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Article

Biomechanical analysis of martial arts movements: Implications for performance and injury prevention

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Abstract: Martial arts have their origins in a variety of cultural traditions that represent a wide range of combat practices and disciplines. Martial arts encompass a variety of practices, extending from ancient traditions such as kung fu and karate to more modern forms like Brazilian jiu-jitsu. The martial arts practitioners engage in the cultivation of self-defense techniques, the enhancement of physical fitness, and the demonstration of profound concepts that transcend the boundaries of the physical domain. Ensuring the safety and efficacy of practitioners is achieved by comprehensive training, increased awareness, devotion to proper techniques, and maintenance of physical fitness. In this study, we gathered primary data from 75 skilled football players with varied training provided for comprehensive football kicking analysis. The research employed the VICON MX40, a three-dimensional (3D) motion-capture system with nine cameras. The system recorded motion at a rate of 200 frames per second. The study aimed to examine the 3D movements observed in adolescent sports through the construction of biomechanical models. This analysis enabled the identification of many risk variables associated with repetitive stress injuries (RSIs). We propose preventative strategies for reducing injuries caused by RSI among young individuals. These strategies encompass specific stretching exercises, dynamic warm-up routines, the restriction of intense movements, and the promotion of sufficient recovery periods. The utilization of biomechanical modeling plays a significant part in the prediction and optimization of strategies designed for minimizing the various elements that contribute to muscular RSIs throughout the process of motor skill acquisition and training.

Keywords: martial arts; biomechanical analysis; injury prevention; fan kick (FK); axe kick (AK); football kicking

1. Introduction

Martial arts are becoming a well-liked sport all around the world. Athletes' professionalism and technical proficiency are increasing annually, making competitions more intense and stunning [1]. In addition to helping with self-defense, martial arts can assist with mental and physical health. The powers of technology are expanding the understanding of some martial arts, which date back hundreds or even thousands of years [2]. Martial arts have a lengthy history and a rich, deep culture that embodies the spirit of ancient China. However, martial arts are synonymous with traditional Chinese culture [3]. Various types of martial arts are mentioned in **Figure 1**. The fundamental nature of martial arts includes not only the acquisition of combat skills but also the development of self-discipline, respect, and a natural equilibrium between the mental as well as physical aspects. Practitioners involve intensive training to improve their athletic ability, agility, and cognitive transparency while aiming to embrace the qualities of respect and integrity that are fundamental to the concept of martial arts [4]. Achieving a high standard of performance in martial

arts usually involves the potential for injury to one's body. Injury prevention is an essential component of any practitioner's journey due to the physically taxing and dynamic nature of these practices [5]. Understanding the basic principles of injury prevention is critical for skilled martial artists and beginners embarking on their first steps on the dojo floor.

Figure 1. Different styles and techniques of martial arts [6].

Practitioners should prioritize the incorporation of practices that ensure their well-being alongside the perfection of techniques when aiming for physical mastery [7]. The foundation of injury prevention in martial arts is in the acquisition of a complete comprehension of the body mechanics associated with diverse motions [8]. The process entails recognizing the physiological pressure that certain procedures exert on joints, muscles, and ligaments. The use of appropriate warm-up protocols, stretching regimens, and conditioning activities has significant importance in priming the body for the physiological challenges associated with training [9]. Furthermore, it is important to prioritize the development of a robust and resilient physique through focused strength training, so enhancing the body's capacity to withstand and reduce the effects of external forces, thereby reducing the probability of sustaining injuries.

Practitioners must recognize the significance of rest and recovery that are attuned to their bodies. An elevated risk of injury, fatigue, and impaired concentration are the consequences of overtraining [10]. Rest days are included in a training schedule where the body finds adequate time to recover itself. This forms the essence of long-term survival in any form of martial art. Integrating a wide health plan where there is wholesome nutrition and intake of water takes an essential dimension in injury control since overall welfare improves [11]. Injury control cuts across various domains such as physical, psychical, or even emotional ends. Mindfulness practices, including meditation and stress management techniques, are essential in preserving attention and emotional stability throughout training sessions, hence minimizing the probability of injuries arising from instances of diminished concentration [12]. Through the cultivation of a balanced and comprehensive methodology, practitioners of martial arts enhance their physical well-being and cultivate their mental faculties to establish a durable basis for a lifetime effort to achieve personal growth with proficiency in martial arts.

To protect practitioners, the biomechanical analysis of injury prevention examines the complex mechanics of movement, integrating principles from physics and physiology. Through a critical examination of the stresses and forces applied to the body during martial arts techniques, the field attempts to improve training methodologies [13]. A comprehension of biomechanics enables the development of individualized approaches to injury prevention, with a focus on conditioning, strength training, and optimal technique. The implementation of the scientific methodology promotes the development of more secure martial arts techniques and enhances the durability as well as the welfare of practitioners as they aim for excellence. This research aims to analyze the biomechanics of martial arts motions to provide insights to improve performance optimization strategies and effective injury prevention measures for participants.

Study contributions

- Primary data is collected from 75 skilled football players with varying training for an investigation including football kicking and AK, FK biomechanics.
- The VICON MX40, an effective 3D motion-capture system with nine cameras that record at 200 frames per second, is utilized for this research.
- Creates biomechanical models to investigate 3D movements in martial arts movements, identifying several risk factors for RSIs.
- We used biomechanical analysis to identify risk factors that contribute to RSIs, improving knowledge and preventive tactics for athletes in martial arts activities.
- We analyze particular actions to prevent RSIs in young athletes, such as dynamic warm-ups, movement limits, focused stretches, and adequate recovery times.

The subsequent sections of this research are classified into multiple segments. Section 2 presents a comprehensive overview of the literature review conducted on the biomechanical study of martial arts movements and its implications for injury prevention. Section 3 provides a comprehensive overview of the research technique

utilized in this study. The outcomes derived from the research are explained in section 4. Section 5 comprises the conclusion of the study.

2. Related works

2.1. Biomechanical analysis of martial arts

Kozin et al. [14] elucidated the combat techniques employed by combat sambo players through a comprehensive investigation of psychophysiological and biomechanical variables. The research methodology employed in the study involved conducting a biomechanical evaluation to examine the velocity of movement at different places and the angular values of joints during a direct impact. The velocity of motion of the fist, "shoulder joint, elbow joint, and knee joint" was established. The measurements of angles formed among the shoulder and thorax, between the shoulders, and forearms, among the inner thigh and lower leg were measured. The utilization of the study findings was recommended to design personalized training programs for combat sambo players, as well as for establishing the most effective approach to organizing competitive matches for skilled sportsmen. To determine the most important kinematic elements for successful performance, Gavagan and Sayers [15] compared the roundhouse kicking kinematics of elite Muay Thai, Karate, and Taekwondo practitioners. Karate and Taekwondo practitioners exhibited higher knee extension velocities, whereas Muay Thai practitioners had shorter execution times and a stronger vertical center of mass movement, according to the results. Impact force and foot velocity were shown to be moderately correlated. The small number of participants (n = 8 per group) could have an impact on generalizability. Overall, quick hip and knee velocities, center of weight shifting toward the target, and pelvic rotation were characteristics of successful roundhouse kicking. Miu et al. [16] conducted a comparison study designed to enhance the effectiveness of "Krav-Maga and Karate-Do martial arts" methods. The study improved upon the findings of earlier research conducted by the researchers and published in prior publications. To validate those hypotheses, three distinct methods from two martial arts were examined, with seven repetitions performed for every approach. The finding generated by the study has validated the initial premise, indicating a higher level of effectiveness in the procedures under investigation. Irawan et al. [17] conducted a biomechanical analysis of the sidekick technique in Pencak Silat, with a special focus on how it was utilized in the framework of "Persinas Aliansi Serikat Anak Bangsa Dharma (ASAD)". Statistics techniques were utilized to collect data on sidekick motions, focusing on a sample of 30 martial arts players that were associated with Persinas ASAD. The data collection process involved capturing videos. The individuals involved in this study, whose mean age was 15.37 ± 1.45 years, performed side kick movements characterized by three discernible stages: the horse posture, take-off, and impact. The analysis indicated that the participants demonstrated proper tactics throughout those times. The study contributed significant contributions by examining the biomechanical intricacies of the Pencak Silat sidekick in the specific martial arts framework of Persinas ASAD. Qiao and Dong [18] employed image segmentation innovation to analyze the biomechanical properties of whirling legs and backflips performed by participants in martial arts

routines. The 720-degree cyclone foot was 4 cm taller in the air than the 540-degree version, with a flying height of 0.47 ± 0.11 m. Therefore, watching where you placed your right foot was essential. The backflip required exceptional synchronization between the two legs and the remainder of the body. A higher body angle can be achieved with efficient braking with the right foot. Upon elevation from the substrate and subsequent arrival, it was seen that the outflow of the "tibialis anterior muscle exceeded that of the gastrocnemius muscle," hence contributing to the preservation of stability between the pivotal points. It was imperative to allow the non-supporting leg to come down first to reach the objective of executing an easy land.

Dal Bello et al. [19] examined and validated the variables related to gender in fighting phases, methods, and biomechanical mechanisms employed in judo bouts, as well as the probability of favorable outcomes in those matches. The researchers conducted an evaluation of elite judo competitors from various weight divisions who had qualified for the Olympic Games. The findings of the study revealed significant disparities in pause frequencies and approach with displacements between males and females. In the realm of athletic performance, it has been shown that female athletes tend to employ approaches characterized by higher frequencies of biomechanical levers for executing assaults. The results of the regression analysis indicated a positive association between the utilization of "Osae-waza, Variable/medium length" performed and accomplished, Arm/foot lever, minimal lever attempted, and female performance probability. The biomechanical factors involved in the effective execution of roundhouse kicks by Taekwondo participants were analyzed by Miziara et al. [20] to examine the key elements of outstanding durability kicks and provide guidance to instructors in designing targeted training programs. A total of eight Taekwondo practitioners were assessed while performing a sequence of kicks against a designated kicker. The data was acquired using a motion reconstructing technique and portable electromyography sensors. The factors were examined during the loading and kicking stages of the study. During the loading phase, the initiation of movements in the kicking stage was facilitated by the expansion of the knee and hip joints. The examination of both stages was crucial in facilitating the successful execution of an optimal kick.

2.2. Analysis of martial arts injury prevention

Myrick et al. [21] suggested that by including martial arts fall training, the participants' neuropathways would be conditioned to identify and prevent high-risk positions by having an alternate reaction. Due to a lack of studies including martial arts falling methods in other sports, the investigation evaluated the biomechanics and risk variables in football players both before and after fall training. The five best football players were divided at random into two distinct categories. Biomechanical analysis of drop-fall hip and knee movements was performed both before and after intervention. The outcome was a substantial drop in knee bending in the sagittal direction at initial contact, as measured before and after the procedure. At 33 milliseconds after heel contact, sagittal bending of the knee was significantly reduced. Inspecting the other places of motion, they found no major shifts. Myrick et al. [22] assessed the self-identified occurrence of orofacial injuries, preventative

measures as well as information on the prevention along with the treatment of sport-related orofacial accidents among young athletes participating in Karate and Taekwondo. The study examined the variables associated with these aspects. A cohort of martial arts athletes from Iran, ranging in age from 11 to 17, participated in an online survey that encompassed many aspects. The scores were computed to assess the preventative practices and knowledge. The statistical study included "linear regression and Pearson correlation techniques." A total of 295 athletes were involved in the research, with 25.1% of them having undergone instruction in orofacial injury prevention. The utilization rate of bespoke mouthguards was found to be 3.7%. The mean preventive practice score was 3.53 ± 1.82, whereas the mean knowledge score was 1.67 ± 1.10.

Maotang et al. [23] examined how joint injuries in martial arts have recently occurred and offered solutions for preventing these moving forward. Participants from different martial arts were studied to determine which joint ailments were most common and how effectively to treat them through training. The contributors were assigned to either the experiment or the control group. Modern investigations influenced the functional preventative training program implemented with the "experimental group, whereas the control group" participated in more conventional forms of exercise. Before following the treatments, participants were given "range of motion (ROM) and Functional Movement Screen (FMS)" assessments. Statistical analysis was used to compare the outcomes. Joint injuries were the most prevalent ailment among martial artists, followed by ligament and synovial inflammation. Athletes' FMS test results improved in the experimental group and the risk of joint damage increased when they engaged in continuous action training. Wauters [24] examined the potential occurrence of risk compensatory behavior in the context of "Historical European Martial Arts (HEMA)" by investigating the effects of wearing increased protective equipment. A total of 30 fencers, organized into 15 duos, participated in two distinct combat scenarios. In the first scenario, the fencers wore a comprehensive ensemble of protective gear, while in the second scenario, they wore a modest amount of safety clothing. The fencers engaged in two rounds of combat against a partner of similar age and experience in both venues. Following the fencing fight, a series of questionnaires were administered to investigate risk compensatory behavior. The occurrence of risk compensatory behavior has been observed in the context of HEMA. Makers of protective equipment as well as contest management needed to consider the behavior while designing and implementing safeguards.

Von Gerhardt et al. [25] methodically designed an injury-protection strategy and evaluated its viability. "Injury Prevention and Performance Optimization Netherlands (IPPON)" were the initials of the initiative. The investigators employed the five-step "Knowledge Transfer Scheme (KTS)" characteristics. The initial two stages of the study were an examination of the prevailing injury issue in the realm of judo, followed by an exploration of potential strategies intended for reducing the incidence of such injuries. The "Knowledge Transfer Group (KTG)" proceeded to operationalize the acquired knowledge by implementing it into practical applications in the context of judo training. The emergence of a need for prevention has been prompted by the high rates of injury observed in judo. The strategy emphasizes the shoulder, knee, and ankle regions, employing dynamic exercises as a means of

prevention. Fares et al. [26] examined the arrangements and trends of head grievances in the context of Mixed Martial Arts (MMA). The reports of ringside physicians on the "Ultimate Fighting Championship (UFC)" matches were analyzed. The data were obtained from the database of the "Nevada State Athletic Commission (NSAC)". In addition, a comprehensive study of the video footage was performed, focusing on a detailed play-by-play examination. During the investigation, a total of 288 incidents of head injuries were documented in 408 instances of physical altercations, resulting in a head injury rate of 35 per 100 athletic exposures. The incidence of head injuries was shown to be higher among males compared to females. It was observed that Technical Knockout finishes exhibited a greater prevalence of head injuries in comparison to decision outcomes. The incidence of head injuries demonstrated a positive correlation with increasing weight divisions.

Patenteu et al. [27] examined the extent to which "A-trait (in physically dangerous environments and unfamiliar situations) and R-TB (instrumental and stimulating risk)" levels in athletes could predict the severity of injuries. The study involved the participation of 154 professional martial arts participants, encompassing individuals from grappling combat activities, striking combat activities, and MMA. The outcome of the multivariate analysis of modification indicated substantial discrepancies in A-trait and R-TB scores across various sports disciplines between participants. The study investigated the associations between the severity of injuries and psychological characteristics among participants involved in striking, grappling, and MMA. Furthermore, the statistical methods employed in the study included t-tests and binomial logistic regression for determining the probability of injury occurrence. Those analyses were conducted using the variables of reaction time bias (R-TB) and trait anxiety (A-trait) as predictors. Son and Cho [28] determined the frequency and attributes of injuries associated with Taekwondo, considering age, gender, and kind of occurrence. That was accomplished by utilizing a "web-based injury surveillance system (ISS)" and conducting a time length of 12 months. A collective number of 285 individuals from the Korea Association conducted part. Throughout the season, a total of 336 injuries were officially documented, leading to an injury rate of 6.31 per 1000 athletic exposures (AEs). The incidence rates of injuries related to the practice and competition of Taekwondo were found to be "4.79 per $1000\ AEs$ and 24.86 per $1000\ AEs$," respectively. The injury rate ratios (RRs) about practice and competition demonstrated greater values in juvenile athletes compared to adult participants. It was shown that adult athletes exhibited a higher propensity for experiencing injuries of a more severe variety. The furtherance of the ISS prompted the exploration of strategies intended for reducing the occurrence of injuries experienced by practitioners.

2.3. Biomechanical for injury prevention in martial arts

Nakanishi et al. [29] analyzed the biomechanical processes of the major neck injuries that judo practitioners sometimes sustain to develop a basis for the first diagnosis and for recommending preventative strategies. Two men judo professionals dropped an anthropomorphic test apparatus employing three tossing strategies. They employed a high-speed digital camera to record the dummy's

kinematic data and load cells to quantify the dummy's neck load and moment. Both the beam criteria and the neck injury criterion (Nij) were determined. The tatami (judo mat) has been touched by the dummy's head in the anterior and parietal areas during the Seoi-nage technique. A biomechanical study of throwing methods in judo was performed to better understand and stop major neck injuries. In comparison to Ouchi-gari and Osoto-gari, Seoi-nage was associated with a greater risk (34.7%–37.1%) of head-ground collision and neck compression. Boroushak et al. [30] examined the biomechanical factors associated with head injury in the context of taekwondo focusing on the simulated impact resulting from a roundhouse kick. A study of 15 male professional taekwondo athletes participated. In determining the head injury process, a head with an artificial neck was used, incorporating a device consisting of a neck and a head attached to a series of force and acceleration sensors along with an automatic arm which made impact deliveries against the head. For calculations, recording, and observing data acquired from experiments, the researchers made use of a personal computer custom-, especially with a recorder package. The data evaluation used a one-sample t-test that was set against a predetermined level of significance. The findings indicated that the linear acceleration resulting from the execution of a roundhouse kick was found to be below the established threshold for head injury in the context of studying the processes of head injury in taekwondo.

Yu [31] investigated how proprioceptive exercise of the ankle joints could assist martial artists in avoiding ankle injuries. The paper examined the mechanisms and causes of those injuries before offering some solutions for treating them. In the investigational section of the paper, sixteen martial arts sportsmen served as subjects and were assigned to one of four groups: two groups of men, two groups of women, and two control groups. Ankle proprioceptive stimulation was shown to enhance martial artists' dynamic and static balance to reduce the risk of ankle injury in a controlled trial. In the publication, researchers evaluated participants' capacity to maintain dynamic balance in the biped standing position while blindfolding and measured the losses of stability index in both the forward and backward directions. Calderón-Díaz et al. [32] conducted a biomechanical analysis to find biomarkers of muscle damage in experienced soccer athletes. They employed several machine learning techniques, including Ensemble methods, Boosted and bagged trees, Naive Bayes, K-nearest neighbor (KNN), Artificial Neural Networks (ANN), Support vector machine (SVM), as well as XGBoost. The research found that maximal hamstring muscle strength and stiffness are significant factors that differentiate groups and have predictive capabilities for injuries. The XGBoost algorithm demonstrated an accuracy rate of 78% while analyzing a total of 35 strategies. The outcome served to underscore the need for incorporating scientific information and expert input to obtain dependable findings for injury avoidance in sports.

3. Methodology

3.1. Data acquisition

This research, collected primary data from a sample of 75 proficient players for football kicking analysis. The data's primary nature guarantees its accuracy and

usefulness while providing insights into the biomechanics and performance of the athletes. The sample group consisted of a varied group comprising a proportionate mix of male and female athletes from university varsity football programs, encompassing individuals aged between 18 and 30 years. Notably, the participants demonstrated a range of football training experiences, which ranged from 8 to 12 years. The use of this complete technique ensures an advanced understanding of kicking abilities and enables the conduct of intelligent research inside our investigation of expert football players. The collected dataset is mentioned in **Table 1**.

Table 1. Demographic and training information of soccer players by team.

Player	Gender	Age	Soccer Training (years)	Weight (kg)	Team Type
1	Male	20	10	68	Team A
2	Male	23	12	72	Team A
3	Female	20	8	60	Team B
4	Female	21	9	66	Team B
5	Female	22	11	63	Team B
6	Male	24	11	75	Team A
7	Male	19	9	70	Team A
8	Male	21	9	69	Team A
9	Female	25	12	64	Team B
10	Female	21	10	65	Team B
11	Male	20	8	67	Team A
12	Female	18	10	62	Team B
13	Female	22	11	61	Team B
14	Male	19	10	73	Team A
15	Male	23	12	71	Team A
…	…	…	…	…	…
75	Male	30	17	85	Team A

Source: By Author.

3.2. Biomechanical simulations and 3D recording of movement

The study utilized the VICON MX40, a technologically advanced nine-camera 3D motion-capture system, to achieve accurate and precise tracking. The experimental setup involved the attachment of 42 reflective markers, each with a diameter of 9 mm, onto the individuals. The system captured these markers at a frequency of 200 frames per second. The aforementioned technology, recognized for its high level of precision records delicate motions by arranging the markers on specific anatomical locations throughout the body, enabling comprehensive analysis of motion. Markers were placed at the key anatomical landmarks: hips, knees, and ankles, to break down the body into 15 segments, thereby completing the biomechanical model. The motion data was then processed to obtain a detailed skeletal model from which the joint angles, angular velocities, and accelerations could be computed. Muscle forces were also included in the model, based on inverse dynamics estimations. Results from the biomechanical model highlighted muscle

lengthening and shortening, joint kinematics, and patterns of dynamic movements. The detailed results from this model showed precise activation sequences by specific muscles within the football kicking technique, hence used to test efficiency and the biomechanics behind such a movement. The calibration residuals, by the VICON criteria, were able to maintain positioning precision with a tolerance of 1 mm. The process of biomechanical modeling involves the conversion of positional information into skeletal movement, hence enabling the characterization of joint kinematics and muscle activity patterns. The use of distances, velocities, and accelerations in this method has yielded comprehensive insights into the dynamic muscular lengthening, reducing, and movement patterns associated with the examined football kicking technique, so adding to an in-depth understanding of the subject matter.

3.3. Data gathering process

Participants engaged in appropriate warm-up activities to prepare themselves for the testing configuration, as determined by their readiness levels. Following the warm-up session, each participant executed their chosen skill three times, at a speed they specified to achieve an ideal state of individual control. The underdone 3D statistics were processed utilizing a five-point smoothing filter and are taken as the input to biomechanical computations through a 75-segment model. Utilization of Microsoft Excel (2019) supports executing descriptive statistical study approaches that take into account measures such as averages and standard deviation; thus, illustrating the inherent qualities of the skills. In this biomechanical study, an independent *t*-test was done to analyze any significant change in muscle lengthening between the fan kick and axe kick. This statistical analysis is necessary because it determines the injury risk.

3.4. Assessment of fan kick (FK) and axe kick (AK)

Effective martial arts techniques that exhibit strength, flexibility, and accuracy are FK and AK. A fan kick is characterized by a sweeping action of the leg in a semi-circular direction, similar to the opening of a fan. An axe kick, on the other hand, is a downward striking action that mimics the swing of an axe. Both kicks demand quickness and control, making them significant techniques in disciplines such as taekwondo and capoeira. The ability to master these kicks reveals a martial artist's ability to execute forceful and visually striking techniques. The selection of dancing and martial arts as subjects of study was motivated by their elevated incidence of injuries, notably in the lower arms and legs, which range from 65% to 85%.

Muscle strains have been found as a commonly occurring injury type in the dancer population, as evidenced by previous investigations. The excessive utilization of prolonged dancing postures, such as the fan kick, has the potential to lead to the occurrence of injuries. The present study investigates comparable body positions, such as the axe kick utilized in martial arts, through the utilization of three-dimensional motion capture technology and biomechanical modeling techniques.

This research conducted a quantitative analysis to examine the ROM and muscle dynamic lengthening features associated with two different kicking capabilities.

3.5. Assessment of football kicking

Football kicking is a fundamental talent that is critical to the sport's success. To control and guide the ball with accuracy, players use a variety of tactics like the instep drive or turning kick. The instep drive focuses on the laces for power and precision, whilst the swerve kick incorporates spin for surprising trajectories. Mastering these kicks requires a combination of strength, timing, and delicacy. Football kicking is a key component of players' strategic and scoring talents, whether it's a forceful goal attempt or an intelligent pass. The ROM and adaptive lengthening of muscles in the legs during the football kick process were examined using 3D movement capture and biomechanical simulation approaches. The objective of this study was to evaluate the efficacy of the biomechanical model in identifying susceptible muscles, hence facilitating the formulation of preventative measures for motor skill acquisition and training in youngster's sports.

3.6. Biomechanical comparison of martial arts and football kicking

The muscular requirements and movement patterns of football kicking and martial arts moves are examined in this research utilizing biomechanical models. Martial arts principles like strength, flexibility, and coordination are comparable to the intricate motion needed for a successful football kick. Both exercises are prone to RSIs because they require force application, joint rotation, and dynamic muscle activation. Common risk factors including excessive muscular usage, poor technique, and inadequate recuperation are identified by the investigation. For both disciplines, preventative measures including stretching and appropriate warm-ups are advised. The investigation highlights the significance of biomechanics in preventing injuries by considering these motions. The results are intended to maximize safety and performance in football and martial arts.

4. Results

4.1. Findings gathered from AK and FK

The modeling findings indicated that the relative leg locations of the AK and FK exhibit a significant degree of similarity, as displayed in **Figure 2**. The first action involves raising the active leg diagonally across the entire body until it reaches its highest point directly in front of the subject. The extended leg is swung outward and downward, away from the body. On the other hand, the second flexibility entails elevating the heel of the kicking foot, along with the extended leg, to its maximum height. Following this, the raised leg is lowered forcefully and directly. Obtained ROM values for Knee and Hip are mentioned in **Table 2**. Given the significant variation seen in the abilities of the kicking leg, this research deliberately concentrates on analyzing, comparing, and discussing the hip, knee, and main muscles associated with the regulation of those 2 joints. **Table 3** presents the speeds of muscle lengthening that occurs, focusing on the FK and AK muscles.

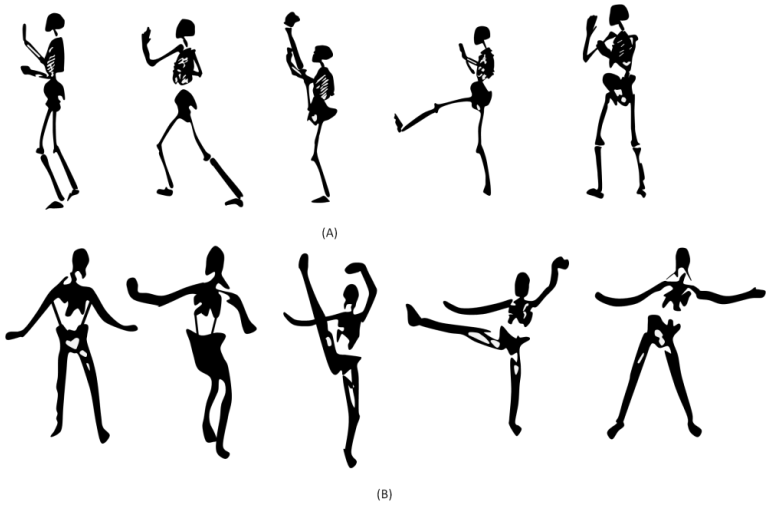

Figure 2. Detailed comparison of kinematic parameters in **(A)** AK and **(B)** FK dance movements.
Source: By Author.

Table 2. Joint ROM measurements for hip and knee in football kicking (FK) and athletic kicking (AK).

Joints	**ROM** (°)	
	FK	**AK**
Hip		
Abduction	89.8 ± 7.6	53.6 ± 8.1
Flexion	148.3 ± 8.6	164.4 ± 10.6
Rotation	56.1 ± 6.1	59.6 ± 7.3
Knee		
Abduction	29.4 ± 6.6	30.8 ± 6.1
Flexion	110.9 ± 8.3	67.3 ± 6.7
Rotation	29.2 ± 6.1	23.5 ± 6.3

Source: By Author.

Table 3. Analysis of muscle lengthening and speed in knee and hip muscles during football kicking.

Selected Muscles	**Maximum lengthening (%)**		**Muscle Lengthening speed (m/s)**	
	FK	**AK**	**FK**	**AK**
Knee				
Semimembranosus	131.3 ± 4.6	135.8 ± 6.3	0.52 ± 0.05	0.81 ± 0.09
Adductor magnus	199.7 ± 7.3	173.3 ± 4.9	0.42 ± 0.04	0.61 ± 0.06
Gracilis	136.9 ± 4.9	135.8 ± 5.6	0.15 ± 0.00	0.51 ± 0.08
Glutaeus medius	129.9 ± 6.0	118.3 ± 3.9	0.29 ± 0.04	0.31 ± 0.04
Hip				
Vastus lateralis	11.5 ± 6.5	105.6 ± 5.9	0.11 ± 0.00	0.22 ± 0.03
Rectus femoris	106.2 ± 6.1	107.9 ± 7.0	0.28 ± 0.04	0.52 ± 0.07
Biceps femoris	129.3 ± 7.2	134.0 ± 6.7	0.46 ± 0.05	0.71 ± 0.05

Source: By Author.

From the findings semi-membranosus and Adductor Magnus muscles demonstrate substantial elongation during both kicks. The FK kick results in a maximum lengthening of 131.3% ± 4.6% for the semi-membranosus and 199.7% ± 7.3% for the Adductor Magnus. The AK kick leads to a maximum lengthening of 135.8% ± 6.3% for the Semimembranosus and 173.3% ± 4.9% for the Adductor Magnus. The velocity of muscle elongation exhibits variability, with FK demonstrating comparatively reduced values in comparison to AK. As an example, it can be observed that the Adductor Magnus muscle exhibits a higher velocity in the adductor kinetic chain (0.61 ± 0.06 m/s) compared to the flexor kinetic chain (0.42 ± 0.04 m/s). The aforementioned studies offer valuable insights into the intricate muscle motions involved in FK and AK, which are of the greatest significance in comprehending and enhancing kicking techniques. **Figures 3** and **4** present an inquiry about the lengthening of specific muscles during the execution of axe kicks and fan kicks.

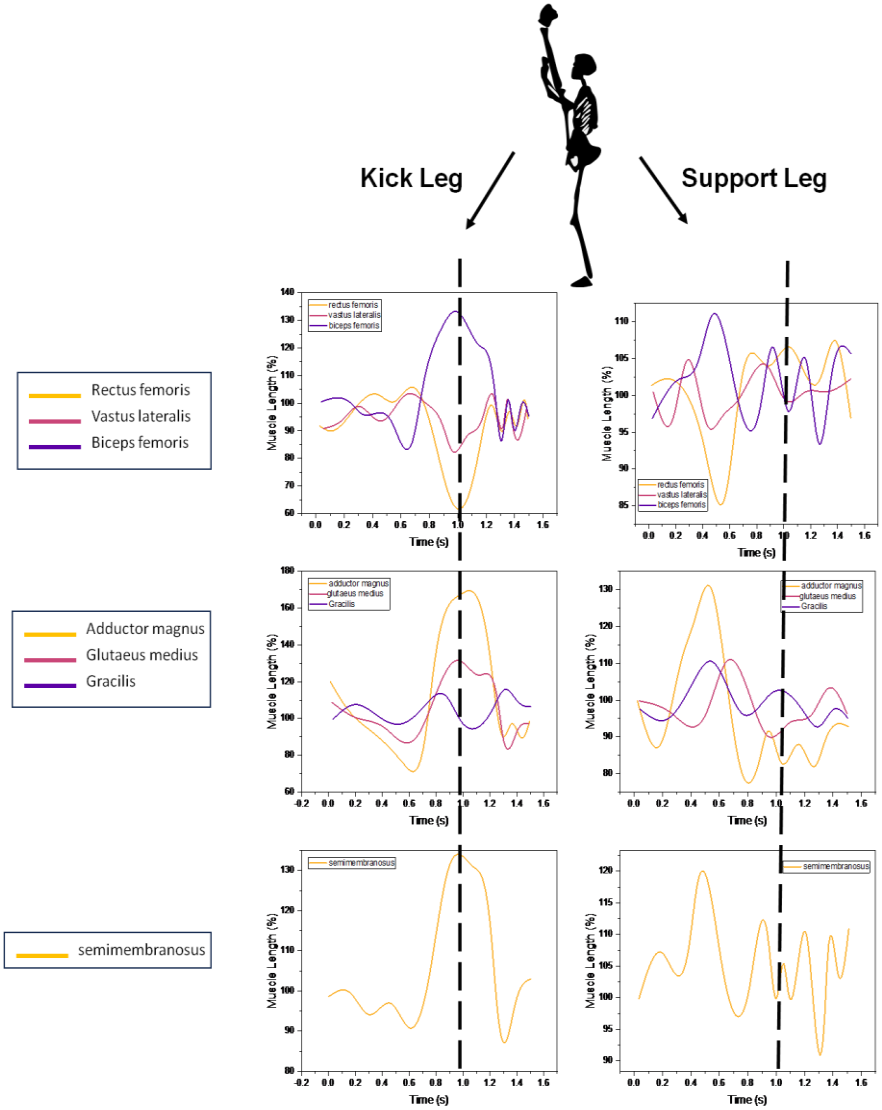

Figure 3. Muscle lengthening measurements in the anterior and posterior kicking muscles.

Source: By Author.

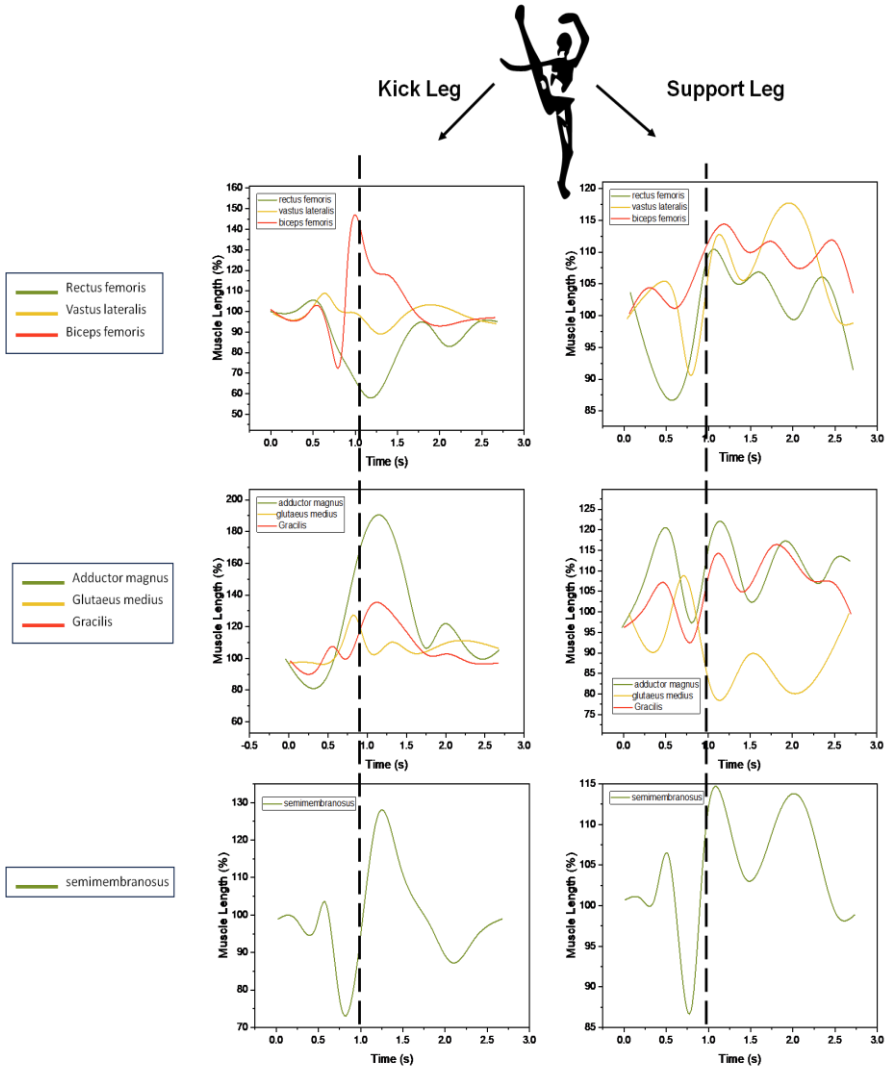

Figure 4. Graphical representation of muscle lengthening measurements in football kicking (FK).
Source: By Author.

The primary goal of the investigation is to compare the lengthening of muscles in a football kick while focusing on special techniques such as the axe kick and fan kick, using 3D motion capture technology and the methodologies of biomechanical simulation. The study findings indicated that there were significant similarities in the patterns of muscle lengthening, where the kicking leg showed a higher level of disproportion compared to the support leg. High velocity and intensity were observed for axe kicks, which ended up causing considerable overstretching of the muscles biceps femoris, adductor magnus, gracilis, and semi-membranosus. The experimental findings show that axe kicks have a higher value of muscle activation intensity and lower performance periods compared to FKs, implying that this style is more susceptible to injuries.

A study on dancers demonstrated the possible changes in training approaches, thus showing the need for tailored treatments that may reduce the risk of injuries. The findings recommend alterations to the choreography of dances, increased time between rehearsals for recovery, incorporation of strength exercises, adaptation of

the practice time, and proper nutritional practices. These adjustments are intended to cultivate a physique that is well-suited for the demands of dance, hence improving efficiency, and performance and mitigating the risk of injuries. It is strongly recommended that more studies should be conducted to corroborate these results and provide guidance for future practices in the realms of martial arts and dance instruction.

4.2. Biomechanical analysis of football kicking

This work illustrates the efficacy of employing 3D motion capture and biomechanical modeling techniques to elucidate discernible patterns of joint ROMs and lengthening of muscle features during the act of football kicking. The highest possible instep football kick biomechanical model is displayed in **Figure 5**. The research verifies the tension-arc problems observed in talented participants, highlighting the excessive extension of the hip on the kicking side, resulting in the elongation of certain muscles in both legs. The study primarily examined the ROM in hip and knee motions, focusing on seven muscles: hip flexors, extensors, adductors, abductors, and a 2-joint muscle that contributes to extending the bending of the knee and hip. **Table 4** provides the ROM findings (Knee and Hip). These results provided valuable insights into the possible dangers associated with young physical activity, hence contributing to the development of preventative interventions. **Table 5** presents the evaluation of the side muscles of the kicker, revealing noteworthy increases in length measurements for important muscle groups.

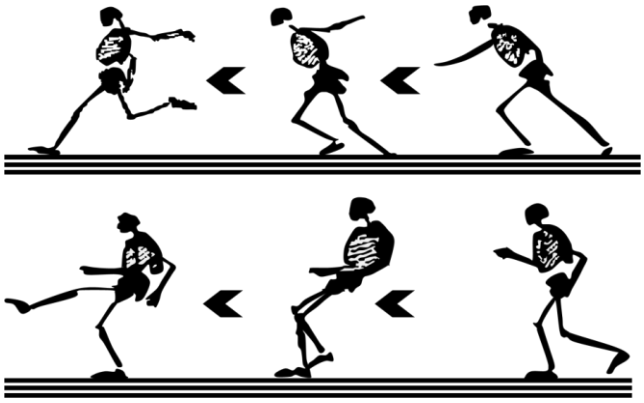

Figure 5. Biomechanical model of the highest possible instep football kick.
Source: By Author.

Table 4. Range of motion (ROM) outcomes for knee and hip during football kicking.

ROM findings	Values (Degree)
Knee Flexion	113 ± 10
Rotation	19 ± 7
Abduction	23 ± 6
Hip Flexion	129 ± 11
Rotation	17 ± 4
Abduction	26 ± 5

Source: By Author.

Table 5. Muscle lengthening measurements during football kickings.

Muscles Lengthening	Values (%)
Gracilis	135.1 ± 8.6
Biceps femoris	119.3 ± 6.6
Rectus femoris	112.8 ± 8.4
Gluteus medius	113.2 ± 6.9
Adductor Magnus	174.6 ± 11.6
Vastus materials	104.2 ± 6.1
Semimembranosus	127.7 ± 8.6

Source: By Author.

The analysis of ROMs of the knee and hip joints during football kicking demonstrates significant findings. It is worth mentioning that knee flexion is quantified at an average of 113 ± 10 degrees, rotation at an average of 19 ± 7 degrees, and abduction at an average of 23 ± 6 degrees. The measurement of hip flexion yields a mean value of 129 ± 11 degrees, accompanied by rotation measuring 17 ± 4 degrees and abduction of 26 ± 5 degrees. The adductor magnus muscle exhibited the highest lengthening, measured at 174.6% ± 11.6%. The result indicates that the muscle is of utmost importance in the biomechanics involved with the kicking mechanism in football. The results from this research provide essential contributions to understanding the biomechanical demands involved with the kicking movement, thus enabling focused training programs and injury prevention interventions.

The medical literature states that leg RSI related to football often involves compression of the muscles or tendons, which is a result of constant stress without adequate time for self-recovery Miller [33]. The result of the experiment reveals that there is an evident improvement in the ROM of the hip and knee. These findings indicate that there can be certain dangers associated with inadequate training, including the excessive elongation of muscle fibers. Coaches should prioritize particular strategies to reduce injury dangers in football. To begin, include targeted muscle stretching strategies to improve flexibility. Second, use vigorous warm-up activities to prepare muscles and relieve tension. Third, to reduce the danger of strain and imbalance, minimize repetitive kicking exercises. Finally, provide individualized training plans that allow for enough recuperation time for individuals depending on their specific demands. Coaches can increase overall player well-being and minimize the chance of injuries by concentrating on these tactics, promoting a more sustainable and successful football training environment.

The purpose of these measures is to improve muscular flexibility, decrease tightness, decrease the accumulation of micro-trauma, and promote adequate repair cycles. These measurements highlight the need to maintain a balance between the accumulation of micro-trauma and the subsequent repair cycles to prevent RSI. The importance of personalizing training durations to individual needs originates from the recognition of the diverse recovery timeframes associated with muscle discomfort.

5. Conclusion

The motion-capture technology explores the biomechanical motions of football kicking and identifies risk factors for RSIs in young players. Providing insight into the movement dynamics and any hazards involved, this research offered biomechanical algorithms of football kicking. To thoroughly examine football kicking, this research collected primary data from 75 talented football players who underwent a range of training. The VICON MX40 3D motion-capture device was used to obtain movement information at a high frame rate of 200 frames per second, allowing us to examine the muscle strains and joint motions associated with the kicking motion in detail. It is concluded that in muscle groups of the gracilis and biceps femoris, stress during kicking movements was highly noticed and if these extensions are not kept under strict control, elongations can easily develop into overuse injuries. On this basis, a balanced regimen is also the major issue of emphasis. The appropriate regime should concentrate on muscular fitness, flexibility, and proper technique. One drawback of this research is that it focused solely on football kicking, which can restrict how broadly the results can be applied to different sports or martial arts fields where various movement patterns are used. Further research could investigate whether biomechanical modeling might play a role in preventing injuries from occurring in multiple sports by considering team sports or other martial arts with complex dynamics of movement.

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