A PILOT STUDY OF BALL IMPACT CHARACTERISTICS IN VARIED BALL LAUNCHED DIRECTIONS IN SOCCER INSTEP KICK

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The purpose of the present study was to identify the characteristics of ball impact foot motion in various ball launched directions. Eighteen trials of soccer instep kicking targeting six areas of the full-size soccer goal at 11 m, were analysed. The collision between the foot and ball was recorded using three ultra-high-speed cameras at 2000 Hz. The foot contact point on the ball and the foot swing direction had a strong correlation with the ball launch direction. It can be interpreted that the foot contact point and swing direction are essential factors to kick the ball towards the targeting direction. Moreover, the roll angle of the foot segment significantly affected the ball launch direction. This result suggested that the roll angle has a role in facing the instep of the foot towards the target direction in order to control the ball launch direction.

KEYWORDS: foot shape, foot posture, swing direction, contact point.

INTRODUCTION: Instep kicking is one of the essential techniques among various type of kicks in soccer. In a match situation, soccer players need to pass and shoot towards goal using instep kicks. A few studies have investigated kicking motion in consideration of the resultant kicked directions, and it has been revealed that experienced soccer players emphasize twist of their support leg knee joint (Kellis, Katis, & Gissis, 2004) and rotation of their pelvis (Scurr & Hall, 2009) when kicking the ball towards more angled directions.
While the kicking motion includes complex movements of the whole body, as shown in the above previous studies, the motion can be considered as a simple phenomenon of collisions between the ball and foot (shoe) in the final phase of the kicking. Shinkai, Nunome, Isokawa, and Ikegami (2009) investigated the details of three-dimensional foot and ball interaction during ball impact of soccer instep kicking using ultra-high-speed cameras. They reported that the ankle joint experienced multiaxial motion which includes passive dorsi-plantarflexion, abduction and eversion. However, this study only analysed the ball impact action when players executed straight-forward kicking.
In considering the physical collision of two objects, the direction of the kicked ball would be influenced by the foot posture, contact point and swing direction at ball impact. Therefore, it can be expected that to explain the essential factor to kick the ball towards the aimed direction, it is necessary to clarify the relationship between the foot motion and the ball launch direction. The purpose of the present study was to identify the characteristics of ball impact foot motion corresponding to various ball launched direction.

METHODS: Eighteen trials of instep kicking were analysed in the present study. A male trained soccer player (mean 166.0 cm, 57.7 kg, soccer experience: 12 years) conducted these trials. The participant appropriately warmed-up and performed familiarisation trials before data collection. The participant conducted instep kicks of a stationary ball 11 m towards a full-size soccer goal (Width: 7.32 m, Height: 2.44 m). The participant kicked the ball with his preferred leg (right). Approach run-up angle was set at 30º through all trials. Six targets areas were set by dividing the soccer goal into two vertically and three horizontally sections. The participant was instructed to aim toward each target area in a random order, completing three successful shots for each. The experiment protocol was approved by the ethics committee of a university and informed written consent was obtained before testing.
To compute better quality parameters concerning the foot and ball impact , three-dimensional foot (shoe) shape was constructed using the following procedure: 1) eight criteria markers were attached on the lateral side of the shoe, and 124 markers also covered the entire shoe surface (Figure 1a), 2) the coordinates of all the markers on the shoe were calculated using

standing calibration, 3) the local reference frame of the foot was defined using the eight criteria markers and relative coordinates of the 124 shoe surface markers were defined, 4) the coordinates of the dots on the shoe surface were estimated by interpolating the coordinates among the all shoe surface markers using a spline function (Figure 1b).

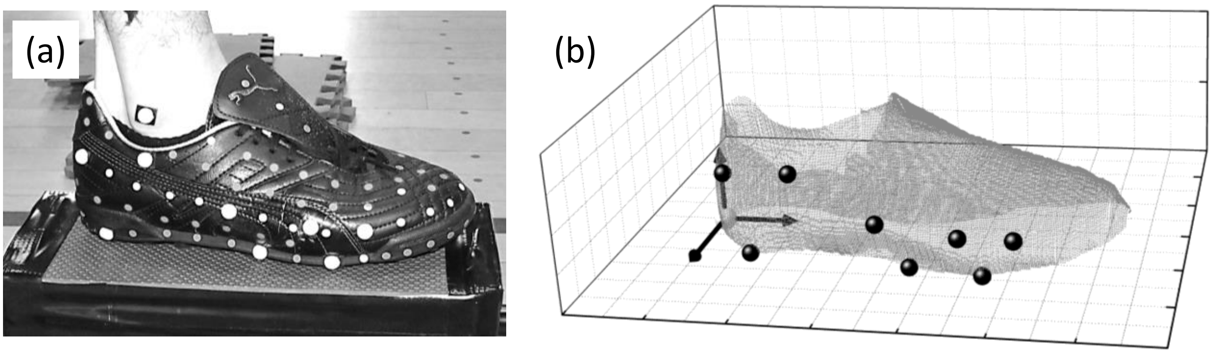

Figure 1. (a) The shoe for the standing calibration. The white markers are criteria markers. (b) The foot shape which represented by the dots along the shoe surface.

Three ultra-high-speed cameras (Fastcam Mimi AX50, Photron, Japan) captured the foot and the ball motions at 2000 Hz. The cameras were positioned on the right side, backwards and diagonally backwards right. The foot shape during kicking was estimated using the foot local reference frame which constructed by three-dimensional coordinates of the criteria markers of each trial (figure 2). The coordinates of the centre of the ball were estimated using surface markers and the known radius of the ball (0.11 m). The coordinates were expressed by global reference frame, in which Z axis was vertical and pointed upward, the Y-axis was horizontal and pointed to the midpoint of the soccer goal, and the X-axis was a normal vector of the YZ-plane.

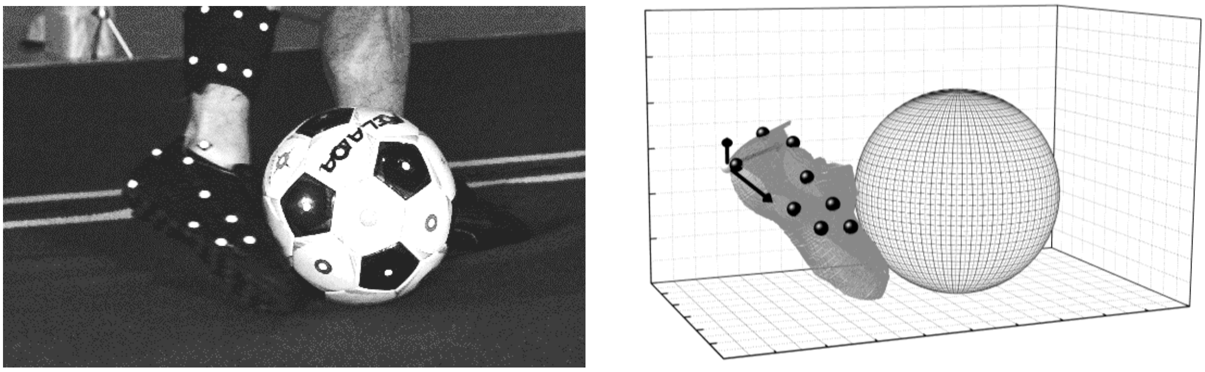

Figure 2. The sample image at the instance of ball impact, and the foot shape estimated using the images of video cameras and the data of standing calibration.

The launch direction of the kicked ball was represented as the angle between Y-axis and the initial velocity vector of the ball projected onto the horizontal plane. The initial ball velocity vector was calculated from the data of the centre of the ball centre 5 ms after the ball left from the foot. The kicking towards a right side of the soccer goal corresponded to the positive value for the ball launch direction.
The initial contact point between the foot and ball was determined to utilise the distance between the estimated foot surface coordinates and the ball surface, as calculated by the ball centre coordinates and the ball radius. The contact point was identified as the foot surface coordinate in which the estimated dots on the foot surface approached the closest to the ball surface. The present study only deals with the right-and-left position of the contact

point. Hence, the positive value indicated that the foot strike on the right side from the centre line of the ball.
The foot swing direction was defined as the angle between Y-axis and the foot velocity vector projected onto the horizontal plane. The foot velocity vector was calculated from the foot centre of mass data during 5 ms immediately before ball impact. The foot moving towards the right corresponded to a positive value for the foot swing direction.
The foot posture at the ball impact was expressed by the pitch, roll and yaw rotation of the foot segment. The axes of each rotation were defined using the data collected during the standing calibration. The yaw axis was vertical and pointed upward, the roll axis was the vector from heel to toe within the horizontal plane, and the pitch axis was perpendicular to the yaw and the roll axis. The origin of this local reference frame was placed on the heel side edge of the shoe sole. These rotational angles were computed in order of pitch, roll and yaw using Cardan angle.
Statistical analyses were conducted to reveal the parameters affecting the ball launch directions. A correlation coefficient was applied to analyse the relationship between the contact point, the swing direction and the ball launch directions. A partial correlation coefficient was utilised for analysing the relationship between the foot postures, which defined as pitch, roll and yaw angle and the ball launch direction. The statistical significance level was set at $p < 0.05$.

RESULTS: Figure 3a shows the relationship between the contact point and the ball launch directions. The contact point had a significant negative correlation with the ball launch direction. Its correlation coefficient was -0.99 ($p < 0.001$). Figure 3b shows the relationship between the swing direction and the ball launch directions. There is a significant positive correlation between these parameters, and its correlation coefficient was 0.98 ($p < 0.001$).

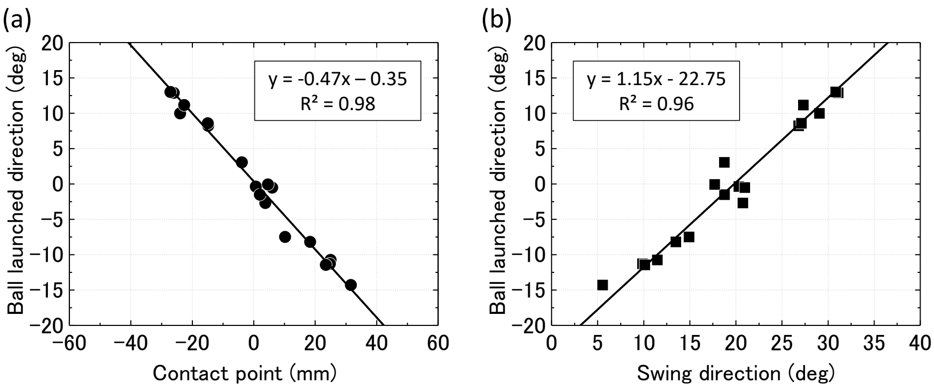

Figure 3. (a) The relationship between the contact point and the ball launch direction. (b) The relationship between the swing direction and the ball launch direction.

The three-dimensional foot posture was expressed by the rotation angles around the pitch, roll and yaw axis. The average pitch angle was -60.6 ± 4.2 º, the average roll angle was -11.9 ± 7.7 º, and the average yaw angle was -52.3 ± 5.0 º. The ball launch direction had a significant partial correlation with the roll angle and yaw angle. The partial correlation coefficient between the roll angle and the ball launch direction was 0.83 ($p < 0.001$), and between the yaw angle and the ball launch direction was -0.52 ($p = 0.04$). On the other hand, there was no significant partial correlation between the pitch angle and the ball launch direction, and the partial correlation coefficient was 0.04 ($p = 0.87$).

DISCUSSION: To date, several studies have investigated the ball impact characteristics in soccer kicking with ultra-high speed video images (Shinkai et al., 2009; Tsaousidis & Zatsiorsky, 1996) or pressure sensors attached to the shoe surface (Hennig & Sterzing, 2010). The present study attempted to analyse the foot motion during ball impact using a new technique that utilises the whole foot shape estimation.

The contact point on the ball had a strong negative correlation with the ball launch direction, and the intercept of the linear regression line was approximately 0. These results indicate that the offset distance from the centre line of the ball to the contact point plays an important role to determine the ball launch direction, i.e. when the foot hits the right side of the ball, the ball will be launched towards the left. Although Asai, Carre, Akatsuka, and Haake (2002) reported that the offset distance on the ball affects the rate of ball spin, our study demonstrates a new finding that this offset distance has a substantial effect on the ball launch direction.

The robust positive correlation was also obtained between the foot swing direction, and the ball launch direction. This result indicated that the swing direction is another crucial factor to control the ball launch direction. However, the range of the swing direction was from 5.6 º to 30.8º, whereas the contact point shows a symmetrical offset (-27.1 mm to 31.6 mm) between the kicks towards the right and left direction. That is, the foot is always swinging toward the right (when kicking with the right foot) even when the participant made contact on the right side of the ball.

The pitch angle was -60.6 ± 4.2º on average, and there was no partial correlation with the ball launch direction. This data indicated that the foot segment was rotated downwards about 60 degrees regardless of the target direction. This angle was consistent even when the foot segment was rotating around the roll axis, thereby controlling the direction of the instep of the foot. In our data, the roll angle had a strong partial correlation with the ball launch direction. These results suggest that the roll angle of the foot segment has an essential role in facing the instep of the foot towards the target direction at the moment of ball impact.

As this is a pilot study, our results include some limitations. Only one soccer player participated in the present study. Therefore, additional measurements with more participants is warranted. Moreover, a multiple linear regression analysis may provide the ability in computing a predicted regression model better than the correlation analysis applied in the present study.

CONCLUSION: The present study concluded that the contact point and the swing direction are important factors to control the ball launch direction, and also the foot roll angle has a role in facing the instep of the foot to the target direction.

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