Kinematics of the Foot Joint in Female Soccer Players during the Ball Impact Phase of Kicking

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Abstract

The purpose of this study was to reveal the kinematic interactions that occur in female soccer players during the ball impact phase of kicking. A total of 34 soccer players (17 females and 17 males) performed maximal instep kicks, infront kicks, and inside kicks while the behavior of the ball and kicking foot were captured three dimensionally by two high-speed cameras at 1,000 fps. Statistically significant differences emerged between the male and female players. Specifically, the mean values for ball velocity and foot velocity of the three types of kicks were lower among female players than male players (p < .05). Moreover, the coefficient of restitution of the inside kick was larger for female players than for male players (p < .05).

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1. Introduction

Although the majority of research on soccer kinematics to date has focused on the movements of kicking, the interaction between the foot and ball at the moment of impact has not been made sufficiently clear, particularly with respect to gender differences. For example, Dorge et al. [1], Ishii et al. [2], and Shinkai et al. [3] conducted research on the impact phase of soccer kicks, but Orloff et al. [4] and Barfield et al. [5] are among the few who have studied the kicking motion of female players. Thus, to better identify the fundamental characteristics of ball impact for female competitors, this research analyzed the movements of female soccer players at the moment of impact and compared them to those of males.

2. Methods

The test sample consisted of 34 soccer players; 17 subjects were female and 17 were male. All of the participants had at least five years of experience playing soccer. Markers were applied to three locations on the players’ lower legs (knee, outer ankle, and midway between the knee and outer ankle) and five locations on the toes and heels of
their feet. The players were asked to kick a ball with their dominant leg toward a soccer goal (FIFA regulation; 2.44 m high, 7.32 m wide) positioned in front of them and were allowed a free run-up to the kick (see Fig. 1a).

Three types of kick were analyzed: Instep kicks, in-front kicks, and inside kicks (see Fig. 1b). The players were instructed to kick the ball as hard/fast as they could and to be as technically accurate as possible. None of the subjects self-reported any errors or mis-kicks during testing. Two high-speed cameras (Photoron FASTCAM) with a frame rate of 1000 fps, an exposure time of 1/2000 sec, and a resolution of 1024×1024 dpi were used simultaneously to film the players. Both of the high-resolution cameras were situated to the right of the direction of the kick. One was placed behind the kicker and the other was placed to the side. Footage was loaded onto a computer as an AVI file, and a video motion analysis system (DHK’s Frame-DIAS) was used to digitize each coordinate marker. A time span of approximately 30 frames (beginning 10 frames prior to impact and ending 10 frames after the ball had left the foot) was digitized for each test kick. In addition, the ball was digitized for 10 frames after the moment of impact. Following that, coordinates from the two directions were combined using DLT to give three-dimensional coordinates. Foot velocity, ball velocity, and coefficients of restitution were calculated to evaluate the fundamental characteristics of kicks. Further, to evaluate the movement of the foot during impact, the flexion-extension, external rotation - internal rotation (vector variation), and inversion-eversion of the foot were investigated.

Fig. 1. (a) Set-up of the experiment, (b) location of impact on the foot.

3. Results and Discussion

3.1. Foot-swing kinematics

Figures 2a-2f show the foot-swing velocities for instep kicks, infront kicks, and inside kicks performed by male and female players. These figures indicate that for the instep and infront kicks, foot velocity tended to increase during impact, decrease after impact, and then increase again after ball release. Additionally, the change in velocity of the toes at the moment of impact tended to be larger than the change in velocity of the ankle joint or heel. Regarding changes in velocity during the forward swing for the three types of kicks, velocity tended to increase for the instep and infront kicks until just prior to impact, and this acceleration was due to the forward swing movement. However, no obvious increase in velocity was observed for inside kicks.

As for changes in velocity at the point of ball impact, all kicks showed deceleration but inside kicks tended to decelerate (exhibit negative acceleration) less than instep or infront kicks. This may be because foot velocity for inside kicks was less than that for instep or infront kicks and was therefore less affected by the reaction force from the ball. Another reason for the small change in velocity at impact for inside kicks compared to that for instep and infront kicks may be that the swing velocity prior to impact was low. That is, extension of the knee joint during inside kicks may have made a lesser contribution to the forward swing than it did for instep or infront kicks.
However, since toe markers have a higher velocity during instep and infront kicks, the results may also suggest that the foot was rotating just prior to ball contact in the instep kick. This means that the stiffness of the ankle at that moment might have been lower than for the other kicks, as the toe velocity was not much greater than the velocity of the heel. The ankle is probably a stiffer system during inside kicks, a premise which is supported by results showing the coefficient of restitution between the kicks (to be discussed shortly).

The rapid deceleration after impact represents the mutual interaction between the foot and the ball. As the ball separated from the foot, the foot accelerated again, after which there was a tendency to decelerate during the follow-through.

Fig. 2. Horizontal velocity of the toe, ankle, and heel [a = instep kick of female players; b = instep kick of male players; c = infront kick of female players; d = infront kick of male players; e = inside kick of female players; f = inside kick of male players].
3.2. Comparison of Male and Female Players

The average ball velocity for female players was $22.0 \pm 2.0$ m/s for instep kicks, $21.3 \pm 2.5$ m/s for infront kicks, and $18.3 \pm 1.6$ m/s for inside kicks (see Fig. 3a). In comparison, the average ball velocity for male players was $26.6 \pm 1.6$ m/s for instep kicks, $26.6 \pm 1.6$ m/s for infront kicks, and $21.9 \pm 1.4$ m/s for inside kicks. Thus, the average ball velocities for all three types of kicks were lower for female players than for male players, and the differences were statistically significant ($p < .05$).

One major reason for this finding may be the players’ average foot swing velocity, which was significantly lower for the females than for the males ($p < .05$). Figure 3b shows that the average foot velocity for female players was $19.3 \pm 2.1$ m/s for instep kicks, $8.6 \pm 2.2$ m/s for infront kicks, and $15.3 \pm 1.1$ m/s for inside kicks. Nevertheless, while this average foot velocity was lower than that of the male players, it was $3.1$ m/s higher than the $16.2 \pm 2.3$ m/s velocity of Barfield et al.’s [5] female subjects. This means that the average foot velocity of the female players in the current study was comparatively high, and though it can be assumed that Barfield and colleagues’ participants

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Fig. 3. Comparison of kicking parameters for female and male players [a = ball velocity; b = foot velocity; c = coefficient of restitution; d = angular displacement of foot joint (flexion-extension); e = angular displacement of foot joint on inertia coordinate (external rotation - internal rotation); f = angular displacement of foot joint (inversion-eversion)]. The bars and asterisks represent significant differences between males and females ($* p < .05$); significant differences between kicks are not shown on the graphs.
were in better physical shape, it may also indicate that the female players here had better kicking technique and that this technique served to raise their foot swing velocity.

Figure 3c shows the average coefficient of restitution for male and female players. Among females, the average value was 0.57 ± 0.10 for instep kicks, 0.57 ± 0.12 for infront kicks, and 0.64 ± 0.15 for inside kicks. For male players, the average value was 0.59 ± 0.12 for instep kicks, 0.57 ± 0.12 for infront kicks, and 0.77 ± 0.10 for inside kicks, with statistically significant differences \( p < .05 \) between instep and inside kicks and between infront and inside kicks. The figures for inside kicks by male and female players tended to be larger than for instep or infront kicks. One reason for this may be the fact that the point of impact affected the amount of change in the angle of the ankle joint during impact. For inside kicks, the impact was on the inside surface of the foot and may have therefore had little effect on the angle of plantar-dorsal flexion. This made it easier to achieve impact at the center of the ankle joint than with instep and in-front kicks. Furthermore, limiting the range of motion of the ankle joint to outward rotation during inside kicks may have reduced the variation in internal-external rotation.

The coefficient of restitution for inside kicks was higher for male players than for female players, and this difference was statistically significant \( p < .05 \). Comparison between males and females in the internal-external rotation of the ankle joint at ball impact showed greater rotation by female players during instep and infront kicks, but greater rotation by male players during inside kicks. Here, comparing the swing locus of inside kicks revealed a tendency among the males to display a linear swing motion, with the heel pushed out obliquely to the right. The swing motion of the females, on the other hand, tended to be rotational and described an arc (see Fig. 4). In fact, the swing of female players showed a locus similar to that for instep and infront kicks, which suggests that in these tests, the similarity between the females’ swing motions for inside kicks and instep kicks was greater than the similarity between the two types of kicks for males.

![Fig. 4. Examples of trajectory [a = inside kick of female players; b = inside kick of male players; c = instep kick of male players].](image)

### 3.3. Comparison of upper and lower groups for coefficients of restitution

The players were divided equally into high and low groups for the coefficient of restitution categories. The high group was made up of 8 subjects with the highest values for coefficient of restitution; the low group consisted of 8 subjects with the lowest values. Interactions revealed that for angular displacement of the foot joint, the low group had a higher coefficient of restitution than the high group, and this was true for both male and female players. There was interaction among the elements as well. When foot velocity was high, angular displacement of the foot joint was also high, and when angular displacement of the foot joint was high, the coefficient of restitution was low.

To obtain a higher coefficient of restitution and a higher ball velocity, it is important to reduce angular displacement when foot velocity is high. Since angular displacement of the foot tends to be higher in female players than in male players, it is thought that female players can improve their impact technique by keeping the foot joint more stable.
Fig. 5. Comparison of kicking parameters in coefficient of restitution categories for high and low groups [a = angular displacement of foot joint (flexion-extension) of female players; b = angular displacement of foot joint (flexion-extension) of male players; c = angular displacement of foot joint (external rotation - internal rotation) of female players; d = angular displacement of foot joint (external rotation - internal rotation) of male players].

4. Conclusion

The purpose of this study was to reveal the kinematic interactions that occur in female soccer players during the ball impact phase of kicking. When the velocity displacements of three kinds of forward swings were compared, the velocity of instep kicks and infront kicks tended to accelerate right before impact, while inside kicks did not show any sign of a marked acceleration. One proposed explanation is that the extension movement of the knee joint during the forward swing of inside kicks is thought to be smaller than it is during instep and infront kicks. In addition, the mean values for ball velocity and foot velocity during instep kicks, infront kicks, and inside kicks of female players were smaller than they were among male players, and these differences were statistically significant ($p < .05$). As for the coefficient of restitution of inside kicks, the value for male players was larger than for female players, and this difference was also statistically significant ($p < .05$). Lastly, when external rotation - internal rotation of the foot joint was compared at ball impact, the values for female players were greater than for males during instep kicks and infront kicks, but smaller during inside kicks. As such, the tracks of the swing during inside kicks were compared and indicated that the swing motion of male players followed a straight line by pushing the heel out in a right diagonal direction. The swing motion of females, on the other hand, followed an arc pattern.

References