USEFUL KICKING FOOT BEHAVIOR OF SOCCER INSTEP KICKING TO LAUNCH THE BALL IN VARIOUS DIRECTIONS

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The present study aims to illustrate the distinct characteristics of foot motion at ball impact, manipulating various ball launch directions. Seven experienced male university players conducted a total of 126 trials of soccer instep kicking, targeting three areas of the soccer goal. Three ultra-high-speed cameras recorded the ball impact aspect at 2000 Hz. We computed the foot contact point, the foot instep direction, and the foot swing direction. The multiple regression model demonstrated that the variance of ball launch directions was explained significantly by the foot contact point and the foot instep direction, while the foot swing direction was not. This result suggested that the foot contact point on the ball and the instep facing directions must be controlled appropriately to facilitate players to kick the ball in the desirable directions.

KEYWORDS: kicking direction, foot posture, swing direction, contact point, football

INTRODUCTION: In soccer, the instep kick is the most fundamental technique. Players occasionally rely on the kick to pass and shoot with power towards various launching directions during the match. A few previous studies have investigated the characteristics of the kicking motion towards various directions. Those studies found that experienced soccer players exaggerate the external rotation of the support leg knee (Kellis, Katis & Gissis, 2004) and the orientation of the pelvis and the tilt of the kicking leg (Scurr & Hall, 2009) when they are asked to kick the ball towards more angled directions.
The nature of the collision between the ball and the foot is the key to determining the resultant ball launching directions, while a series of complex movements throughout the body is necessary to kick the ball in various directions. Shinkai et al. (2009) was the first study to investigate three-dimensional foot and ball interaction during the ball impact using ultra-high-speed cameras. Their findings revealed that the ankle joint experiences multiaxial motions, including passive dorsi-plantarflexion, abduction, and eversion. Recently, Kimachi et al. (2022) tried to illustrate the exact ball impact point on the dorsal surface of the foot, encompassing straight, curved, and knuckle kicks. They reported that the contact points between the dorsal surface of the foot and the ball varied, corresponding to these kick types. However, no studies have described the ball-impacting action of the foot when players execute the instep kick towards angled directions.
In the context of the physical collision between the two objects, we hypothesised that these three parameters: foot contact point on the ball, foot posture at ball impact, and foot swing direction most likely explain the resultant launching directions of the kicked ball. To identify the critical factor in determining the kicked ball directions, it is necessary to clarify the relationships between the foot motions and the directions of the ball launch in detail. The present study, therefore, aims to illustrate the distinct foot motions at the ball impact that affect the ball launch directions.

METHODS: Seven experienced male university soccer players (Age: 20.9±1.3 years, Height: 172.9±4.7 cm, Mass: 66.1±4.7 kg, soccer experience: > 11 years) volunteered to participate in the present study. The participants underwent adequate warm-up exercises and familiarisation trials before data collection. Each participant conducted instep kicks of a stationary ball 11 m away from an official-size soccer goal (Width: 7.32 m, Height: 2.44 m). All participants kicked the ball with their preferred leg (right). The approach run-up angle was pre-set at 30 degrees for all trials to standardise relative kicking directions among the subjects. Three target areas were designated by dividing the soccer goal vertically into three equal sections (left, centre and right), prompting participants to direct the ball in the three

directions. The participant was instructed to aim at each target area randomly and completed six successful shots for each, resulting in 126 instep kicking trials (7 participants × 3 target areas × 6 trials).
We created a three-dimensional model of the shape of the shod foot based on our earlier work (Inoue & Nunome, 2018). The procedural steps were as follows: 1) eight key markers and 124 shoe surface markers (Figure 1a) were attached on the lateral side of the foot and the entire shoe surface, respectively; 2) the coordinates of all the markers on the shoe were recorded in a static calibration; 3) the local reference frame of the foot was set using the eight key markers to express the local coordinates of the 124 shoe surface markers, and 4) the point cloud coordinates forming shoe shape were reconstructed by interpolating among all shoe surface markers using a spline function (Figure 1b).
Three ultra-high-speed cameras (Fastcam Mimi AX50, Photron, Japan) were used to record the motion of the foot and ball through ball impact at 2000 Hz. From the coordinates of the eight key markers, the shoe shape was reconstructed in each trial (Figure 1c). The ball shape and the coordinates of the ball centre were also estimated from the markers on the ball surface and the known ball radius (110 mm).

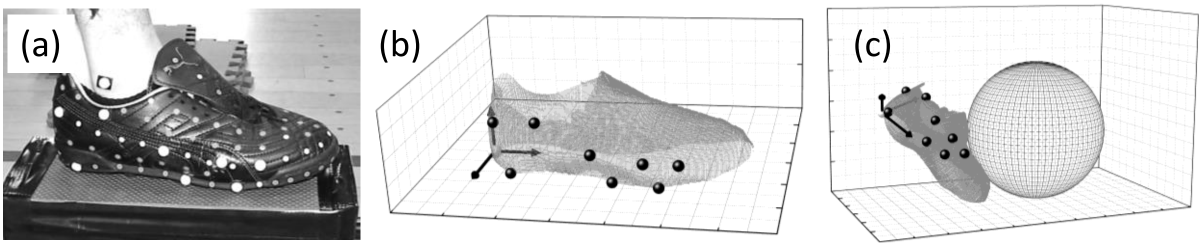

Figure 1: The modelling process of foot shape. From the definition of markers (a) in the static calibration, the foot shape (b) is illustrated by the point cloud along the shoe surface. The foot shape during kicking (c) is reconstructed using the eight key markers.

The ball launch direction was defined as the angle between the global Y-axis—which is horizontal and pointed to the middle of the soccer goal—and the initial velocity vector of the ball projected onto the horizontal plane. The initial ball velocity vector was calculated from the ball centre coordinate 5 ms (10 frames) after the ball left the foot. Kicking towards the right side of the soccer goal corresponded to the positive value (+) for the ball launch direction. The contact point of the foot and the ball was determined by the distance between the ball surface and the point cloud forming the foot dorsal surface. As the present study evaluated the lateral offset distance from the ball centre to the foot contact points, a positive value (+) signified that the foot made contact on the right side of the ball centre. The foot instep direction at ball impact was determined as the angle between the global Y-axis and the vector normal to the foot's instep. The angle was projected onto the horizontal plane. If the foot faced (normal vector pointed) to the right, this value was expressed as a positive (+). The foot swing direction at the ball impact was defined as the angle between the global Y-axis and the foot velocity vector projected onto the horizontal plane. The foot velocity vector was calculated from the foot centre of mass coordinates during the 5 ms before the ball impact. The foot velocity vector pointing to the right corresponded to a positive (+) value for the foot swing direction.
The foot posture at the ball impact was expressed as the foot segment's pitch, roll, and yaw rotation. The axes of each rotation corresponded to the axes of the foot local reference frame derived by static calibration. The yaw axis was perpendicular to the shoe sole and pointed upward, the roll axis was the vector from heel to toe along the shoe sole, and the pitch axis was perpendicular to the yaw and roll axis. The origin of this local reference frame was the heel side edge of the shoe sole. These rotational angles were computed in pitch, roll, and yaw order using the Cardan angle.
A multiple regression analysis was performed to identify the factors influencing the ball launching directions as the direction was set as the dependent variable. The independent

variables were the contact point, the foot instep direction, and the foot swing direction at the time of ball impact. Furthermore, a single correlation coefficient was utilised to examine the relationship between foot postures—characterised by pitch, roll, and yaw angles—and the direction of ball launch. The level of statistical significance was established at $p < .05$.

RESULTS: The ball launched angles ranged from -14.8° to 16.5°. The ball locations when the ball passes through the goal line are plotted in Figure 2.

The forced entry linear regression led to a significant regression model (R^2=.91, *p*<.001). Table 1 exhibits the summary of testing the regression coefficient. The model indicated that the foot contact point on the ball has the strongest influence on the ball launch directions (β=-.649, p<.001), followed by the foot instep direction (β=.324, *p*<.001).

For the foot postures, significant correlations were found between the roll and yaw angles of the foot and the ball launch direction. The single correlation coefficients for the ball launch direction with pitch, roll, and yaw angles were r=-.122 (*p*=.172), r=.791 (*p*<.001), and r=-.496 (*p*<.001), respectively.

The foot contact points on the ball are distributed almost symmetrically and horizontally around the ball centre from -44 mm to 38 mm (Figure 3). The foot instep direction varied from -16° to 40°. Conversely, the foot swing direction ranged from 1° to 32°, with all values being positive.

Figure 4 compares the foot postures expressed by the average pitch, roll, and yaw angles when the participants kicked the ball towards the left (Figure 4a) and right (Figure 4b) target areas.

Table 1: Multiple regression model to predict ball launch direction.

Variables	Coefficient (B)	SE	Standardised Coefficient (β)	t	p		VIF
(intercept)	- 4.916	1.001		- 4.910	< .001	***	
Foot contact point	- .310	.029	- .648	-10.677	< .001	***	5.027
Foot instep direction	.265	.031	.324	8.617	< .001	***	1.929
Foot swing direction	.078	.077	.062	1.015	.312		5.014

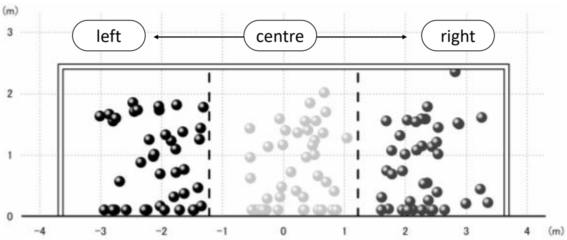

Figure 2: The estimated locations where the ball passed through the soccer goal mouth.

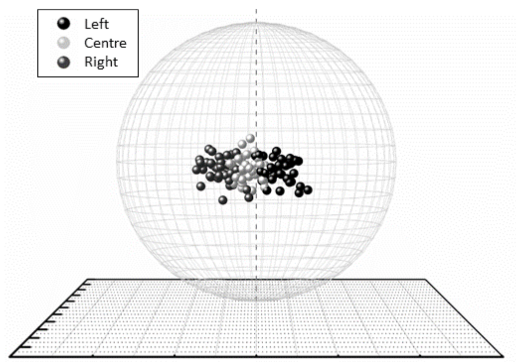

Figure 3: The plots of the foot contact point on the ball.

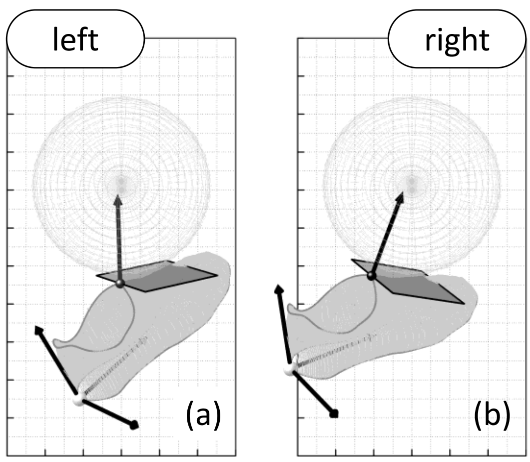

Figure 4: The overhead view of the foot instep orientation when kicking towards left (a) and right (b) directions.

DISCUSSION: We hypothesised that three parameters describing the nature of ball impact characteristics would explain the resultant ball launch directions. Our multiple regression model (Table 1) accepted the foot contact point on the ball and the foot instep direction as significant factors in determining the ball launch directions, while the foot swing direction did not, thereby partially contracting our hypothesis.

The multiple regression model indicated that the point where the foot hit the ball significantly most dominantly explains the variance of the resultant ball launch direction. As its coefficient was negative (B=-.320), it can be explained that to kick the ball towards the aimed direction, for example, to the left, the foot needs to contact the ball at its opposite side (right). As shown in Figure 3, the foot-hitting points on the ball are almost horizontally and symmetrically distributed around the ball centre, corresponding to the aimed directions.

Also, the multiple regression model demonstrated that the foot instep direction was another significant factor in explaining the variance of the ball launch directions. As shown in Figure 4, a clear difference can be seen in the foot-facing direction between the two conditions. This result suggests that players direct their foot instep towards the target. In addition, of the three angles that define the foot orientation, the roll and yaw angles at ball impact (roll: $r=.791$, $p<.001$; yaw $r=-.496$, $p<.001$) significantly correlated with the ball launch directions. Thus, it can be assumed that the foot instep direction was controlled by combining these two angles according to the aimed directions. This manipulation is assumed to facilitate players consistently striking the ball in the appropriate part of their instep, regardless of the kicking directions.

In contrast to our hypotheses, the multiple regression model did not accept the swing direction as a significant factor explaining the variance of ball launch directions. The range of the foot swing direction (1° to 32°) was notably narrower compared to the foot instep direction (-16° to 40°). The given smaller variance is a possible reason why the foot swing direction was not accepted in the multiple regression. It is worth noting that all the foot swing directions are biased and only possess positive values, unlike the foot instep direction and foot contact point on the ball. Eventually, there was no trial in which the participants swung their kicking foot towards the left. The finding indicated the foot always had a velocity towards the right even when the participants kicked the ball towards the left. This might suggest a practical difficulty in drastically changing the direction of the foot velocity during instep kicking. In the present study, all participants were right-footed and approached the ball diagonally (30 degrees) from left to right. In this condition, a linear momentum towards the right was already given to the kicking foot during the approach run. Exaggerated pelvic rotation was reported when players kicked the ball towards the left (Scurr & Hall, 2009). This action likely encourages the player's body to face the target, which helps to swing the foot in the desired direction. However, as the effect of the pelvis motion on changing the direction of foot velocity is probably insufficient to cancel out the lateral momentum caused by the approach run, it can be speculated that it is very hard to drastically alter the leg swing direction against the given linear momentum towards the right. In this context, manipulating the foot contact point on the ball and the foot instep direction at the time of the ball impact seems a more reasonable solution, which may facilitate players to control ball launching directions in the instep kicking.

CONCLUSION: From the present findings, we concluded that the foot contact point on the ball and the direction of the foot instep are feasible factors in manipulating the direction of the kicked ball. Players need to hit the ball with their foot at the opposite side where they intend to kick and need to direct the dorsal part of the foot towards the aimed direction. These results are likely to provide valuable insights for the training of soccer kicking skills in practical situations, specifically in controlling the ball direction.

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