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Ball impact dynamics of knuckling shot in soccer

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Abstract

The flight trajectory of a non-spinning or low-spinning soccer ball may fluctuate in unpredictable ways, with anomalous horizontal shaking or rapid falling. This "knuckling shot" is famously exploited by Cristiano Ronaldo in his free kicks. However, the technical aspects of kicking a knuckling shot are still unclear, and considerable analysis is required. In this study, we used high-speed video cameras to compare the knuckling shot with curve and straight shots. The results indicate that the angle of attack in the knuckling shot (3.3 ± 0.9°) was smaller than those in the straight and curve shots (19.3 ± 2.4°, 32.6 ± 3.9°, respectively). In sum, we demonstrated that in the knuckling shot, reduced angles of attack between the face and swing vectors at the impact surface and the primarily translational motions at ball impact are fundamental mechanisms.

Keywords: Impact dynamic; knuckle ball; knuckling effect; knuckling shot; non-spinning

1. Introduction

In soccer, the knuckling shot is a kicking technique in which no or low rotations are applied to the ball, thereby making it move irregularly. As a result of the excitation of an irregular vortex oscillation in the ball wake, the knuckling shot, also known as the knuckleball, results in a ball path that wavers or drops [1]. Previous studies on the non-spinning knuckleball have measured the steady aerodynamic forces in a wind tunnel [2, 3] and have investigated the causes of irregular variation in ball flight path using the visualization tests [4, 5]. However, there are few studies on the kicking motions and ball impact characteristics during a knuckling shot.

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Indeed, at present, the mechanisms of kicking this shot are not known, possibly because this phenomenon occurs at extremely high speeds. Moreover, there are relatively few soccer players who can intentionally make a knuckling shot, and of them, most have low success rates [6]. In this study, we used a system of four high-speed video cameras to study university soccer players capable of performing the knuckling shot, comparing the angle of attack between the face and swing vectors at the impact surface in the knuckling shot to that of the curve shot and straight shot. In this manner, we elucidated the impact process of the kicking foot at ball impact by the angle of attack.

2. Methods

Five male adult soccer players (height: 1.77 ± 0.04 m; weight: 68.2 ± 3.6 kg; age: 22.4 ± 1.1 years) from the Tsukuba University soccer team, without any history of major lower limb injury or disease, 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 (11.4 ± 0.9 years). Each player kicked either a non-spinning or low-spinning soccer ball toward the front of the goalpost a total of 20 times. The results of these kicks were analyzed by three instructors, each with over 10 years of experience in soccer instruction. The analysis was subject to 10 instances where the kicked ball reached the goalpost with a significant observed knuckling effect. Furthermore, 10 straight and 10 curve shots kicked with instep and curve kicks, respectively, were also analyzed for comparison.

Fig. 1. Adidas +Teamgeist II soccer ball

Twenty-four reflective markers (diameter, 10 mm) were attached to anatomical landmarks of each participant's body, on the forehead, sacrum, and the right and left of the acromion process, olecranon process, ulnar head, anterior superior iliac spine, greater trochanter, fibular head, tibial medial epicondyle, medial malleolus, later malleolus, fifth metatarsal head, and second metatarsal head. A FIFA-approved size 5 soccer ball (+Teamgeist II (Figure 1), Adidas Inc., Herzogenaurach, Germany; mass: 430 g; diameter: 220 mm) was shot from 25 m away from a full size goal (7.32 × 2.44 m). Two reflective circular stickers (diameter: 20 mm) were placed on the sides of the ball to determine its rotation and the resultant velocity from the motion capture data after impact.

Two high-speed cameras (Fastcam, Photron Inc., Tokyo, Japan; 1000 fps, 1024 × 1024 pixels) were set up 2 m from the site of impact with a line of sight perpendicular to the kicking leg. In addition, two semi-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 2). From the high-resolution images obtained by the high-speed cameras at 1000 fps, ankle joint displacement, and angle of attack between face vector and swing vector were calculated for the impact process, and the ankle joint and the ball were kinematically analyzed. From the images taken by the two semi-high-speed cameras (300 fps), twodimensional (2D) coordinates were obtained through digitizing. After digital filtering with a three-point moving average, ball velocity, and ball rotational frequency were determined.

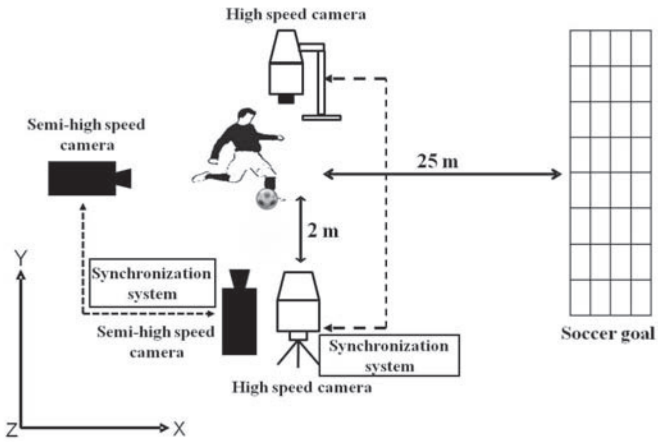

Fig. 2. Experimental set up

The face vector at impact was defined as a normal vector of the line from the toe point to the heel point in the horizontal plane. The swing vector at impact was defined as the average velocity vector of the toe and heel points. The angle of attack was defined as the angle between the face and swing vectors (Figure 3).

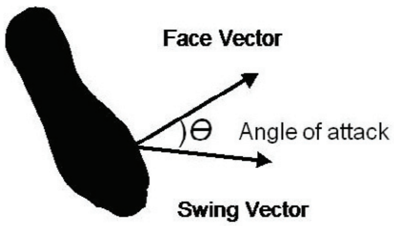

Fig. 3. Definition of the angle of attack

3. Results and Discussion

3.1. Ankle joint displacement at ball impact

As shown in the typical example in Figure 4, during ball impact from the top view (a), the straight shot and knuckling shot are nearly identical: the direction of motion of displacement in both is somewhat bent toward the inside of the swing. However, the direction of motion is significantly directed toward the outside in the curve shot. Moreover, this displacement is considerably greater in the curve shot (-50 mm) than in the straight shot and knuckling shot (4 mm and 1 mm, respectively). In the side view (b), the straight shot moves downward (-10 mm) whereas both the knuckling shot and curve shot moves upward (5 mm and 15 mm, respectively). Similar trends were observed for the other subjects as well (Table 1).

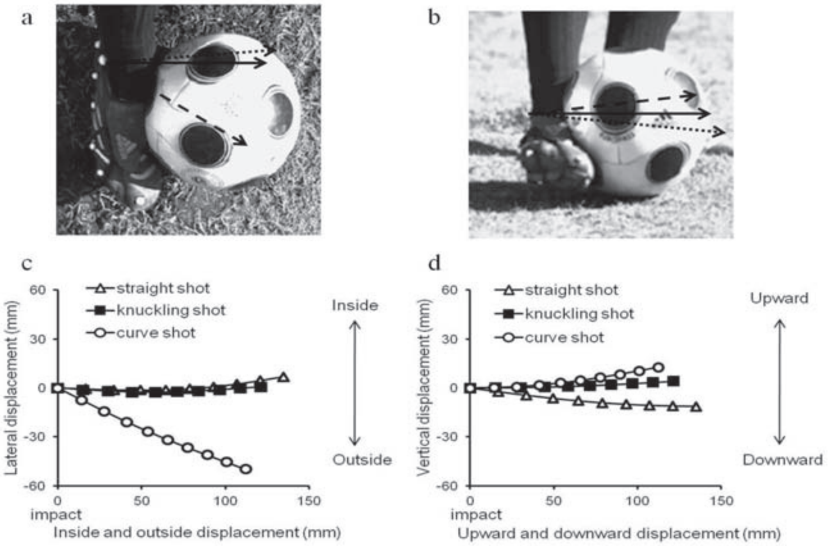

Fig. 4. Sample images of ankle joint displacement during ball impact from the top view (a, c); the side view (b, d)

In addition, the average ball rotational frequency in the horizontal axis was highest for the straight shot (-4.0 ± 1.8 r/s) and lowest for the knuckling shot (0.9 ± 0.5 r/s). Moreover, on the vertical axis, the curve shot showed the highest average rotational frequency (7.4 ± 1.2 r/s), while the knuckling shot had the lowest one (0.6 ± 0.3 r/s). From these results, it can be considered that the ankle joint motion during ball impact for the knuckling shot has greater translational motion than in the case of the other shots.

Furthermore, we analyzed the lateral and horizontal velocities of the ankle joint during ball impact. The deceleration in the lateral velocity is greater for the curve shot (-2.3 ± 0.5 m/s) than those for the straight and knuckling shots (-1.1 ± 0.3 m/s and -0.6 ± 0.2 m/s, respectively), while the deceleration in the horizontal velocity is greater for the straight shot (-3.8 ± 0.5 m/s) than those for the knuckling and curve shots (-2.5 ± 0.3 m/s and -2.1 ± 0.4 m/s, respectively).

From these results, it can be considered that the ankle joint motion during ball impact for the knuckling shot has greater translational motion than in the case of the other shots.

Table 1. Lateral and vertical displacements and revolution number of ball (mean ± *SD*). (- and + show outside and inside directions respectively in the lateral displacement; - and + show lower and upper directions respectively in the vertical displacement.) V-axis is side spin and H-axis is top (+) or back spin (-) in the revolution number of ball

	Lateral displacement (mm)	Vertical displacement (mm)	Revolution number of ball (r/s)	
			V-axis	H-axis
Straight shot	10.2 ± 4.2	-8.5 ± 1.9	1.2 ± 0.5	-4.0 ± 1.8
Knuckling shot	2.3 ± 1.1	6.1 ± 2.1	0.6 ± 0.3	0.9 ± 0.5
Curve shot	-45.9 ± 5.0	13.1 ± 2.1	7.4 ± 1.2	2.4 ± 1.1

3.2. Angle of attack

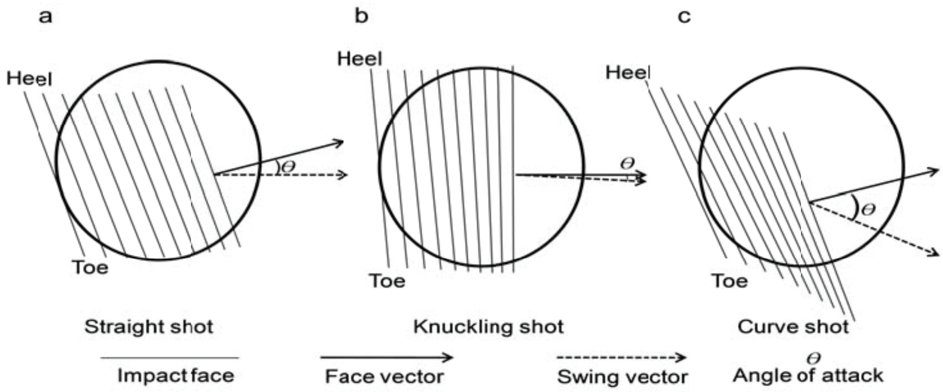

Fig. 5. A sample of the angle of attack at ball impact: (a) straight shot; (b) knuckling shot; (c) curve shot

As shown in the typical example in Figure 5, the face and swing vectors as well as their angles of attack for the straight shot, knuckling shot, and curve shot, respectively. The angle of attack for the knuckling shot was approximately 4°, which was smaller than those for the straight and curve shots, approximately 19° and 35°, respectively. These angles of attack are believed to correlate with the production of rotational forces at the surface of ball contact [7]. In addition, the average values of the angle of attack formed by the face and swing vectors at impact (the first frame of the impact process) were 19.3° (± 2.4°), 3.3° (± 0.9°), and 32.6° (± 3.9°) for the straight shot, knuckling shot, and curve shot, respectively (Table 2).

Table 2. Angle of attack at ball impact for the straight, knuckling, and curve shots (mean ± *SD*)

	Angle of attack (deg.)
Straight shot	19.3 ± 2.4
Knuckling shot	3.3 ± 0.9
Curve shot	32.6 ± 3.9

From these results, it can be considered that the lower angle of attack for the knuckling shot in comparison with that for the other shots is the reason for the low rotational frequency of the ball.

4. Conclusion

The ankle joint motion during ball impact for the knuckling shot has greater translational motion than in the case of the other shots. The angle of attack in the knuckling shot was smaller than that in the other shots.

References

[1] Asai T, Seo K, Yousuke S, Ito S, Koike S, Murakami M. A study of knuckling effect of soccer ball, The Engineering of Sport 2008;7(1):555–62.
[2] Iwai Y, Murakami M, Seo K. Wind tunnel experiment of knuckle effect of a soccer ball, The Impact of Technology on Sport 2009;3:179–84.
[3] Murakami M, Kondoh M, Iwai Y, Seo K. Measurement of aerodynamic forces and flow field of a soccer ball in a wind tunnel for knuckle ball, Procedia Engineering 2010;2(2):2467–72.
[4] Asai T, Seo K, Kobayashi O, Sakashita R. Flow visualization on a real flight non-spinning and spinning soccer ball, The Engineering of Sport 2006;6:327–32.
[5] Hong S, Chung C, Nakayama M, Asai T. Unsteady aerodynamic force on a knuckleball in soccer, Procedia Engineering 2010;2(2):2455–60.
[6] Hong S, Chung C, Sakamoto K, Asai T. Analysis of the swing motion on knuckling shot in soccer, Procedia Engineering 2011;13:176–81.
[7] Asai T, Nunome H, Maeda A, Matsubara S, Lake M. Computer simulation of ball kicking using the finite element skeletal foot model, Science and Football 2005;5:77–82.