

The activity and technique principle of football shooting are investigated from the viewpoint of nano-bio-mechanics

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Abstract. This research aims to investigate the effect of strength training on soccer ball shooting speed, comparing biomechanical characteristics. Some important biomechanical parameters, including the maximum angular velocity of the hip and knee joints, the maximum torque of the hip and knee joints in the forward movement and impact phases, and finally, the maximum ball speed, were selected for analysis. One-way analysis of variance with repeated measures and Tukey's test showed a significant decrease in the maximum ball speed and the maximum angular speed of the knee joint between the first and fifth shots and subsequent shots. Compared to the first shoot, the hip joint's maximum angular velocity, and torque significantly decreased from the sixth shot onwards. After five weeks of performing strength and flexibility exercises, a test was taken comparing two methods of strength and flexibility. Ultimately, the data were analyzed with correlated and uncorrelated t-student statistical methods. The results showed that the selected strength training program significantly affects shot range and dribble speed. Also, to increase the physical and mechanical resistance of soccer balls, nanotechnology has been used by the production of plastics with nanomaterials.

Keywords: biomechanics; dynamic; football shooting; nano-bio-mechanics; nanotechnology; soccer ball; strength training

1. Introduction

All over the world, in developed and developing countries and among different classes, in every gender, every social and economic situation, everyone talks about football (Milanović *et al.* 2022). The elders in this field are much more famous than the world's political, social, engineering, and economic elites (Blake and Solberg 2023). By looking at this sport's evolutionary process and progress, we find that correct, moral, and scientific education in some countries has led to its significant progress (Peng *et al.* 2022). Sports biomechanics is one of the crucial branches of sports sciences that have made tremendous progress (Toto 2022). Along with the development and complexity of sports skills, the biomechanics of sports movements have also undergone many changes (Farana *et al.* 2023). In this regard, it has dramatically helped improve sports movements and the quality of skills (Hribernik *et al.* 2022). Therefore, biomechanics can be studied in different human, animal, and even plant branches. In sports biomechanics, only people involved in sports activities are examined. Sports

biomechanics examines and analyzes the athlete's performance using physical laws such as movement, friction, torque, levers, and the study of internal and external forces and their effects on the athlete (Quittmann *et al.* 2022). The main goal of sports biomechanics is to improve the performance of athletes and, in the next degree, to prevent sports injuries and provide appropriate rehabilitation guidelines (Fletcher *et al.* 2021). Today, with the help of biomechanics, many training and sports types of equipment are designed and manufactured to prepare athletes for competition (Ahir *et al.* 2019). Biomechanics is a relatively new science, but its application in sports science has attracted the attention of many enthusiasts. It has provided great hope for coaches and athletes for better performance in the future (Waters *et al.* 2019, Taborri *et al.* 2020).

1.1 Types of movements in biomechanics

Biomechanics provides a framework for understanding human movement by analyzing the physical laws that regulate it (Wu *et al.* 2024, 2025, Zhan *et al.* 2025). In sports biomechanics, the categorization of motions into various kinds is critical for evaluating and improving athletic performance. The categories help to identify the individual demands placed on athletes during different activities, which informs the formulation of training

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programs targeted at increasing efficiency and reducing injury risk (Wang *et al.* 2023b, Kou *et al.* 2024a, b). Transitional, circular, and common motions are important categories of movement that underlie the bulk of athletic acts, including those observed in football.

Transitional movement

Transitional motion is the uniform displacement of a body or its components over a straight or curved route, ensuring that all pieces move the same distance, direction, and time (Lu *et al.* 2022). This sort of movement is distinguished by linear kinematics, in which the body's center of mass travels constantly without rotation. Transitional movements in football occur while running, leaping, and passing, all of which need continuous speed and direction. For example, when a player moves towards the goal, their body surges forward steadily, displaying transitional motion. Mastering excellent transitional motions is critical for moving quickly and effectively over the field (Wang *et al.* 2023a, 2024i, Hu *et al.* 2024).

Circular movement

Circular or rotational motion is the movement of an item along a circular route around an axis in space, with all components moving in the same direction at the same time (Lindén *et al.* 2022). Unlike transitional motion, rotational movement is based on angular kinematics and prioritizes body segment rotation above linear displacement. In football, circular motions occur during spinning, pivoting, and turning, which need perfect control and balance. A player may pivot on one foot while moving the upper body to guard the ball from opponents or prepare for a shot. These motions are necessary to make quick directional adjustments and remain stable during dynamic play (Alves *et al.* 2023, Ariyanto *et al.* 2023, Liang *et al.* 2024a).

Common movements

The complexity of most sports is evident in fundamental movements, including translational and rotational motions (Kitagawa *et al.* 2021). Athletes often execute motions in sports that need concurrent linear and rotational displacements. In football shooting, transitional movement (the leg stretching forward) and circular movement (the hip and knee joints rotating to generate force) are integrated. Similarly, players must synchronize rotational adjustments and linear movements when dribbling to maintain ball control. By analyzing typical movements, researchers may gain insights into the intricate interactions among different body components and develop targeted medicines to enhance performance (Duan *et al.* 2024, Xiao *et al.* 2024, Zhu *et al.* 2024a).

Relevance to Football Shooting

Understanding the interaction between these distinct movement patterns is critical for football shooting efficiency and effectiveness. A good shot often consists of a set of motions that flow smoothly from the preparation phases to the act of execution. During the preliminary phase, transitional movement is firmly focused as the player approaches the ball. The circular motion in which the hip and knee joints spin to create torque becomes more visible as the point of contact with the ball approaches. Finally, combining these two movement modalities ensures better accuracy and power transfer during the impact period. By

meticulously perfecting each phase of this process, players may improve their shot accuracy, velocity, and scoring opportunities. Furthermore, studying different types of movement goes beyond just improving individual skills. Coaches and trainers may use biomechanical assessments to create training programs that concentrate on specific aspects of transitional, circular, and typical motions. For example, strength training that targets the quadriceps may help the knee joint expand more quickly, increasing the leg's speed before contact (Romero *et al.* 2022). Similarly, flexibility training may improve the fluidity of rotational motions, lowering the risk of injury during strenuous activity (Huang *et al.* 2024b, Wang *et al.* 2024h, Liu *et al.* 2025b).

1.2 Application of biomechanics in football shooting

In modern football, skill plays a fundamental and decisive role in today's football. Players can control the ball well and dribble or shoot it with high speed, so they play an essential role in winning and determining the game's outcome (Uehara *et al.* 2020). The skills are influenced by various factors such as strength, speed, agility, mental preparation, and biomechanical tests (Bukowska *et al.* 2021). One of the issues of interest to researchers in this field is how to provide training to get the most efficient. For this purpose, different training methods for improving biomechanical parameters have been evaluated, and special attention has been paid to them (Nocera *et al.* 2023). Achieving the maximum speed of the shot is one of the most important goals of soccer players, and shooting on the feet is the best choice (Engler *et al.* 2023). In recent years, many researchers have calculated the speed of the shot as an essential parameter in the kinematic analysis of the shot's movement. Recent studies show the speed of the shot (Engler *et al.* 2023, GizemBaşkaya 2023). The foot at the moment of shooting the ball directly affects the speed of the ball after the impact (Yunita *et al.* 2022). The biomechanical investigation of the soccer shot is usually summarized by studying the details of limb movements. To make a shoot, many muscles are activated throughout the body (Bastiaansen *et al.* 2022). The quadriceps muscles play an essential role in the quick opening of the knee joint and ultimately increasing the speed of the leg before impact (Romero *et al.* 2022). Ground and aerial shots are two types of different performances of shooting on the feet, according to the conditions used during the competition (Sarajärvi *et al.* 2020). It is essential to execute a shoot on the foot with the maximum speed of the ball because it gives the goalkeeper less time to react, increasing the probability of scoring (Ou *et al.* 2023). During football training, the coaches sometimes ask the players to consecutively shoot on the leg to improve this skill's power and strength (Daichi *et al.* 2023). Since players perform this skill to their maximum ability, improving technique and physical performance may be harmful and a risk factor (Pacholek and Zemková 2020). The use of strength training to increase sports performance has a history of thousands of years (Clauss *et al.* 2021). Historically, resistance exercises have the concept of increasing muscle strength and size (Jones *et al.* 2021). However, various people have recently

used strength training to increase strength, speed, and endurance, increase muscle stiffness, help in rehabilitation and prevent injuries, increase neuro-muscular coordination and help maintain muscle function in old age. Strength is one of the most critical factors for the success of a football player (Sandon *et al.* 2022).

Football activities like, Tackling, jumping, shooting and punching, impact power, running, and changing direction are high-powered and explosive (Williams *et al.* 2020). During such activities, the power output depends on the muscles' strength. Therefore, having high muscle strength that can be achieved with strength training is valuable for soccer players (Li *et al.* 2024a, b, Ma *et al.* 2024, Wang *et al.* 2024c, f, Xue *et al.* 2024, Zhang *et al.* 2024b, Zhao *et al.* 2024, Zhu *et al.* 2024b, c). Power affects the abilities of football players in different ways. Football improves fitness and cardiovascular endurance. Soccer involves beneficial activities such as running on the field for long periods, translating into several miles per game and calories burned. Soccer increases coordination and speed (Zouhal *et al.* 2020). During a soccer game, the player focuses on foot-eye coordination as the player shoots the ball or receives a pass. Complex movements such as blocking and passing at speed and moving in different directions can increase the agility of a footballer (Amra and Soniawan 2020).

Nanotechnology can be used to increase the power of soccer balls and the range of the balls. The use of nanomaterials as reinforcement has attracted much attention (Dai *et al.* 2021, Huo *et al.* 2021, Zhang *et al.* 2021, Chen *et al.* 2022, Li *et al.* 2022, Shi *et al.* 2022, Zhu *et al.* 2022, Wang *et al.* 2024b). The use of well-distributed nanomaterials in the rubber matrix is vital for better physical and mechanical properties. In ball making, natural or synthetic rubber is heated and placed in a circular mold to create a suitable shape. The primary material of most soccer balls is usually foam, and rubber and leather are also used, which all have their characteristics and meet different needs (Ten Eyck and Hernandez 2009, García-Pertusa *et al.* 2016).

Given the thorough examination of biomechanics and strength training in the field of sports science, it is clear that several gaps and shortcomings remain, necessitating additional focus (Guo *et al.* 2024, Huang *et al.* 2024a, Jin *et al.* 2024, Man *et al.* 2024, Wang *et al.* 2024e, g, Yu *et al.* 2024, Zhang *et al.* 2024c, Zhiqiang *et al.* 2024, Zisong and Habibi 2024). Prior research has highlighted a significant constraint arising from the inadequate integration of nano-bio-mechanical principles in traditional biomechanical assessments of football shooting (Liang *et al.* 2024b, Liu *et al.* 2024, Wang *et al.* 2024a, d, 2025, Yin *et al.* 2024, Jining *et al.* 2025, Li *et al.* 2025, Liu *et al.* 2025a, Xia *et al.* 2025, Zhou *et al.* 2025). Contemporary research has primarily concentrated on macro-level biomechanical parameters, including joint angles, torques, and muscle activations (He *et al.* 2024, Song *et al.* 2024, Zhang *et al.* 2024a). However, the significant potential that advancements in materials science, particularly nanotechnology, may have to improve the physical properties of soccer balls has been disregarded. This gap has hindered our understanding of the possible effect of increased ball resistance on player performance and shooting efficacy. A key concern has been identified: a

paucity of longitudinal research examining the long-term impact of specialized strength training regimens on firing speed and accuracy. Despite the fact that some research has examined the immediate effects of strength training, there is a significant lack of comprehensive data regarding its long-term effects over extended periods. Further, the potential synergistic effect of the combination of strength exercises and flexibility training has frequently been disregarded, resulting in a neglect of its potential to enhance athletic performance.

A novel technique has been employed to study the interplay between nano-enhanced soccer balls with the biomechanical changes caused by focused strength and flexibility training. Advanced statistical methods, like as one-way ANOVA with repeated measurements and Tukey's test, have been utilized to give strong evidence for the effectiveness of personalized strength programs in improving shooting range and dribbling speed. The use of nanoparticles in ball manufacture has resulted in considerable improvements in ball durability and responsiveness under high-impact conditions. This study's originality stems from its multidisciplinary approach, integrating nano-bio-mechanical viewpoints with traditional sports science methods. This study examines the potential of nanotechnology to revolutionize soccer ball design and concurrently analyzes the biomechanical effects of recurrent shooting under situations of exhaustion. This combined approach enhances the knowledge of football dynamics and offers a basis for future study to improve training procedures and material engineering techniques in professional sports. This study signifies a substantial development in the sector, addressing current knowledge gaps and facilitating future improvements.

2. Research methodology

The current research is one of applied research, 30 male football players who were not suffering from neurological disease or physical disability, who trained professionally and regularly, and who had no history of significant injury in the lower body volunteered to participate in this research. The right foot of the players was chosen as the shooting foot for biomechanical analysis. After an excellent warm-up program, which included 10 minutes of slow jogging, 10 minutes of static stretching, and 10 repetitions of soccer kicks, each player performed 10 leg shoots with a fixed ball in succession. The ball was shot from a distance of 5 meters towards the goal with dimensions of 1 × 1 meter. The subjects were asked to shoot the ball with great force. The ball weighed 0.5 grams. After each shoot, the ball's air pressure (50,000 Pa) was regularly controlled by a unique pressure gauge. High-speed and high-precision cameras were used to record the movements of the lower body during shooting. Motion analysis software (Vicon Nexus 1.2) digitized lower body movements. The maximum angular velocity of the hip joint, the maximum angular velocity of the knee joint, the maximum torque of the hip joint, and the maximum torque of the knee joint of the shoot foot in the forward movement and impact phases were

selected for analysis. Joint torques by Nexus app using force and position data Calculated (Mohammadi *et al.* 2020, Wang *et al.* 2020, 2023c, Ugurlu and Ozturk 2021, Dehghanbanadaki *et al.* 2022). For the reference of the angles of the lower body joints, the fully standing position for the thigh was considered 180 degrees, the fully opened knee was 180 degrees, and the natural position of the ankle was 90 degrees. The speed of the ball was selected for analysis based on the unit of meters per second (m/s). The speed of the ball was also obtained based on formula (1):

$$\text{Ball speed} = 1.23 \times v_{\text{foot}} + 2.72 \quad (1)$$

where 'v' is foot speed (m/s).

One-way analysis of variance with repeated measures was used for statistical analysis. Tukey's test was also used to check the significant difference between each of the biomechanical variables of the shot. The significance level was also considered $\alpha = 0.5$.

In the second research phase, to compare the two selected methods of strength and flexibility training in the range of kicks, football players were randomly divided into two groups of strength and flexibility training. Their personal information, medical and sports records were collected through a questionnaire. To measure the shot range, the Pro Sports model obstacles were used to measure dribble speed, and the Pro Sports model chronometer was also used to measure time. In order to carry out the tests, first on the appointed day, to familiarize the subjects with the tests, the test implementation steps and how to perform each test were explained. The subjects first warmed up for 20 minutes and then performed the dribbling and hitting the ball tests, respectively, to measure the characteristics of dribbling speed and hitting speed in the pre-test stage, and the results were recorded. Then the strength group for 5 weeks and 3 sessions per week and each session 60 to 80 minutes of strength training, strength training program in movements such as: Forearm, thigh, back arm, thigh, and leg exercises. Then the subjects performed the light to heavy strength training program. First, in the first set, they performed weights equivalent to 50% of 10RM (Repetition maximum) for each person in 10 repetitions. In the second set, 70% of 10RM and 10 repetitions, and in the third set, 100% of each person's 10RM with 10 repetitions. Each subject was given 2 minutes of rest between periods. The flexibility group also performed flexibility exercises for 5 weeks and 3 sessions per week, each lasting 60 to 80 minutes, in such a way that they first ran softly for 10 minutes. They performed stretching movements up to the pain threshold, so each movement was 20 seconds long. Stretched, each person ran for 10 minutes at 70% speed and immediately performed the stretching movements again. Finally, the same movements were repeated for the third time. These movements were chosen according to the importance of the muscles involved in each group in football, especially shooting and dribbling. In the end, after 5 weeks of training to collect data after the test, both groups did the desired tests again. Athletes did not use any drugs or stimulants during the study. Also, to equalize the time of measuring the variables for all the subjects, all the measurements were done between 4 and 6 in the afternoon.

Table 1 Formulation of the studied samples

Consuming materials	The amount of (phr)
Carbon nanotubes	100
Butadiene rubber	5
Antioxidants	2
Stearic acid	1.4
Accelerator	1
Zinc oxide	1.7
Sulfur	1.5, 1, 0.5, 0

Table 2 Individual characteristics of the game

Group	Variable	(years) Age	Weight (Kg)	Height (cm)
Strength group before the test	Average	20.4±1.03	69.75±4.32	177.34±2.43
Strength group after the test	Average	20.4±1.03	74.18±5.65	175.3.54±5.84
Flexibility group before the test	Average	22.34±2.15	72.87±4.26	179.6.12±2.54
Flexibility group after the test	Average	22.34±2.15	70.6.12±3.18	176.86±4.28

After extracting the data, mean, standard deviation, and descriptive statistics were used to describe them, and to compare the variables within the group, correlated and uncorrelated t-student inferential statistics tests were used with the help of spss statistical software. The test of the research hypotheses was also considered to have a significance level of $\alpha \geq 0.05$.

3. Experimental materials and preparation of samples

All samples were prepared with a laboratory roller at a mixing temperature of 50 to 60 degrees Celsius according to the Table 1 formula. First, butadiene rubber is softened for 5 minutes on a roller, and then carbon nanotubes are added to the rubber mixture. After that, the accelerator, activator, and, finally, sulfur curing agent were added to the mixture. The amount of consumables is in Parts per Hundred Resin(phr). A laboratory roller was used to mix the mixtures. The characteristics of nanocomposite curing were determined by Zwick rheometer model 4308 made in Germany at 180°C according to ASTM standard D208.

4. Discussion and research findings

Table 2 shows the athletes' age, height, and weight mean and standard deviation.

As Fig. 1 shows, there is a significant drop in peak ball speed between the first and tenth shoots. ($P = 0.02$, -1.8 ± 0.108 m/s).

The maximum angular velocity of the knee joint showed a significant decrease between the first shot and the fifth and subsequent shots ($P = 0.01$, -0.99 ± 0.26 rad/s, Fig. 2a). Compared to the first shot, the hip joint's maximum angular

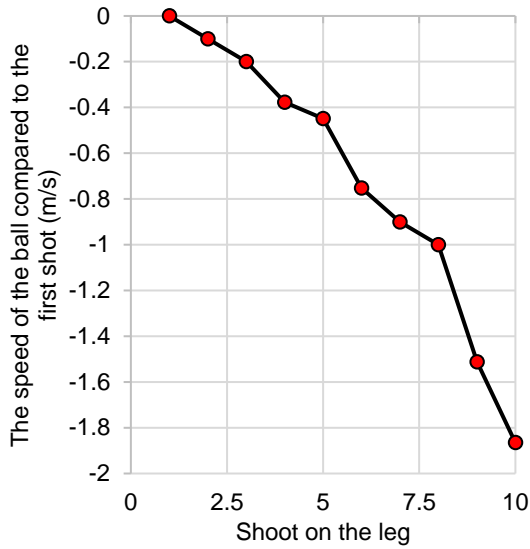


Fig. 1 The descending curve of the ball speed during 10 consecutive shots on foot

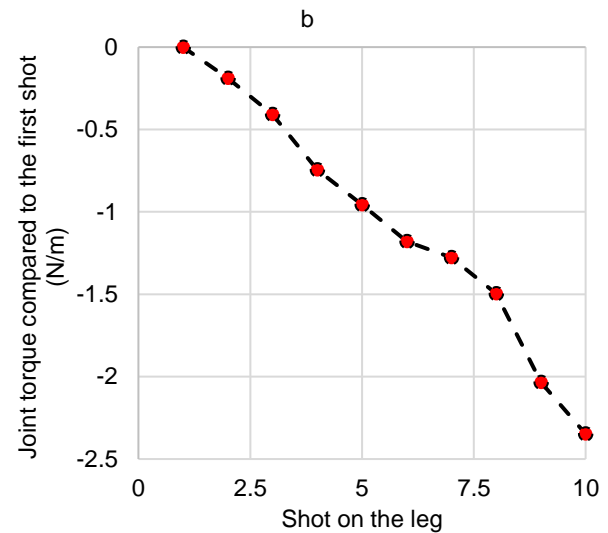
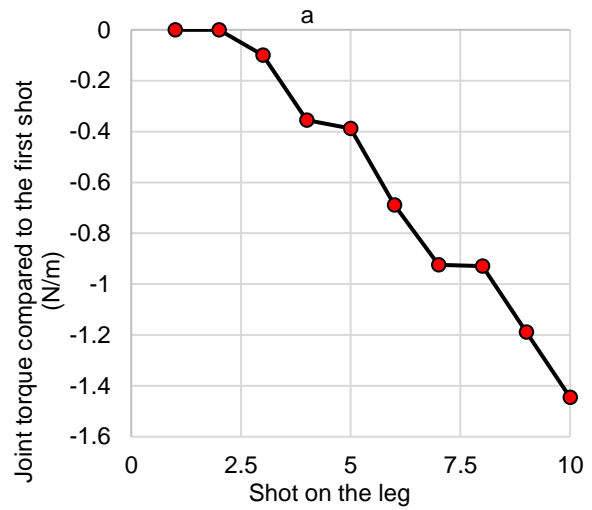


Fig. 3 Descending curve of torque of thigh (a) & knee (b) joints during 10 consecutive shots on the leg

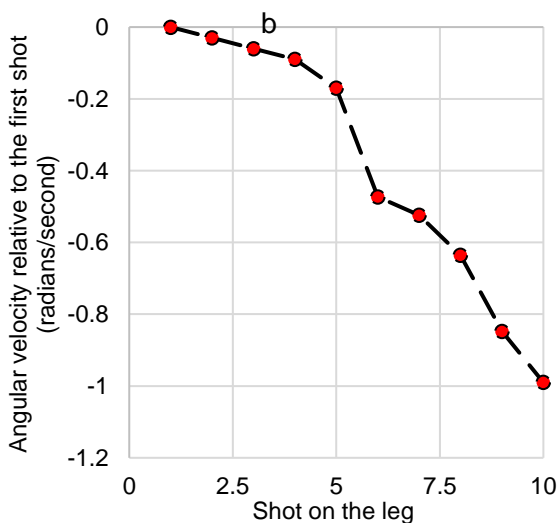
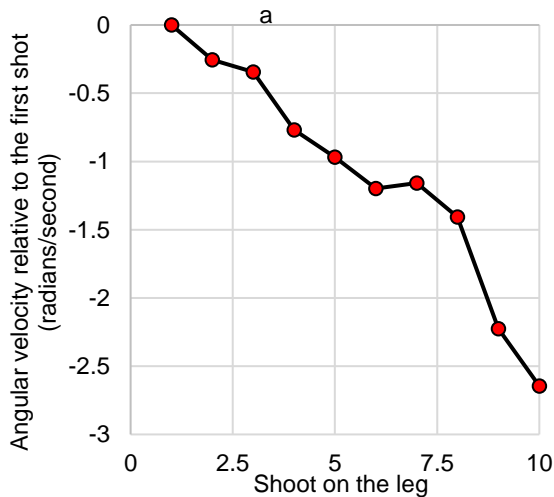


Fig. 2 Descending curves of the angular velocity of the knee (a) & thigh (b) joints during 10 consecutive blows to the leg

velocity and torque significantly decreased from the fifth shot onwards ($P = 0.01$, -0.17 ± 0.23 rad/s & -0.95 ± 0.31 N/m, Figs. 2b and 3b).

The maximum torque of the knee joint showed a significant decrease between the first shot and the fifth shot and subsequent shots (Fig. 3a). The results of data analysis using the correlated t-test show that the selected strength training program significantly increases the player's shot range and dribbling speed ($P=0.000$). Also, the selected flexibility training program leads to a significant increase in the players' shot range and dribbling speed ($P=0.000$). There is a significant difference between the effect of the two training methods on players' shot range (0.007). This difference is also available in dribble speed. In both cases, strength training is more effective compared to flexibility training.

Increasing the percentage of carbon nanotubes by phr 1 decreases the optimal curing time. One of the benefits of using carbon nanotubes is eliminating the difference between the transverse connections between the surface and

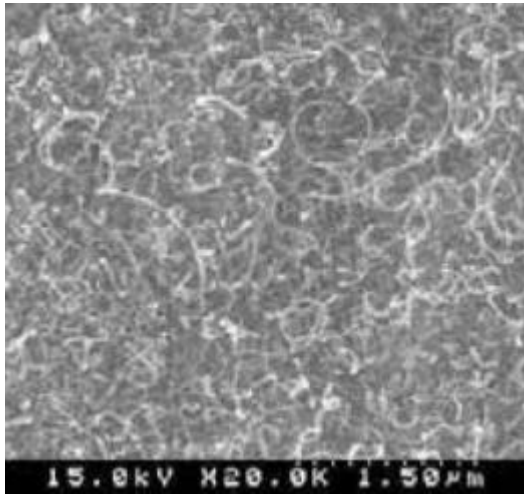


Fig. 4 FESEM image of the sample containing 1phr

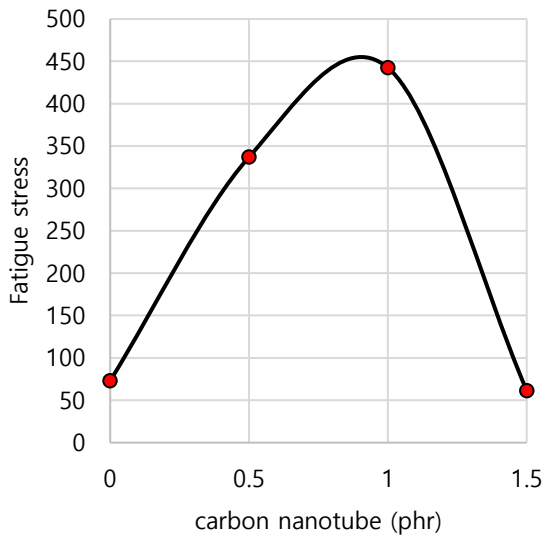


Fig. 5 Fatigue diagram of samples containing carbon nanotubes 0, 0.5, 1 and 1.5 phr

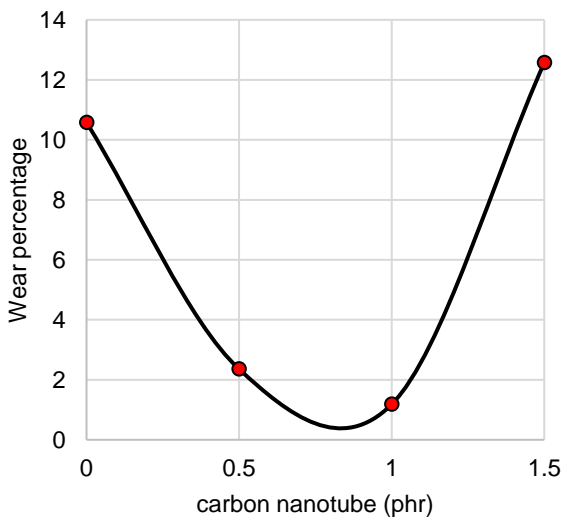


Fig. 6 The wear percentage of the sample containing 0, 0.5, 1 and 1.5 phr of carbon nanotubes

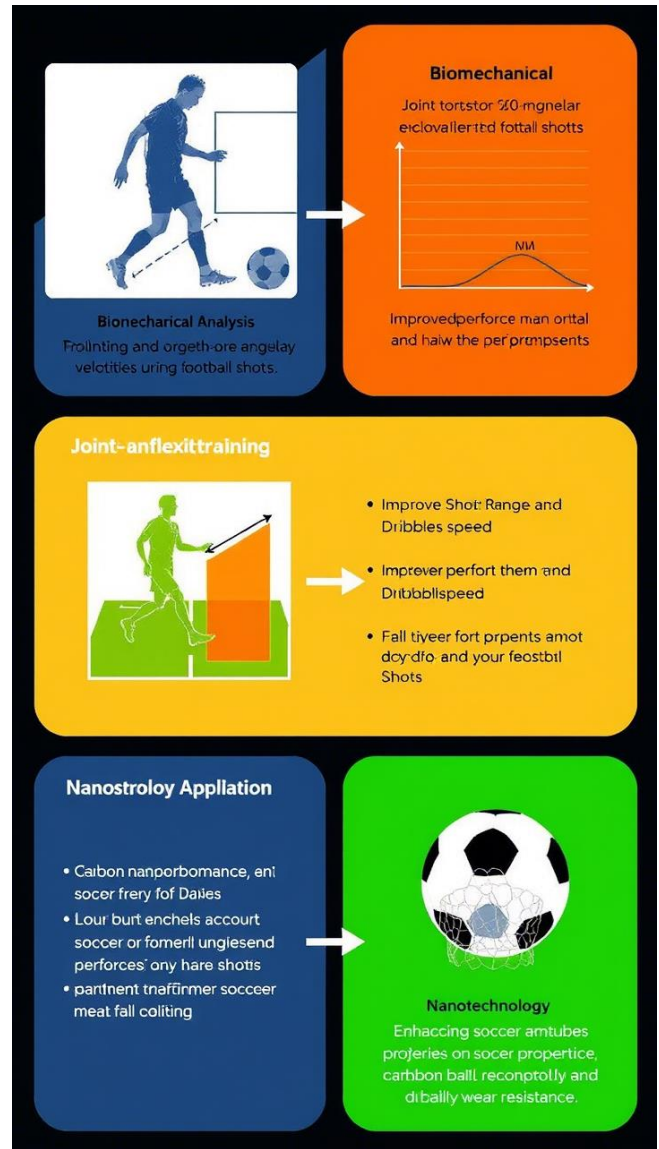


Fig. 7 Schematic Representation of the Integration of nano-bio-mechanics in football shooting performance enhancement

the inside of a thick rubber ball. The fracture surface morphology of the samples (failure in liquid nitrogen) has been investigated using a field emission scanning electron microscope (FESEM) manufactured by Hitachi, model S4160, Japan (Fig. 4). The distribution of carbon nanotubes in the mixture containing 1 phr of carbon nanotubes has been done very well, while the mixture containing 1.5 phr of carbon nanotubes has a heterogeneous distribution in the mixture, and many carbon nanotube accumulations are observed in the sample. Carbon nanotube aggregates are mechanical weaknesses.

Fig. 5 shows the fatigue life curve of the examined mixtures. It can be seen that increasing the carbon nanotube in rubber compounds up to 1 phr increases the fatigue life of the compound.

By increasing the amount of carbon nanotubes, the bounce has decreased. Since carbon nanotubes have low bounce and due to energy absorption, they reduce the bounce of samples filled with carbon nanotubes. By

increasing the number of carbon nanotubes up to phr 1, the wear resistance of composites increases compared to pure plastic (Fig. 6).

Fig. 7 depicts the actual application of our research, which combines nano-bio-mechanical concepts to improve football shooting performance. The figure is broken into three main parts. (1) Biomechanical Analysis, which focuses on essential biomechanical characteristics such as maximal angular velocity, joint torque, and ball speed following successive shoots, (2) Strength and Flexibility Training demonstrates how personalized training programs improve athletic performance by delaying tiredness and increasing shot range and dribble velocity, and (3) Nanotechnology The application stresses the importance of carbon nanotubes in improving the physical properties of soccer balls, such as durability, wear resistance, and ideal rebound. This integration is a holistic approach that combines athlete physiology, biomechanics, and advanced materials research to improve player performance and equipment quality.

5. Conclusions

This research examined the biomechanics involved in football shooting, the effects of strength and flexibility training on shooting efficacy, and the role of nanotechnology in altering the physical characteristics of soccer balls. The results illuminate the intricate connections among athletic physiology, biomechanical variables, and the principles of material science. The experimental findings indicated a notable decrease in ball speed, the maximum angular velocity of the knee joint, and the torque at the hip joint with successive shots, implying a decline in performance due to fatigue. The decrease in peak ball speed was significant when comparing the initial shot to the tenth ($P = 0.02$), accompanied by a reduction in angular velocities and torques in both the knee and hip joints after the fifth shot ($P = 0.01$). The findings underscore the necessity of reassessing training methodologies to mitigate fatigue and sustain optimal performance in competitive settings. The statistical examination employing correlated t-tests confirmed that the selected strength training protocol significantly enhanced players' shooting range and dribbling speed ($P = 0.000$). Similarly, flexibility training yielded improvements in comparable metrics, however, strength training has demonstrated greater effectiveness than flexibility training in enhancing both shooting range and dribbling speed. This highlights the critical role of tailored strength training in improving athletic performance, particularly for skills that require explosive force, such as shooting in football. The research examined the use of nanotechnology in the creation of soccer balls, alongside biomechanical assessments. The integration of carbon nanotubes into butadiene rubber compounds resulted in enhancements in fatigue life, wear resistance, and structural uniformity. The ideal curing duration dropped as the proportion of carbon nanotubes increased, and their even distribution throughout the matrix markedly improved mechanical characteristics. Excessive concentrations of carbon nanotubes (exceeding 1 phr) led to uneven

dispersion and diminished bounce, highlighting the need for meticulous optimization of nanomaterial content. This research adeptly combined traditional biomechanical principles with modern advancements in materials science, yielding important consequences for the training protocols of athletes and the design of their equipment. The use of nano-bio-mechanical methods has significantly enhanced our understanding of the intricate dynamics of football, while also providing practical solutions for enhancing player performance and extending ball longevity. Future study may concentrate on the enduring effects of combining strength and flexibility training, along with alternative nanomaterials for soccer ball manufacturing.

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