Initial Ball Flight Characteristics of Curve and Instep Kicks in Elite Women’s Football

Alison Alcock, Wendy Gillear, Nick A.T. Brown, John Baker, and Adam Hunter

1Southern Cross University, Lismore, Australia; 2Australian Institute of Sport

Initial ball flight characteristics of curve and instep kicks were investigated. Fifteen international female footballers performed curve and instep kicks from a distance of 20 m from goal and at a 1 m² target. Seventeen Vicon cameras tracked three-dimensional coordinates of four reflective markers adhered to the ball. Ball flight characteristics were quantified, and the coordinates of the ball relative to the target center were recorded. The lateral launch angle and the angle of the spin axis relative to the horizontal best predicted the horizontal placement of the ball relative to the target. The vertical launch angle, antero-posterior velocity and amount of backspin best predicted the vertical coordinate. Regression models demonstrated how carefully controlled the flight characteristics must be with launch angles constrained within 3° to hit the target. Curve kicks were characterized by significantly greater lateral and vertical launch angles, increased sidespin and spin about the antero-posterior axis, and a more vertical spin axis. This information is beneficial for coaches in training players to achieve the characteristics required to score a goal and avoid a defensive wall. For example, if players consistently kick above or below the target, these findings identify the variables that will help rectify that error.

Keywords: free kick, set play, soccer, female

The flight trajectory of a ball is influenced by its initial linear velocity, launch angle, spin rate, spin axis orientation and the air density (Kreighbaum & Hunt, 1978). In football (soccer) many shots and passes are played with sidespin to produce a curved trajectory in the horizontal plane (Neilson, Jones, Kerr, & Sumpter, 2004). The curved trajectory results from an imbalance of pressure distribution around the spinning ball causing it to deflect as a result of the Magnus effect (Passmore, Tuplin, Spencer, & Jones, 2008). For example, in a direct free kick, a defensive wall is set up to prevent a straight shot at goal, but for players able to strike a ball with spin, this constraint can be overcome by swerving the ball over or around the wall and into the goal. A well executed free kick gives a goalkeeper little chance of saving a goal, yet despite the prevalence of free kicks in creating goals at an elite level, surprisingly few studies have investigated the initial launch conditions of the ball that produce these goal-scoring techniques (Bray & Kerwin, 2003).

Theoretical and experimental comparisons have shown curve kicks to be characterized by a reduced ball velocity, increased spin rate, more spin about the vertical axis, a greater launch angle and an increased flight time compared with instep kicks (Carré, Asai, Akatsuka, & Haake, 2002; Whiteside, Alderson, & Elliott, 2010). An instep kick, where the ball is hit with the medial-superior portion of the boot (Levanon & Dapena, 1998), is kicked with a straight trajectory and is commonly used for generating a fast ball speed (Nunome, Asai, Ikegami, & Sakurai, 2002). For male footballers, instep kick ball velocities have been reported with values up to 34.6 m·s⁻¹ (Manolopoulos, Papadopoulos, & Kellis, 2006; Nunome, Ikegami, Kozakai, Apriantono, & Sano, 2006; Nunome, Lake, Georgakis, & Stergioulias, 2006). For curve kicks that simulate a free kick, linear velocities ranging from 15.1 to 28.3 m·s⁻¹ and spin rates between 4.0 and 9.4 revs·s⁻¹ are reported in the literature (Bray & Kerwin, 2003; Griffiths, Evans, & Griffiths, 2005; Whiteside et al., 2010). This difference in ball velocity between kick types can be attributed to the trade-off between the development of ball spin rate and ball velocity (Asai, Carré, Akatsuka, & Haake, 2002). That is, as the distance from the point of force application and the ball center increases, ball spin increases, but ball velocity decreases. Neilson & Jones (2004) reported that professional male footballers are capable of producing spin rates up to 14 revs·s⁻¹. However, increased spin may not be beneficial because of the ensuing reduction in velocity. Players should therefore aim to create no more spin than is necessary to ensure...
the ball reaches the goal as quickly as possible, giving the goalkeeper minimal time to move and save the ball.

Despite the recent increase in the number of goals scored directly from free kicks in elite women’s football (Alcock, 2010), initial flight characteristics of curve kicks by females in realistic match situations remain neglected in the literature. Gender comparative studies of instep kicks indicate that females are generally not capable of achieving ball velocities as high as their male counterparts (Barfield, Kirkendall, & Yu, 2002; Shan, 2009; Tant, Browder, & Wilkerson, 1991). It is therefore likely that other ball launch variables would differ between genders also. Comparing the initial ball flight characteristics with the more commonly investigated instep kick from the same location would quantify the magnitude of the modifications in the initial flight characteristics used by elite females to achieve a curved trajectory that is required to both avoid the defensive wall and still score a goal. This would be useful to coaches who could train players to achieve those required flight characteristics.

In this study, ball linear and angular velocities, the orientation of the spin axis, and launch angles of curve kicks, which simulated a direct free kick, were compared with those of instep kicks for elite female footballers. The aims of the study were (1) to determine the initial ball flight characteristics that best predicted the final placement of the ball relative to a target center and (2) to compare the initial ball flight characteristics of a direct free kick (curve kick) that would likely score in an elite women’s football match with those of an instep kick at goal from the same location. It was hypothesized that the curve kicks would be kicked with more sidespin and greater vertical and lateral launch angles than the instep kicks to avoid the defensive wall.

Methods

Kicking Trials

After providing informed consent to the procedures which were approved by the institutional ethics committee, 15 international female footballers performed 15 instep and 15 curve kicks of a stationary ball. All kicks were performed in an indoor laboratory to reduce any airflow effects. Participants wore their own football boots and four FIFA approved Nike balls were used at random to reduce time retrieving balls between trials. Tasks were performed on artificial turf (Enduroturf Supreme, Enduroturf Pty Ltd, Australia).

The structure of the tasks was based on previous research (Alcock, 2010) that showed direct free kicks with the greatest goal scoring potential in elite women’s football were taken from central areas less than 27 m from the goal and placed in the top corner within approximately one meter of the goalpost and crossbar. The ball was kicked from a distance of 20 m at a 1 m² target positioned in the top corner of a projected image of a full size football goal. The ball was kicked from directly in front of the target. For curve kicks, a wall of four “players” 1.83 m tall and 1.78 m wide (Soccer Wall Company, Lewisville, Texas) was placed 9.15 m from the ball to simulate a direct free kick in match conditions. The wall position was determined by the national team coach and placed so that 1.5 mannequins were outside the near goalpost when viewing the target from the ball position. One participant was left-footed, for whom the laboratory set-up was mirrored so that the tasks for right- and left-footed players were the same. Left-footed player data were manipulated such that all results are presented for right-footed players. Participants were instructed to drive the ball straight at the target for the instep kick and to curve the ball around the wall for the curve kicks. For both tasks the instruction was to kick with the same focus on velocity and accuracy as in a game situation, that is, attempting to hit the top corner of the goal while also beating the goalkeeper. There was, however, no goalkeeper for the task. No constraints were placed on the number of steps or angle of the approach to the kick.

Four pieces of retro-reflective tape with approximate dimensions 2 cm² were attached to each of four footballs. Tape was used instead of spherical markers to minimize any effect on the aerodynamic properties of the balls. While these markers were not placed in specific locations, they were placed such that they were not coplanar and three were not collinear. Markers were tracked three dimensionally by 17 Vicon cameras (Vicon Motion Systems, Oxford, UK) sampling at 250 Hz. A digital video (DV) camera (Sony DCR-TRV950E, Sony Corporation, Tokyo) sampling at 25 Hz was positioned behind the ball with the goal in the field of view to monitor kick accuracy.

Data Analysis

Visual observation of the shot accuracy revealed that all participants had five or more curve and instep kicks that were close to the target and considered acceptable for the purpose of the study. Therefore, the five most accurate curve and instep kicks for each participant were used for analysis to offset individual player bias (curve: n = 75; straight: n = 75). To quantify the accuracy of each trial, the distance from the ball center to the target center was determined by digitizing and then converting the image-based pixel coordinates of the DV camera footage into real-world target coordinates using customized software written in Visual Basic for Applications (Microsoft Corporation, Washington, USA). The accuracy measure was taken one frame (up to 0.04 s) after impact with the target. Medio-lateral (x) and vertical (z) coordinates of the placement of the ball relative to the target were recorded with the target center at the origin. Measures of known points and repeat measures of the same points demonstrated that this method of measuring shot accuracy was valid to 0.02 ± 0.01 m and could reliably locate the same position within 0.008 ± 0.007 m. All kicks were within 2.2 m of the target center, with the exception of one straight kick for one player, which was 3.97 m away. Following an exploration into the effect of this outlier on results, the effects were found to be negligible and it was therefore included for analysis.
Three-dimensional coordinates of the four reflective markers were used to calculate the ball center. From analytic geometry, there is a unique sphere that passes through four non-coplanar points (Beyer, 1987). All Vicon trials were trimmed from the end of the foot–ball impact until the end of the available ball data (trials ranged from 10 to 42 frames which is approximately 0.9–3.7 m of ball flight). The end of the foot–ball impact was taken as the frame following peak ball linear velocity, based on the assumption that the ball can no longer accelerate, and can only decelerate, once the application of the kicking force has ceased. Ball linear velocity was calculated using the finite difference method (Winter, 2005):

\[
V_{x,i} = \frac{x_{i+1} - x_{i-1}}{2\Delta t} \text{ m} \cdot \text{s}^{-1}
\]

where \( V_{x,i} \) is the velocity at the \( i \)th sample, and \( \Delta t \) is the time between samples. The trimmed trials were then filtered using a Woltring quintic spline and a mean square error level of 20 (Vicon Nexus V1.4; Vicon Motion Systems, Oxford, UK). Only foot–ball postimpact data were treated because of problems associated with filtering through impact and ball flight characteristics were the focus of this study. All results are presented as the average of the first ten frames so that the same time frame was used for all trials, which was important because these variables do not remain constant throughout the flight. The average was used to account for any data oscillation over the initial part of ball flight.

The vertical launch angle (\( \gamma \)) was defined as the angle between the \( x-y \) plane (laboratory floor) and the vertical velocity vector (Figure 1). The angle between the medio-lateral (\( x \)) and antero-posterior (\( y \)) velocity vectors represented the lateral launch angle (\( \phi \)) (Figure 1). The angular velocity of the ball and its spin axis orientation were calculated based on the methods reported by Jinji & Sakurai (2006) and Sakurai et al., (2007). Briefly, a local coordinate system was created for the ball with the ball center at its origin. The angular velocity of the ball was calculated by performing a rotation matrix to translate the local coordinate system of the ball to the global coordinate system of the laboratory and then determining the relative rotation of the ball around that origin in each axis (Craig, 2004). The elevation angle (\( \theta \)), defined as the angle between the spin axis and the horizontal, and the alpha angle (\( \alpha \)), defined as the angle between the ball spin axis and the linear velocity vector were calculated (Figure 1). This method has been used previously to determine ball spin and spin axis orientation angles in tennis (Sakurai et al., 2007), cricket (Chin, Elliott, Alderson, Lloyd, & Foster, 2009) and men’s football (Whiteside et al., 2010). A validation of the ball calculations revealed an average error of 0.75 ± 0.58° in elevation angle values and 0.01 ± 0.01 revs s\(^{-1}\) in spin rate (Whiteside, Middleton, & Chin, in press).

![Figure 1](image_url)

**Figure 1** — The vertical (\( \gamma \)) and lateral (\( \phi \)) launch angles were calculated from the ball center linear velocity vectors. The ball elevation angle (\( \theta \)) is the angle between the spin axis and the horizontal, and the alpha angle (\( \alpha \)) is the angle between the spin axis and the ball linear velocity.
All the calculated variables were used in standard least squares regression analyses (JMP version 8.0.1, SAS Institute Inc., Cary, USA) to determine the flight characteristics that best predicted the x- and z-coordinates of the kicks relative to the target. The horizontal and vertical placement of the ball were considered separately due to problems associated with quantifying the absolute distance which does not account for the direction from the target center. All 75 curve and 75 instep kicks were used for the regression analyses to provide a spread of data. Of the kicks that hit the target (curve: \( n = 39 \); straight: \( n = 33 \)), initial ball flight characteristics were compared with an independent t test. Only accurate kicks were used for this analysis to identify the initial launch conditions required to hit the target. A criterion of \( p < .05 \) was used to indicate statistical significance.

Results

The resultant linear and angular ball velocities, along with the elevation and alpha angles from a typical curve and instep kick trial are presented in Figure 2. The average range of the first ten data frames for these variables are provided in Table 1.

The least squares regression analyses demonstrated that the lateral angle and the elevation angle were the best predictors of the \( x \)-coordinate on the target area. Using the predictive models provided in Equations (2) and (3), the relationship between the actual and predicted \( x \)-coordinates was high for both curve (\( r^2 = .87 \)) and instep kicks (\( r^2 = .91 \)). The variables that best predicted the target \( z \)-coordinate were the vertical angle, antero-posterior velocity and the amount of backspin of the ball. Equations (4) and (5) could predict the \( z \)-coordinate of where the ball hit the target with an \( r^2 = .78 \) for curve kicks and \( r^2 = .68 \) for instep kicks.

\[
X_{\text{curve}} = -162.29 + 31.36(\text{LateralAngle}) - 0.93(\text{ElevationAngle}) \\
X_{\text{instep}} = -40.52 + 30.4(\text{LateralAngle}) - 2.46(\text{ElevationAngle})
\]

\[
Z_{\text{curve}} = -1392.46 + 32.17(\text{VerticalAngle}) + 38.23(\text{LinVelY}) + 23.63(\text{AngVelX})a
\]

\[
Z_{\text{instep}} = -1163.2 + 27.83(\text{VerticalAngle}) + 34.82(\text{LinVelY}) + 14.05(\text{AngVelX})a
\]

Of the kicks that hit the target, there was no significant difference between the resultant linear velocity of the curve and instep kicks. However, when considered in three separate axial components, curve kicks had a significantly higher velocity in the lateral and vertical directions, and a significantly lower antero-posterior velocity compared with the instep kicks (Table 2). As a result, the vertical and lateral launch angles were significantly greater in the curve kicks.

The average resultant spin rate was 6.00 and 3.19 revs s\(^{-1}\) for the curve and instep kicks respectively. The curve kicks had significantly greater sidespin and rotation about the \( y \)-axis while the instep kicks had greater backspin. Subsequently the spin axis of the curve kicks was significantly more vertical (Table 2).

Discussion

The objective of this study was to compare the initial ball flight characteristics of laboratory simulated free kicks that would likely score in elite women’s football with those of an instep kick at goal from the same location and determine the characteristics that best predicted the placement of the ball relative to a target. After removing the data during impact and filtering the data during flight, the average of the first 10 frames removed the effect of oscillations in the early part of the trajectory and provided a good representation of the initial flight characteristics for each of the calculated variables.

The lateral and vertical launch angles were important predictors of the \( x \)- and \( z \)-coordinates of the ball impact point with the target respectively. The elevation angle (angle of the spin axis relative to the horizontal) was also a strong predictor of the \( x \)-coordinate. This demonstrates that for the curve kicks when the ball was kicked with a larger lateral angle than the instep kicks to avoid the defensive wall, the increased spin about the vertical axis indicating greater sidespin was the most important variable for bringing the ball back on target. For the instep kicks, a more horizontal spin axis was important because the lateral angle was small. The antero-posterior linear velocity and the amount of backspin are important predictors of the \( z \)-coordinate because if they are too high, the ball continues to rise over the crossbar. If the velocity is too slow for a given vertical angle, the ball will dip too much before reaching the goal. These findings are useful for coaching applications, for example if a player consistently kicks the ball high or low or continually to the left or right of

<table>
<thead>
<tr>
<th></th>
<th>Resultant Linear Velocity (m s(^{-1}))</th>
<th>Resultant Angular Velocity (revs s(^{-1}))</th>
<th>Elevation Angle (°)</th>
<th>Alpha Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range over first 10 frames</td>
<td>0.42 ± 0.03</td>
<td>1.12 ± 0.12</td>
<td>6.77 ± 1.03</td>
<td>7.3 ± 1.12</td>
</tr>
</tbody>
</table>
the target, it is possible to identify which variables will help to rectify that error.

The regression models demonstrate how carefully controlled the launch conditions must be to hit the target in a controlled environment. For example, for a direct free kick with an initial antero-posterior velocity of 20 m s\(^{-1}\) and a backspin rate of 0.6 revs s\(^{-1}\), the vertical launch angle must be constrained between 17.6° and 20.6° to hit the 1 m\(^2\) target in the vertical direction. Accounting for the fact that if the ball center hit the top edge of the target in a match, it would hit the crossbar, the range reduces to 2.5°. Similarly, the antero-posterior velocity must be within 2.5 m s\(^{-1}\) and the backspin rate within 4.3 revs s\(^{-1}\) to hit the target. In windy conditions, the required

Figure 2 — The initial resultant linear velocity, resultant angular velocity and elevation and alpha angles for a typical curve and instep kick for the first 15 frames of flight. Only the first 10 frames for each trial were used for analysis as that was the number of frames available for the shortest trial and it was important to use the same number of frames for each trial for accurate comparisons. A deceleration in linear ball velocity was evident even in the first 10 frames of flight.
The resultant linear ball velocities of the kicks that hit the target were comparable to those achieved by elite male footballers aiming at a target for both instep kicks (Lees & Nolan, 2002) and curve kicks (Whiteside et al., 2010). In contrast to findings of previous research that a trade-off exists between ball linear velocity and spin rate (Asai et al., 2002; Sakurai et al., 2007), there was no difference in the resultant linear velocities of the instep and curve kicks that hit the target. Potential reasons for this could be that the difference in spin rates in this study were not sufficient to reduce the ball velocity or because of individual player bias. For example, the participant with the fastest kicks had five accurate curves traveling at 24.79 m·s⁻¹, but only two accurate instep shots with a mean velocity of 25.44 m·s⁻¹.

The vertical launch angles of the kicks that hit the target in the current study were comparable to the findings of Asai (2000) who reported vertical angles of 13.5° for instep kicks in amateur males and Bray & Kerwin (2003) who found an angle between 16.5° and 17.5° was required for a curve kick taken 18.3 m from goal with pure sidespin and an initial velocity of 25 m·s⁻¹. Lateral launch angles have not previously been reported. Curve kicks had significantly greater lateral and vertical velocities and a significantly smaller antero-posterior velocity vector compared with the instep kicks. Along with the increased lateral and vertical launch angles of the curve kick compared with the instep kick, this indicates that the curve kicks traveled significantly more laterally and vertically to avoid the defensive wall of players whereas the instep kick traveled more directly toward the target. Although there was no difference in the resultant linear velocity, the larger antero-posterior velocity in the instep kicks means they would reach the target quicker than the curve kicks and give the goalkeeper less time to react. These findings highlight the important role played by the defensive wall of players in deviating the shot and providing the goalkeeper with an increased time to move and save the ball in a direct free kick.

The spin rates were similar to those reported by Whiteside and colleagues (Whiteside et al., 2010) for semiprofessional males performing curve kicks (5.7 revs·s⁻¹) and straight kicks (3.6 revs·s⁻¹) from 20 m in front of the goal at a 1.2 × 1.5 m target. They attributed the substantial amount of rotation in the instep kicks to the contact point being below the horizontal midline of the ball, thereby imparting backspin. This study investigated the direction of the spin and supported the suggestion of Whiteside and colleagues (2010) as the majority of spin for the instep kicks about the medio-lateral axis. Some sidespin was evident, likely because of the difficulty in hitting the ball exactly in the center since the distance of the point of contact away from the center is directly related to the amount of spin (Asai et al., 2002).

In contrast to the instep kicks, the majority of spin in the curve kicks was around the vertical axis, indicated also by the greater elevation angle, which represented a more vertical spin axis orientation. This sidespin is important for the curve kicks because when a ball is spinning and moving forward, a Magnus force acts at right angles to the plane containing the linear velocity.

Table 2 Initial ball launch conditions (mean ± SE) of the kicks that hit the target (curve: n = 39; instep: n = 33)

<table>
<thead>
<tr>
<th></th>
<th>Curve</th>
<th>Instep</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linear Variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resultant linear velocity (m·s⁻¹)</td>
<td>21.62 ± 0.24</td>
<td>22.05 ± 0.31</td>
<td>0.269</td>
</tr>
<tr>
<td>x axis (medio-lateral)   *</td>
<td>–2.61 ± 0.07</td>
<td>–1.10 ± 0.13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>y axis (antero-posterior)</td>
<td>20.28 ± 0.25</td>
<td>21.34 ± 0.33</td>
<td>0.012</td>
</tr>
<tr>
<td>z axis (vertical)        *</td>
<td>6.99 ± 0.07</td>
<td>5.30 ± 0.13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Vertical launch angle (°) *</td>
<td>18.95 ± 0.26</td>
<td>14.07 ± 0.47</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lateral launch angle (°) *</td>
<td>7.35 ± 0.20</td>
<td>3.02 ± 0.36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Angular Variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resultant angular velocity (revs·s⁻¹) *</td>
<td>6.00 ± 0.15</td>
<td>3.19 ± 0.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>x axis (positive is backspin) *</td>
<td>0.65 ± 0.15</td>
<td>2.50 ± 0.24</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>y axis (positive is clockwise about antero-posterior axis) *</td>
<td>–2.15 ± 0.09</td>
<td>–0.48 ± 0.12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>z axis (positive is clockwise sidespin) *</td>
<td>–5.44 ± 0.14</td>
<td>–1.17 ± 0.26</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Elevation angle (φ; angle of spin axis relative to horizontal; °) *</td>
<td>65.97 ± 0.97</td>
<td>16.88 ± 4.49</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Alpha angle (α; angle between spin axis and linear velocity; °)</td>
<td>88.60 ± 0.97</td>
<td>91.29 ± 2.14</td>
<td>0.231</td>
</tr>
</tbody>
</table>

*Indicates statistical significance at p < 0.05.
vector and the spin axis (Bray & Kerwin, 2003) causing a lateral deviation of the ball trajectory. Thus, the more vertical the spin axis, and the higher the spin rates, the higher the lateral deviation will be. The curve kicks also had significantly more rotation about the antero-posterior axis than the instep kicks, resulting from the application of the force from the foot whereby players kick up and over the ball to generate spin. The angle between the spin axis and the linear velocity vector (alpha angle) was effectively perpendicular, regardless of the kick type, supporting previous findings in football (Whiteside et al., 2010) and tennis (Sakurai et al., 2007).

Of the kicks that hit the target (Table 2) there was less variation in the flight characteristics of the curve kicks compared with the instep kicks, likely because of the constraints imposed by the defensive wall. The small standard errors in the launch angles and spin axis orientation of the curve kicks demonstrate how carefully controlled the flight characteristics of the kick must be to both avoid the defensive wall and hit the target. In addition, it indicates that the 15 participants used similar methods to achieve such a trajectory. The larger variation in flight characteristics for instep kicks suggests a greater number of ways of achieving a kick that hits the target were used. This information on the kicks that hit the target is beneficial for football practitioners because, through an understanding of the initial ball launch conditions required to score a goal, coaches can train players to achieve these flight characteristics.

A limitation of this study is that the findings relate to this sample of Nike footballs and it is possible that they may not transfer to other types of balls. However, the present results provide an insight into the initial ball launch conditions employed by elite female footballers performing a laboratory simulated direct free kick that would likely score in a match and how these differ to those of an instep kick from the same location. The orientation of the valve on the ball affects ball flight because it shifts the center of mass (Griffiths et al., 2005) and research has shown that significantly higher vertical launch angles are achieved when the valve is positioned at the top of the ball rather than the bottom before impact (Neilson et al., 2004). No attempt was made to control the valve position in this study as the intention was to determine values realistic to how participants would control the flight characteristics of the kick must be to both avoid the defensive wall and hit the target. In addition, it indicates that the 15 participants used similar methods to achieve such a trajectory. The larger variation in flight characteristics for instep kicks suggests a greater number of ways of achieving a kick that hits the target were used. This information on the kicks that hit the target is beneficial for football practitioners because, through an understanding of the initial ball launch conditions required to score a goal, coaches can train players to achieve these flight characteristics.

Future research should investigate the entire ball trajectory as the spin rate and orientation angle are not stable throughout the flight and the ball velocity can reduce by up to 8 m·s⁻¹ from 0.1 s to 0.9 s after ball impact (Griffiths et al., 2005). In addition, an investigation into the kinematics of players performing curve and instep kicks would provide an insight into the different techniques used to create the modifications in ball launch conditions that are required to avoid a defensive wall and still hit the target. Such an analysis would be beneficial to coaches and players in indentifying the fundamental coaching points for successful performance of the skills.

**Acknowledgments**

The authors gratefully acknowledge Chris Barnes for his contribution to this article.

**References**


