'BEND IT LIKE BECKHAM': BALL ROTATION IN THE CURVED FOOTBALL KICK

David Whiteside, Jacqueline Alderson and Bruce Elliott

School of Sport Science, Exercise and Health, the University of Western Australia, Perth, Western Australia, Australia

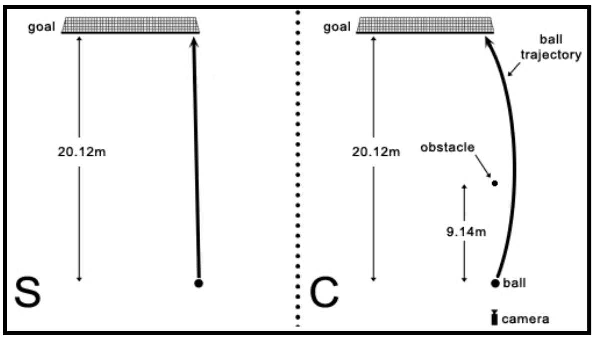
The objectives of this study were to quantify the 3D angular velocity and spin axes of a curved versus straight kick for goal in football. A 12 camera 250 Hz 3D Vicon motion analysis system recorded 4 semi-professional soccer players, as they performed 5 straight (S) and 10 curved (C) kicks. While the velocity of the ball was similar for both kicks (~20 $m.s^{-1}$), spin rate was significantly different (S=22.6 $rad.s^{-1}$; C=36.4 $rad.s^{-1}$). While the level of spin for the straight kick was surprising, the elevation angle of its spin axis was significantly lower in the straight compared with curved kicks (S=30.4°; C=62.6°).

KEYWORDS: Aerodynamics, football, ball rotation

INTRODUCTION: Football is frequently termed the 'world game' because of its playing numbers and spectator appeal, with scoring goals the key to success at all levels of play. The curved (C) kick is one of the key skills used to score goals and as such is an important aspect of the game. For such an important skill, the C kick has received significantly less attention from researchers compared with other types of football kicks. Successful C kicks rely first on a high velocity, off-centre contact and on the aerodynamic properties of the spinning ball, thereafter. The C kick is generally performed at sub-maximal velocities (Wang & Griffin, 1997), allowing the kicker more control over the position of the foot at ball contact. The few studies that have examined kicking a football with spin have recorded ball velocities between 15.1 and 25.4 $m.s^{-1}$ (Asai et al., 2002; Griffiths et al., 2005), values lower than those measured for maximal instep kicks, which have been reported between 28.0 and 32.6 $m.s^{-1}$ (Asai et al., 2002; Nunome et al., 2006). The further the foot contact point lies from the mid-line of the ball, the smaller the resultant ball velocity will be, while the spin rate will logically be greater owing to the eccentric force applied to the ball. There is a paucity of data investigating spin rate for curved kicks, with a single study establishing that the spin rate varies between 25 and 59 $rad.s^{-1}$(Griffiths et al., 2005). Other flight characteristics of the spinning soccer ball, such as the nature of the spin axis, have been neglected in the literature. The aims of this study were to identify the ball's 3D rotational and flight characteristics in a C compared with straight (S) kick for goal in football.

METHOD*:* Four semi-professional right footed soccer players aged 21.3 ± 1.0 years, height 173.5 ± 4.0 cm and mass 69.5 ± 10.1 kg, who were expert exponents of the curved kick were recruited. Testing was performed in an indoor laboratory that opened onto a grassed area, where the target goal was placed. The capture volume was calibrated using Vicon's standard procedures with the reconstruction volume large enough to record at least 5 m of ball flight post impact. A conventional size 5, FIFA approved ball was fitted with 4 hemispheric foam retro-reflective markers, so as to limit their effect on the mass and aerodynamic properties of the ball. A 12-camera 250 Hz, Vicon motion analysis system (Oxford Metrics Inc., UK) was used to track these markers, while a digital video camera, sampling at 50 Hz was positioned behind the kicker to record the ball's lateral deviation in the frontal plane (Fig 1). A 1.2 x 1.5 m target area was positioned in the top right hand corner of the goal. Following a warm up, participants completed S and C kicks at a set distance of 20.12 m from the goal (Fig 1). During the S kick, participants were instructed to aim for the target and to kick the ball without spin, using a technique they would normally use to perform an instep drive pass for distance in a game situation. Five successful S kicks that impacted the target area were recorded in order to establish baseline data. In the C kick, a 2 m vertical pole was placed between the kicker and the goal to represent the position where the outermost player in a defensive wall would stand if a direct free-kick was to be taken from the same position. The players were then instructed to curve the ball around this pole, with their preferred right foot, aiming at the same target area of the goal. The order of the kicks was randomised to eliminate order effects and successful kicks were required to curve around the pole and impact the target area.

Figure 1. Experimental set-up of the motion capture laboratory for the straight and curved kicks.



A local coordinate system was established for the ball that enabled the angular velocity vector in the global coordinate system to be calculated using the methods established by Sakurai et al. (2007). The direction of ball spin was expressed by three coordinate values and spin rate was defined by the absolute value of the angular velocity vector. A helical axis of rotation was calculated and expressed as two separate angular deviations from the x-axis, across two different planes (Fig 2a). The oblique angle (θ) was measured as the spin axis' deviation from the x axis in the x-z plane. The elevation angle (ø) was measured from the horizontal (or x-axis), in the x-y plane (Fig 2b). The angle between the velocity vector of the ball and its axis of rotation was calculated as the alpha angle (α). Digital video footage from the posterior camera was analysed using Siliconcoach software (Dunedin, New Zealand). The maximum lateral deflection of the ball was measured as the horizontal distance from the most extreme point of deviation in the ball's trajectory to the point where it crossed the goal line.

a)

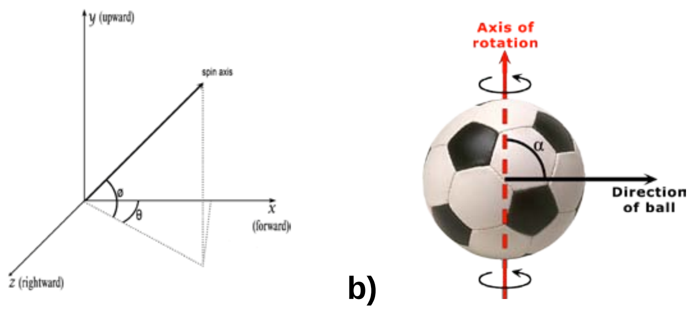


Figure 2. Illustration of a) the measurement of the ball rotation axis in three dimensions and b) the angle (α) between the velocity vector of the ball and its axis of rotation.

As this was a pilot test, no inferential statistics were run; however, a bivariate correlation was used to establish the association between, ball spin and ball velocity, and ball spin and lateral deviation.

RESULTS: As would be expected, the angular velocity of the ball was significantly higher in the C (36.4 rad.s^{-1}) compared with S kick (22.6 rad.s^{-1}), whereas velocity was similar.

Table 1. Mean, standard deviation and range of selected ball flight variables (n=4).* significant (p<0.05)

	Mean	S.D.	Range
Ball Rotation (rad.s^{-1})			
Straight Kick	22.6	4.5	3.1 – 4.7
Curved Kick	36.4	5.1	4.8 – 6.6
Ball Velocity (m.s^{-1})			
Straight Kick	22.1	2.9	18.3 – 25.4

Curved Kick	19.2	2.1	16.9 – 21.2
Alpha angle (α) (deg)			
Straight Kick	93.0	14.1	78.3 – 110.9
Curved Kick	85.3	12.8	66.2 – 93.0
Oblique angle (θ) (deg)			
Straight Kick	85.4	16.0	62.5 – 99.8
Curved Kick	95.2	24.3	62.0 – 113.4
Elevation angle (ø) (deg)			
Straight Kick	30.4	18.7	14.8 – 57.5
Curved Kick	62.6	3.9	56.9 – 65.3
Lateral Deflection of ball (m)			
Curved Kick	1.49	0.08	1.37-1.55

The elevation angle (ø) of the spin axis was significantly greater in the C (62.6°) compared with S kick (30.4°). The spin axis remained relatively perpendicular to the velocity vector of the ball, irrespective of the kick being performed (α - S: 93.0°; C: 85.3°). A strong negative correlation (r=-0.81) between ball velocity and spin rate existed, whereas a strong positive relationship (r=0.89) was found between ball angular velocity and lateral deflection. Collectively, the rotational characteristics above resulted in the ball deviating 149.3 cm from the lateral extreme of its parabolic trajectory, to where it crossed the goal line.

DISCUSSION: Whilst the respective linear foot velocities were not significantly different between kicks, ball velocity was approximately 3 $m.s^{-1}$ lower in the C kick. As the ball is kicked off-centre to produce rotation, it is logical to assume that there is a decreased transfer of energy through the centre of mass of the ball, explaining the lower ball velocity seen in the C kick. Kicking literature states that linear foot velocity is the best predictor of ball velocity (Lees & Nolan, 1998) however; it would appear that this theory may be less applicable to C kicks. The product of linear foot velocity and offset distance of impact would be an appropriate predictor of ball velocity in C kicks. The high spin rate in the C kick was to be expected. The explanation as to why such a noticeable angular velocity (22.6 $rad.s^{-1}$) existed in the S kicks most likely lies in the contact point on the ball. This point of contact seemed to lie inferior to the horizontal midline of the ball and as a result, backspin was imparted to the ball. The angular velocity seen in the S kick was not unexpected, as it is reasonably impossible to apply zero eccentric force to a ball when kicking. Contacting the ball even slightly off-centre with as much force, as is seen in a kick for distance, will decisively cause a degree of ball rotation. The spin axis remained relatively perpendicular to the velocity vector of the ball, irrespective of the kick being performed. In the transverse plane, the spin axis was essentially aligned with the goal line in both kicks. The slight differences seen in this oblique angle can be explained by considering the contact point on the ball. In the S kick, the ball was aligned with the target area, so the kicker merely had to contact the inferior aspect of the ball at its midline, to send it directly at the target. In the C kick however, the kicker had to initially direct the ball slightly away from the target area, in order to avoid the obstacle and let the curvature in its trajectory bring it back on target. In order to direct the ball in such a manner, the player kicks *across* the ball, again contacting the inferior aspect of the ball but this time to the right of its midline. The reactive motion of the ball to this horizontally *and* vertically aligned off-centre impact is enough to shift the oblique angle of the spin axis and account for the 10 degree difference. The most noteworthy difference in the rotational axis of the ball was its elevation from the horizontal (Fig 3). In the S kick, the participants seemed to be attempting to position their kicking foot as parallel to the ground as possible, so as to expose a large, flat surface to contact the ball slightly below its horizontal midline (which, in theory, would create a horizontal spin axis). However, such a foot position is mechanically impossible to achieve when kicking, so the foot was actually held oblique to the ground at impact, thus explaining the slightly elevated spin axis (~30°). This contrasts with the C kick, where the elevation angle of the spin axis was more than twice that seen in the S kick (62.6°). This is explained by the kicker contacting the ball off-centre, thus creating a horizontal torque around a more vertical axis. This axis orientation seems logical as the sideways force acting on a spinning sphere acts perpendicular to the velocity vector and the spin axis (Mehta, 1985). Therefore an upright spin axis would enhance lateral deflection. The increased elevation angle in the C kick allows the ball to deflect more horizontally and since the players were trying to curve the ball from right to left in the horizontal plane, a vertical rotational axis would be the most efficient way to achieve their goal. Obviously creating a perfectly upright axis of rotation is unattainable when kicking, but the increased elevation of the spin axis seen in the C kick is proof of the kickers' intent.

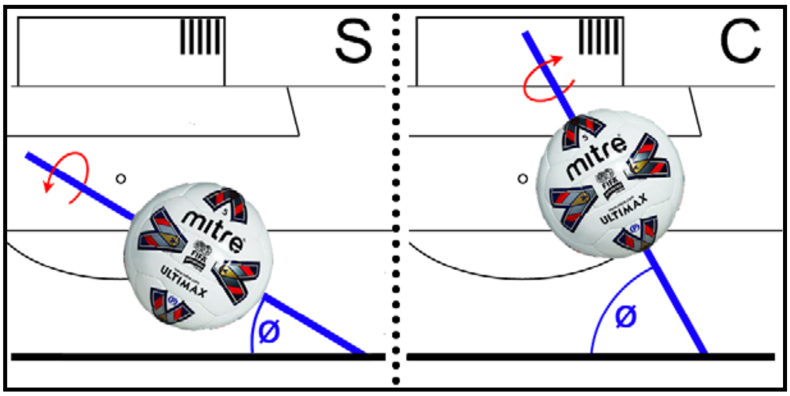


Figure 3. The elevation angle (ø) in the straight (30.4°) and curved (62.6°) kicks.

The strong negative correlation (r=-0.81) between ball velocity and spin rate supports the notion of a trade off existing between the two which has previously been alluded to in the literature (Asai et al., 2002). However, maximising ball spin may not be in the best interests of a player, as the ensuing velocity trade off would provide the goalkeeper with more time to react to the kick. The strong relationship between ball spin and lateral deflection (r=0.89) is supported in the literature.

CONCLUSION: Ultimately, it would appear that it is not in the kicker's best interests to apply excessive eccentric force to the ball when taking a free kick. Instead, the velocity-ball spin trade off suggests that players should aim to create no more ball rotation than is necessary for their given kick. This would reduce the detriment on ball velocity and ensure the ball reaches the goal as quickly as possible. The ball should be directed as close to the edge of the defensive wall as possible. Even in C kicks, kicking with power must be a primary goal. From the perspective of the goalkeeper these findings have direct implications regarding the positioning of their defensive wall. Many goalkeepers use the imaginary line drawn between the ball and the nearest goalpost to align their wall. They will direct the outermost player on the defensive wall to stand along this line, effectively blocking any straight access to the goal for the kicker. This study suggests that it is not beyond high level kickers to curve the ball around this player and into the goal, at high velocities. Therefore, as a rule, we suggest that for free kicks within 25 yards (23 m) of goal; the second-to-outermost player in the wall should stand on this imaginary line. This will increase the deviation required for a successful kick by ~50-60 cm, and in turn the ball rotation required to achieve this deviation. This will negatively affect ball velocity and allow the goalkeeper more reaction time to save the ball.

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