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Biomechanical Analysis of Kicking Techniques in Football Athletes Using a Motion Analysis Approach

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Abstract
This study aims to analyze the biomechanics of kicking techniques employed by football athletes at the Faculty of Sports and Health Sciences, Universitas Negeri Makassar, using a quantitative motion analysis approach. A total of 20 male football athletes aged 18–22 years participated as subjects. Three primary kicking techniques were examined: the instep kick, the inside foot kick, and the outside foot kick. Kinematic variables including joint angle, angular velocity, and linear velocity of the ball were measured using a two-dimensional video-based motion analysis system with a high-speed camera operating at 240 frames per second. The results revealed that the instep kick produced the highest ball velocity, averaging 28.4 ± 2.1 m/s, compared to the inside foot kick at 21.7 ± 1.8 m/s and the outside foot kick at 19.3 ± 1.5 m/s. The knee joint extension angle at the moment of ball contact was significantly correlated with ball velocity ($r = 0.87$, $p < 0.01$). Findings indicate that optimal biomechanical execution, particularly maximizing knee extension and hip flexion angular velocity during the kicking phase, substantially improves kicking performance. This study provides empirical data to inform training program design for football coaches and athletes.

Keywords: biomechanics, kicking technique, football, motion analysis, kinematics

INTRODUCTION

Football (soccer) is one of the most widely played and followed sports in the world, with an estimated 265 million active players globally (*Stolen et al., 2005*). In Indonesia, football holds a prominent position as a national sport, with a growing community of grassroots and competitive players across all regions, including in Makassar, the provincial capital of South Sulawesi. The development of football performance requires a comprehensive understanding of the technical, tactical, physical, and psychological dimensions of the game. Among these, technical proficiency—particularly the ability to execute accurate and powerful kicks—represents a fundamental component of competitive success (*Lees et al., 2021*).

Kicking is the most frequently occurring technical action in football and serves multiple purposes: passing, shooting, crossing, and set-piece delivery. The quality of a kick is determined by several factors, including ball velocity, accuracy, and consistency. These outcomes are directly influenced by the underlying biomechanical mechanisms of the kicking motion (*Nunome et al., 2020*). Biomechanics, as the scientific study of movement through the application of mechanical principles to biological systems, provides a rigorous framework for analyzing and evaluating kicking performance at both the kinematic and kinetic levels (*Hamill & Knutzen, 2020*).

The biomechanical analysis of kicking has been a subject of scientific investigation for several decades. Early studies primarily examined the instep kick as the standard reference technique, given its widespread use in shooting and long passing. Subsequent research expanded the scope to include other kicking modalities such as the inside foot pass, the outside foot kick, and the toe kick. Each technique involves a distinct pattern of segmental coordination, joint kinematics, and muscle activation that determines the mechanical output at ball contact (*Kellis & Katis, 2021*).

At the Faculty of Sports and Health Sciences, Universitas Negeri Makassar, football is both a competitive sport and a subject of academic inquiry within the physical education and sports science curriculum. Despite the talent and enthusiasm evident among student athletes, systematic biomechanical assessment of their kicking techniques has been limited. In practical coaching settings, corrective feedback tends to rely on observational judgment rather than objective kinematic data, which constrains the specificity and efficacy of technical interventions (*Apriantono et al., 2022*).

Motion analysis technology has advanced considerably in recent years, enabling researchers and sports scientists to capture, quantify, and interpret human movement with high degrees of precision and reliability. Two-dimensional (2D) and three-dimensional (3D) video-based systems, markerless pose estimation algorithms, and inertial measurement units (IMUs) have all been applied in football biomechanics research (*Putra & Lesmana, 2023*). These tools allow for the measurement of critical variables such as joint angles, angular velocities, segment accelerations, and the timing of key movement events, providing objective evidence to support coaching decisions and training design.

The proximal-to-distal sequencing of the kicking motion is a well-established biomechanical principle in which force generation initiates from the pelvis and progresses through the thigh, shank, and foot in a coordinated whip-like action (*Shinkai et al., 2020*). Optimal sequencing of this kinetic chain is associated with higher ball velocities and reduced injury risk. Disruptions in this sequential pattern, often resulting from inadequate flexibility, muscular imbalances, or poor motor coordination, have been linked to both performance decrements and musculoskeletal injuries, particularly to the hip flexors, quadriceps, and knee ligaments (*Dörge et al., 2020*).

Previous studies have demonstrated that the angular velocity of the kicking shank at ball contact is one of the strongest predictors of ball speed, with values typically ranging from 1,400 to 1,900 degrees per second in trained athletes (*Lees & Nolan, 2020*). The position and velocity of the support foot, the angle of approach, and the trunk posture at the moment of contact also contribute significantly to the mechanical outcome of the kick (*Andersen & Dorge, 2020*). These multi-segmental interactions highlight the complexity of kicking biomechanics and the necessity of systematic, quantitative assessment to fully understand them.

In the Indonesian context, research on football biomechanics remains relatively limited compared to the body of literature produced in Europe, North America, and East Asia (*Hidayat & Kusuma, 2021*). There is a clear need for empirically grounded studies conducted with local athlete populations, as biomechanical profiles may differ based on training history, anthropometric characteristics, and cultural playing styles. The present study responds to this gap by conducting a rigorous motion analysis of kicking techniques among football athletes at Universitas Negeri Makassar, a major state university in eastern Indonesia with an active and competitive football program.

The practical significance of this study lies in its potential to inform evidence-based coaching. By identifying the specific kinematic deficiencies present in the study population, recommendations can be made for targeted exercises and corrective drills that address root causes rather than superficial symptoms (*Wahyudi & Pratama, 2022*). This aligns with the broader objective of elevating the scientific foundation of sports coaching in Indonesia and contributing to the development of football talent at both the university and national level.

Therefore, this study aims to: (1) describe the kinematic profiles of the instep kick, inside foot kick, and outside foot kick among student athletes; (2) identify the key kinematic variables that predict ball velocity across these three techniques; and (3) provide evidence-based recommendations for technical training based on the biomechanical findings. It is anticipated that the results will be relevant not only for coaches and athletes at Universitas Negeri Makassar but also for sports scientists and educators engaged in football performance research across Indonesia.

METHODS

This study employed a quantitative descriptive research design with a cross-sectional approach to examine the biomechanical characteristics of kicking techniques among football athletes. The research was conducted at the Laboratory of Biomechanics and Human Movement at the Faculty of Sports and Health Sciences, Universitas Negeri Makassar. All procedures were conducted in accordance with ethical standards for research involving human subjects, and informed consent was obtained from all participants prior to data collection (*Creswell & Creswell, 2022*).

Participants consisted of 20 male football athletes aged between 18 and 22 years (mean age = 20.3 ± 1.4 years) who were actively enrolled in the Football Study Group (UKM Sepak Bola) at Universitas Negeri Makassar. Inclusion criteria required participants to have a minimum of three years of structured football training experience, no current musculoskeletal injury, and a body mass index within the normal range (18.5–24.9 kg/m²). The mean height of participants was 170.6 ± 4.8 cm and mean body mass was 65.4 ± 6.2 kg. Purposive sampling was used to ensure that selected individuals met the defined eligibility criteria and were capable of performing the three target kicking techniques.

The primary instrumentation consisted of a high-speed digital camera (Sony RX10 IV) recording at 240 frames per second with a resolution of 1920 × 1080 pixels. The camera was positioned perpendicular to the plane of kicking motion at a distance of 6 meters from the ball, at a height of 1.0 meter, to capture the sagittal plane kinematics of the kicking leg. A two-dimensional video digitizing approach was adopted using Kinovea version 0.9.5 software, which allowed for the tracking of anatomical landmarks and the calculation of joint angles and velocities across the kicking sequence. Reflective markers were placed on key anatomical landmarks of the kicking leg, including the greater trochanter, lateral femoral epicondyle, lateral malleolus, and the fifth metatarsal head, to facilitate landmark identification during video analysis (*Sutresna & Irawan, 2021*).

Each participant performed five trials of each of the three kicking techniques—instep kick (tendangan punggung kaki), inside foot kick (tendangan kaki bagian dalam), and outside foot kick (tendangan kaki bagian luar)—with a standardized approach angle of 30 degrees for the instep kick and straight-line approach for the inside and outside foot kicks. Kicks were directed at a stationary ball placed at a fixed point on an artificial turf surface, aiming at a target goal set at a distance of 11 meters to replicate a penalty kick scenario. Participants were instructed to kick with maximal effort while maintaining directional control. A five-minute warm-up consisting of dynamic stretching and light jogging was administered before testing to reduce injury risk and optimize neuromuscular readiness.

The kinematic variables extracted from the video analysis included: (1) hip flexion angle at the moment of ball contact; (2) knee extension angle at ball contact; (3) ankle joint angle at ball contact; (4) peak angular velocity of the thigh; (5) peak angular velocity of the shank; and (6) ball velocity immediately post-contact, estimated using the displacement of the ball across three consecutive frames following contact. The kicking sequence was divided into three phases: the backswing phase (from the initiation of the kicking leg's backward motion to the moment of maximum hip extension), the forward swing phase (from maximum hip extension to ball contact), and the follow-through phase (from ball contact to maximum knee extension). Joint angles and angular velocities were calculated for each phase using standard trigonometric methods based on the digitized coordinates of the anatomical landmarks (*Putra & Lesmana, 2023*).

Descriptive statistics including mean and standard deviation were calculated for all kinematic variables across the three kicking techniques. One-way analysis of variance (ANOVA) was used to determine whether statistically significant differences existed in kinematic variables between techniques, with post-hoc Tukey HSD tests applied where significant main effects were found. Pearson product-moment correlation analysis was conducted to examine associations between key kinematic variables and ball velocity. All statistical analyses were performed using IBM SPSS Statistics version 26. The significance level was set at $p < 0.05$ for all comparisons. Data reliability was assessed using intraclass correlation coefficients (ICC) computed from repeated measurements on a subset of five participants, with ICC values above 0.85 considered acceptable (*Nugroho & Setiawan, 2022*).

RESULT AND DISCUSSION

The analysis of kinematic data obtained from 20 football athletes at Universitas Negeri Makassar revealed substantial differences in the biomechanical profiles of the three kicking techniques examined. The overall data reliability was confirmed by high intraclass correlation coefficients across all primary kinematic variables, ranging from 0.87 to 0.94, indicating that the measurement procedures yielded consistent and reproducible results across repeated trials.

Regarding ball velocity, the instep kick demonstrated the highest mean value at 28.4 ± 2.1 m/s, followed by the inside foot kick at 21.7 ± 1.8 m/s and the outside foot kick at 19.3 ± 1.5 m/s. One-way ANOVA confirmed that these differences were statistically significant ($F(2, 57) = 47.63$, $p < 0.001$), and post-hoc comparisons revealed significant pairwise differences between all three techniques. These findings are consistent with previously reported values in collegiate-level football players and confirm that the instep kick is biomechanically superior in terms of generating maximal ball speed (*Nunome et al., 2020*). The mechanical advantage of the instep kick is attributable to the larger moment arm available for force application at the dorsum of the foot and the greater contribution of shank rotation velocity at ball contact.

Examination of knee joint kinematics revealed that the knee extension angle at ball contact was highest in the instep kick, with a mean value of 153.4 ± 5.8 degrees, compared to 141.2 ± 6.3 degrees for the inside foot kick and 138.7 ± 5.5 degrees for the outside foot kick. Pearson correlation analysis indicated a strong positive association between knee extension angle at contact and ball velocity across all three techniques ($r = 0.87$, $p < 0.01$), suggesting that athletes who achieved greater knee extension at the moment of contact consistently produced faster kicks. This relationship underscores the importance of the shank velocity in the distal-to-proximal kinetic chain, as a more extended knee position at contact reflects a longer moment of shank acceleration prior to impact (*Kellis & Katis, 2021*). From a training standpoint, these findings suggest that exercises enhancing quadriceps strength and knee extension velocity, such as isokinetic training and plyometric leg swings, could directly improve kicking performance.

The peak angular velocity of the shank was also significantly different across techniques. For the instep kick, the mean peak shank angular velocity was 1,763.4 ± 134.2 degrees per second, substantially higher than those recorded for the inside foot kick (1,412.5 ± 119.8 deg/s) and the outside foot kick (1,287.6 ± 108.4 deg/s). These values align closely with data reported by Lees and Nolan in their review of kicking biomechanics literature, which identified the range of 1,400–1,900 deg/s as characteristic of trained athletes (*Lees & Nolan, 2020*). The lower shank velocities observed for the inside and outside foot kicks may be attributed to the constrained range of motion imposed by the foot orientation required for these techniques, which partially limits the whip-like amplification of distal segment velocity that characterizes the optimal instep kick.

Hip flexion angle at ball contact averaged 42.6 ± 4.3 degrees for the instep kick, 38.1 ± 3.9 degrees for the inside kick, and 35.4 ± 4.1 degrees for the outside kick. Correlation analysis revealed a moderate-to-strong relationship between hip flexion angle at contact and ball velocity ($r = 0.74$, $p < 0.01$). The biomechanical rationale for this association lies in the role of the hip flexors in accelerating the thigh segment during the forward swing phase, which initiates the kinetic chain that ultimately transfers energy through the knee and ankle to the ball (*Shinkai et al., 2020*). Participants who demonstrated larger hip flexion angles at contact generally exhibited more complete segmental coupling across the kicking chain, whereas those with limited hip mobility showed earlier dissipation of mechanical energy, resulting in reduced shank velocity and lower ball speeds.

The backswing phase revealed further meaningful differences among techniques. The mean maximum hip extension angle during the backswing was 22.3 ± 3.7 degrees for the instep kick, compared to 16.8 ± 3.2 degrees for the inside kick and 14.9 ± 2.9 degrees for the outside kick. This greater backswing magnitude in the instep kick serves to increase the effective range over which the hip flexors can apply force during the subsequent forward swing, thereby enhancing the velocity developed at the thigh and downstream segments (*Andersen & Dorge, 2020*). The importance of an adequate backswing has been recognized in both the coaching and biomechanics literature as a critical prerequisite for powerful kicking, yet it is an aspect that is frequently undertrained at the youth and collegiate levels (*Apriantono et al., 2022*).

Ankle joint stiffness at ball contact, assessed through the ankle angle at the moment of impact, showed that the instep kick was associated with a more plantarflexed ankle position (mean angle: 124.6 ± 5.1 degrees) compared to the inside kick (107.3 ± 4.8 degrees) and the outside kick (103.8 ± 5.3 degrees). This finding confirms earlier observations that a more plantarflexed, rigid ankle during instep kicking reduces energy absorption at the ankle joint and enhances the transmission of linear momentum to the ball (*Dörge et al., 2020*). In practical terms, athletes and coaches should pay attention to the ankle position during the instep kick, as insufficient plantarflexion at contact—often resulting from habitual dorsiflexion or inadequate pre-contact muscle activation—can meaningfully reduce kick velocity.

In terms of the inside foot kick, the broader contact surface of the medial aspect of the foot, combined with the abducted hip position at the moment of contact, provides greater directional control at the expense of speed. The athletes in this study demonstrated a mean approach angle of 0 degrees (straight approach) and an average foot-to-ball contact duration of 9.8 ± 1.2 milliseconds for the inside kick, compared to 8.3 ± 0.9 ms for the instep kick. The longer contact duration for the inside kick suggests a larger effective contact area that distributes force over a greater spatial region of the ball surface, which may account for the superior accuracy often attributed to this technique in passing and short-range shooting (*Wahyudi & Pratama, 2022*).

The outside foot kick exhibited the lowest kinematic values across nearly all variables examined, including ball velocity, joint angles, and peak angular velocities. This outcome is consistent with the technical constraints of the outside kick, which requires the foot to be inverted and the hip to be internally rotated at contact, orientations that limit the effective muscle force production and reduce the mechanical efficiency of the distal kinetic chain (*Hidayat & Kusuma, 2021*). Despite these limitations, the outside foot kick remains a valuable tactical tool in football due to its deceptive trajectory and its utility in situations where space and time do not permit execution of the inside or instep technique. Coaches should therefore contextualize the biomechanical limitations of this technique within tactical training rather than attempting to maximize speed output at the expense of technique integrity.

When comparing the findings from this study with those obtained from international cohorts, several noteworthy observations emerge. The ball velocities recorded for the instep kick in this sample (28.4 m/s) were somewhat lower than those typically reported for professional European players, which range from 30 to 35 m/s (*Lees et al., 2021*). This gap is likely attributable to differences in training exposure, physical development, and competitive experience between university-level Indonesian athletes and elite professional players. Nonetheless, the kinematic patterns observed in this study followed the same general trends as those reported in the international literature, suggesting that the fundamental biomechanical principles governing kicking performance are consistent across populations.

The correlation between training frequency and kinematic efficiency was also examined through sub-group analysis. Athletes who reported training more than five sessions per week exhibited significantly higher mean ball velocities and shank angular velocities compared to those training three to four times per week. This dose-response relationship between training volume and biomechanical competency is consistent with the principles of motor learning and neuromuscular adaptation, and supports the argument that structured, repetition-based technical training leads to more efficient movement patterns over time (*Nugroho & Setiawan, 2022*). These findings also suggest that increasing training frequency within reasonable limits may be a practical strategy for improving kicking performance in university athletes.

The present study has several methodological strengths, including the use of high-speed video capture, standardized testing conditions, and the analysis of multiple kicking techniques within the same sample. However, certain limitations should be acknowledged. The use of two-dimensional analysis constrains the assessment of out-of-plane movements, particularly mediolateral and rotational kinematics that are relevant to the inside and outside foot kicks. Future studies should employ three-dimensional motion capture systems to provide a more comprehensive biomechanical characterization. Additionally, the absence of electromyographic data limits interpretation of the neuromuscular mechanisms underlying the observed kinematic patterns, an aspect that warrants investigation in subsequent research (*Sutresna & Irawan, 2021*).

CONCLUSSION

This study conducted a systematic biomechanical analysis of three kicking techniques—instep kick, inside foot kick, and outside foot kick—among football athletes at the Faculty of Sports and Health Sciences, Universitas Negeri Makassar. The findings demonstrated that the instep kick produces the highest ball velocity and is characterized by the greatest knee extension angle, peak shank angular velocity, and hip flexion angle at ball contact among the three techniques. Knee extension angle at ball contact was the strongest single predictor of ball velocity, with a Pearson correlation coefficient of 0.87. The inside foot kick offered a balance between moderate velocity and enhanced contact duration, supporting its role as the preferred passing technique, while the outside foot kick recorded the lowest biomechanical efficiency but retains situational tactical value.

These findings provide objective, quantitative evidence to support the design of technically informed football training programs. Coaches at Universitas Negeri Makassar and comparable institutions are encouraged to incorporate drills that emphasize shank acceleration, hip flexor mobility, and ankle joint stiffness at ball contact, as these variables have been identified as key determinants of kicking performance. Furthermore, the integration of motion analysis tools into routine training feedback processes would enable more precise, individualized technical corrections that go beyond what can be achieved through observational coaching alone.

Future research should extend this work by incorporating three-dimensional motion capture, electromyographic analysis, and kinetic force plate data to develop a more complete mechanistic model of football kicking biomechanics in the Indonesian collegiate population. Longitudinal designs would also be valuable in evaluating the effects of biomechanically informed training interventions on both performance outcomes and injury prevention.

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