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Effect of Lower Extrmity Muscle Fatigue on the Kinematic Parameters of Change of Direction Movement in Amateur Football Athletes

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Abstract

Muscle fatigue is known to affect movement patterns and increase the risk of knee injury, especially during change of direction (COD) tasks. This study aims to analyze changes in lower-extremity kinematics and physiological responses due to fatigue. The study used a quasi-experimental pre–post design was used to evaluate the effects of induced fatigue on joint mechanics and metabolic responses. A total of ten participants underwent the Functional Agility Short-Term Fatigue Protocol and carried out COD tests before and after fatigue. Lactate levels were measured as an indicator of fatigue, while joint kinematics were assessed using SkillSpector and Kinovea. Results showed a significant increase in lactate levels from 3.02 ± 0.79 mmol/L to 13.78 ± 3.89 mmol/L ($p = 0.000$), confirming the presence of physiological fatigue. Fatigue induced notable kinematic alterations, including reduced hip abduction and hip adduction, as well as a substantial increase in knee valgus from 14.90 ± 7.549° to 32.60 ± 6.022° ($p < 0.001$), indicating greater medial knee deviation. In the sagittal plane, increases in hip flexion, knee flexion, and ankle dorsiflexion reflected compensatory postural strategies. Overall, muscle fatigue disrupts movement stability and increases mechanical knee loading, thereby elevating the risk of ACL injury during directional changes.

How to Cite

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INTRODUCTION

Football is a complex and dynamic sport that combines aerobic and anaerobic energy systems, with high physical demands such as sprinting, acceleration, and sudden change of direction (COD) (Alves Ferreira & da Silva, 2019). At a competitive level, players operate at high intensity and frequently perform repetitive COD, which can increase neuromuscular load as well as the risk of injury, especially in amateur athletes with more limited recovery capacity (Dos›Santos et al., 2021; Harper & Kiely, 2018) The condition has significant implications for joint health, particularly the knee, which is prone to injury when faced with excessive biomechanical load.

Knee injuries in football players often occur when performing dynamic movements such as rapid COD, sudden deceleration, or unstable landing, which strain the knee structure. Video analysis shows that about 88% of knee injuries occur without direct contact, especially during a change of direction or landing (Della Villa et al., 2020). These findings are in line with reports that ±70% of knee injuries are from non-contact mechanisms, particularly during COD maneuvers, where fatigue in the muscles of the lower extremities can decrease neuromuscular control and increase the risk of injury (Alimoradi et al., 2024). The mechanism is influenced by decreased neuromuscular control and changes in movement patterns (kinematics) due to accumulated fatigue, with decreased braking time and impulse when performing COD after a tired state (Pablo et al., 2024). In this context, COD is a component of the game that demands optimal joint stability. Fatigue has been shown to affect movement kinematics, including decreased hip and knee flexion and increased knee valgus moment, which biomechanically increases the risk of non-contact ACL injury (Zago et al., 2021). In addition, fatigue of the lower extremity muscles can also reduce neuromuscular control during COD, especially in unexpected situations, thus increasing the risk of knee injury (Alimoradi et al., 2024)

Some Kinematics is a branch of biomechanical science that studies body movements without considering the force of the cause, covering aspects of the position, speed, and acceleration of body segments or joints during an activity (Weiner, 2023). In football, kinematics analysis is important for understanding complex movements such as rapid change of direction (COD) and the influence of lower extremity muscle fatigue. Kinematic changes, such as decreased knee flexion and increased knee valgus moment, have been shown to increase the load on the anterior cruciate ligament (ACL) and the risk of non-contact injury, especially when athletes experience fatigue due to rapid changes in direction (COD) (Donelon et al., 2024; Zago et al., 2021). Biomechanical parameters such as joint angle, angular velocity, and ground contact period are important indicators to assess the impact of fatigue on the implementation of COD, as analyzed in the study joint and step kinematics previously (Falch et al., 2020). However, most of the studies focused on elite athletes, so there is still a gap in the literature regarding the effect of fatigue on the kinematics of COD in amateur athletes with different fitness and techniques.

Based on this, this study was conducted to analyze the effect of lower extremity muscle fatigue on kinematic changes in COD movement in amateur football players, especially related to knee valgus deviation and potential risk of non-contact knee injury. The novelty of this study lies in the integrated analysis of frontal- and sagittal-plane kinematics combined with physiological verification through lactate measurements to examine fatigue-induced alterations in COD movement patterns an approach rarely addressed in previous biomechanical research. This provides new insight into mechanisms underlying increased knee valgus and ACL injury risk in amateur athletes, a population that remains underrepresented in existing literature. This study aims to provide a relevant biomechanical understanding as the basis for the development of injury prevention strategies in the amateur athlete population.

METHOD

This study used a quasi-experimental design to evaluate the effect of lower extremity muscle fatigue on the kinematics of change of direction (COD) movements in amateur football players. A total of ten participants met the inclusion criteria and participated in all stages of the research. The instruments used include SkillSpector for 2D kinematics analysis, Kinovea for knee valgus angle measurement, and capillary lactate measuring device to determine physiological fatigue levels.

The research procedure begins with an initial lactate level examination, familiarization stage, and standard warm-up. Participants conducted a COD pre-test, then underwent a fatigue protocol using Functional Agility Short-Term Fatigue Protocol (FAST-FP) designed to produce neuromuscular fatigue through a functional range of movements resembling the demands of a game (Cortes et al., 2012). A set consists of countermovement jumps (10 times), Lateral Bounds (10 times), Drop Jumps from a box 30–40 cm (10 times) high, and Unanticipated Sidestep/Cut (10 times). Participants complete three sets of maximum intensity and a 10–15 second gap between sets. The fatigue condition was confirmed through blood lactate measurements, and participants were declared to have achieved fatigue if lactate ≥ 8 mmol/L as an indicator Metabolic fatigue (Beneke et al., 2011; Goodwin et al., 2007). After achieving fatigue, participants carried out a COD post-test.

The research procedure began with a 10-minute warm-up, followed by pre-fatigue measurements. Participants then underwent fatigue protocols until they achieved an increase in lactate according to the fatigue category. Afterwards, participants performed a reactive COD test, in which a change of direction was made based on a random stimulus to simulate the demands of the game. Movements are recorded and analyzed using predefined software, and lactate levels are measured again after activity.

All movements were recorded at a frequency of 50–120 fps and analyzed using SkillSpector and Kinovea to obtain joint angle values. Statistical analysis used the Paired Sample t-test with a significance level of $p < 0.05$ to compare pre and post fatigue values, according to the previous biomechanics research approach.

Figure1. Change of Direction Movement.

RESULTS AND DISCUSSION

Based on the **Table 1** of the characteristics of the research subjects, it is known that the participants consisted of ten amateur football players with an age range of 19–20 years and an average age of 19.3 years. The average height of the players is 168 cm, with an average body mass of 64 kg, and a BMI value of around 24 kg/m² which is included in the normal category to close to the ideal weight according to WHO standards. Standard deviations in the variables of age (0.46), height (6.4 cm), and body mass (4.1 kg) showed relatively small variation between individuals, indicating that the physical condition of the players was quite homogeneous. Overall, these findings illustrate that the research sample has uniform and adequate physical proportions, thus supporting a more accurate and representative biomechanical analysis of change of direction / COD movements.

Table 1. Sample characteristics (Age, height, body mass, and BMI)

N	Mean ± Elementary School Age (thh)	Red ± SD Height (cm)	Red ± SD Body Mass (kg)	Red ± SD BMI (kg/m2)
10	19.3 ± 0.46	168 ± 6.4	64 ±4.1	24 ± 0

Table 2. Blood Lactate Response to Pre- and Post-Fatigue Testing Using the FAST-FP Protocol.

Subject	Pre Lacate (mmol/L)	Post Lactate (mmol/L)	Sig.	Information
Mean	3,02	13,78	0.000*	Significant
Std.D	0,79	3,89		

Based on the **Table 2** of lactic acid level measurement results, it can be seen that the values before activity (Lactic 1) and after activity (Lactic 2) in the ten samples show a clear difference. The average initial lactate level was recorded at 3.02 mmol/L with a standard deviation of 0.79, while after carrying out the protocol activity, fatigue increased sharply to 13.78 mmol/L with a standard deviation of 3.89. The increase illustrates the occurrence of a considerable lactate buildup in response to high-intensity activity, indicating the dominance of the work of anaerobic energy systems during the implementation of the technique. High lactate levels after activity also indicate the appearance of muscle fatigue as a result of increased work demands on the leg muscles and upper body to make sudden movements and changes of direction. Overall, this suggests that the change of direction activity triggers an increase in anaerobic metabolism and results in physiological changes that describe the high muscle workload in the sample.

The increase in lactic acid levels from pre-fatigue to post-fatigue conditions in this study showed a strong metabolic response to high-intensity activity. The lactate spike reflects a shift in the dominance of the energy system from the aerobic to the anaerobic pathway, a condition that usually occurs when work intensity exceeds the oxidative capacity of the muscles (Ferguson et al., 2018). Large amounts of lactate accumulation are also the main indicators of the occurrence of lactate Metabolic fatigue, which marks a decrease in the muscle's ability to maintain repetitive power production (Hargreaves & Spriet, 2021). Furthermore, some recent findings suggest that lactate levels of ≥8 mmol/L are closely related to decreased neuromuscular function as well as the appearance of changes in movement patterns that can increase the risk of injury in explosive activities such as change of direction (Brooks, 2020).

Table 3. Pre- and Post-Fatigue Alterations in Lower-Limb Joint Kinematics on the (Frontal Plane During COD Task).

Variable analysis	Before Fatigue Means ± SD	After Fatigue Mean ± SD	Sig.	Information
Hip Abduction (degree)	10.79 ± 20.99	-7.35 ± 18.47	0.012*	Significant
Knee Valgus (degree)	14.90 ± 7,549	32.60 ± 6.022	0.000*	Sigmificant
Hip Adduction (degree)	23.10 ± 34.64	11.15 ± 33.07	0.021*	Significant

Table 3 shows that all kinematic variables in the frontal plane experienced a significant decrease in angle after fatigue, which illustrates the weakening of lateral control during a change of direction. The value of hip abduction before fatigue was recorded at 10.79° and decreased drastically to –7.35° after fatigue, indicating a fairly pronounced decrease in pelvic stability. The knee valgus experienced a significant increase from 14.90° to 33.80°, after fatigue, while the hip adduction decreased from 23.10° to 11.15°. A decrease in all of these variables indicates that lower extremity muscle fatigue makes it more difficult for athletes to maintain lateral balance, which is an important aspect of the ability to change of direction.

Significant changes in the angle of hip abduction, knee valgus, and hip adduction after fatigue showed a decrease in the lateral control ability of the lower extremities during movement change of direction. This is in line with research that states that fatigue can weaken the activation of the pelvic muscles, especially the gluteus medius, which has an important role in maintaining the stability of motion control in the frontal plane (Hollman et al., 2009). The decrease in pelvic control also increases knee valgus, a movement pattern that has long been identified as a risk mechanism for non-contact ACL injuries when neuromuscular capacity decreases due to fatigue (Benjaminse et al., 2019). In addition, other research suggests that fatigue can affect landing quality and increase the frontal deviation of the lower extremities, including the knee valgus, thus contributing to an increased risk of knee injury in rapid movements such as changes in direction (Borotikar et al., 2008) . Overall, these findings confirm that lower extremity muscle fatigue contributes significantly to decreased frontal stability and increased biomechanical risk of injury to explosive activities.

Table 4. Pre- and Post-Fatigue Alterations in Lower-Limb Joint Kinematics on the (Sagittal Plane During COD Task).

Variable analysis	Before Fatigue Means ± SD	After Fatigue Mean ± SD	Sig.	Information
Hip Flexion (degree)	4.32 ± 17.87	27.04 ± 20.90	0.017*	Significant
Knee Flexion (degree)	31.5 ± 31.11	35.98 ± 22.99	0.033*	Significant
Ankle Dorsiflexion (degree)	5.92 ± 17.67	15.27 ± 19.05	0.028*	Significant

Table 4 shows that all kinematic variables in the sagittal plane actually experienced an increase in angle after fatigue, which indicates that there is movement compensation due to a decrease in the ability of the lower extremity muscle. Hip flexion increased from 16.32° to 27.04°, knee flexion from 31.50° to 35.98°, and ankle dorsiflexion from 5.92° to 15.27°. The increased angle in these three joints indicates that when the muscles are fatigued, athletes tend to increase flexion in the hips, knees, and ankles to maintain stability and reduce the risk of losing balance during directional changes. These findings reinforce that lower extremity muscle fatigue significantly affects movement strategies in the sagittal plane in the context of change of direction.

Increased hip flexion angle, knee flexion, and ankle dorsiflexion after fatigue illustrate the biomechanical compensation strategies the body uses to maintain dynamic stability during movement change of direction. A number of studies show that after a high-intensity training or fatigue training protocol, athletes tend to land with greater hip, knee, and ankle flexion, accompanied by decreased quadriceps activation in an effort to lower the center of mass and improve postural control in the support phase (Alanazi et al., 2021). This more "soft" landing pattern also serves to increase force absorption ability and reduce axial load on the knee joint, although fatigue decreases the muscle's capacity to generate force and stabilize the joint (Brazen et al., 2010). In addition, fatigue was shown to increase the speed of hip and knee flexion during landing, reflecting changes in neuromuscular control strategies to manage impact forces and maintain motion stability (Tamura et al., 2017). Thus, this kinematic change in the sagittal plane can be understood as a compensation mechanism for the body to maintain dynamic stability when muscle capacity decreases due to fatigue.

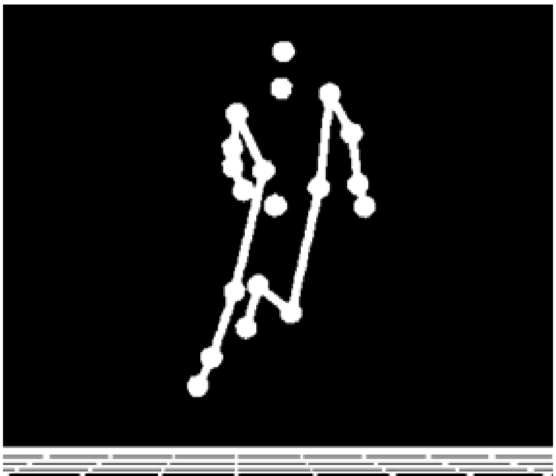

Figure 2. Change of Direction Movement in Skillspektor.

CONCLUSION

This study shows that fatigue has a real influence on the physiological response and movement patterns of athletes when changing direction. Muscle fatigue has been shown to decrease the quality of motion control and stability of the lower extremities, which can be seen from changes in joint angles in the hips, knees, and ankles. One of the most important changes is the increased inward deviation of the knee, which is a biomechanical indicator that is closely related to an increased risk of Anterior Cruciate Ligament (ACL) injury. Overall, the results of this study confirm that the fatig condition can interfere with the stabilization mechanism of the knee and increase susceptibility to ACL injury during directional change movements.

For further research, it is recommended to conduct a multi-session or longitudinal analysis to see how motion adaptation develops over time. The addition of Electromyography (EMG) examination and Ground Reaction Force (GRF) kinetic analysis will provide a more comprehensive understanding of neuromuscular mechanisms during fatigue. In addition, the use of a larger sample and the variation in athletes' ability level will increase the generalization of the study's findings.

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