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Biomechanical Factors Influencing Post-strike Ball Velocity in Football Players: A Cross-sectional Study

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ABSTRACT

Introduction: Optimising post-strike ball velocity is essential for success in football. Biomechanical factors play a significant role in determining ball speed. However, further investigation is needed to understand the specific relationships between the biomechanical factors and post-strike ball velocity in football players.

Aim: To identify the key biomechanical factors contributing to post-strike ball velocity and provide insights for enhancing performance in league-level football players.

Materials and Methods: A cross-sectional study was conducted in the Department of Arthroscopy and Sports Medicine at the Sri Ramachandra Centre for Sports Science, Tamil Nadu, India. The duration of the study was five months, from January 2022 to May 2022. The study included 25 professional male football players from national-level league teams. Participants performed maximal instep kicks while various kinematic variables were measured using Vicon cameras, Advanced Mechanical Technology Inc., (AMTI) force footplates, and a radar speed gun. Data processing was performed using Vicon Nexus software version 2.7. The data were analysed using R statistical software version 4.0.2. The Analysis of Variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) post-hoc tests, were used to compare the various kick matrices across the players. Pearson's r correlation analysis was used to check for a correlation between post-strike ball velocity and other kick matrices. Multiple regression analysis was conducted to examine the relative effects of various kick matrices on post-strike ball velocity, with significance set at a p-value <0.05.

Results: The mean age of the study participants was 18.8 years. A significant positive correlation was observed between prestrike foot velocity (r=0.58) and training experience (r=0.48) with post-strike ball velocity. Step-wise multiple linear regression analysis revealed that 39% of the variance in post-strike ball velocity could be attributed to training experience and prestrike foot velocity.

Conclusion: Training experience and prestrike foot velocity could be the most important factors to consider in order to maximise post-strike ball velocity among league-level football players.

Keywords: Kicking, Kinematics, Kinetics, Sports performance

INTRODUCTION

Ball velocity plays a crucial role in the success of kicks in football [1]. The ability to generate high post-strike ball velocity is a desirable skill for football players, as it can lead to powerful shots, accurate passes, and effective set-piece executions [2]. Understanding the biomechanical factors that influence post-strike ball velocity is essential for optimising performance and enhancing player capabilities [3]. Kicking is also the most easily reproducible action in football and hence is widely studied under laboratory environments [4]. The instep kick is the commonly used kick to generate maximal force [4]. Free kicks, including the penalty kick, are crucial and deterministic moments of the football game. Every player develops their own individual skills and strategies for free kicks, with the most frequently used technique being the "instep kick" [5,6]. Understanding the biomechanics behind a soccer kick is important to improve performance and reduce the risk of injuries [7]. The musculoskeletal movements involved in a soccer kick are a combination of proximal-to-distal sequencing of lower limb segments and trunk movements. There is the formation of a dynamic arc in the kicking leg through various phases of kicking, which has a direct correlation with the quality of the kick [3].

Apart from the commonly studied biomechanical factors involved in a kick, such as ground reaction force, angular and linear velocities at the hip, knee, and ankle, a few other lower segment variables have been extensively studied in relation to post-strike ball velocity in football players [3,5]. Ankle plantar flexion is one such variable that has been identified to influence ball velocity [8]. When the foot makes contact with the ball, the ankle is passively plantar-flexed, which is associated with an increase in ball velocity. The support leg plays a significant role in kicking performance, as the player's entire body weight is supported on that leg. Maintaining good balance, proper landing, and correct posture is crucial for optimal performance [9]. The kick is essentially an act of the kicking limb. Kicking involves the summation of forces, wherein the momentum is generated in a proximal-to-distal sequencing manner. The shoulder and trunk constitute the proximal elements of the kinetic chain that transfer kinetic energy onto the kicking foot [3]. The angular kinetic energy transfers along the trunk, pelvis, and kicking limb during a maximal instep kick [7]. The pelvic-shoulder separation angle influences the performance and quality of the kick [3]. A lower pelvic-shoulder angle in the players denotes a poor quality of the tension arc formation and thus results in a poorer kick quality.

While several studies have examined the biomechanics of kicking in football, there is still a need to specifically investigate the factors that contribute to post-strike ball velocity. By identifying these factors, coaches, trainers, and players can gain valuable insights into how to improve their kicking technique, generate greater ball velocity, and ultimately achieve better on-field outcomes. There is a lack of comprehensive research specifically focused on the factors influencing post-strike ball velocity in football among Indian players. Therefore, the present study aimed to examine the impact of biomechanical factors on post-strike ball velocity in league-level male football players. The assessment involved Three-dimensional (3D)-instrumented and standardised instep kicks, enabling a comprehensive analysis of the kicking technique.

MATERIALS AND METHODS

A cross-sectional study was conducted in the Department of Arthroscopy and Sports Medicine at Sri Ramachandra Centre for Sports Science, Tamil Nadu, India, where national league teams visited for precompetition medical assessment between January 2022 and May 2022. The sample size was calculated based on a previous study conducted by Athanasios Katis et al., (2015) [10], and due to logistic reasons, 25 professional male football players comprised the sample size for the study. The selection of participants was based on their representation of national league teams. Ethical clearance for the study was obtained from the Institutional Ethics Committee, with the approval number IEC/19/FEB/148/16. Prior to participation, all players were provided with detailed information about the study, its objectives, procedures, and potential risks and benefits. Written informed consent was obtained from each participant, ensuring their voluntary agreement to take part in the study.

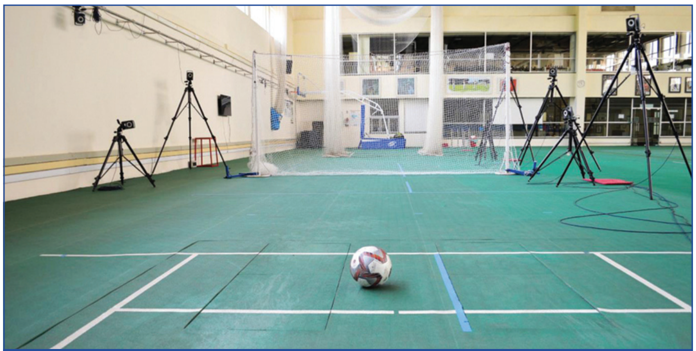
Inclusion criteria: Professional male football players with a minimum of five training years, age group between 18-25 years, players, who were playing league or division level were included in the study.

Exclusion criteria: Any musculoskeletal injury in the past six months that led to the loss of training sessions for more than a week were excluded from the study.

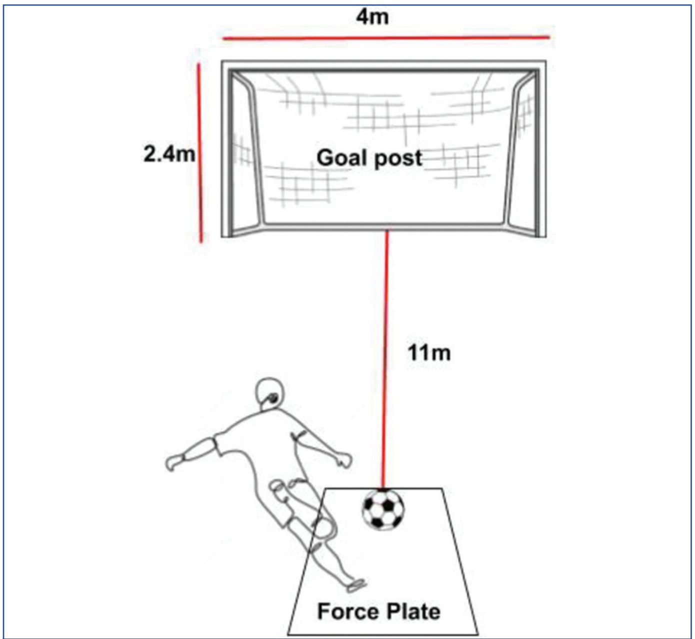
Study Procedure

Subjects were asked to perform the instep kick wearing suitable soccer shoes used during the game at an indoor facility with artificial turf (Uni-Turf Sports Surfaces Ltd., UK). Testing was scheduled at a fixed time of the day under ambient natural light supplemented with controlled indoor lighting at around 1200 lux. All subjects were explained about the study, and written informed consent was obtained. A set of 35 retroreflective markers was affixed to the player's skin over anatomical landmarks using a preadhesive spray and double-sided tape [Table/Fig-1]. Anthropometric measurements were taken as per the recommendations using a joint anthropometer. Sixteen Vicon MX T20-S cameras (@250 fps) (Vicon, Oxford Metrics, Oxford, UK) were used to collect the kinematic data. Two Bonita Two-dimensional (2D) video cameras (@125 fps) were placed behind and to the side of the subjects. Ground reaction forces were recorded simultaneously using two force footplates (AMTI BP600900-1000 Advanced Mechanical Technology Inc., USA), which were embedded beneath the surface. A Federation Internationale de Football Association (FIFA) standard football of size 5 was placed over the force plates [Table/Fig-2]. A standard distance of 11 meters from the goal post, simulating the penalty kick rules of football, was maintained during testing. The dimensions of the goalpost used were 4×2.4 meters. An illustration of the laboratory set-up is shown in [Table/Fig-3]. Post-strike ball velocity was recorded using a handheld radar speed gun (Pocket Radar Ball Coach, Pro-Level Speed Training Tool, and Radar Gun, USA), placed behind the goal post.

[Table/Fig-1]: Placement of retroreflective markers and anthropometric measurements prior to data collection.



[Table/Fig-2]: Biomechanics laboratory set-up with goal post, football, and vicon cameras.

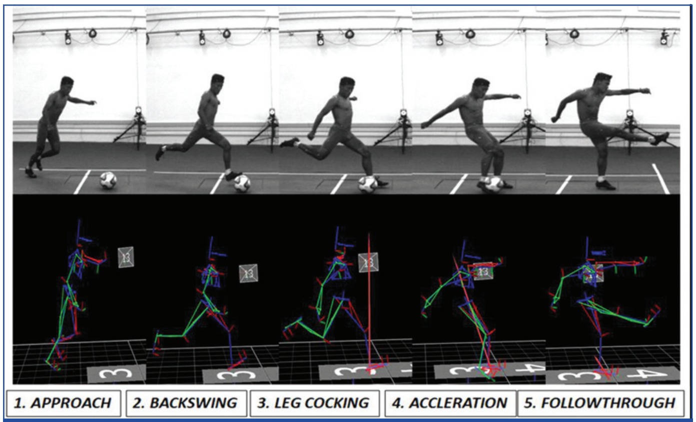


[Table/Fig-3]: Illustration of the laboartory set-up where instep kick was performed.

Following the static and dynamic calibration of the laboratory using a Vicon active wand, the players were asked to undergo a self-directed warm-up and also practiced two to three trial kicks to orient themselves to the artificial turf and the goal post. Each player was asked to perform five maximal football instep kicks targeting the goalpost. The kick that hit the goal with the maximum ball velocity was chosen for analysis. The phases of the instep kick in two and 3D frames have been shown in [Table/Fig-4]. In the selected kick, the completeness of data capture (radar gun, markers, and force plate data) was confirmed prior to the measurement of various kinematic variables. The pipeline was run in the Nexus software version 2.7, the Woltering filter was applied, and the required outputs were generated as follows:

- **Peak vertical ground reaction force (Pvgrf):** The largest peak vertical force measured in the z-axis of the force plate data.
- **Pelvic-shoulder separation angle:** The pelvis-shoulder separation angle was calculated by subtracting the pelvis projection angle from the shoulder projection angle in the z-axis.
- **Peak hip flexion velocity:** Hip flexion angles were differentiated with respect to time to obtain hip flexion velocity. Maximum hip flexion velocity was obtained at the end of the leg cocking phase for all players.
- **Support leg knee flexion at ball contact:** The knee flexion angle of the support leg on the force plate was measured on the x-axis at the time of ball impact.
- **Ankle plantar flexion at ball contact:** The plantar flexion of the kicking foot was measured at ball impact in the x-axis.

- **Peak trunk rotation velocity:** The trunk rotation angle was differentiated with respect to time to obtain trunk rotation velocity. Peak velocity throughout the entire cycle was obtained.
- **Prestrike foot velocity:** Measured two frames just before ball contact along the y-axis.



[Table/Fig-4]: A 2D and 3D capture of various phases of instep kick.

STATISTICAL ANALYSIS

All data were fed into the computer and analysed using R statistical software version 4.0.2. Categorical variables were presented as frequencies (n) and percentages (%), and continuous variables were presented as means and Standard Deviations (SD) of the sample or medians and Interquartile Ranges (IQR). The post-strike ball velocity was specified as the dependent variable. All other variables were considered independent variables or factors. ANOVAs, followed by Tukey's HSD post-hoc tests, were conducted to compare the various kick matrices across the players. Pearson's r correlation analysis was used to check for a correlation between post-strike ball velocity and other kick matrices. Multiple regression analysis was conducted to examine the relative effects of various kick matrices on post-strike ball velocity. The significance level was set at a p-value <0.05.

RESULTS

Baseline study characteristics are presented in [Table/Fig-5]. The mean age of the players was 18.8 years. The descriptive statistics of all the continuous dependent and independent (predictor) variables in the model are provided in [Table/Fig-6]. [Table/Fig-7] summarises the between-player (between defenders, goalkeepers, midfielders, and strikers) differences for various kick performance matrices and found no significant difference (p<0.05). The correlation between post-strike ball velocity and other kick performance variables as shown in [Table/Fig-8]. Prestrike foot velocity (r=0.58) and training experience (r=0.48) had a moderate positive correlation with post-strike ball velocity. Similarly, max knee flexion at acceleration (r=0.30), peak hip flexion velocity at leg cocking (r=0.29), ankle plantar flexion at ball contact (r=0.30), and length of the last stride/step (r=0.24) had a weak positive correlation with post-strike ball velocity. Whereas support leg knee flexion at ball contact (r=-0.29) alone had a weak negative correlation with post-strike ball velocity, however, the association was statistically significant (p-value <0.03). Multiple linear regression analysis showed [Table/Fig-9] that only training experience and prestrike foot velocity were significant predictors for post-strike ball velocity among Indian league football players. Other variables were not significant predictors or determinants of post-strike ball velocity. The adjusted R^2 value was 0.39, so 39% of the variation in post-strike velocity would be explained by the model containing training experience and prestrike foot velocity.

Variables	n (%)
Number of players (N)	25
Age (in years)	18.8 (0.96)
18	13 (52)
19	5 (20)
20	6 (24)
21	1 (4.0)
Height (meters) (Mean±SD)	1.73±1.69, 1.77
Weight (kg) (Mean±SD)	64.9±57.8,70.4
BMI (kg/m^2) (Mean±SD)	22.09±20.93, 22.47
Pvgrf (N) (Mean±SD)	2,226±1,918, 2,393
Pvgrf (BW) (Mean±SD)	32.7±28.7, 39.8
Player position	
Defender	9 (36)
Goalkeeper	4 (16)
Midfielder	9 (36)
Striker	3 (12)

[Table/Fig-5]: Baseline characteristics of the study participants.
Pvgrf: Peak vertical ground reaction force; BW: Body weight

Kick performance variables	Mean±SD
Max hip extension at backswing (°)	21.25±7.03
Max knee flexion at acceleration (°)	117.07±9.24
Lateral trunk flexion (°)	8.86±5.09
Prestrike foot velocity (m/s)	19.40±1.07
Support leg knee flexion at ball contact (°)	43.76±9.18
Ankle plantar flexion at ball contact (°)	33.97±11.50
Pelvic shoulder separation angle at backswing (°)	20.33±6.15
Peak hip flexion velocity at leg cocking (°/s)	565.86±129.81
Peak trunk rotation velocity (°/s)	437.95±118.37
Length of last stride/step (m)	1.61±0.14
Post-strike ball velocity (m/s)	97.80±6.93

[Table/Fig-6]: Details of kick performance metrics for the study participants.

Variables	Defender, n=9	Goalkeeper, n=4	Midfielder, n=9	Striker, n=3	p-value
Pvgrf (N)	2,111.46 (305.63)	2,238.44 (341.33)	2,219.72 (425.83)	2,147.36 (300.64)	>0.9
Pvgrf (BW)	33.80 (6.18)	32.02 (6.95)	34.87 (5.87)	32.68 (6.96)	0.8
Max hip extension at backswing (°)	20.38 (6.18)	23.70 (11.44)	22.30 (6.58)	17.43 (5.36)	0.7
Max knee flexion at acceleration (°)	117.79 (9.35)	121.88 (10.33)	110.88 (5.17)	127.10 (6.00)	0.08
Lateral trunk flexion (°)	10.03 (4.28)	11.47 (6.11)	7.56 (5.69)	5.80 (3.17)	0.3
Prestrike foot velocity (m/s)	19.02 (0.81)	19.46 (1.41)	19.52 (1.22)	20.12 (0.89)	0.4
Support leg knee flexion at ball contact (°)	42.90 (12.57)	42.30 (10.99)	46.46 (5.39)	40.17 (4.82)	0.5
Ankle plantar flexion at ball contact (°)	36.31 (9.59)	36.12 (12.48)	29.07 (13.39)	38.80 (9.59)	0.5
Pelvic shoulder separation angle at backswing (°)	24.69 (6.16)	20.18 (2.32)	16.40 (5.43)	19.27 (4.45)	0.07
Peak hip flexion velocity at leg cocking (°/s)	517.47 (65.07)	471.05 (192.76)	639.38 (76.58)	616.90 (222.12)	0.06
Peak trunk rotation velocity (°/s)	420.89 (140.42)	463.05 (90.37)	452.20 (123.13)	412.93 (109.33)	0.7
Length of last stride /step (m)	1.61 (0.14)	1.63 (0.09)	1.61 (0.17)	1.61 (0.12)	>0.9
Post-strike ball velocity (m/s)	95.33 (4.90)	98.50 (7.19)	96.22 (5.65)	109.00 (6.93)	0.07

[Table/Fig-7]: Details of kick performance metrics comparison across the player positions.
Pvgrf: Peak vertical ground reaction force
Test applied: One-way ANOVA; p-value <0.05 set as significant

Kick performance metrics	Correlation coefficient (r)	p-value
Training experience	0.48	0.03*
Max hip extension at backswing (°)	-0.06	0.54
Max knee flexion at acceleration (°)	0.30	0.01*
Lateral trunk flexion (°)	-0.13	0.98
Prestrike foot velocity (m/s)	0.58	0.001*
Support leg knee flexion at ball contact (°)	-0.29	0.03*
Ankle plantar flexion at ball contact (°)	0.30	0.02*
Pelvic shoulder separation angle at backswing (°)	-0.07	0.44
Peak hip flexion velocity at leg cocking (°/s)	0.29	0.03*
Peak trunk rotation velocity (°/s)	-0.2	0.22
Length of last stride/step (m)	0.24	0.02*

[Table/Fig-8]: Correlation between post-strike ball velocity and other kick performance metrics.
test applied: Pearson's correlation test; *p<0.05

Variables	Estimate (β)	Std. Error	t-value	p-value
Intercept	34.362179	25.072398	1.371	0.18
Training experience	0.99	0.43	2.22	0.03*
Prestrike foot velocity (m/s)	1.30	1.4	0.96	0.03*
Peak hip flexion velocity at leg cocking	0.01	0.009	1.19	0.24
Length of last stride	19.80	10.28	1.92	0.07
Max knee flexion at acceleration (°)	0.05	0.15	0.33	0.74
Support leg knee flexion at ball contact (°)	-0.13	0.15	-0.87	0.39
Ankle plantar flexion at ball contact (°)	0.04	0.11	0.43	0.67

[Table/Fig-9]: Multiple linear regression analysis on the correlation between post-strike ball velocity and other variables after adjustment for potential confounders.
Multiple R-squared: 0.54, Adjusted R-squared: 0.39, *p-value <0.05
Multiple linear regression analysis tests were done

DISCUSSION

Training experience and prestrike foot velocity were significant predictors of post-strike ball velocity among the participants, suggesting that a higher velocity of the foot before striking the ball contributes to greater ball velocity. In the present study, the mean post-strike ball velocity of the football players was 26 m/s (97.8 km/hr). As expected, the ball velocity of strikers was found to be higher than that of goalkeepers, defenders, and midfielders. This finding is consistent with previous studies that have reported similar ball velocities in soccer players [11-15]. Post-kick ball velocity is a crucial performance-related biomechanical variable in soccer, influenced by multiple factors such as ankle plantar flexion, prestrike foot velocity, peak angular thigh velocity, hip-shoulder separation angle, and mean peak trunk rotation velocity [15]. These factors highlight the complexity and interplay of various biomechanical components in achieving optimal ball velocity after a kick.

In the present study, a significant positive correlation (r=0.30) was found between ankle plantar flexion (33.97±9.5°) at ball contact and post-strike ball velocity. The mean ankle plantar flexion obtained was higher compared to the study conducted by Tol JL et al., among Dutch football players, where the ankle plantar flexion at ball impact was 26.1° [8]. This shows that the Indian players exhibited a greater flexion angle at the ankle, which contributed to a higher ball velocity. Another study conducted by De Witt JK and Hinrichs RN showed that peak angular thigh velocity had a significant correlation with post-strike ball velocity (r=0.64) [16]. However, in the current study, only a weak positive correlation (r=0.29) was observed between peak hip flexion velocity and post-strike ball velocity, and it was not a significant predictor of ball velocity.

The support leg knee flexion at ball contact in the present study was 43.756±9.18°, which was similar to that obtained by Inoue K et al., [9]. Augustus S et al., have shown that maximal instep kick performance following a technique refinement to the support leg improved ball velocities to a significant extent by increasing the passive power flow to the kicking leg [17]. The support leg (also known as plant leg) knee flexion can be measured during foot plant or ball contact. The mean difference of measurement in these two instances was found to be 19 degrees by Orloff H et al., [18].

The pelvic shoulder separation angle measured at the backswing phase of the ball kick was 20.33° and showed no significant association with post-strike ball velocity in the current study. Lees A and Nolan L described pelvic shoulder separation to be 27.9° [19]. Similarly, the mean peak trunk rotation velocity was 437.95±118.37 degrees/sec, which was similar to the studies by Da Silva Carvalho D et al., and Fullenkamp AM et al., [20,21].

The findings of the present study showed no significant association with any of the upper segment variables, such as pelvic shoulder separation angle or peak trunk rotation velocity, and post-strike ball velocity, which is in contrast to previous studies [7,21]. This may be explained by differences in several factors such as ethnicity, anthropometry, and kicking techniques followed by the Indian players. A strong, positive, and significant correlation was observed in the current study with only two of the parameters. First, the post-strike velocity showed a positive correlation with 'years of training' (r=0.48), which reinstates the fact that precision and power of kicking improve over time and with experience. Similarly, the foot velocity at impact with the ball was previously reported to have a significant correlation with post-strike ball velocity [22,23]. Levanon J and Dapena J proved a strong relationship between the speed of the foot and the speed of the ball, having a positive correlation of r=0.83 in their study with professional football players from the West. The present study also had a significant positive correlation between the prestrike foot velocity (r=0.58) and post-strike ball velocity [6].

Possible explanations for these findings can be attributed to the biomechanical principles of the kicking technique. A higher prestrike foot velocity allows for a greater transfer of energy to the ball upon impact. Moreover, players with more training experience may have developed better coordination, timing, and technique, resulting in improved ball velocity. Furthermore, the association between training experience and post-strike ball velocity suggests that accumulated practice, skill development, and improved coordination play a vital role in enhancing kicking performance. Experienced players may have honed their technique, timing, and power generation, leading to superior ball velocity compared to less experienced counterparts. It is noteworthy that other variables examined in the present study did not emerge as significant predictors of post-strike ball velocity.

This suggests that factors such as maximum knee flexion, peak hip flexion velocity, ankle plantar flexion, and length of the last stride/step may have less direct influence on ball velocity among the studied population. Other unmeasured factors, such as muscle strength, coordination, and variations in technique, could potentially influence post-strike ball velocity.

Limitation(s)

The limitation of the present study was smaller sample size and the indoor laboratory environments, especially the artificial turf, cannot exactly match the field of play, hence variability exists in the subjects' performance. The retroreflective markers placed can lead to skin movements while performing actions, leading to motion artifacts and processing errors.

CONCLUSION(S)

Prestrike foot velocity is the most determinant biomechanical factor that contributes to a higher ball velocity. The precision gained over the years of training in football also has an impact on developing a higher ball velocity. Therefore, these factors should be considered when framing training protocols to obtain a better kick and optimal performance.

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