Article

Biomechanical Characteristics for Identifying the Cutting Direction of Professional Soccer Players

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Abstract: (1) Background: To understand the movement characteristics of soccer players when cutting in two directions (45° for the right and left cutting movements) through biomechanical analysis of the lower limbs to identify the cutting direction of the attacker; (2) Methods: A motion analysis system was used to capture the movements of 12 male professional soccer players dribbling to the left and right. Kinematics of the players' cutting were analyzed, and the paired t-test was used for statistics, with a significant level of $\alpha = 0.05$; (3) Results: When cutting towards the right, the height of the hip joint during the run-up was low (effect size, $ES = 0.41$, $p = 0.031$) at 91.8 ± 7.0 cm. When cutting towards the left, the value was 94.6 ± 6.7 cm. While cutting, the front foot was abducted by $4.3 \pm 4.0^\circ$ at landing when cutting towards the right and adducted by $2.7 \pm 5.1^\circ$ when cutting towards the left ($ES = 0.38$, $p = 0.003$); (4) Conclusions: When the attacker carries out the cutting action while approaching the defender, the cutting direction may be predicted by observing the attacker's hip and foot movements.

Keywords: football; attack; defense

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1. Introduction

Soccer biomechanical analysis includes instep shots [1,2], side-foot kicking [3], and curveball kicks [4], which have been widely investigated in related studies. Soccer is a group confrontation sport. Players need both attack skills and defensive ability. If the attack and defense skills and the interaction between the two sides of the attack and defense can be quantified, the competition can be mastered more comprehensively [5]. The actions in a competition are categorized into attack, defense, switching from attack to defense, and switching from defense to attack. The first task of the attacker with the ball is to score and breakthrough; that of the defender is to challenge for the ball, block or delay, and try to switch from defense to attack.

There is a lot of information processing and decision-making in the movement processes between the attacker and defender. The attacker and defender form a closed system, in which the elements affect each other and are in balance when the two are in confrontation [6]. In this mode, the attacker cannot breakthrough easily, and the defender cannot steal the ball easily. In a balanced state, the defender can delay and wait for teammate support. When the defender adds pressure, the distance between the attacker and defender will change. At this point, the attacker may choose to pass the ball, cut, protect the ball, or re-establish balance. When under pressure, the reaction time and space will be limited, and the mode of attack may also change [7]. Therefore, if the defender can understand

the favorable position distance, the defender can affect the attack mode of the attacker. In this linked system, there is stable symmetry and destabilization between attack and defense situations. If the defender can understand the influence of distance on the attacker, the defender can affect the attacker's action through the defense distance. Further understanding of the kinematic characteristics of the human body in the cutting direction can reduce the possibility of a breakthrough. Davis, Button, and Bennett [8] proposed a theory of the coordination view. When a player is dexterous with their motor skills, the body can increase the degree of freedom and range of motion of the joints to improve athletic performance. When describing the cutting action in different directions from this point of view, the body should be able to use relatively large body movements and the full range of motion of the joints to cut in the direction in which the player is customary. Related studies have found that the foot eversion angle is relatively large when cutting in the customary direction [9]. There is a significant change in the knee joint angle during the initial landing period of the cutting action [10].

Previous research on the defenders' visual search strategy found that excellent players pay attention to their opponents' hip and knee areas. Therefore, the hip and knee may be the main areas used to predict the ball handler's attack action [11]. The application of distance perception enables players to master the attack and defense positions. In the attack and defense system, whether one party breaking the distance balance is also an opportunity for the other party, whether the balance can be rebuilt after breaking, and whether the distance between the attacker and defender and the time of confrontation after the balance is broken will influence factors that are yet to be investigated. The distance perception between the attacker and defender can be trained. If the action taken by the attacker can be further predicted and applied during competition, it can help the player control the rhythm of the competition [12]. Previous studies seldom used the biomechanics method to identify the cutting direction or intention in soccer games. Therefore, to better understand the movement of attackers from two different cutting directions, this study measured the differences of biomechanical characteristics, which can be applied to identify the cutting direction. This study aimed to understand the characteristics of an attacker's body movements during cutting to the right and left directions and analyzed the decision distance, body position, and joint angle of the attacker's cutting action.

2. Materials and Methods

2.1. Participants

Twelve male professional soccer players volunteered to participate in the study (average height, 173.3 ± 5.0 cm; body weight, 67.4 ± 6.0 kg; age, 18.9 ± 1.1 years; training experience, 8.8 ± 2.0 years). Subjects were players of the Taiwan Football Premier League. Their customary kicking and dribbling foot is the right foot. The customary movement for cutting is the right foot landing first (cutting foot) and the left foot serving as the following foot (steering foot). The subjects had no history of injury to the trunk, arms, or lower extremities within the past 6 months. Subjects were informed of the test content and rights and signed the informed consent form before the experiment, and the study was reviewed by the Medical Research Ethics Committee.

2.2. Instruments

The Vicon MX 13+ motion analysis system (Oxford Metrics Ltd., Oxford, UK) with 10 high-speed cameras was used to capture human motion at a sampling frequency of 200 Hz.

2.3. Experiment Process

Forty-seven reflective markers were placed onto the subject's body in a plug-in-gait manner (Figure 1), and the subject warmed up and practiced the cutting action. The field settings are shown in Figure 2A,B, and the cutting direction was 45° to the left front or 45° to the right front (Figure 2B). The order of cutting directions was determined by drawing

lots. Both directions were cut six times (three times for 45° cutting movements to the front on the left direction and three times for 45° cutting movements to the front on the right direction), and the fastest movements to the front on the left and right directions were included in the analysis. In the formal test, the cutting action was performed at the customary dribbling speed that was used in the competition. Before cutting, subjects know which direction they would be cutting and then were running towards the defender with a ball. The subject dribbled along a straight line from 5 m behind the measuring area to the front of the defender to perform the cutting action (Figure 2). After the front foot stepped onto the measuring area, the subject moved forward in the cutting direction. If the attacker performed the cutting action before stepping onto the measuring area, the experimenter would adjust the position of the defender so that the subject who performed the cutting could step on the measuring area when cutting. In addition, if the attacker stopped when dribbling, hit the defender, or lost the ball, it was considered a test failure, and a retest was performed after rest and adjustment. The movements of the subject from the run-up to the landing period of the cutting foot (front foot landing to taking off) and to the steering period (rear foot taking off to landing) were collected and analyzed.

Figure 1. Plug-in-gait reflective marker setting.

Figure 2. Schematic diagram of cutting angle and distance for attacking player dribbling.

2.4. Data Analysis

The positions of reflective markers in the space were collected by Nexus software (V1.4, Oxford Metrics Ltd., Oxford, UK), stored as C3D files, and imported into Visual3D software (V5.0, C-motion Inc., Germantown, MD, USA). The human body model was built after 12 Hz low-pass filtering to calculate the kinematic parameters. Kinematic parameters included cutting decision distance, hip joint height, joint angle, and center of mass (COM) speed. The cutting decision distance was the distance projected on the horizontal plane from the toe position of the attacker to the center point of the defender's chest front wall at the moment of the attacker's cutting foot landing (Figure 2A), which was divided into vertical and horizontal distances (Figure 2B). The cutting foot/leg was defined as the right (front/lead) foot/leg, and the rear foot/leg was defined as the left foot/leg. The height of the hip joint was calculated based on the height of the reflective marker at the anterior superior iliac spine (ASIS) from the ground and normalized to the height of the hip joint (the mean height of the reflective marker in the right and left ASIS) from the ground divided by the body height. The angles of the hip, knee, and ankle joints were set according to the angles defined by Wu and Cavanagh [13], and the anatomical posture of each joint when standing still was set to 0°. When acting, the clockwise movement was considered positive, and the counter clockwise movement was considered negative according to the right-hand rule. The sagittal plane angle is defined in Figure 2A, and the hip joint rotation and ankle joint adduction and abduction are defined in Figure 2C. Hip internal rotation, knee extension, knee adduction, and ankle adduction were considered positive values, while external hip rotation, knee flexion, knee abduction, and foot abduction were considered negative values. The value of the trunk was 0° when standing upright, and forward-leaning was positive and backward-leaning was negative.

2.5. Statistical Analysis

Data were expressed as mean $\pm$ SD and effect size (ES). Cohen's d-value was used to report the effect size (ES), which is the number of standard deviation units. The ES was calculated as $(M2 - M1)/\text{pooled SD}$, and the ESs 0.2, 0.4, and 0.6 were considered small, medium, and large effects, respectively. Paired *t*-test was used to compare differences of the decision distance, hip height, COM speed, the hip, knee (cutting leg), ankle joint angles (cutting foot), and ground reaction force in the left and right cutting directions by SPSS (21.0, IBM SPSS Inc., New York, NY, USA). The significance level was set at $\alpha = 0.05$ ($p < 0.05$).

3. Results

3.1. Distance at Which the Cutting Decision Was Made and Characteristics of Cutting Action

See Figure 3 for the distance at which the cutting decision was made by the attacker and the height of the hip joints from the ground during the run-up and at landing. The study found that the attacker chose to cut 1.2 m from the defender, whether to the left or right. The forward-backward distance between the cutting foot and the defender was consistently 1.2 ± 0.1 m (ES = 0.21, $t = -0.978$, $p = 0.349$); the horizontal distance was 2.2 ± 4.1 cm when cutting to the right and 3.7 ± 9.1 cm when cutting to the left (ES = 0.23, $t = -0.495$, $p = 0.630$). When a cutting direction was selected, the height of the hip joint was different: The height during run-up when cutting towards the right was significantly lower than that when cutting towards the left (0.92 ± 0.07 m and 0.95 ± 0.07 m, respectively, ES = 0.41, $t = 2.471$, $p = 0.031$). The landing height at the moment of cutting towards the right was also significantly lower than that when cutting towards the left (0.86 ± 0.06 m and 0.89 ± 0.06 m, respectively, ES = 0.50, $t = 2.851$, $p = 0.016$). However, there was no significant difference in the change of height from the run-up to landing in different cutting directions (ES = 0.04, $t = 0.690$, $p = 0.504$; 6.0 ± 5.1 cm when cutting towards the right and 5.8 ± 5.1 cm when cutting towards the left). The height of the hip joints normalized when using the ratio to body height. The average height during the run-up was 0.53 ± 0.04 when cutting towards the right, and 0.55 ± 0.03 when cutting towards the left (ES = 0.57, $t = 2.471$, $p = 0.031$). After normalization, the height of the hip joint at the moment of landing when

cutting towards the right was about half of the body height, and the normalized value was 0.50 ± 0.03 , which was lower than the value of 0.51 ± 0.03 when cutting towards the left ($ES = 0.33$, $t = 2.471$, $p = 0.031$).

Decision distance of cutting and hip height from the ground

Figure 3. The decision distance of cutting and the hip height during run-up and landing.

There was no significant difference in the COM speed during run-up, when landing, and at the completion of cutting between different directions. The speed during run-up was 3.2 ± 0.4 m/s when cutting to the right and 3.1 ± 0.4 m/s when cutting to the left ($ES = 0.03$, $t = -0.443$, $p = 0.666$). The speed when landing was 3.1 ± 0.3 m/s when cutting to the right and 3.0 ± 0.3 m/s when cutting to the left ($ES = 0.03$, $t = -0.796$, $p = 0.443$). The average speed from the moment of landing to completion of the cutting action was 2.6 ± 0.5 m/s when cutting to the right and 2.6 ± 0.3 m/s when cutting to the left ($ES = 0.00$, $t = -0.266$, $p = 0.795$).

3.2. Lower Limb Joint Angles

In different cutting directions, the abduction and adduction angles of the cutting foot ($ES = 0.38$, $t = 3.708$, $p = 0.003$) were significantly different. The cutting foot when landing was abducted by $4.3 \pm 4.0^\circ$ when cutting to the right and adducted by $2.7 \pm 5.1^\circ$ when cutting to the left. The joint angles in different cutting directions are shown in Table 1. The internal rotation angle of the hip joint was relatively large when cutting to the right ($ES = 0.72$, $t = -2.461$, $p = 0.032$). There was no difference in the trunk forward-leaning angle ($ES = 0.27$, $t = -1.817$, $p = 0.097$) or the knee joint angle in sagittal plane (cutting leg, right knee: $ES = 0.18$, $t = 0.300$, $p = 0.770$) between the two different cutting directions.

Table 1. Joint angles during cutting in different directions.

Unit: Degree	Knee Angle in Sagittal Plane (Cutting Leg)	Hip Rotation Angle	Trunk Forward-Leaning Angle
Left cutting	16.2 ± 5.5	-0.1 ± 10.0 *	6.3 ± 9.2
Right cutting	15.2 ± 5.9	7.8 ± 11.9	8.7 ± 8.7

* Significant difference in different directions. Hip internal rotation was considered positive values.

4. Discussion

4.1. Characteristics That Determine Soccer Players' Cutting Movements

This study found that when a soccer player cut in different directions, the body showed different movement characteristics, so the defender can predict the attack direction through the height of the hip joints and rotation direction and adduction or abduction of the ankle joints. The results of the attacker's cutting decision distance and speed were the same in the two cutting directions, i.e., the attacker would choose to cut 1.2 m from the defender. The run-up speed of the attacker can reach 3.1 m/s. After the cutting foot lands, body speed will decrease to 2.6 m/s. From the run-up to the landing of the cutting foot, the height of the body (hip joints) will decrease by about 6 cm.

Previous research and analysis on soccer players' cutting movements found that the foot will show a relatively large eversion angle when cutting in the direction of the customary foot [9], and the knee joint angle will change significantly at the initial stage after the landing of the supporting foot during the cutting movements [14], so the attacker's intention to cut can be predicted by observing the joint motion. The results of this study show that the defender can predict the cutting direction chosen by the attacker by identifying the angles of adduction and abduction of the attacker's foot and the height and rotation angle of the hip joints, among which the angles of adduction and abduction of the foot provide good directivity, as it is easy to observe the difference in such angles. Defenders can observe the heel-toe position of the cutting foot for identifying the intention of cutting direction. When the attacker cuts to the right, the cutting foot (front foot) presents the regular characteristics of abduction, which is 7° different from the angle when cutting to the left. When the attacker's cutting foot lands, if the defender recognizes that the attacker's front foot is abducted, it can be presumed that the attacker will cut towards the right, and if the front foot is adducted, then the attacker will cut towards the left.

According to the gait model established by Mackinnon and Winter [14], when the hip joints rotate, the ankle joints also rotate. Houck, Duncan, and De Haven [15] found that hip joint angles will affect the position of the cutting foot from the body centerline, so when the hip joint movements change, the ankle joints also change, which affects the direction that the feet point. When the attacker cuts to the right, the hip joints have a relatively large internal rotation angle; however, when the attacker cuts towards the left, there is little internal rotation action. In sports biomechanics, the position of the center of mass is used to indicate the movement of the human body. However, during competition, it is difficult for the defender to identify the position of the center of mass of the attacker (the height of the center of mass is difficult to judge by vision). The hip joints are close to the height of the center of gravity, and their position is close to the junction of the pants and shirt, which is convenient for the defender to identify and judge. Observing the changes in the height of the hip joints is one of the methods used to predict the cutting direction of the attacker.

4.2. The Spatial Relationship between Attack and Defense of Soccer Players

The focus of the defense is to reduce the space and time available to the ball-handler, reduce his or her alternative attack methods, and thus, achieve the goal of defense [16]. Therefore, how to judge the opponent's actions in a very short time is the key element of the defense strategy. Attack and defense are a system and affect each other during the competition. Gibson [17] proposed the Theory of Affordance, which shows that sports behaviors are the results of interaction in a specific space according to a specific purpose. Sports behaviors are changed by individuals, environment, and work [18]. In this study, the attacker and the defender are individuals who perform different tasks, and they form an interactive system. The changes in the environment between the two are the changes in attack and defense distances. The results of this study show that the distance at which the attacker makes the decision to cut is 1.2 m, which is greater than the distance that the legs of the soccer player can stretch forward when standing. Under the condition of stability on a single foot, the legs of the male soccer player can stretch forward by 0.8–0.9 m [19], so it is a safe distance for the attacker at which the ball is not easy to be intercepted. If the

defender can keep a distance of over 1.2 m away from the attacker, although it is difficult to grab the ball, it is not easy for the opponent to change direction and cut. If the defender presses the distance to within 1.2 m, it will be easier to grab the ball, but it may also make it easier for the opponent to cut. Therefore, for the defender or attacker, 1.2 m is a reference distance for the attack–defense balance. When the attacker and defender break this safe distance, both sides will carry out the next step of their action strategy.

4.3. Identification of Cutting Direction of the Attacker by the Defender in Soccer

Cowley et al. [9] found that when cutting in the direction of the customary foot, the foot will have a relatively large eversion angle, and the knee joint angle will change significantly with gender difference at the initial stage of the landing of the supporting foot during cutting; female players have a smaller knee joint flexion angle and larger eversion angle [10]. Kim et al. [20] analyzed the characteristics of lower limb movements in soccer players when cutting at 45 degrees to the left or the right and found that when cutting in a non-predetermined direction, the landing period is relatively long, and the knee joint flexion angle is also relatively large. This study found that for the defender, observing the angle between the attacker's trunk and knee joints is not of great application value in predicting the cutting direction. It has been pointed out in related research on the prediction of the kicking direction that goalkeepers will focus their vision on the supporting foot, the kicking foot, and the movements of the foot touching the ball. The position between the supporting foot and the ball is the basis for goalkeepers to judge the direction of the penalty kick [21]. The direction of the penalty kick can be predicted by observing the characteristics of body movements [22]. This study analyzed the sports biomechanics of professional soccer players with the ball and while cutting. It was found that the height of hip joints is different during the run-up, which is higher when cutting towards the left and lower when cutting towards the right. However, this study has not investigated the interaction between the attacker and the defender, including the effects of deceptive movements, pressure defense, and physical confrontation on the characteristics of related movements in the cutting direction. Some limitations should be noted. There were some marks, lines, and force plates on the ground, which may affect the movement of the attackers. Because the force plates have different colors on the ground, subjects may treat them as an area for performing the cutting movement, which would bias the result of the forward-backward distance between the attacker and the defender. It is suggested that future studies explore the influences of the above factors on the movement characteristics of the attacker and the related biomechanical mechanisms, which will be more conducive to application in competition practice.

5. Conclusions

The cutting intention and direction of soccer players can be predicted by observing the attacker's body movements. When the attacker is about to break through by cutting, the defender can prevent the attacker's breakthrough if the attacker's movements can be observed and the cutting path is predicted. The cutting intention of an attacker can be predicted by observing the changes in the joint angle. When the attacker cuts to the right, the hip joints are relatively low, with greater rotation, while the feet also point to the attacker's right.

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