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Article

# A study of the effect of fatigue state on soccer players' shooting movements based on Mediapipe

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**Abstract:** Soccer is recognized as one of the most widely played and commercially significant sports globally. An athlete's performance is typically impaired during states of fatigue. Investigating the body mechanics of soccer players under states of fatigue can provide insights for coaches regarding the physical capabilities and movement deficiencies of their athletes. This understanding can facilitate the adjustment of game strategies and the development of tailored training regimens following competitive matches. Advancements in artificial intelligence have led to the maturation of image recognition technologies, which are increasingly applied across various industries, including promising applications within the realm of soccer. Consequently, this study analyzed a cohort of 5 amateur soccer players (mean age 19.8 years; mean height 1.82 m; mean weight 73.6 kg). The study involved participants who completed 10 shootings on goal as a control group before the implementation of a fatigue protocol, followed by an additional 10 shootings on goal as an experimental group after the completion of the fatigue protocol. Mediapipe image recognition tools and high-speed cameras were utilized to capture data on the various skeletal nodes of the athletes' bodies and the velocity of the shooting ball, which were subsequently analyzed. The results of the study revealed that when in a state of fatigue, there were significant alterations in the angular displacement of the hip and knee joints in comparison to the ankle joint during shooting by soccer players. The decreased angular displacement of the hip and knee joints resulted in inferior contact between the foot and the ball, as well as a reduction in the speed applied to the ball, leading to a decline in shooting accuracy and ball speed. The findings substantiate the impact of fatigue on the shooting movements of athletes.

**Keywords:** artificial fatigue; Mediapipe image recognition; soccer; shooting movements; motion analysis; kinematics

## 1. Introduction

Soccer is a globally renowned and highly popular sport, which holds significant potential for practical applications and research endeavors [1]. The existing studies on soccer have been extensively examined from various perspectives, including biomechanics, technical analysis, and muscle engagement during kicking movements [2–4]. Among the diverse research, fatigue has emerged as a crucial factor that influences kicking performance [5].

Fatigue is characterized by a decline in maximal strength and explosive power during sustained movement, resulting in a significant decrease in athletic performance [6]. Athletes who experience fatigue during competition or training may display signs of temporary exhaustion both throughout the match and toward its conclusion [7]. Fatigue can negatively impact neuromuscular coordination and control, leading to altered movement patterns and difficulty maintaining proper posture during physical activity [8]. Furthermore, fatigue increases the likelihood of musculoskeletal injuries, particularly in the lower extremities, such as strains, sprains, and stress fractures [9,10].

Soccer is a sport that is characterized by high-intensity and high-load activities, and a typical soccer match lasts for 90 min, which imposes significant demands on the physical fitness of athletes. During the game, athletes are required to maintain a high level of concentration and engage in intense confrontations for an extended period, making fatigue a critical factor that affects their performance. Fatigue not only impairs the physical function of athletes but also has the potential to cause deformations in technical movements, which can subsequently affect the accuracy and efficiency of goal shooting [11].

Muscle fatigue is a prevalent and remarkable form of fatigue in soccer. It is primarily characterized by muscle soreness, stiffness, and reduced strength [12]. Muscle soreness arises from the accumulation of metabolites, such as lactic acid, produced by the muscles during exercise. This accumulation stimulates nerve endings, resulting in soreness commonly experienced in the leg muscles after frequent sprints, sharp stops, and directional changes during a soccer match [13]. Muscle stiffness, on the other hand, is a state of muscle tension that limits the range of motion. This affects the flexibility of the player's movements, such as during passing, receiving, and shooting movements, where muscle stiffness can impede accurate completion of the movement [14]. Decreased strength is also a crucial indicator of muscle fatigue. Soccer players rely on muscle strength to execute various movements during the game, such as shooting, passing, and running. When muscle fatigue occurs, the strength of these movements is significantly weakened, resulting in a lack of strength in the shooting movement, slowing down the speed of the ball, and affecting the accuracy of the shot [15].

Traditional methods of analyzing and training soccer players rely heavily on manual observation and subjective judgment, which are obviously limited in terms of data accuracy, comprehensiveness, and analytical depth and efficiency. However, the advent of image recognition technology has opened up new avenues for addressing these limitations. By leveraging image recognition technology in the context of soccer, it is now possible to accurately and expeditiously identify and analyze various scenes and behaviors that occur during games and training sessions [16].

In contemporary times, the rapid advancement of digitalization and intelligence has led to the widespread adoption of image recognition technology as a key component of artificial intelligence in various industrial sectors [17]. In the realm of sports, an increasing number of AI algorithms are being progressively integrated and utilized for the analysis of sporting events and the daily training of athletes, with the aim of enhancing their performance [18].

In recent years, posture estimation and movement recognition techniques have emerged as a key area of research in sports science, with the aim of enhancing the efficacy of training programs. These techniques enable the quantification of motion analysis by capturing the skeletal motion data of athletes, thereby providing valuable insights into the optimization of motion and training strategies [19].

While deep learning algorithms have been applied to movement recognition and classification in soccer with promising results [20], there remains a lack of in-depth exploration into the underlying implications of these applications. However, leveraging existing image recognition tools, such as Kinect and Mediapipe, has enabled the extraction of more detailed action information, leading to their successful application in other sports, such as basketball and badminton. These tools have facilitated researchers in achieving more robust research outcomes [21–23].

In summary, the integration of image recognition technology with soccer has the potential to enhance the competitive level, training quality, and tournament viewing experience of the sport. Furthermore, this integration can facilitate the digital and intelligent transformation of the soccer industry, which holds significant practical implications and broad application prospects.

The present study utilizes Mediapipe technology to capture data pertaining to each joint node of the athlete's body skeleton, with the aim of investigating the impact of fatigue on the athlete's goal kicking action. Compared to traditional observation methods, the use of Mediapipe technology does not require specialized equipment, thereby simplifying the test process and reducing costs, ultimately increasing the efficiency of the test. Specifically, this study aims to observe changes in joint angles during the shooting movements of soccer players' lower extremities in the fatigue state, including angular displacement and angular velocity of the lower extremities, which may impact ball velocity and the path of motion after impact. Five highly trained amateur soccer players with varying professional experience were recruited for the study, and detailed kinematic data were captured using Mediapipe image recognition technology and a high-speed camera. The study provides valuable insights for practitioners in related fields, such as professional soccer players and coaches, by offering a kinematic profile of soccer players' shooting movements under a fatigue state.

This paper is organized as follows: Section 1 provides an overview of the current state of research on the relationship between fatigue and image recognition algorithms in soccer, and outlines the methodology employed in this study to investigate the negative impact of fatigue on soccer players. Section 2 details the experimental methodology, including the experimental design, participants, fatigue protocol, and measurement tools. Section 3 presents the experimental results, focusing on the angular displacements and velocities of the hip, knee, and ankle joints before and after the fatigue protocol. Ball velocity is used as an evaluation index to assess athletic performance. This section also discusses the findings of the study and the effects of fatigue state on athletic performance. Section 4 discusses the possible causes of the results and identifies the limitations of the study. Finally, Section 5 summarizes the key points of the paper, including the practical implications of the results, and provides suggestions for future research.

## 2. Methodology

### 2.1. Participants

The present study recruited five male college students majoring in soccer-related fields from local sports colleges, all of whom were amateur soccer players. These participants were selected based on their specialized knowledge of soccer and extensive experience in the sport. To ensure the relevance and quality of the data, all participants met strict inclusion criteria. The age of the participants ranged from 18 to

25 years, with a mean age of 22.3 years. All participants were in good physical health, with no reported musculoskeletal injuries or surgeries to the back or lower extremities in the past six months, and were able to complete the fatigue protocol without injury. Participants had a minimum of two years of playing experience and were professionally trained in soccer, demonstrating the ability to make standard shots in various situations.

The participants' average height was 1.82 m, ranging from 1.78 to 1.88 m. The mean weight was 73.6 kg, with the lightest being 68.1 kg and the heaviest being 80.3 kg. The mean body mass index (BMI) was 22.3 kg/m$^2$ with a range of BMI values from 20.0 to 25.3 kg/m$^2$, which is within the healthy range for this age group. Confirmation of these details was important to study the effect of fatigue state on soccer players' shooting movements. The physical characteristics of the participants are shown in **Table 1**.

**Table 1.** Physical characteristics.

| Characteristic | Average | Range |
|---|---|---|
| Age (years) | 19.8 | 19–21 |
| Height (m) | 1.82 | 1.78–1.88 |
| Weight (kg) | 73.6 | 68.1–80.3 |
| Body Mass Index (BMI) (kg/m$^2$) | 22.3 | 20.0–25.3 |

Prior to conducting the study, informed consent was obtained from all participants, indicating their voluntary agreement to participate in the research.

## 2.2. Experiment design

First, each participant was asked to perform a warm-up lasting 15 min, which consisted of stretching, jogging, sprinting, and kicking a ball, similar to the warm-up performed by soccer players before a game. After completing the warm-up, participants were asked to shoot 10 times. While the shooting trials were taking place, data such as the participants' lower extremity joint flexion angles and ball speeds were measured and recorded. Participants were then asked to implement a fatigue protocol. After inducing fatigue in the leg muscles, participants were again asked to shoot 10 times, and the data were recorded. Participants were required to repeat the fatigue protocol once ($n$ = 1 in this study), with a shooting trial following each fatigue protocol. Participants were not permitted to rest during the execution of the fatigue protocol and were required to complete the fatigue protocol within 30 min, which was intended to reduce the variation in recovery time between participants after the fatigue workout. The time interval between the fatigue protocol and the shooting trials was less than one minute for each participant. The overall flow of the trial is shown in **Figure 1**.

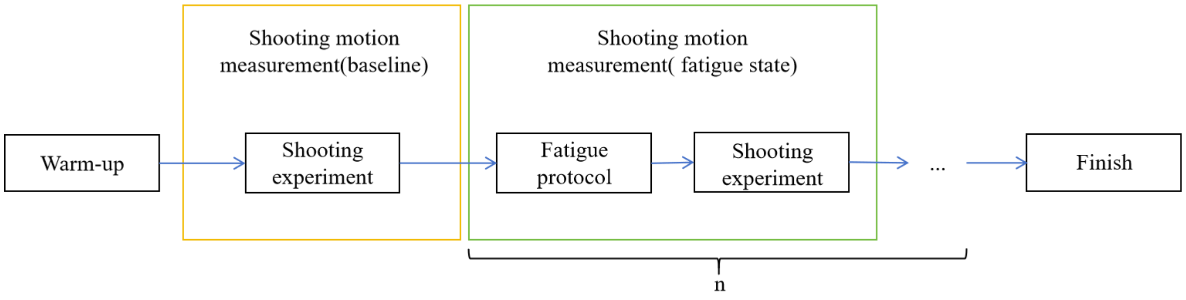


**Figure 1.** Outline of the experimental procedure.

### 2.3. Fatigue protocol

A soccer program was developed to simulate a real game scenario, which includes running, pivoting, cutting, jumping, and shooting, and is designed to fatigue the participants' muscles [11]. At the same time, fatigue of the knee extensors and flexors can be effectively induced by performing knee extension and flexion exercises and setting the load on the knee extensors at 50% of body weight and the load on the knee flexors at 40% of body weight [12].

Therefore, in this paper, a fatigue protocol is designed that can effectively bring participants into a fatigue state, thus amplifying the characteristics of the shooting movement in the fatigue state. The fatigue protocol includes running 3 sets of 100 m each, sprinting 6 sets of 50 m each, skipping 3 sets of 50 m each, running back and forth 2 sets of 3 × 50 m each, running in a change of direction 2 sets of 30 m each, jumping 3 sets of 5 times each for a total of 10 m each, running with a ball for 150 m, running in a change of direction with a ball for 30 m, and finally performing 15 repetitions of knee extensions and 10 repetitions of knee flexions in a load-bearing exercise. The specific process of the fatigue protocol is shown in **Figure 2**.

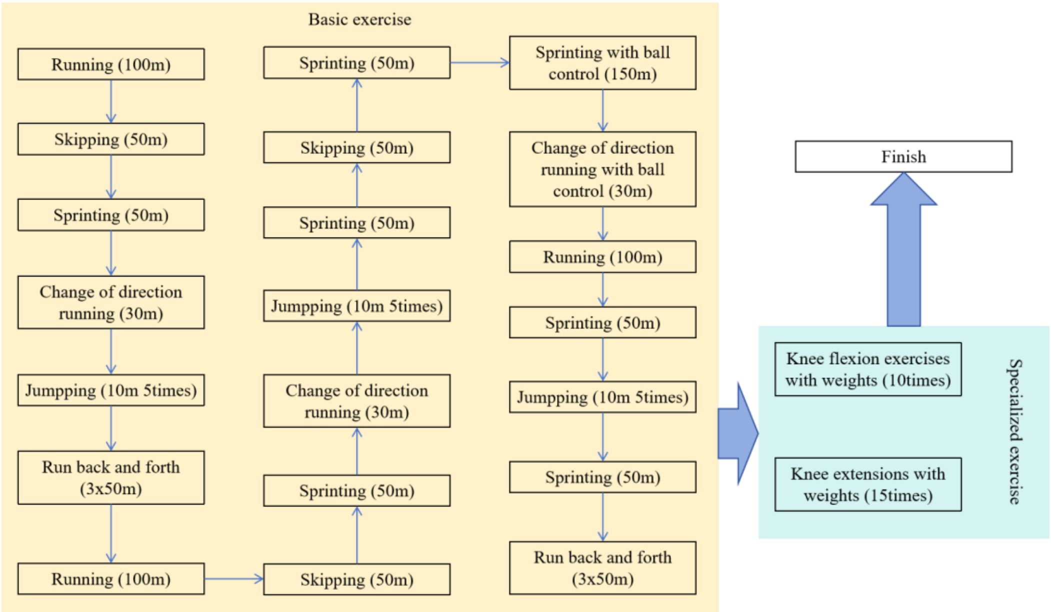


**Figure 2.** Fatigue protocol flowchart.

## 2.4. Data acquisition and processing

The conventional motion capture technology for soccer players necessitates the use of reflective markers on the body parts to be monitored, along with multiple camera devices to simultaneously capture motion data. This data acquisition method imposes high demands on the testing equipment and is susceptible to external environmental factors, leading to significant errors. To address these limitations, this study proposes the use of Mediapipe, an image action recognition tool, to capture data related to soccer players' shooting movements. This approach reduces testing costs, enhances testing efficiency, and improves the accuracy of the acquired data. The human model joint nodes in Mediapipe are illustrated in **Figure 3**. This study focuses on the data of six joint nodes, namely 23. left hip, 24. right hip, 25. left knee, 26. right knee, 27. left ankle, and 28. right ankle, to investigate the impact of fatigue on soccer players' shooting movements.

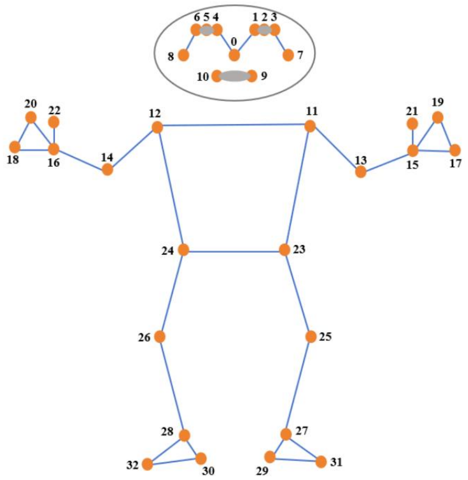


**Figure 3.** 3D model of human body based on joint points in Mediapipe.

Notes: 0. nose; 1. left eye inner; 2. left eye; 3. left eye outer; 4. right eye inner; 5. right eye; 6. right eye outer; 7. left ear; 8. right ear; 9. mouth left; 10. mouth right; 11. left shoulder; 12. right shoulder; 13. left elbow; 14. right elbow; 15. left wrist; 16. right wrist; 17. left pinky; 18. right pinky; 19. left index; 20. right index; 21. left thumb; 22. right thumb; 23. left hip; 24. right hip; 25. left knee; 26. right knee; 27. left ankle; 28. right ankle; 29. left heel; 30. right heel; 31. left foot index; 32. right foot index.

The experimental setup in this paper consists of 2 high-speed cameras (sampling frequency: 200 Hz) and Mediapipe, a tool for image motion recognition. One high-speed camera is connected to a computer and analyzed in real time based on Mediapipe, which is used to capture kinematic data from the participant's shooting. Another high-speed camera was used to capture the ball speed of each shot during the shooting trials. These devices accurately tracked changes in the angle of lower extremity joints during the shot, providing a detailed understanding of how fatigue status affects the shooting movement. Data were collected both before and after implementing the fatigue protocol, facilitating a comprehensive comparison of movement patterns in pre- and post-fatigue states. The shooting movements of the participants in Mediapipe are shown in **Figure 4**.

**Figure 4.** Illustration of participant's shooting motion in Mediapipe.

In this study, each participant completed shooting trials in both non-fatigue and fatigue states, with 10 shots per trial, resulting in a total of 100 shots (5 participants × 10 shots × 2). The acquired trial data will be analyzed using standard 2D kinematic analysis techniques.

Ball velocities as well as angular displacements and angular velocities of the hip, knee, and ankle joints were calculated in different states using statistical software to compare non-fatigue state and fatigue state. Paired *t*-tests (*t*-tests) or one-way repeated measures analysis of variance (ANOVA) were applied to determine whether significant changes in lower extremity joint angles and ball velocities occurred. Based on the kinematic profile provided by the results of the study, a full understanding of the effect of fatigue state on the soccer player's shooting movements can be obtained.

## 3. Results and analysis

The present study employed a one-way repeated-measures ANOVA with a significance level of $\alpha = 0.05$ to statistically analyze the ball speed-related data obtained from two shooting trials conducted before and after fatigue training. The results, presented in **Table 2**, indicate a mean difference of 3.7 m/s with a *p*-value of less than 0.001. The mean ball speeds were found to have decreased by 14.5% after entering the fatigue state, with a *p*-value of less than 0.001, indicating a significant difference between the mean values of the data before and after fatigue. The changes in ball speed were utilized as an evaluation index, revealing that the fatigue state had a negative impact on the soccer players' shooting movements. **Figure 5** displays the changes in the average ball speed of each participant in the two shooting trials conducted before and after entering the fatigue state, respectively.

**Table 2.** Ball velocity in shooting trails.

| | **Non-Fatigue state (m/s)** | **Fatigue state (m/s)** | **Mean Difference (m/s)** | ***p*-value** |
|---|---|---|---|---|
| Ball velocity (m/s) | 25.6 | 21.9 | 3.7 | < 0.001 |

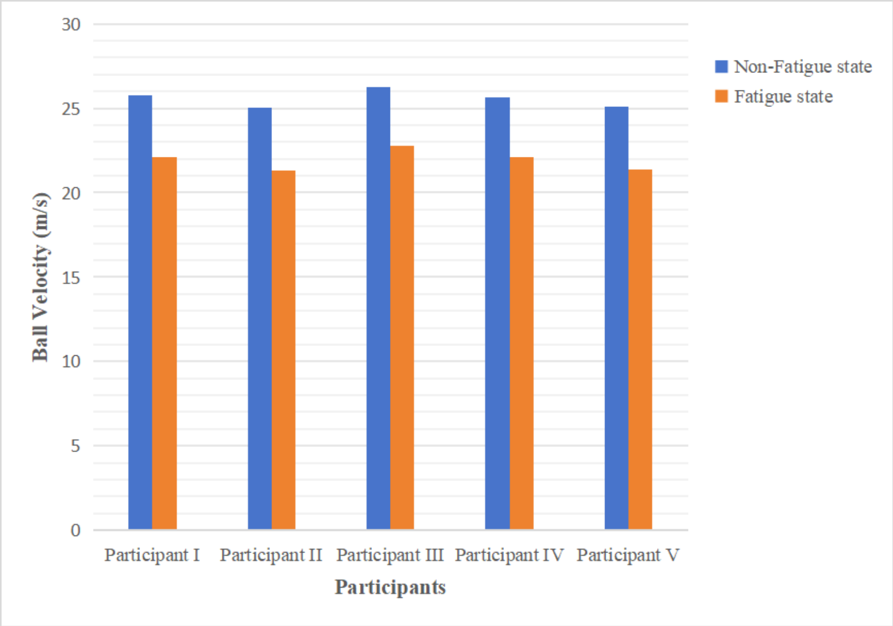


**Figure 5.** Changes in ball velocity.

The present study employed a one-way repeated-measures ANOVA with a significance level of $\alpha = 0.05$ to statistically analyze the angular displacement-related data of the lower extremity joints during two shooting trials conducted before and after fatigue training. The results, presented in **Table 3**, indicate that the *p*-values of the angular displacement of the hip and knee joints were less than 0.05, indicating a significant difference. The changes in the angular displacement of the hip and knee joints during shooting after entering the fatigue state were significant compared to before entering the fatigue state, while the changes in the angular displacement of the ankle joint were not significant. The decrease in the angular displacement of the hip joint suggests a reduction in the swing of the thigh, leading to a decrease in the force applied to the ball and ultimately resulting in a decrease in ball speed. Similarly, a decrease in the angular displacement of the knee joint indicates a decrease in the swing of the lower leg, resulting in a decrease in the mass of the foot in contact with the ball, and consequently, a decrease in shot accuracy and ball speed. **Figure 6** displays the changes in the average angular displacement of the lower extremity joints for each participant in the two shooting trials conducted before and after entering the fatigue state, respectively.

**Table 3.** Angular displacement of lower extremities in shooting trails.

| | **Non-Fatigue state (°)** | **Fatigue state (°)** | **Mean Difference (°)** | ***p*-value** |
|---|---|---|---|---|
| Hip | 155.5 | 152.49 | 3.01 | < 0.001 |
| Knee | 71.11 | 69.8 | 1.31 | 0.017 |
| Ankle | 32.12 | 32.07 | 0.05 | 0.91 |

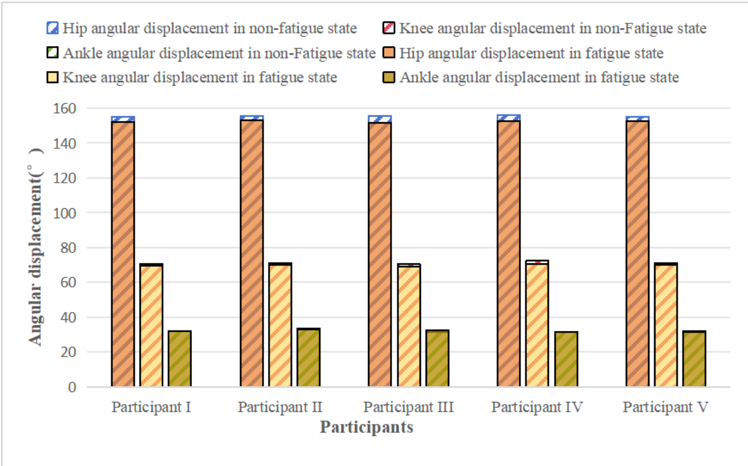


**Figure 6.** Changes in angular displacement of lower extremities.

The present study employed a one-way repeated-measures ANOVA with a significance level of $\alpha = 0.05$ to statistically analyze the angular velocity-related data of the lower extremity joints during two shooting trials conducted before and after fatigue training. The results, presented in **Table 4**, indicate that the *p*-values of the angular velocities at the hip, knee, and ankle joints were all greater than 0.05, indicating no significant difference. There was no significant change in the angular velocity of the hip, knee, and ankle joints during shooting after entering the fatigue state compared to before entering the fatigue state. **Figure 7** displays the average angular velocity of the lower extremity joints in the two shooting trials conducted before and after entering the fatigue state for each participant, respectively.

**Table 4.** Angular velocity of lower extremities in shooting trails.

| | Non-Fatigue state (°/s) | Fatigue state (°/s) | Mean Difference (°/s) | *p*-value |
|---|---|---|---|---|
| Hip | 155.5 | 152.49 | 3.01 | < 0.001 |
| Knee | 71.11 | 69.8 | 1.31 | 0.017 |
| Ankle | 32.12 | 32.07 | 0.05 | 0.91 |

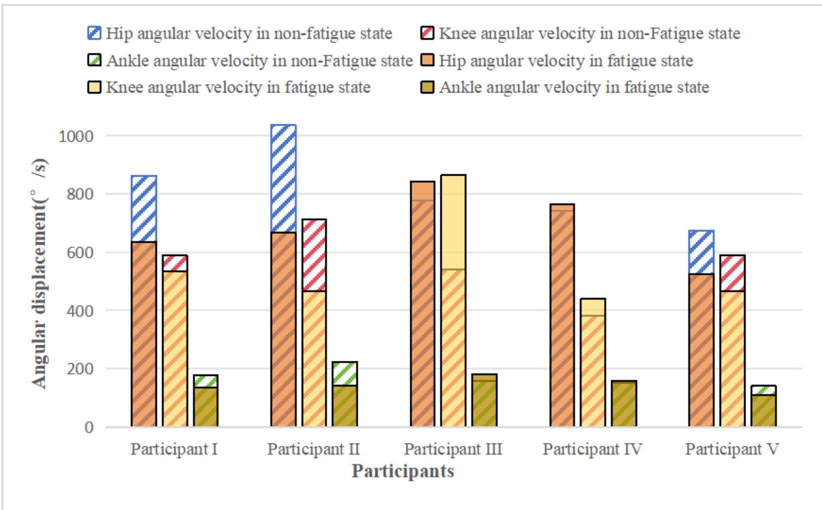


**Figure 7.** Changes in angular velocity of lower extremities.

## 4. Discussion

The effect of fatigue on soccer players' shooting movements is a complex process influenced by both physiological and psychological factors. Fatigue can be categorized into muscle fatigue, psychological fatigue, and emotional fatigue, with this paper focusing specifically on the impact of muscle fatigue on shooting movements. Using the Mediapipe image recognition tool, detailed kinematic data were obtained for joint angle displacement and angular velocity of the hip, knee, and ankle joints before and after the fatigue protocol to analyze the effects of fatigue on lower extremity kinematics in soccer shooting skills.

In order to achieve the purpose of the study, a fatigue method was designed in this paper to simulate a real soccer game scenario to put the participants into a fatigue state and effectively induce fatigue of the knee extensor and flexor muscles. Based on the research data in section 3, it can be seen that after the fatigue scenario, the ball velocity decreased, the angular displacement of the hip and knee joints decreased significantly, and the angular displacement of the ankle joint did not show a significant difference, but there was no significant change in the angular velocity of the hip, knee and ankle joints. The results of the study showed that the fatigue state had a negative effect on the soccer player's shooting action, reducing the speed of leg swing and the quality of ball contact.

The reasons for the negative effects may be caused by numerous physiological factors. For example, in the state of fatigue, the contraction capacity of muscle fibers decreases, resulting in weakened muscle strength and poor muscle coordination, which causes changes in the leg torque prior to ball contact and affects the accuracy and stability of the shooting movements [5]. In the state of fatigue, the function of the nervous system is affected, resulting in a slowing of nerve conduction and a decrease in reaction ability, which will make it difficult for the athlete to make a quick and accurate response [24]. In the state of fatigue, the metabolic function of the body will be affected, leading to the accumulation of these metabolites in the body, these metabolites will stimulate the muscles and the nervous system, affecting the normal function of the muscles and nerve conduction [25].

The findings of this study have significant implications for the training and competition of soccer players. By utilizing image recognition technology to investigate the underlying mechanisms by which fatigue affects shooting movements, athletes can adopt evidence-based exercise methods, nutritional support, rest and sleep, and psychological interventions to enhance their fatigue tolerance and mitigate the negative impact of fatigue on shooting movements, thereby improving their competitive performance. Additionally, this study provides valuable insights for soccer coaches and practitioners, enabling them to optimize tactical arrangements and training strategies to enhance the overall quality of the game.

This study has certain limitations that should be acknowledged. Firstly, the sample population consisted solely of male participants, and as such, the findings may not be generalizable to female soccer players due to the inherent physiological differences between the sexes; secondly, the influence of psychological factors of the participants could not be controlled during the test and when the participants entered a fatigue state they may have been emphasized to continue the testing procedure, which may have affected the results of the test.

The psychological factors that may influence the performance of soccer players in fatigue state can be categorized into four aspects:

- Impaired attention: Fatigue can significantly hinder athletes' ability to maintain focus and concentration during gameplay.
- Decline in self-confidence: Physical exhaustion often leads athletes to doubt their capabilities, resulting in hesitation during critical moments, such as taking a shot.
- Heightened emotional fluctuations: Fatigue can exacerbate negative emotions such as anxiety, frustration, and irritability. These emotional disturbances may adversely affect decision-making and behavior on the field.
- Perceptual biases: Fatigue may impair spatial, temporal, and bodily perception. Athletes might misjudge timing, angles, or distances, leading to errors in critical actions such as shooting.

Psychological training and the implementation of effective rest and recovery strategies can mitigate the impact of these psychological factors in fatigued states. Future studies will aim to provide detailed findings and effective solutions to address this issue comprehensively.

## 5. Conclusion

The present study aims to investigate the impact of fatigue state on soccer players' shooting movements by recruiting a sample of five amateur soccer players as test subjects. A fatigue protocol was designed to induce a state of fatigue in the participants after exercise. The results of the experiment revealed a significant reduction in the angular displacement of the hip and knee joints of the lower extremities in the fatigue state. Additionally, the quality of ball contact and leg swing speed were significantly reduced, which ultimately led to a decrease in ball speed during shooting. These findings suggest that the fatigue state has a detrimental effect on soccer players' shooting movements.

In this paper, the Mediapipe image recognition tool was used to collect movement data during the shooting movements of participants. This approach was found to be more efficient, accurate, and cost-effective than traditional testing methods. As such, the Mediapipe image recognition tool holds significant potential for application in kinematics research related to sports movements.

This study provides a comprehensive understanding of the mechanisms underlying the impact of exercise-induced fatigue on soccer players' performance during matches. In the future, more artificial intelligence algorithms in the field of image recognition can be introduced to assist the research, such as predicting the time when the athlete enters the fatigue state, predicting the probability of successful goal shooting in the current state of the soccer player, etc. Using this information, coaches can further understand the physical condition or movement deficiencies of soccer players, determine the best time for a soccer player's substitution to keep the soccer player competitive in the game, or help practitioners develop appropriate strength training and fitness training for soccer players to improve their performance.

The results of this study further demonstrate that the proposed method is applicable to research in other sports domains. For instance, it can be employed in basketball to analyze shooting mechanics or in dance-related sports such as figure skating and gymnastics to assess athletes' landing techniques. Utilizing this method in such investigations has the potential to enhance athletic performance across various disciplines while simultaneously reducing the likelihood of injuries.

**Ethical approval:** Not applicable.

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

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