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Analysis of the swing motion on knuckling shot in soccer

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Abstract

The purpose of this study is to analyze the swing characteristics of the kicking leg in order to elucidate the technical mechanisms of the knuckling shot. The tendency to impact with the heel pushed out towards the inside of the foot was considered. Hip external rotations in the knuckling shot exerted greater external rotation torque of the hip joint than the other shots. In this manner, it can be considered that compared to the other shots, the knuckling shot exerts a greater external rotation torque on the hip and has a tendency to impact with the heel pushed towards the inside of the foot.

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1. Introduction

In soccer, effective kicking techniques are extremely important for skilful ball manipulations during passes and shots [1, 2, 3]. Furthermore, quantitative measurements and analyses of kicking techniques are necessary for learning and acquiring such effective techniques [4, 5]. There are many types of soccer kicks, for example, the straight shot that generates power and the curling or curving shot that applies a curved trajectory from dead ball positions such as free kicks or corner kicks. In recent times, ball impact techniques have improved, and various ball position alignments, swing motions, and more complicated curving kicks are being performed by soccer players. For example, top professional athletes who use the instep while kicking curve shots are often able to apply topspin in addition to sidespin. Such an intentional application of topspin to a ball is an extremely specialized technique that results in shots that drop more

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than conventional curve shots. A few top-level soccer players (e.g. C. Ronaldo) are also capable of kicking the knuckling shot, or the knuckleball, in which a ball is intentionally kicked with very low or no spin; due to effects of random turbulence, such balls have an unpredictable wobble. Moreover, as a result of the excitation of an irregular vortex oscillation in the ball wake, the knuckleball results in the ball wavering or dropping unpredictably [6].

Several studies on the non-spinning soccer ball (knuckleball) have measured the steady aerodynamic forces in a wind tunnel [7] and have investigated the reasons for irregular variations in the ball flight path using fluid mechanics [8, 9]. However, there are virtually no knuckleball studies on the kicking motions or ball impact characteristics; as a result, the mechanisms of this shot have not been elucidated, possibly because this phenomenon occurs at extremely high speeds. Moreover, there are relatively few soccer players who can intentionally perform knuckling shot, and even among them, most have low success rates.

In this study, we have used a system of two high-speed video cameras to investigate the swing characteristics of the kicking leg while kicking the knuckling shot. University soccer players capable of kicking the knuckleball were selected, and the swing motions of their kicking feet while kicking the knuckling shot were compared with those while kicking the curve and straight shot.

2. Methods

Five male adult soccer players (mean height: 1.76 m, $SD = 0.03$; mean weight: 67.2 kg, $SD = 4.2$; mean age: 21.6 years, $SD = 1.3$) from the Tsukuba University soccer team, without any history of major lower limb injuries or diseases, volunteered to participate in this study; informed consent was obtained from them. All the participants had been playing regularly for the university team and each had a minimum of 10 years of soccer playing experience (mean: 10.6 years, $SD = 1.1$).

Each player kicked either non-spinning or low-spinning soccer balls towards the front of the goalpost a total of 20 times. The results of these kicks were analyzed by three instructors each with an experience of more than 10 years in soccer instruction. The analysis was subject to 10 instances where the kicked ball reached the goalpost with a knuckle effect being observed at a significant level. Furthermore, 10 straight and 10 curve shots kicked with instep and curve kicks, respectively, were also analyzed for comparison with the knuckling shot.

Twenty-four reflective markers (diameter: 10 mm) were attached to the following anatomical landmarks of each participant's body: forehead and sacrum, and on the right and left acromion processes, olecranon processes, ulnar heads, anterior superior iliac spines, greater trochanters, fibular heads, tibial medial epicondyles, medial malleoli, lateral malleoli, fifth metatarsal heads, and second metatarsal heads. A FIFA-approved size 5 soccer ball (plus-Teamgeist II, Adidas Inc., Herzogenaurach, Germany; mass: 0.430 kg; diameter: 220 mm) was shot 25 m towards a standard goal (7.32×2.44 m). Two reflective circular stickers (diameter: 20 mm) were placed on the sides of the ball to determine its rotations and the resultant velocities from the motion capture data after impact.

Two high-speed cameras (EX-F1, Casio Computer Co., Ltd., Tokyo, Japan; 300 fps; 720×480 pixels) were positioned at the rear and on the kicking leg sides (Figure 1).

To calibrate the performance area, a calibration frame ($2.0 \times 2.0 \times 2.0$ m) with 27 control points was recorded before the trials. A digitising system (Frame DIAS IV, DKH Inc., Tokyo, Japan) was employed to manually digitise the anatomical body landmarks. The direct linear transformation (DLT) method [10] was used to obtain three-dimensional (3D) coordinates of each landmark. The performance area ($2.0 \times 2.0 \times 2.0$ m) was calibrated with a net root mean square error of 5 mm. The 3D coordinates were expressed as a right-handed orthogonal reference frame fixed on the ground (X-axis: the horizontal forward direction from the ball set point; Y-axis: the horizontal left direction; Z-axis: the vertical direction).

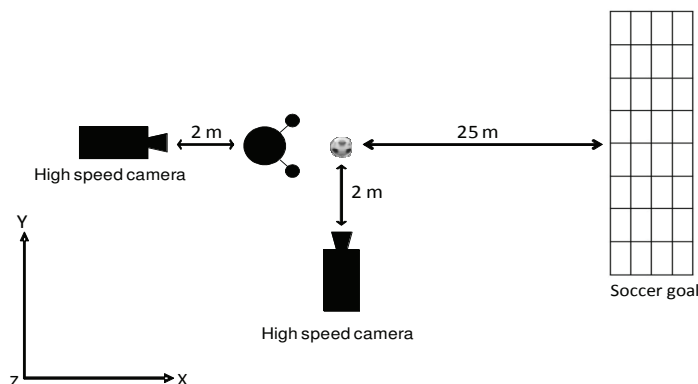


Fig. 1. Diagram of experimental setup.

3. Results and Discussion

Figure 2 depicts sample images of the straight shot, knuckling shot, and curve shot at the ball impact. In contrast to the comparatively extended position of the ankle joint in the straight shot (a, d), in the curve shot, an L-shaped flexion of the ankle joint at the impact (c, f) can be observed [11]. Further, the ankle joint at the impact in the knuckling shot (b, e) was flexed in an approximate L-shape that is similar to that of the curve shot. In other words, the ankle joint posture when impacting the ball was closer to that of the curve shot than that of the straight shot. Although similar trends were observed in the other subjects as well, some individual differences were noticed in the ankle joint angle and ankle joint posture and the alignment at ball impact; it is possible that the same knuckling shot could be performed using impact methods other than those measured in this study.

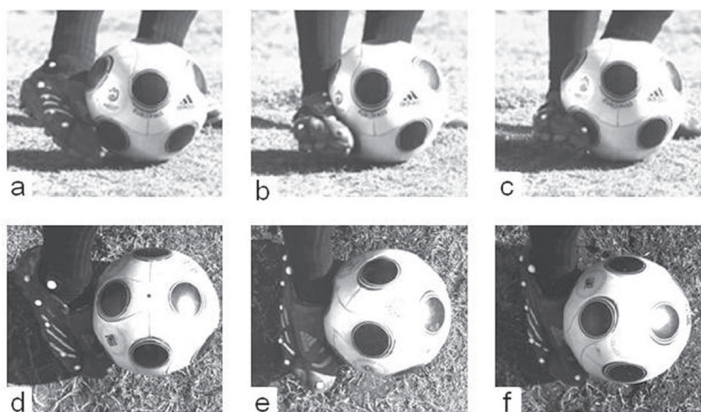


Fig. 2. (a, d) Straight shot; (b, e) knuckling shot; and (c, f) curve shot at impact (a, b, c: side view; d, e, f: top view).

The average ball velocities for the straight shot, knuckling shot, and curve shot were 28.3 m/s, 25.8 m/s, and 26.0 m/s, respectively (Table 1); the straight shot had the highest velocity, while the knuckling shot had the lowest velocity. This result corresponds to several studies that have reported the average ball velocities of the instep (straight shot) and curve kicks (curve shot) to be within 24.7–29.9 m/s and 25.4–27.4 m/s, respectively [1, 4, 12].

In addition, the average maximum ankle joint velocities for the straight shot, knuckling shot, and curve shot were 17.8 m/s, 16.9 m/s, and 16.4 m/s, respectively; the straight shot had the highest velocity, while the curve shot had the lowest velocity. The average ball rotational frequency in the horizontal axis was highest for the straight shot (4.3 r/s (back spin)) and lowest for the knuckling shot (-0.5 r/s (top spin)). Moreover, on the vertical axis, the curve shot showed the highest average rotational frequency (7.2 r/s), while the knuckling shot had the lowest one (0.4 r/s). A few studies have reported similar results; the average ball rotations of the curve kick and knuckleball were within 4–10 r/s and 0–2 r/s, respectively [6, 8, 9]. It can be considered that although the ball in the knuckling shot is not completely non-rotating, the rotational frequency is still lower than that of the other shots.

Table 1. Velocity of ankle joint, ball velocity, and rotational frequency of ball during straight, knuckling, and curve shots.

| Sub | Trial | Ball velocity (m/s) | | | Velocity of Ankle joint (m/s) | | | Revolution number of Ball (r/s) | | | | | |
|------|-------|---------------------|------|------|-------------------------------|------|------|---------------------------------|--------|--------|--------|--------|--------|
| | | St | Kn | Cu | St | Kn | Cu | St | | Kn | | Cu | |
| | | | | | | | | V-axis | H-axis | V-axis | H-axis | V-axis | H-axis |
| A | 1 | 27.6 | 25.5 | 24.6 | 17.3 | 17.6 | 15.4 | 0.3 | 2.8 | 0.3 | -1.3 | 7.5 | 1.5 |
| | 2 | 26.6 | 24.1 | 24.4 | 16.8 | 16.5 | 14.2 | 0.4 | 3.0 | 0.1 | -0.1 | 6.0 | 2.5 |
| B | 1 | 28.8 | 26.6 | 27.1 | 17.7 | 17.8 | 17.7 | 0.3 | 3.3 | 0.2 | -0.3 | 5.9 | 1.6 |
| | 2 | 29.8 | 25.7 | 26.4 | 19.3 | 17.1 | 17.7 | 0.6 | 4.5 | 0.5 | -0.1 | 7.5 | 2.0 |
| C | 1 | 29.1 | 24.7 | 25.2 | 18.6 | 15.1 | 15.8 | 0.5 | 2.5 | 0.3 | -0.5 | 7.5 | 2.5 |
| | 2 | 28.1 | 25.3 | 26.2 | 18.7 | 15.8 | 16.2 | 0.4 | 2.8 | 0.5 | -0.2 | 8.5 | 0.2 |
| D | 1 | 27.7 | 25.9 | 25.5 | 16.6 | 16.4 | 15.8 | 0.2 | 6.5 | 0.2 | -1.5 | 8.2 | 0.4 |
| | 2 | 27.2 | 27.7 | 26.7 | 16.5 | 16.8 | 15.7 | 0.8 | 5.3 | 0.5 | -0.3 | 7.5 | 2.5 |
| E | 1 | 29.5 | 27.1 | 26.3 | 18.5 | 18.2 | 18.1 | 0.5 | 6.0 | 0.9 | -0.5 | 7.0 | 0.2 |
| | 2 | 29.2 | 26.1 | 27.6 | 17.5 | 17.7 | 17.2 | 1.0 | 6.5 | 1.2 | -0.3 | 6.5 | 2.0 |
| Mean | | 28.3 | 25.8 | 26.0 | 17.8 | 16.9 | 16.4 | 0.5 | 4.3 | 0.4 | -0.5 | 7.2 | 1.5 |
| S.D. | | 1.07 | 1.07 | 1.05 | 0.98 | 0.97 | 1.24 | 0.2 | 1.6 | 0.3 | 0.5 | 0.9 | 0.9 |

Figure 3 contains stick diagrams of the side view, top view, and back view depicting the straight shot, knuckling shot, and curve shot at ball impact. Although the side view does not show any significant differences overall, the ankle joint in the curve shot and knuckling shot has greater flexion than in the straight shot. In the top view, the curve shot has a greater swing plane than the other shots. Further, in the back view, the curve shot has a greater swing plane than the other shots. Other subjects also showed similar trends. Consequently, it can be suggested that the curve shot has a greater lateral motion than the straight shot, while the knuckling shot has a swing motion that is closer to that of the straight shot than to that of the curve shot.

The lateral velocities of each joint of the kicking leg during each shot, i.e. the ankle joint velocities at impact, for the curve shot, straight shot, and knuckling shot were 4.1 m/s, 0.7 m/s, and 0.5 m/s, respectively; the value for the curve shot was higher than that for the other shots. The peak lateral velocities of the ankle joint for the curve shot, straight shot, and knuckling shot were 9.1 m/s, 6.8 m/s, and 5.4 m/s, respectively; the value for the curve shot was higher than that for the other shots. A similar trend was observed in the other attempts as well, and this indicates that the ankle joint has a greater lateral motion in the curve shot than in the other shots; this can be considered to be one of the kinematic characteristics of the shot. These results also indicate that the lateral motion of the knuckling shot, which is a kinematic characteristic of this shot, was comparatively less.

Figures 4(a) and 4(b) demonstrate the knee extension and hip external rotation torques, respectively, of the straight shot, knuckling shot, and curve shot from leg cocking to impact. The peak values for the knee extension in the straight shot, knuckling shot, and curve shot were 108.0 N·m, 106.2 N·m, and 114.9

N·m, respectively. Table 2 lists the peak torques of the knee joint and hip external rotations (mean ± SD). The mean peak torque values of the knee extensions were 110.0 N·m (SD = 8.4 N·m), 106.1 N·m (SD = 8.5 N·m), and 116.7 N·m (SD = 9.4 N·m) for the straight shot, knuckling shot, and curve shot, respectively. The patterns of the knee extension for all the three shots were clearly similar. In addition, the values were within the range of peak values (83–122 N·m) of previous researches on knee extensions [12, 13, 14].

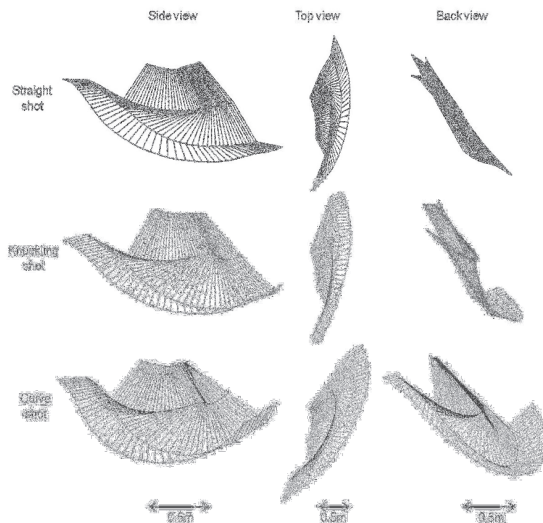


Fig. 3. Stick diagrams of the straight, knuckling, and curve shots at impact.

From Figure 4(b), the peak values for hip external rotation due to the knuckling shot (67.0 N·m) was higher than that due to the straight shot (41.2 N·m) while that of the curve shot was 58.1 N·m. Moreover, the mean peak values of the hip external rotation were 39.1 N·m (SD = 3.4 N·m), 67.2 N·m (SD = 6.0 N·m), and 53.1 N·m (SD = 5.8 N·m) for the straight shot, knuckling shot, and curve shot, respectively (Table 2). Nunome *et al.* [12] has reported hip external rotation peak values of 56 N·m (SD = 12 N·m) for a side-foot kick and 33 N·m (SD = 8.0 N·m) for an instep kick. Their instep kick results are similar to the hip external rotation values for the straight shot in this study; however, for the knuckling shot, their results for the side-foot kick have greater similarity than their instep kick results. From these results, it can be considered that compared to the other shots, the knuckling shot exerts a greater external rotation torque on the hip and has a tendency to impact with the heel pushed towards the inside of the foot (Figures 2(b) and 2(e)).

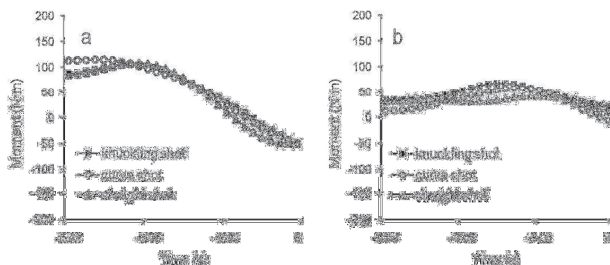


Fig. 4. (a) Knee extension and (b) hip external rotation from leg cocking to impact in the straight, knuckling, and curve shots.

Table 2. Peak torque of knee joint and hip external rotation torques (mean \pm SD).

| | Straight shot | Knuckling shot | Curve shot | <i>P</i> |
|-------------------------------------|-----------------|------------------|------------------|----------|
| Maximal knee extension (N·m) | 110.0 \pm 8.4 | 106.1 \pm 8.5* | 116.7 \pm 9.4* | < 0.05 |
| Maximal hip external rotation (N·m) | 39.1 \pm 3.4* | 67.2 \pm 6.0* | 53.1 \pm 5.8* | < 0.05 |

4. Conclusion

In this study, we have demonstrated the ankle joint at impact in the knuckling shot to be flexed in an approximate L-shape in a similar manner to the curve shot. Further, the ankle joint posture at impact that was more similar to that of the curve shot than that of the straight shot. The hip external rotation in the knuckling shot exerted a greater external rotation torque of the hip joint than the other shots, which suggests a tendency to impact with the heel pushed out towards the inside of the foot.

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