jump, and hamstring test in elite female soccer players. International journal of environmental research and public health, 19(22), p.15069. Doi: https://doi.org/10.3390/ijerph192215069
23. Bedo, B.L., Catelli, D.S., Lamontagne, M., Moraes, R., Pereira, D.R., Graça, J.B. and Santiago, P.R.P., 2022. Fatigue modifies hip and knee kinematics during single-and double-leg dynamic tasks: An investigation with female handball players. Journal of sports sciences, 40(17), pp.1964–1972. Doi: https://doi.org/10.1080/02640414.2022.2123506
24. Zhang, Z. and Zhang, M., 2023. Effect of different ankle braces on lower extremity kinematics and kinetics following special-induced fatigue for volleyball players with functional ankle instability. Heliyon, 9(6).
25. Hosseini, E., Daneshjoo, A., Sahebozamani, M. and Behm, D., 2024. The effects of fatigue on knee kinematics during unanticipated change of direction in adolescent girl athletes: A comparison between dominant and non-dominant legs. Sports Biomechanics, 23(9), pp.1219–1228. Doi: https://doi.org/10.1080/14763141.2021.1925732