Paper : Biomechanics

Kinematic and Electromyographic Analysis of Infront Curve Soccer Kick

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Two types of curve kicks are seen in football (soccer). One is a kick in which the player attempts to rub the ball with the toe trying to keep in contact with the ball as long as possible (hereafter called the Usual Curve Kick). This is frequently described in common tutorial manuals. The second is a kick in which the ball is spun by the angle of attack which is made by the swing direction of the kicking foot and the direction of the impact surface (hereafter called the Angle Curve Kick). No studies have examined the difference between these two types of kicking. The purpose of this study was to clarify these two types of curve kicks using kinematic and electromyographic analysis. Kick movements confined to the vicinity of impact were examined. The subjects were six male college football players. In order to observe the kicks from below, a platform with two plates of hardened glass on top was fabricated. Kicking movements were shot with a high speed camera (250 Hz). The subjects tried to kick a ball at their full strength five times for each type of kick, namely the Usual Curve Kick, the Angle Curve Kick and the Inside Kick which was included for the sake of comparison. The direction of the kicking foot, the swing direction, the initial ball velocity and the number of ball rotations were obtained using the images. Results indicate that there was no great difference in performance between the Usual Curve Kick and the Angle Curve Kick, though muscle discharge of the adductor muscle group showed greater values in the Usual Curve Kick. The impact point of the kick was nearest to the toe in the Usual Curve Kick. In the Usual Curve Kick, the direction of the kicking foot changed toward the right at the target suggesting that the hip joint could externally rotate. These findings led to the conclusion that in a comparison between the Usual Curve Kick and the Angle Curve Kick, the Angle Curve Kick was considered to impose less strain on the adductor muscle group in the case of similar performance level.

Keywords: Curve Kick, Angle of attack, EMG, impact

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1. Introduction

1.1. Background

In a football (soccer) curve kick a kicker intentionally spins a ball so that its orbit can be changed. It is one kicking technique frequently applied in set play. Because of an emphasis on more organized defense in recent football games, the number of goals per game has decreased (Japan Football Association, 2006) and players increasingly expect to score from a set play in a position where they can get a goal. As a result the technique of a curve kick which is frequently used in set play has become a focus of research interest.

Previous studies in biomechanics research on soccer kicks have predominantly focused on instep kicks (Asami, et al., 1976; Asami & Nolte, 1983; Togari, 1983; Levanon & Dapena, 1998; Lees & Nolan, 1998; Lees & Nolan, 2002). However, in recent years, as three dimensional movement analysis has been widely used, more and more studies are focused on inside kicks (Levanon & Dapena, 1998; Nunome, et al., 2002) and curve kicks (Asai, et al., 2002; Asai, et al., 2004; Carré & Asai, 2004), though the number is still much less than those on instep kicks.

Regarding curve kicks Asai, et al., (2004) demonstrated through simulation that a key factor in spinning a ball was the angle difference (the angle

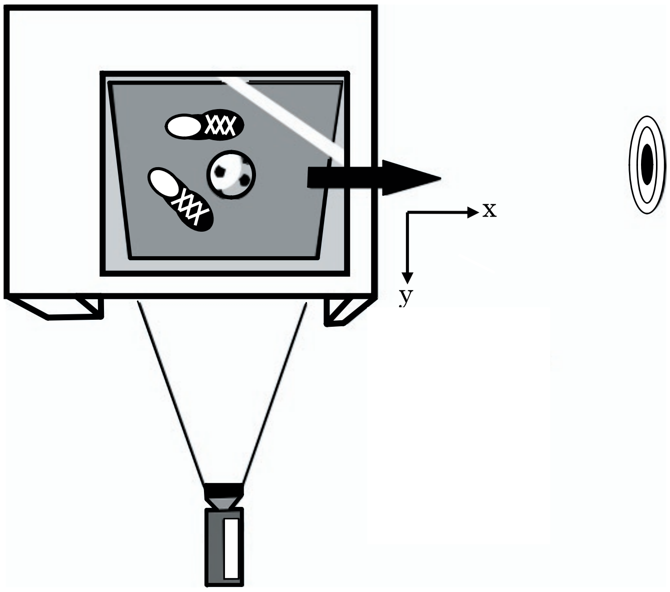

Figure 1 Pattern diagram of experiment.

of attack) between the direction of impact surface of the kicking foot (face vector) and the swing direction (swing vector), and these findings suggested a particular method of curve kick. .

Common tutorial manuals often explain that a kicker applies friction to a ball in order to spin it by utilizing a longer duration of contact between the kicking foot and the ball. While the instruction method of a curve kick is not yet established in the present situation, little research has been done to confirm whether or not different ways of kicking cause any differences in a ball's behavior, or that of the movement of the kicking foot, and if any, what kind of differences they are.

1.2. Purpose

The purpose of this study, using kinematics and electromyography (EMG), is to clarify the kicking movements observed in a kick applying the angle of attack (Asai, et al., 2004) and in a kick as explained in general tutorial materials. We particularly focus on the vicinity of the impact surface because a kicker can only affect a ball while the kicking foot touches the ball. Additionally, it was considered that a ball's behavior is decided by the positional relation between the kicking foot and the ball and the moving direction and velocity of the kicking foot.

2. Experimental Method

2.1. Subjects

The subjects were six healthy male college student football players with a mean age (SD) of 21.2 (±0.4). Their mean height (SD), weight (SD) and experience of soccer (SD) were respectively 172.3 (±5.2) cm, 63.3 (±3.7) kg and 13.2 (±2.6) years. All the subjects were right-handed.

2.2. Method of measurement

In order to observe the swing direction of the kicking foot, the direction of impact surface and the impact point at the time of kicking, kicking movements were video-recorded from below. **Figure 1** shows a pattern diagram of the experiment. A wooden platform (height of 0.8m × width of 2m × depth of 2m), was fabricated for filming the subjects. The top board of the platform was made of two plates of synthetic hardened glass (1m × 1m × 10mm: ASAHI GLASS CO., LTD). Reinforced plastic film was placed between the two plates of glass to increase strength.

The origin point for kicking was placed in the center of the synthetic hardened glass. A circular target with a diameter of 0.3m was placed 2m in front of the origin point and 2m from the floor. The direction of a straight line connecting the origin point and the center of the target was regarded as the x-axis.

A mirror at an angle of 45° from the floor was installed under the hardened glass facing in the direction of the y–axis. A high speed camera (nac Image Technology Inc. HSV-500C[3]) was placed approximately 2m away from the origin point in the direction of the y–axis. The height of the camera platform was adjusted so that the axis of the camera lens could point horizontally through the center of the mirror. The subjects were instructed to perform trials on the hardened glass. The positions of the camera and the light were adjusted so as to capture the image of the subject reflected in the mirror (**Figure 2**). The sampling frequency of the high speed camera was 250Hz, and the shutter speed 1/2,000sec. The subjects, aiming at the target, kicked the ball placed on the origin point with the method with which they were instructed. A FIFA approved ball (Molten® Peleda, size 5) with a diameter of 220.0mm was

Figure 2 Typical image reflected in the mirror.

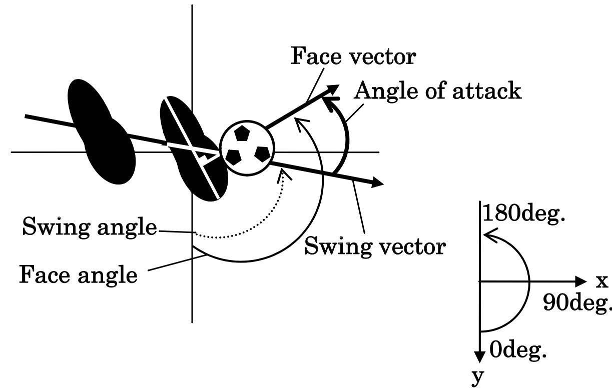

Figure 3 Definitions of indices.

used. Ninety circular markers, each with a diameter of 10.0mm, were attached to the surface of the ball in order to assess the number of rotations. The subjects wore futsal shoes whose soles were somewhat flat. Colored tape was attached from the toe to the heel on the sole of the shoe. This line of tape (herein after called a 'face line') was considered to be parallel to the impact surface. The vector which was perpendicular to the face line and showed the direction of the impact surface was regarded as the face vector.

The face angle is the angle made by the face vector and the y–axis. A swing vector was obtained through observing the direction in which the midpoint of the face line moved between two frames immediately before impact. A swing angle was made by the swing vector and the y–axis. The swing angle and the face angle were calculated as angle data with the direction of the y–axis at 0° and that of the x–axis at 90°. The angle of attack was made by the face and swing angles (**Figure 3**).

The x– and y–axes were drawn intersecting at the origin point on the synthetic hardened glass. In addition, a guide line indicating the face line and swing vector, with the face angle of 120° and the swing angle of 80°, was drawn so that an impact that produced a ball spin by the angle of attack could be easily imagined by each subject. The angle of attack assumed for the guiding line was set at 40° by referring to the study by Asai, et al., (2004).

2.3. Trial techniques used in the experiment

Three techniques were examined. The first was a usual 'infront' curve kick that rotated the ball by friction between the ball and the kicking foot (hereafter called the Usual Curve Kick). The second was an infront curve kick that rotated the ball by the angle of attack as shown in the previous study (Asai, et al., 2004) (hereafter called the Angle Curve Kick). The third technique was an Inside Kick that is the most frequently used kick seen in a football game. This was added as one of the trial techniques in order to compare with the two curve kicks.

The subjects were instructed to perform each kick five times with their utmost power. After practicing each kick several times so as to accustom themselves to the experiment atmosphere, the subjects started the experiment. In the case where the kick was regarded as a failure, either through viewing the video image or by the subject's own view, or when the ball did not hit the target, the trial was carried out again until five successful kicks were video-recorded. As it is known that entrance length could affect ball velocity (Uchiyama, 1996), one step was assigned as an entrance for all kicks in this experiment.

For the Inside Kick, the subjects were required to kick straight at the target in order to prevent any horizontal spinning of the ball. In the Usual Curve Kick, they were instructed that they should intentionally cause friction on the ball using the inside of their foot while kicking. In the Angle Curve Kick, they tried to spin the ball using the angle of attack and referring to the guide line, and not by using friction while kicking.

2.4. Image analysis

Before starting measurements, a picture of a 300mm^2 index placed on the center of the synthetic

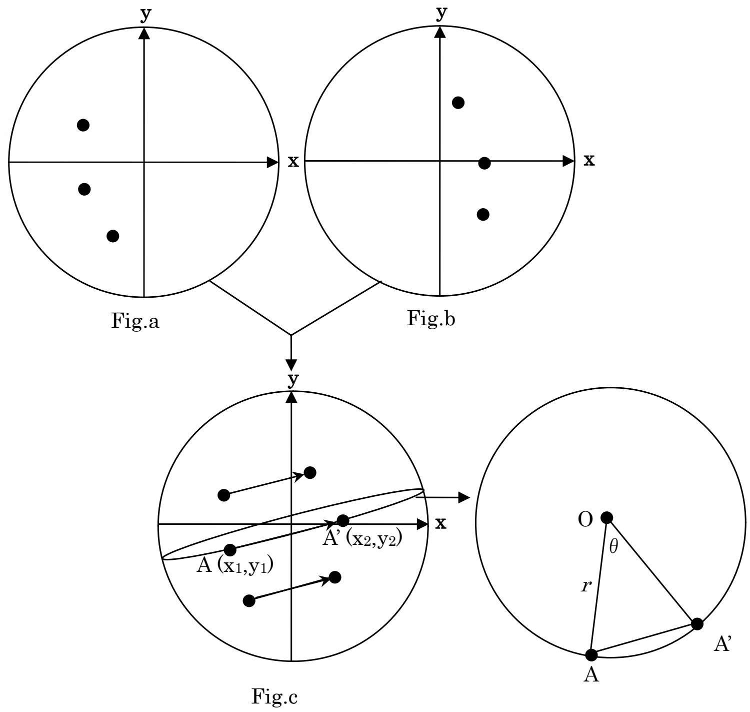

Figure 4 Method of calculation for ball revolutions.

hardened glass was taken to be used in the image analysis software (Movias Pro Ver1.63, nac Image Technology Inc.). The length of one side was measured using the software. After adjusting the setting of the software until the measured value became the same as the actual dimension, another index with a different size was measured several times. The results fell within the range of 500±1mm confirming that there was no distortion on the surface of the mirror.

Using the image analysis software, the swing velocity of the kicking foot and the initial ball velocity were obtained from the images of each subject's kick. The number of ball rotations, the swing angle, the face angle and the ball impact point of the kicking foot were gained through the measurement software for images (Length/area measurement II Ver. 2.00 Shareware). For the analysis, the mean value gained from five trials in each kick was used as a representative value.

2.4.1. Swing velocity and initial ball velocity

Using two frames before the frame taken at the moment when the kicking foot first touched the ball (hereafter called 'impact'), a swing velocity was obtained as the velocity when the midpoint from both ends of the face line horizontally moved. For the initial ball velocity, the frame immediately after the frame in which the kicking foot first detached from the ball was analyzed. In this frame, the velocity of the ball's horizontal movement was calculated from the distance that the closest point to the target on the ball surface moved.

2.4.2. Number of ball rotations

The number of rotations of the ball was obtained with image analysis (**Figure 4**). The image taken immediately after the ball left the kicking foot (**Figure 1**) and the adjacent frame (after 4 ms) were overlapped to gain (**Figure c**). In **Figure c**, the distance from the marker appearing on **Figure a** to that on **Figure b** was measured. The marker whose moving distance was longest was considered as the marker (A) on the ball's equator.

Assuming the coordinates of point A on the **Figure c** are (x_1, y_1), and the coordinates of the position to which point A moved after 4ms are (x_2, y_2), the radius of the ball as r and the center of the ball as point O, the formula (1) is true by the cosine law.

$$\cos\theta = 1 - \frac{1}{2}\left(\frac{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}}{r}\right)^2 \quad \cdots\cdots \quad (1)$$

Using cosθ calculated with formula (1), the number of ball rotations for one second was obtained. The moving distance of point A on the ball surface had a margin of error since it was measured in a two-dimensional image. The error was corrected based on the size of the marker. Because two-dimensional images were used to calculate the number of rotations and the location of the equator was also estimated, an error of approximately 0.3r/s was assumed. This margin of error was considered not to affect any comparison of ball behavior between kicks.

2.4.3. The impact point

The procedure carried out in order to attain the position of ball impact of the kicking foot was as follows. The point of the foot touching the ball at the moment of impact was taken. From this point to the face line, a parallel line to the swing vector was drawn. The intersection of that parallel line and the face line was considered as the impact point. In order to indicate the impact point, percentages (0% to the heel and 100% to the toe) to the length of the face line were utilized.

2.4.4. Swing angle and face angle

Using two frames before impact, the swing angle was obtained from the moving direction of the midpoint of the face line. This was defined as the swing angle at the moment of impact. For the face angle, using three frames before impact and seven frames after impact, ten in total, the value in each frame was gained.

2.5. Electromyographic measurement

Holter electromyography (Mega Electronics Ltd, ME3000P) was used for electromyographic measurement. The rectus femoris, vastus medialis and adductor longus muscles were measured. Disposable Ag/AgCl electrodes (Ambu, Blue sensor M-00-S) were attached 30mm apart along the muscle fiber. Myoelectric potential was derived using the bipolar surface electrode approach (James, et al., 1978). The sampling frequency was 2,000Hz. After full-wave rectification, the data were integrated. In each muscle, the value at the moment of impact was analyzed. From the muscle discharge in the rectus femoris, the extension behavior of the femoral extensors as biarticular muscles was observed. From the muscle discharge of the vastus medialis, the extension behavior in femoral extensors as monoarticular muscles was observed. From the muscle discharge of the adductor longus, the adduction behavior in the hip joint was observed.

In order to synchronize the high speed camera with the EMG, a device for marking with a LED was used.A voltage sensor detected the voltage applied when the LED lit up and the high speed camera recorded the optical signals. After the trial kicks, using the recorded time of each signal, image data from the camera was synchronized with the voltage data from the EMG.

It is known that due to individual differences in muscle development and differential performance depending on a sensor, deviation can occur in EMG measurement and any comparison using absolute values is impossible (US Department of Health and Human Services, 1991). Therefore, in order to examine the muscle action of the Usual Curve and the Angle Curve Kicks, this research compares those values with those of the Inside Kick.

The mean value of five Inside Kick trials was obtained for each subject. Placing this mean value as 100%, the percentage in the Usual Curve Kick and the Angle Curve Kick was calculated. This was implemented for all five trials, and the resulting percentages were used for analysis.

Table 1 Kicking foot velocities (m/s).

Sub.	Inside	Usual	Angle
A	11.7	12.9	11.3
B	11.9	13.1	12.4
C	11.9	12.5	12.7
D	10.8	10.1	10.9
E	10.3	10.5	10.1
F	11.1	11.3	10.7
Mean	11.3	11.7	11.3
SD	0.7	1.3	1.0

3. Statistics

For the swing velocity, impact point, swing angle and face angle, a one-way ANOVA with three factors (Inside Kick, Usual Curve Kick, Angle Curve Kick) was applied to six representative values obtained for each kick, (18 values in total from the three types of kick), Where a significant difference was recognized in the kicking effect, a multiple comparison test with the Bonferroni method was carried out. For the analysis of the EMG measurement, five values showing the percentage of Usual Curve and Angle Curve Kicks against Inside Kick, (60 values in total) were analysed using a paired t-test in order to test if there was any significant difference between the two mean values. The level of significance was set at less than 5%.

4. Results and Discussion

4.1. Swing velocity of the kicking foot and initial ball velocity

Table 1 shows the swing velocity of the kicking foot. Though the Usual Curve Kick showed the highest values (range: 10.1 m/s – 13.1 m/s) in many of the subjects, there were no significant differences between kicks. It is assumed that the data varied among subjects due to individual difference.

The initial ball velocities are shown in **Table 2**. Except for the result of subject B, the Inside Kick (range: 12.6 m/s – 15.2 m/s) tended to be the highest. In a comparison between the Usual Curve Kick (range: 11.2m/s - 14.1m/s) and the Angle Curve

Table 2 Initial ball velocities (m/s).

Sub.	Inside	Usual	Angle
A	15.1	12.0	12.8
B	14.6	14.1	15.0
C	15.2	12.3	14.0
D	12.6	11.2	11.9
E	12.8	11.3	11.3
F	13.2	12.8	11.6
Mean	13.9	12.3	12.8
SD	1.2	1.1	1.5

Table 3 Ball revolutions (r/s).

Sub.	Inside	Usual	Angle
A	2.1	8.4	5.1
B	1.8	4.9	3.7
C	2.1	5.9	5.0
D	1.8	5.4	2.1
E	1.5	5.7	5.5
F	1.8	4.9	4.5
Mean	1.9	5.9	4.3
SD	0.2	1.3	1.3

** (Inside–Usual)
* (Inside–Angle)

*: $p<.05$, **: $p<.01$

Kick (range: 11.3m/s - 15.0m/s) to check which values are higher or lower, no clear tendency was acknowledged. The ANOVA test indicates that there were no significant differences between the type of kicks.

A study which examined inside kicks with a usual running start at the maximal effort reported that the swing velocity of the kicking foot was 18.3 m/s – 19.1 m/s (Nunome, et al., 2002). A second study demonstrated that the swing velocity of the kicking foot with a one-step entrance was an average of 12.2 m/s (Kawamoto, et al., 2006). These results are similar to those in the current study which should be considered in terms of an experiment with a one-step entrance.

4.2. The number of ball rotations

Table 3 shows the results of the number of ball rotations for each subject. The results of the ANOVA reveal a significant difference in effect between kicks (F (2,15) = 21.78, $p < .01$). As a result of multiple comparison, the Usual Curve Kick ($p < .01$) and the Angle Curve Kick ($p < .05$) were significantly higher than the Inside Kick. No significant difference was recognized between the Usual Curve Kick and the Angle Curve Kick.

However, compared to the results of a previous study investigating ball rotations kicked by college soccer players (range 10.2 r/s - 4.4 r/s) (Asai, et al., 2004), the results in this study were slightly low. It is assumed that, the reason for this is that the entrance to the kick was limited to one step.

At the time of calculation of the number of rotations, if the assumed ball's circumference had been deviated from the actual one, the number of rotations would have been larger than actual. In practise, the gained values tended to be smaller than those in the previous study, suggesting that measurement error did not greatly affect the results.

When examining the results which show initial velocity and number of ball rotations at nearly equal levels, there is no significant difference between the two kinds of curve kicks .

4.3. Swing angle, face angle and angle of attack, and impact point of the kicking foot

The results of the swing angle, the face angle and the angle of attack, and the impact point of the kicking foot are shown in **Table 4**, and the pattern diagram of the results is shown in **Figure 5**.

As a result of the ANOVA applied to the swing angle, the effects of kicks show a significant difference (F (2,15) = 17.95, $p <.01$). In multiple comparison, the Inside Kick was significantly smaller than the Usual Curve Kick ($p <.01$) or the Angle Curve Kick ($p <.05$). The Usual Kick was significantly smaller than the Angle Curve Kick ($p <.05$).

The ANOVA test for the face angle revealed a significant difference in the effect by kicks (F (2.15) =12.00, $p <.01$). As a result of multiple comparison, the Inside Kick was significantly smaller than the Usual Curve Kick ($p <.01$) or the Angle Curve Kick ($p <.01$).

As for the angle of attack, the results of the ANOVA test showed a significant difference in the effect of kicks (F (2,15) = 26.49, $p <.01$). The ANOVA test revealed that the Inside Kick was significantly smaller than the Usual Curve Kick ($p <.01$) or the Angle Curve Kick ($p < .05$). Additionally, the Angle Curve Kick was significantly smaller than the Usual Curve Kick ($p <.05$).

Table 4 Mean value of swing angle, face angle, angle of attack and impact point of the kicking foot at impact.

Swing angle (deg.)

Sub.	Inside	Usual	Angle
A	80.8	61.4	72.1
B	85.6	69.1	73.9
C	81.2	58.7	64.7
D	80.0	66.7	85.3
E	79.8	57.7	68.9
F	78.1	66.9	72.2
Mean	80.9	63.4	72.9
SD	2.5	4.8	6.9
	**	*	
		*	

Face angle (deg.)

Sub.	Inside	Usual	Angle
A	94.7	114.7	104.4
B	100.1	112.1	107.8
C	97.2	110.7	109.5
D	89.9	105.3	103.8
E	91.1	101.3	109.4
F	105.5	113.8	115.8
Mean	96.4	109.7	108.4
SD	5.8	5.2	4.4
	**	n.s.	
		**	

Angle of attack (deg.)

Sub.	Inside	Usual	Angle
A	13.9	53.2	32.2
B	14.5	43.0	33.9
C	15.9	52.0	44.8
D	10.0	38.6	18.5
E	11.3	43.7	40.5
F	27.3	46.9	43.6
Mean	15.5	46.2	35.6
SD	6.2	5.6	9.8
	**	*	
		**	

Impact point (%)

Sub.	Inside	Usual	Angle
A	37.6	73.0	58.5
B	41.3	66.6	63.0
C	36.5	64.2	53.9
D	33.1	67.6	53.9
E	27.1	57.2	58.2
F	57.6	65.6	63.5
Mean	38.9	65.7	58.5
SD	10.4	5.1	4.2
	**	*	
		**	

*: $p<.05$, **: $p<.01$, n.s.: non significant

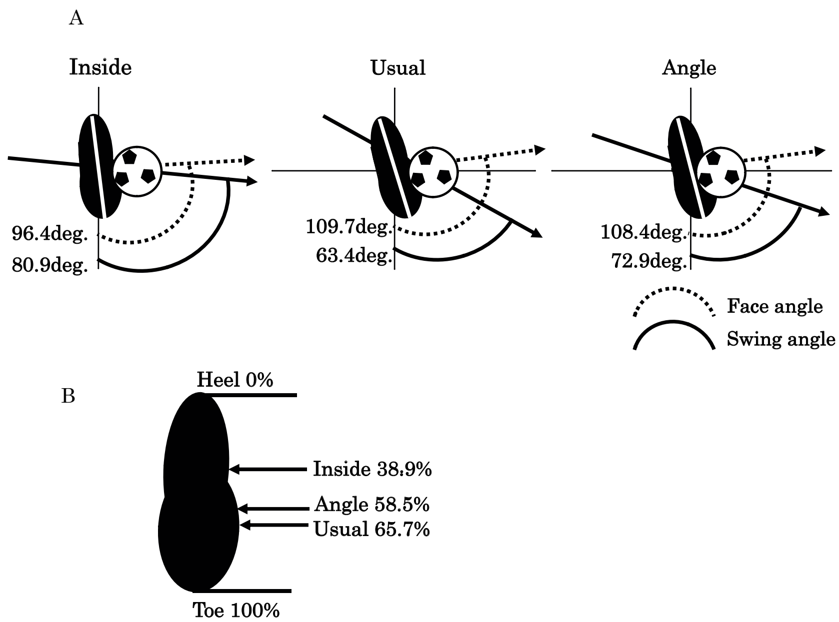

Figure 5 Average of swing angle, face angle (A) and impact points of kicking foot (B).

Earlier research reported that the maximum angle of attack in an infront curve kick by college soccer players was 45.4° and the minimum angle of attack was 21.9° (Asai, et al., 2004). The results of the Angle Curve Kick in this study show similar values. In the Inside Kick, a mean value of the angle of attack of 15.5° suggests that the direction of the face surface was near to the target on impact. The result in which the mean swing angle was 80.9° demonstrates that the direction of the swing surface

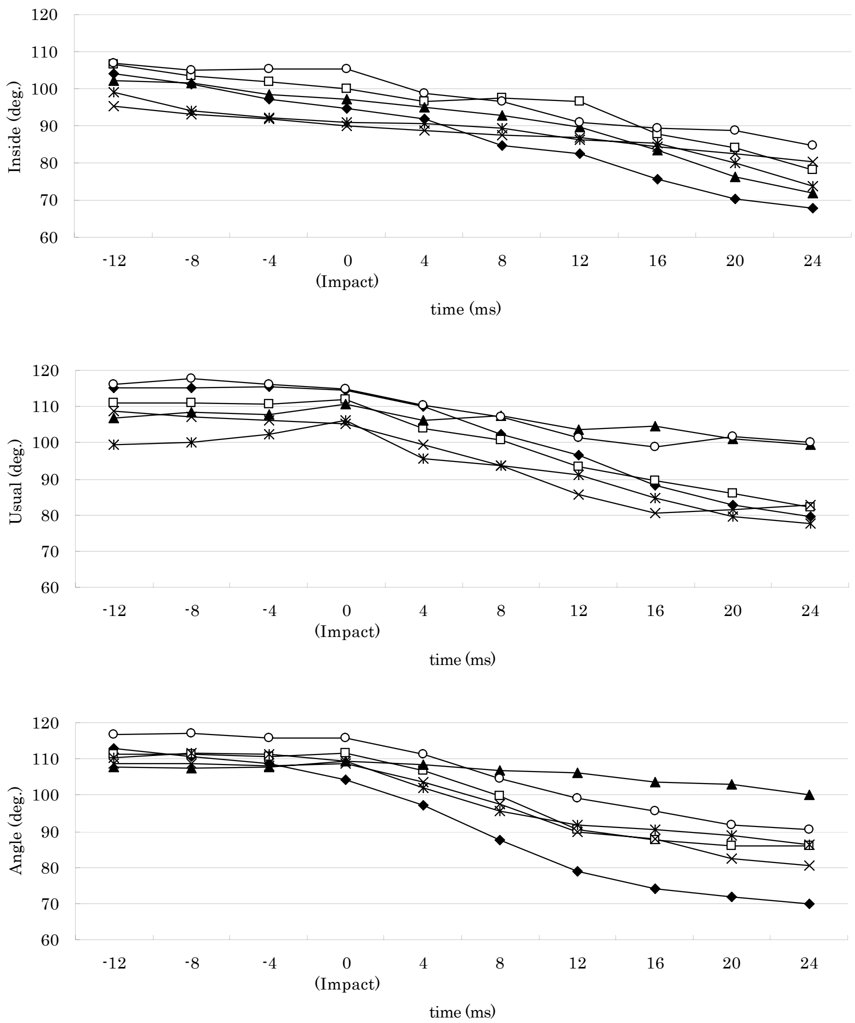

Figure 6 Mean values of face angle for 36ms including impact (Subject. A, ◆; Subject. B, □; Subject. C, ▲; Subject. D, ×; Subject. E, ∗; Subject. F, ○).

was approximately toward the target. In the case of the Inside Kick it was considered that the ball did not rotate horizontally.

It can be seen that the smaller the angle of attack, the higher the ball velocity becomes and the smaller the number of resulting rotations. In contrast, the greater that the angle of attack becomes, the lower the ball velocity and the larger the number of rotations. It has been identified that there is a trade-off relation between the number of rotations and velocity in the ball within a certain range (Asai, et al., 2004). This study has found that for the Inside Kick which has a small angle of attack, the initial ball velocity was higher than for other kicks and the number of rotations was smaller, which supports the results of the earlier research.

Regarding the results of the swing angle, the values for the Usual Curve Kick were significantly smaller than for the Angle Curve Kick. Thus, when trying to spin the ball by means of friction, many of the subjects kicked the ball with a smaller swing angle. In the Usual Curve Kick and the Angle Curve Kick, there were no significant differences in the face angle. Therefore, the difference of the angle of attack could originate from that of the swing angle.

The purpose of this study was to clarify the movement of the kicking foot focusing on the vicinity of impact. The entire swing has not been discussed. However, it is presumed that if the kicking foot moves in the vicinity of impact as in this study, the behavior of the ball will be at least similar to this study.

Then, comparing the movement of kicking foot with the guide line on the synthetic hardened glass, depending on each subject, a maximum 15.3° of deviation from the guide line was observed in the swing angle, a maximum 15.6° in the face angle and a maximum 21.5° in the angle of attack.

In this study, a guide line was drawn so that players could have a concrete idea of the type of kick which could spin the ball by the angle of attack. The deviation between the guide line and the actual results was not evaluated.

As a result of the ANOVA test applied to the impact point of the kicking foot, a significant difference was identified in the effect by kicks ($F(2,15) = 22.95$, $p < .01$). The results of the multiple comparison test show that the Inside Kick was significantly smaller than the Usual Curve Kick ($p < .01$) or the Angle Curve Kick ($p < .01$). The Angle Curve Kick was significantly smaller than the Usual Curve Kick ($p < .05$). These findings illustrate that the impact point in the Usual Kick was located nearer to the toe than in the other two kicks.

4.4. Change of face angle before and after impact

Figure 6 indicates the time serial changes of face angle using ten frames; three before impact and six after impact including the impact for each kick. For

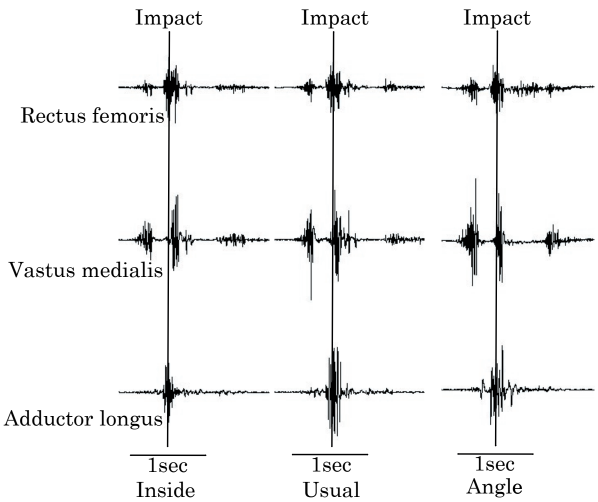

Figure 7 EMG wave pattern for typical subject.

Table 5 Ratios of EMG of kicking leg in Usual Curve Kick and Angle Curve Kick compared with Inside Kick (%).

	Rectus femoris		Vastus medialis		Adductor longus	
Sub.	I vs U	I vs A	I vs U	I vs A	I vs U	I vs A
A	128.02	128.54	104.55	67.55	166.61	147.53
B	92.50	109.14	146.32	154.49	176.76	136.77
C	150.33	157.99	113.38	149.99	82.66	56.81
D	101.70	74.96	86.68	82.15	92.26	91.30
E	117.55	103.48	139.69	162.97	96.47	83.98
F	84.47	83.37	98.48	80.85	37.80	27.75
Mean	112.43	109.58	114.85	116.33	108.76	90.69
SD	24.50	30.42	23.57	43.75	53.12	45.85
	n.s.		n.s.		*	

I vs U: Inside Kick Usual Curve Kick
I vs A: Inside Kick vs Angle Curve Kick
*: p<.05, n.s.: non significant

the Inside Kick, the angles moderately decrease before and after impact. Regarding the Usual Curve Kick and the Angle Curve Kick, the face angles decrease immediately after impact. Particularly in the Usual Kick, many subjects showed a rapid angle decline. The results suggest that immediately after impact in the Curve Kick, the hip joint of the kicking foot is externally rotated.

4.5. Electromyographic measurement

Figure 7 shows an example of an EMG wave. The rectus femoris and vastus medialis muscles mutually reveal similar waves for any kick. In addition, the muscle discharge before impact was recognized in those two muscles. Apparently, this is muscle action produced by movements of hip joint flexion and knee joint extension during the leg acceleration period (Nunome, et al., 2002). In the adductor longus muscle, the waves became larger in the order of Inside Kick, Usual Curve Kick and Angle Curve Kick respectively.

Table 5 indicates the percentage of muscle discharge in each muscle of each subject in Usual Curve and Angle Curve Kicks compared to Inside Kicks. Each kick was t-tested, revealing a significant difference in the rectus femoris muscle (p <.05). As the results of the swing velocity showed no significant differences, the influence of swing velocity on muscle action could be ignored.

Within the group of femoral extensor muscles including the rectus femoris and vastus medialis muscles, subject A's vastus medialis indicates a great difference. However, the other subjects beside subject A show similar results to each other with no statistical differences.

The values of muscle discharge in many of the subjects were over 100% , suggesting that the Usual Curve Kick and the Angle Curve Kick required greater muscle action than the Inside Kick. It is considered that the reason why the Usual Curve Kick shows significantly high values is due to the actions of the glacilis muscle. This is located along the adductor longus muscle, and affects the hip joint's medial rotation (James, et al., 1978). The actions of this muscle are included in the measurement. It is known that a surface EMG not only measures the activities of the target muscle but also of the muscles around it (US Department of Health and Human Services, 1991). Therefore, in the Usual Curve Kick, because the impact point of the kicking foot was far from the center of the foot joint, even in a similar level of exercise strength, the lateral rotation of the hip joint could be great enough to produce the opposed medial rotation.

5. Conclusion

This study has focused on three types of football kick: the infront curve kick (Usual Curve Kick) in which a player kicks a ball by rubbing it up with the toe; the infront curve kick (Angle Curve Kick) in which a player utilizes the angle of attack to spin the ball as suggested by previous studies, and the inside kick. Images were obtained of the kicking movements of subjects from below and the swing velocity of the kicking foot, initial ball velocity, number of ball rotations, swing angle, face angle, angle of attack and ball impact point were investigated. In addition, the actions of a group of femoral extensor muscles and a group of femoral adductor muscles in the kicking foot were observed. The findings are summarized as follows:

1. No statistically significant differences were recognized in the swing velocity or the ball initial velocity between the Usual Curve Kick and the Angle Curve Kick.
2. The Inside Kick was smaller in terms of the number of ball rotations than the other kicks. No significant differences existed between the Usual Curve Kick (range: 4.9 r/s - 8.4 r/s) and the Angle Curve Kick (range: 2.1 r/s - 5.5 r/s), though the values were smaller than those in an earlier study.
3. The angle of attack showed the greatest value in the Usual Curve Kick (range: 38.6°- 53.2°) followed by the Angle Curve Kick and the Inside Kick. At the moment of impact, since the Usual Curve Kick and the Angle Curve Kick indicated no differences in face angle, the difference of the angle of attack was found to originate from that of the swing angle. The high initial ball velocity in the Inside Kick, whose angle of attack was small, supports the results of an earlier study.
4. It was suggested that in the Usual Curve Kick and the Angle Curve Kick, the hip joint of the kicking foot externally rotated immediately after impact.
5. The ball impact point of the kicking foot in the Usual Curve kick was closest to the toe.
6. The percentages of muscle discharge in the adductor longus muscle were higher in the Usual Curve Kick than in the Angle Curve Kick, suggesting that the Usual Curve Kick imposed a greater load on the group of femoris adductor muscles. One probable reason was that the impact point was nearer to the toe.

In a kick utilizing friction with the ball, the impact point was located nearer to the toe, and the face angle greatly changed. Taking the results into consideration and including other viewpoints such as player athletic improvement and safety, we suggest that a kick utilizing the angle of attack be recommended in actual instruction

In a final thought, despite the kicker's intention and consciousness, the direction of the impact surface changed immediately after impact. For the purpose of a precise curve kick, kicking movements considering this change are also necessary.

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