EFFECT OF THE LOCATION OF THE FOOT IMPACT POINT ON BALL VELOCITY IN A SOCCER PENALTY KICK

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The aim of this study was to identify the impact point on the foot that maximizes ball velocity in a soccer instep penalty kick. One male player performed 23 maximum-effort penalty kicks using a wide range of impact points along the length of his foot. The kicks were recorded by a video camera at 100 Hz and a biomechanical analysis was conducted to obtain measures of impact point, ball projection velocity, and kinematics of the kicking leg. We found that ball velocity was insensitive to the location of the impact point (at least for positions between the ankle joint and the base of the toes). This result suggests that players should consider other factors (such as shot accuracy, shot reliability, and foot comfort) when selecting the impact point.

KEYWORDS: collision, football, kinematics.

INTRODUCTION: Attaining a high ball velocity is very important in a penalty kick. The faster the player can kick the ball, the less time the goalkeeper has to react to the shot and so the better the chance of scoring a goal. For a full-instep kick, many coaches recommend that the player's foot should make contact with ball on the cuneiform bones of the mid-foot. This view was confirmed in an experimental study by Ishii, Yanagiya, Naito, Katamoto, and Maruyama (2012). They observed an inverted-u relationship between ball velocity and the location of the impact point. The projection velocity of the ball was greatest when the impact point was about 6 cm distal to the ankle joint (i.e., close to the centre of mass of the player's foot), with ball velocity about 15% less when the impact point was at the base of the toes or at the ankle joint.

Unfortunately, the test conditions in the study by Ishii et al. (2012) did not replicate those for a penalty kick. The impact point on the foot was manipulated by placing the ball on a kicking tee and adjusting the height of the tee from 0 to 12 cm. Also, the kicks were performed with a one-step approach and were aimed at a target that was 4 m away. For a penalty kick, a more ecologically valid method of manipulating the impact point would be to place the ball on the ground and ask the player to adjust their kicking action so that the ball contacted the foot at different positions along the length of the foot. Also, the player should have an unrestricted approach and should shoot from the penalty spot at a set of goals.

The aim of the present study was to quantify the relationship between the location of the impact point and the projection velocity of the ball in a full-instep penalty kick. Our hypothesis was that there would be an inverted-u relationship similar to that observed by Ishii et al. (2012).

METHODS: This study used an experimental research design in which the location of the foot impact point was systematically varied. An experienced intercollegiate male soccer player volunteered to participate in the study (age 23 years; body height 1.82 m; body mass 75 kg). The study adhered to the tenets of the Declaration of Helsinki and was conducted in accordance with procedures approved by our institutional ethics committee. The participant was informed of the protocol and procedures prior to his involvement, and written consent to participate was obtained.

Twenty-three simulated penalty kicks were conducted in still air conditions in an outdoor football facility. The kicks were performed on a 3G artificial grass surface and were aimed at a regulation-sized goal that was 11 m away from the kicking spot. A FIFA-approved match ball (Mitre Calcio, size 5) inflated to the regulation pressure was used, and the participant wore tight-fitting clothes and his own Nike T90 Laser II football boots. Colour-contrasted markers were placed on the participant's skin or clothing directly over the joint centres of the hip (major trochanter), knee (lateral epicondyle of femur), ankle (lateral malleolus of fibula), and toe (lateral aspect of distal head of fifth metatarsus). The participant used a constant run-up of three steps (about 3 m), and the run-up and kicking action of the kicking leg were in the plane of the flight of the ball. The participant performed maximum-effort kicks while attempting to use an impact point that was ‘close to the ankle’, ‘close to the mid-foot’, and ‘close to the toes’. The order of the kicks was randomized and an unlimited rest interval was given between kicks to minimize the effects of fatigue on performance.

A JVC GR-DVL9600 video camera (Victor Company of Japan, Yokahama, Japan) operating at 100 Hz was used to record the movement of the ball and the participant during the kicks. The video camera was mounted at right angles to the kick direction and the movement space was calibrated with three vertical poles that were placed along the line of the kicking plane. An Ariel Performance Analysis System (Arial Dynamics, Trabuco Canyon, CA, USA) was used to digitize the motion of the participant’s kicking leg and the centre of the ball in the video images. Each trial was digitized from about 2 steps before the kick to at least 10 frames after the ball broke contact with the foot. The coordinates of the participant and ball were calculated from the digitized data using the two-dimensional direct linear transform (2D-DLT) algorithm. Joint coordinate data were smoothed using a second-order Butterworth digital filter with a cut-off frequency of 10 Hz for the horizontal direction and 12 Hz for the vertical direction, and the velocities of the joint markers were calculated by numerical differentiation of the coordinate data.

The projection velocity of the ball was calculated using unfiltered ball displacement data from images immediately after the ball broke contact with the foot. The horizontal component of the ball velocity was calculated as the first derivative of a linear regression line fitted to the ball displacement data, and the vertical component of the ball velocity was calculated as the first derivative of a quadratic regression line (with the second derivative set equal to –9.81 m/s^2) fitted to the ball displacement data (Nunome, Ikegami, Kozakai, Apriantono, & Sano, 2006). The uncertainties arising from the fitted curves indicated that the uncertainty in ball velocity was about 0.4 m/s (±95% CI).

The point of impact between the foot and the ball was identified in the first frame in which the foot made contact with the ball. During the collision the ball deformed and so the foot and ball appeared to make contact along line. The point of impact was taken as the midpoint of this line (Nunome et al., 2006; Shinkai, Nunome, Isokawa, & Ikegami, 2009). Re-digitising a trial five times indicated that the uncertainty in the location of the impact point was about 1.3 cm (±95% CI).

The participant’s kicking technique was quantified with measures of foot velocity at impact, rotational range of motion of the thigh, knee angle at maximum knee flexion, maximum angular velocity of the thigh, and angular velocities of the thigh and shank at impact (Ball, 2007; Linthorne & Patel, 2011). We also measured the angle of the knee joint and the angle to the horizontal of the shank and thigh segments at the instant of impact. The horizontal velocity of the hip at touchdown of the support leg was taken as a measure of the participant‘s run-up velocity. In this study the greatest source of uncertainty in the kick technique variables arose from the sampling frequency of the video camera (Hay & Nohara, 1990). The uncertainties were: foot velocity, 2.0 m/s; run-up velocity, 0.3 m/s; segment angle or joint angle, 7 deg; and segment angular velocity or joint angular velocity, 60 deg/s.

The ball velocity and kicking technique variables (y) were plotted as a function of the location of the impact point (x). A straight line, $y = mx + c$, and an inverted-u function, $y = y_{\text{opt}} - a(x - x_{\text{opt}})^2$, were fitted to the data (Linthorne & Patel, 2011). The most appropriate curve for the data was decided by examining the distribution of the residuals and with calculations of Akaike’s Information Criterion (Motulsky & Christopoulos, 2004).

RESULTS: A straight line was a better fit to the ball velocity data than an inverted-u function. For the linear fit, the gradient was zero ($m = -0.01 \pm 0.12$ m/s per cm; ±95% CI) and so ball projection velocity was independent of the location of the impact point with no clear optimum location (Figure 1). Foot velocity mirrored the relationship for ball velocity and also had a gradient of zero ($m = 0.03 \pm 0.07$ m/s per cm). The participant maintained a constant kicking action in all the kicks and there was no systematic variation with the location of the impact point. The participant displayed the characteristic whip action of the kicking leg, where the thigh angular velocity at impact was close to zero (480 ± 120 deg/s; mean ± SD) and the shank angular velocity reached a maximum (1650 ± 160 deg/s) at close to the instant of impact. The maximum knee flexion angle was 52 ± 8 deg, the maximum angular velocity of the thigh was 850 ± 70 deg/s, and the run-up velocity was 4.3 ± 0.5 m/s. The ball projection velocity was 23.9 ± 1.2 m/s (mean ± SD), the foot velocity was 17.3 ± 0.7 m/s, and the ball projection angle was 8 ± 5º. There was no systematic effect of the order of the kicks on ball velocity or kicking mechanics, and hence no evidence that fatigue influenced the results.

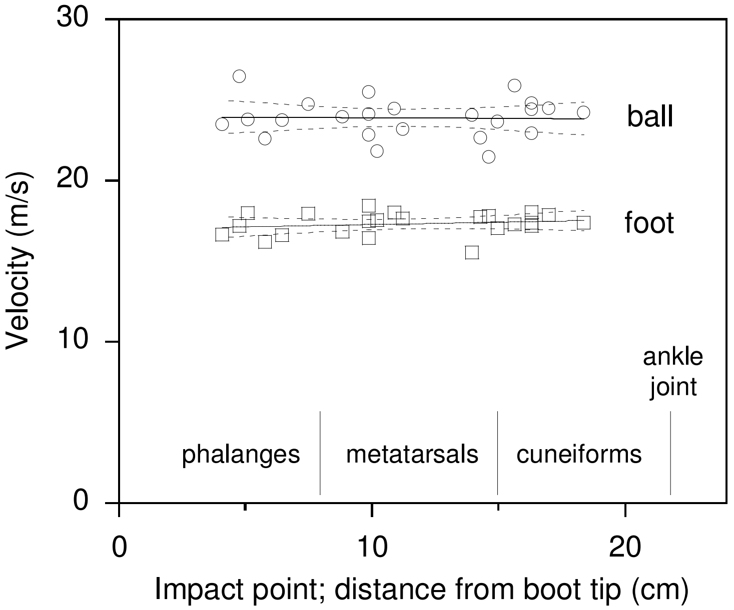

Figure 1: This plot shows that the projection velocity of the ball was insensitive to the location of the foot impact point. The participant maintained a constant foot velocity at impact. The solid lines are the linear regression fits and the dashed lines show the 95% CI of the regression line.

DISCUSSION: Kicking involves the transfer of momentum from the player to the ball. According to a well-known collision model of kicking, the projection velocity of the ball is determined by the impact velocity of the player's foot, the effective mass of the player's foot, and the amount of energy that is dissipated during the collision (Daish, 1972; Lees & Nolan, 1998). The location of the impact point on the foot was expected to influence the ball velocity in two main ways. For a foot that is swinging about the hip joint, a more distal impact point has a greater linear velocity and therefore should produce a greater ball velocity. In contrast, a more distal impact point on the foot is expected to produce a greater torque about the ankle joint and hence dissipate more energy through inelastic deformation of the foot (Ishii et al., 2012). Overall, there should be an optimum impact point that is determined by the interplay between the advantage of increased foot velocity and the disadvantage of increased energy loss. However, in the present study we observed a linear relationship between the location of the impact point and ball velocity, with no clear optimum impact point.

Although a linear relationship was the best fit to the ball velocity data, our data do not exclude an inverted-u relationship. However, for an inverted-u fit the upper 95% confidence limit of the curvature is only a = 150 m/s per m^2, whereas Ishii et al. (2012) observed a curvature of about 700 m/s per m^2. Our ability to identify an inverted-u relationship in the data was limited by the resolution of our measurements. Repeating the study using a video camera with a higher frame rate (>500 Hz) would give more accurate measures of impact point, foot velocity, and ball velocity, and this would confirm (or otherwise) our observed linear relationship.

The uncertainty in the linear fit to our ball velocity data indicates that the difference in velocity between an impact at the ankle joint and an impact at the base of the toes (separated by a distance of 15 cm) is no greater than 1.8 m/s (±95% CI). Inter-trial variations in ball velocity were considerably greater than this, and underlines that precise selection of the impact point is not important (at least for the participant in this study).

In this study we did not monitor the position of the support leg, movements of the upper body, or 3D motions of the kicking leg out of the plane of the flight of the ball. Therefore, we cannot exclude the possibility that the observed relationship between impact point and ball velocity was affected by systematic changes in these factors.

A limitation of our study is the use of only one participant, and so the results we obtained might be idiosyncratic. However, we observed measures of kicking technique that were similar to those obtained in other studies of male players (Ishii et al., 2012; Nunome et al., 2006; Shinkai et al., 2009). Therefore, it appears likely that the results from the present study would also apply to other adult male players of similar standard.

CONCLUSION: We found that the ball velocity in an instep penalty kick is insensitive to the location of the impact point (at least for impact points between the ankle joint and the base of the toes). This result suggests that players should consider other factors (such as shot accuracy, shot reliability, foot comfort, and deceiving the goalkeeper) when selecting the impact point.

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