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Kinematic Determinants of Right Upper-Corner Placement Accuracy in Soccer Penalty Kicks

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Abstract: *The purpose of this investigation was to examine the linear kinematic characteristics associated with successful and unsuccessful soccer penalty kicks directed toward the right upper corner. Five competitive male football players participated in the study with mean age, height and weight of 22.0 ± 2.1 years, 175.2 ± 4.3 cm and 62.6 ± 3.8 kg respectively. Each participant performed five instep penalty kicks following a standardized warm-up protocol. Kicking motion was recorded using two synchronized high-speed video cameras. This study based on two-dimensional and motion analysis was a conducted using Kinovea software. Linear velocity and acceleration variables were analyzed during the preparatory to ball contact phase and the post ball contact to follow-through phase (before deceleration) of the instep kick. Statistical comparisons between successful and unsuccessful kicks were performed using paired sample t-tests with significance set at $p < 0.05$. The Result was found that most linear kinematic variables did not differ significantly between successful and unsuccessful attempts. However, a significant difference was observed in knee velocity during the preparatory to ball contact phase with unsuccessful kicks demonstrating higher values.*

Keywords: *Soccer biomechanics, Penalty kick, Kinematic analysis, linear, Lower limb mechanics, Instep kicking and Performance analysis.*

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I. Introduction

Soccer penalty kicks are high-stakes moments where success depends on a mix of mental toughness and technical precision. Targeting the upper corners of the goal is one of the most effective scoring strategies. While aim is always important, targeting the upper corners of the goal is a "high-risk, high-reward" strategy. It is incredibly difficult for goalkeepers to reach these zones, but the kicker faces a slim margin of error to avoid overshooting of the target. Despite substantial interest in penalty performance, detailed biomechanical studies specifically examining kinematic determinants underlying placement accuracy toward high goal regions remain limited in the contemporary literature.

Accurate placement of a penalty kick toward the upper corners is crucial in soccer because it significantly increases the likelihood of scoring, often determining the outcome in decisive match situations such as shootouts or tied games. Research shows that tailored cognitive-motor strategies and biomechanical execution directly influence kicking accuracy, highlighting that precision training enhances performance more than power alone (Niźnikowski, T.,et, al. 2025).

Previous biomechanical work has begun to quantify aspects of scoring accuracy in soccer penalty kicks. For example, developed a novel height to width ratio (HWR) method to assess penalty kick accuracy across different goal sectors, revealing significant relationships between selected ball kinematics and accuracy measures within goal subsections (including zones relevant to upper targets) using motion digitization software in controlled settings (Attaallah, M., et, al. 2021). Concurrently, demonstrated that instructional emphasis on accuracy versus velocity alters ball speed and hit precision across distinct target positions within the goal, indicating that biomechanical strategies vary with the intended placement targets (Sørensen, A., et, al. 2024).

Beyond group level accuracy metrics, emerging kinematic analyses have identified specific body and movement cues that predict ball trajectory and direction. Recent motion capture research highlights trunk and lower-limb variables such as trunk rotation and foot position height at contact as significant predictors of vertical and horizontal ball direction in penalty kicks, suggesting these pre-impact cues may directly influence placement outcomes (Secco Faquin, B., et, al. 2023). Furthermore, studies focusing on foot and support limb orientation underline the role of preparatory body postures in determining the direction and success of penalty strikes (Fattah,et, al. 2023).

Most existing studies look at general accuracy or broad targets. There is a lack of data on the subtle mechanical differences needed to navigate the tight space of the upper corners. This study aims to fill that gap**,** by using 2D motion analysis, we will examine specific variables such as limb orientation, linear kinematic to identify exactly what determines a successful high-placement penalty. Our goal is to provide coaches and players with evidence based cues to improve performance in these critical game winning moments.

II. Methods

Participants

Five male right-foot dominant competitive football players participated in this study. All participants belong to Aligarh Muslim University Football club. All they were participated at national or inter-university levels. The age range of all the participants were 18-25 years and average body mass, height were 62.6 ± 3.8 kg and 175.2 ± 4.3 cm. All participants were free from lower limb injuries in the study. Written informed consent was obtained from each participant before data collection.

Experimental Protocol

Data collection was conducted on the M.M. Hall natural grass football field at Aligarh Muslim University (A.M.U.) under controlled environmental conditions. A standard size-5 football was placed on the official penalty spot (11 m from the goal). Absence of goalkeeper with circular target of circumference of 85cm is placed at the right side top corner of the goal post. Following a standardized 10-minute dynamic warm-up, each participant performed five (5) instep penalty kicks, consisting of five kicks with the right foot. A rest interval of 60–90 seconds was provided between attempts to minimize fatigue. For biomechanical analysis, one representative trial from each foot was selected based on proper execution technique and clear visibility of the reflective markers.

Motion Capture and Data Processing

Two digital video cameras synchronized in time were used to record the kicking movement. A Sony FDR-AX700 camera (100 Hz) was positioned 4 m from the player, perpendicular to the sagittal plane at a height of 0.92 m. A Canon Legria SF-100 camera (50 Hz) was placed 12.2 m away at a diagonal angle to capture additional movement perspectives. Both cameras operated with a shutter speed of 1/1000 s to ensure accurate capture of high-speed movement.

Two dimensional coordinates were obtained using the Direct Linear Transformation (DLT) method. Reflective markers were placed on key anatomical points were identified including the acromion, greater trochanter, lateral femoral epicondyle, lateral malleolus, and the head of the fifth metatarsal. The recorded motion data were digitized using Kinovea motion analysis software and fourth-order low-pass Butterworth filter (6 Hz cut-off) was applied to reduce signal noise.

Variables and Statistical Analysis

Linear kinematic variables were calculated during two phases of the kicking movement: the Preparatory to Ball Contact and Post- ball Contact to Follow-Through before deceleration phase. Successful and unsuccessful kicks directed toward the right upper corner were compared. Statistical analysis was performed using the paired-sample t-test to determine differences between conditions. Critical *t*-value of 2.776, Degrees of freedom (df = 4) and the significance level was fixed at $p < 0.05$. All analyses were performed using SPSS software.

III. Results

Variable	Phase	Successful (Mean ± SD)	Unsuccessful (Mean ± SD)	t	p
Hip Velocity (m/s)	Preparatory to Ball Contact	22.50 ± 2.45	21.54 ± 3.74	.999	.375
	Post- ball Contact to Follow-Through before deceleration	11.87 ± 3.40	12.14 ± 3.62	-.123	.908
Hip Acceleration (m/s²)	Preparatory to Ball Contact	-540.7 ± 243.0	-521.3 ± 181.2	-.292	.785
	Post- ball Contact to Follow-Through before deceleration	-290.7 ± 103.5	-380.2 ± 253.4	.887	.425
Knee Velocity (m/s)	Preparatory to Ball Contact	45.74 ± 6.74	48.93 ± 6.62	-3.08*	.037
	Post- ball Contact to Follow-Through before deceleration	12.54 ± 3.83	13.53 ± 2.07	-.433	.687
Knee Acceleration (m/s²)	Preparatory to Ball Contact	-1871.2 ± 508.7	-2007.3 ± 329.2	1.356	.246
	Post- ball Contact to Follow-Through before deceleration	-1581.8 ± 485.1	-1856.4 ± 350.8	1.054	.351
Foot Velocity (m/s)	Preparatory to Ball Contact	62.39 ± 18.08	62.05± 19.82	.058	.956
	Post- ball Contact to Follow-Through before deceleration	11.88 ± 8.01	6.63 ± 8.15	1.204	.295

Foot Acceleration (m/s^2)	Preparatory to Ball Contact	-3155.6 ± 1710.6	-3724.4 ± 1549.2	1.233	.285
	Post- ball Contact to Follow-Through before deceleration	-3904.8 ± 1324.8	4403.0 ± 841.8	.963	.390

Table- 1. Comparison of Linear Kinematic Variables between Successful and Unsuccessful Right Upper-Corner Penalty Kicks

Figure- 1: Comparison of linear kinematic variables between successful and unsuccessful penalty kicks directed toward the right upper corner.

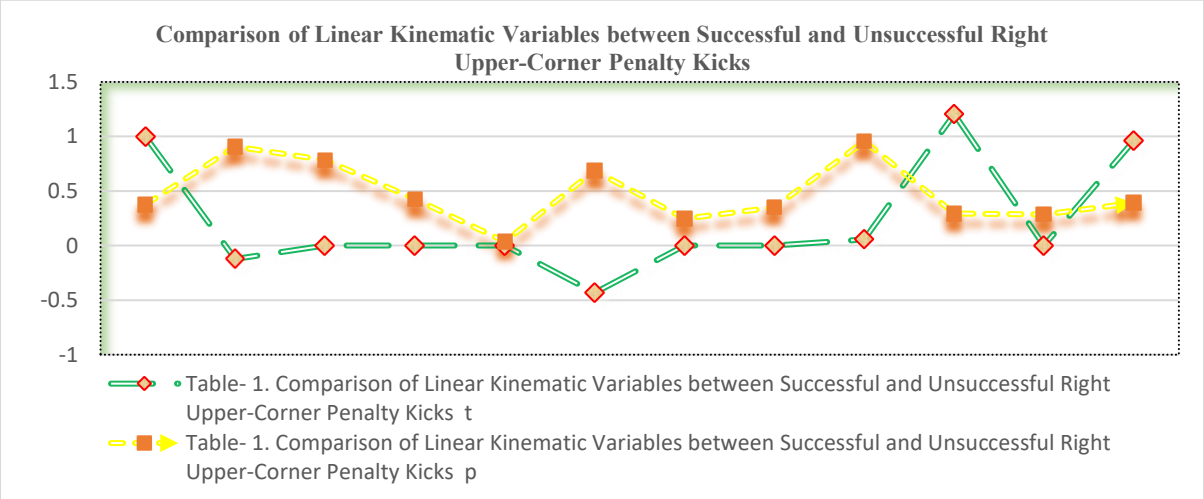

Table- 1 Figure- 1: The statistical analysis of data revealed that a statistically significant difference was observed only in knee velocity during the preparatory to ball-contact phase between successful and unsuccessful right upper-corner penalty kicks, as the obtained *t*-value ($t = -3.08$) exceeded the critical *t*-value of 2.776 at the 0.05 level of significance ($df = 4$; $p = 0.037$). However, no significant differences were found in hip velocity, hip acceleration, knee acceleration, foot velocity, or foot acceleration during either the preparatory to ball-contact or post-ball-contact to follow-through phases, as all remaining obtained *t*-values were below the critical *t*-value of 2.776 ($df = 4$; $p > 0.05$). These findings indicate that among the examined linear kinematic variables, only knee velocity during the preparatory phase significantly differentiated successful from unsuccessful right upper-corner penalty kicks.

IV. Discussion

Linear kinematic analysis revealed no significant differences in most segmental velocity and acceleration variables between successful and unsuccessful penalty kicks toward the right upper corner, indicating that the general proximal-to-distal sequencing pattern of the instep kick remained consistent irrespective of outcome. This supports previous findings that skilled soccer players maintain stable segmental coordination and energy transfer during repeated kicking actions (Vieira et al., 2022; Zhang et al., 2025).

However, unsuccessful kicks demonstrated significantly greater knee velocity during the preparatory to ball contact phase, suggesting that excessive or premature shank acceleration may disrupt optimal kinetic-chain sequencing. Efficient instep kicking depends on precise temporal coordination of proximal-to-distal momentum transfer, and excessive knee extension velocity may reduce control during terminal swing, thereby impairing football contact precision and directional accuracy (Augustus et al., 2024).

The absence of significant differences in foot velocity and acceleration further indicates that penalty kick accuracy was not determined solely by distal segment speed. Instead, successful kick placement appears to depend more on the timing and coordination of segmental interactions than on absolute linear kinematic output. This is consistent with recent biomechanical evidence highlighting inter-segmental coordination and impact mechanics as key determinants of kicking accuracy (Inoue & Nunome, 2025).

Overall, the findings suggest that successful penalty kick placement toward the right upper corner is influenced more by coordinated temporal sequencing and movement control than by greater linear velocity or acceleration production alone.

V. Conclusion

The present study concludes that successful and unsuccessful penalty kicks directed toward the right upper corner demonstrate largely similar linear kinematic characteristics, indicating that overall segmental velocity and acceleration patterns alone do not determine kick outcome. The only significant difference observed

was greater knee velocity during the preparatory to ball contact phase in unsuccessful kicks, suggesting that excessive shank speed may negatively affect movement control and football contact precision. These findings indicate that successful penalty kick performance is influenced more by effective temporal sequencing and inter-segmental coordination within the kinetic chain than by greater linear velocity or acceleration production. Therefore, penalty kick accuracy toward the right upper corner appears to depend primarily on controlled movement execution and optimal coordination of lower-limb segments during the kicking action.

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