Motion Analysis and Biomechanics of the Side-Foot Soccer Kick

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Abstract — Soccer, otherwise known as football, holds the title as the most popular worldwide sport. Soccer players rely heavily on the ability to execute an accurate delivery of the ball to a target using primarily the lower body. Sports science research includes a focus on the most basic kicking techniques, the side-foot kick. In addition to a discussion on recent literature of the biomechanics of this motion, a comparative kinematic study evaluated determinants of an accurate side-foot kick based on subject kicking foot velocity and the subsequent ball velocity. The results revealed that subjects with the lowest foot and ball velocities (3.6±1.5 m·s⁻¹ and 8.0±1.6 m·s⁻¹, respectively) also had the most accurate shots on straight targets (2.7°±1.5° deviation). However, a PCC correlation test revealed a significant correlation between higher foot velocity and higher accuracy. Although the study determined no significant correlation, there existed a trend in the calculated averages of the raw data showing that higher ball velocity resulted in higher accuracy.

Introduction

An estimated 200 million active players participate in soccer, the most widely played sport today [1]. Basic motions of the sport include passing and shooting with the foot. The initial lessons of beginning players incorporate such actions, while also vigorously practiced by professional athletes. Players most frequently use the basic kicking technique, the side-foot kick. During an average ninety-minute game, a player has approximately fifty-one contacts with the ball, twenty-six of with the feet [2]. Not all twenty-six kicks would perfectly execute side-foot kicks, but the accuracy of any kick can improve. To this end, studying the physical performance of a soccer player’s kick can occur through motion and biomechanical analysis. This study analyzed the velocity of kicking foot, the velocity of the soccer ball, and accuracy of the kicks with respect to three distinct targets using twelve subjects.

To execute a side-foot kick involves striking the ball with the medial aspect of the foot. This kick embodies an essential ability for playing the game. Novice level instruction includes the side-foot kick. The method may include a running start. The player utilizes different muscles and bones for each scenario of running and stationary kicks. For this paper, the analysis focuses on the primary anatomy of the kicking limb during a side-foot kick with a one-step preparation phase. Muscles and bones connected at the hip, knee, and ankle accelerate the kicking foot towards the soccer ball.

Specific muscles used for hip flexion include the psoas, iliacus, rectus femoris, pectineus, sartorius, and tensor fascia latae. Conversely, the gluteus maximus, the bicep femoris, semitendinosus, and semimembranosus of the hamstring constitute muscles used for hip extension. The hip also undergoes abduction and adduction during a side-foot kick [2]. Hip abduction involves the gluteus medius and gluteus minimus, while the longus, brevis, magnus,
and gracii adductor perform hip adduction. The femur and bones of the pelvic girdle directly interact with these hip muscles to control the lateral rotation of the kicking limb. At the knee, hamstring muscles and the sartorius enact knee flexion. The rectus femoris, vastus lateralis, intermedius, and medialis of the quadriceps exhibit knee extension. These muscles move the femur, tibia, and fibula at the knee joint like a hinge allowing for the foot to accelerate towards the soccer ball [3].

Primary muscles connected to the ankle include the anterior tibialis, gastrocnemius, and soleus. The anterior tibialis along the shin controls dorsiflexion. Gastrocnemius and soleus completes plantar-flexion. Although the side-foot kick uses all the bones of the foot, mainly the medial bones, such as the medial cuneiform and navicular bone, experience the most contact with the ball [4]. The achilles tendon connects gastrocnemius and soleus muscles to the calcaneus bone. The tendon regulates control over the angle of the foot. The calcaneous fibular, talofibular, and tibiofibular ligaments act as shock absorbers during ball contact, in addition to connecting the many bones of the foot and ankle joint [3].

Brophy, et al., proposed a succinct description of the coordination of muscles used in performing the side-foot kick (Figure 1). Preparation initiates by planting the supporting limb, with a slight bend at the knee, adjacent to the ball while the toe points in the direction of desired aim. A combination of knee extensors, hip extensors, and gluteus muscle contractions enact the backswing of the kicking limb [2]. Since the angle of the backswing contributes an important factor in the amount of energy transferred to the ball, a maximum hip extension prior to the end of this phase allows for greater kicking power. The backswing will eventually reach a turning point due to eccentric contraction of the hip flexor muscles, which marks the beginning of the leg-cocking phase [5].

In side-foot kicks, the thigh-shank plane rotates clockwise during the leg cocking phase due to the rotational motion generated by the hip external rotation torque. This allows the player to face the medial side of their foot towards the direction of aim (Figure 2) [6]. Also during this phase, the eccentric contraction of knee extensors play a dominant role in reducing the rate of knee flexion of the backswing and hip flexor concentric moment of force. Thereafter, the hip flexor muscles act in concentric contraction, which causes the leg to swing towards the ball with
a maximum knee extension. Meanwhile, adduction torque of hip flexors act to control the hip abduction angle, thus guiding the kicking limb in the correct orientation during the acceleration phase [5].

Figure 2. Overhead view of the acceleration phase. Subsequent to the external hip rotation, the velocity of the medial side of the foot increases towards the direction of the ball [6].

While the kicking leg accelerates towards the ball, some degree of knee extension occurs by brief concentric contraction of knee extensors. However, knee flexors quickly become dominant prior to ball contact. This acts eccentrically to reduce the rate of knee extension. Also prior to ball contact, the hip extensors become dominant, causing the thigh and knee to slow down until ball impact [5]. The follow-through phase, a dynamic beyond the scope of this paper, follows this process.

**Motion Analysis In Recent Literature**

Since soccer has become such a competitive sport, scientific research has been done to accurately determine the details of the player’s physical performance through motion analysis. This has allowed soccer players and coaches to measure and enhance passing, shooting and running with the ball, which has led to a high demand for research by scientist and improvement from players. Although most of the motion analysis research focuses on players’ physical performance as a whole during a game, there have also been studies concentrated on examining the biomechanics of the most common type of soccer kicks, especially the instep and side-foot kick [6].

Nunome, et al., [7] aimed to comprehend how the leg swings to produce an instep and a side-foot kick by investigating the kinetic details. The study utilized a three-dimensional video analysis technique that analyzed five experienced, male high-school soccer players. The subjects performed both kicks aimed at the goal while two high-speed cameras recorded their motions at 200 frames/second. Calculations tabulated angular velocity vectors from the hip, knee and ankle joints from the thigh, shank, and foot segments. To simplify results, three phases show the kicking motion by four major movements (Figure 3).
Numone, et al., demonstrated a significant difference in the hip external rotation torque and angular velocity between both kicks. The hip external rotational angular velocity from the side-foot kick dominated the last phase with a large magnitude of 11.1±2.4 rad/s compared to 6.0±2.0 rad/s from the instep. Based on all the results, the conclusion stands that in the later stage of kicking the hip external rotation torque from the side-foot kick produces the clockwise rotation of the thigh-shank plane. This could offer an enhanced way of swinging the leg to attain a sufficient square orientation and a forward velocity from the medial side of the foot. Nunome, et al., concluded that the thigh-shank plane rotates clockwise and allows the hip external rotation motion to increase directly the forward velocity of the medial side of the foot [7]. On the other hand, Levanon, et al., believed that the hip external rotation does not contribute to speed of the foot, but that it only adds a normal component velocity to the thigh-shank plane. This makes the resultant velocity vector of the foot point more perpendicular to the longitudinal axis of the foot, thereby facilitating the impact of the medial side of the foot squarely against the ball [8]. The resultant average ball velocities in these studies total between 16-23 m·s⁻¹ [7, 8].

A study analyzing the performance of kicks by Brophy, et al., focused on comparing and quantifying the duration of the five dephases and muscle activation of the lower limbs from instep and side-foot kicks. A motion capture system of eight cameras and electromyography (EMG) recorded and analyzed both kicks from thirteen male, NCAA soccer players. The evidence failed to show significant difference for the duration of each phase between both kicks. Phase five remained the longest, while phases three and four as the shortest. From the acquired EMG data, considerable interaction effects appeared in the hamstrings and the tibialis anterior, with more activity in the hamstrings during phase five and in the tibialis anterior during phases two, three, and four for the side-foot kick. However, significant differences existed for all the muscles between the kicking limb and the supporting limb from both soccer kicks [2].

Methods

A. Subjects

The Institutional Review Board from Florida Gulf Coast University approved the following protocol to measure the accuracy of a soccer side-foot kick when dependent on proper orientation and velocity of the foot. Twelve subjects participated in this study with informed
consent. Subjects of twenty-two and thirty-two years of age participated. The subjects did not have serious lower-limb injuries during the prior two years. No exclusion occurred on the basis of gender, height, weight, or preference of kicking limb. The side-foot kick constitutes a fundamental motion performed in soccer for all age groups, regardless of gender or athletic ability. The study included a total of twelve subjects solely on the availability of participants.

B. Equipment

An eight-camera Qualisys motion-tracking system recorded the position of the reflective markers. The time rates of 60 and 200 Hz documented the side-foot kicks. Prior to collecting data, calibrations occurred. The subjects wore eight reflective markers to track their motions. Markers tracked the right and left anterior interior iliac crests (RIIC, LEIC). Another marker tracked greater trochanter of the kicking limb (KLGТ). Two additional markers recorded the movements of the knee, one on the lateral side (LKNE) and another on the medial side (MKNE). The last three markers traced the dynamics of the kicking foot; above the lateral malleolus (TANK), located 2.5cm directly below the lateral malleolus (BANK), and on the fifth metatarsal (TOE5). Besides having reflective markers on the subjects, the ball also needed to have markers to track its movements. Therefore, six round cut outs (~1 cm diameter) of reflective tape documented the surface of the ball at equal distances from each other. In order to measure the accuracy of the kick, reflective tape (2 cm long) demarcated the correct path on the floor for each target, 2.5 m from the position of the ball (Figure 4).

C. Testing Protocol

Subjects aimed to kick the soccer ball at three different targets with the medial aspect of their kicking foot, while imagining passing the ball to the foot of another soccer player. They performed a side-foot kick five times for each target, first to the straight target, then to the left and lastly to the right, for a total of fifteen kicks. The setup located the targets, 11 cm above the ground, as marked by X symbols on the wall. The formation situated targets straight in front of the subject and 1.8 m to the right and left of the middle target. The position of the soccer ball starting point totaled 4.5 m from the middle target. Therefore, the angle between the subject and the right and left targets trigonometrically equaled 21.8°. Refer to Figure 4 for visual aid of the setup.

The preparation phase equated a single step with the supporting limb. Some subjects exhibited hesitancy in their steps, tending to overthink their preparation stride. Therefore, all subjects took several practice kicks prior to initiating the motion-capture recording. Furthermore, the study calculated a designated limit of only one step. A ratio of height to the distance that the supporting limb stepped during the preparation phase determined an approximate starting position of subject to ball. We used the ratio of a standard soccer player with a height of 181 cm and step distance of 76 cm.
Figure 4. Setup of the testing protocol with the targets (red X's) equidistant from each other and their exact positions with respect to the soccer ball. Orange rectangles represent the reflective tape positioned on the floor. Subjects performed side-foot kicks from the starting position of the ball (4.5m directly from the wall) to each one of the three targets.

D. Outcome Measures

The accuracy of a side-foot kick also entails the distance the soccer ball travels, dependent on its maximum velocity. In one study, the conclusion asserted that the ball velocity observed for the side-foot kick did not depend on the quality of impact, but due almost exclusively to the final speed of the kicking foot [8]. Therefore, the study needed to measure both the velocity of the foot and of the soccer ball. The literature documented a very rapid increase in kicking-foot velocity, until a peak magnitude at ball impact [7]. This study expected to observe the same dynamic.

E. Data Analysis

All data collected by Qualisys enabled kinematic computations using Matlab. The data provided by the Qualisys system displayed a three-dimensional model. The measurements of position vectors matched the origin of each reflective marker. In some cases, the position vector of a marker related to another marker. All statistical analyses performed used the SPSS predictive analytical software.

Velocity of Kicking Foot

Calculations tracked the velocity of the kicking foot in the x- and z-directions. The position vector of markers KLGT and TOE5 offered evidence used to calculate the position of the kicking foot with respect to the hip. The calculation of the velocity of the kicking foot, with reference to the hip, derived from distance with respect to time.
Velocity of Soccer Ball

Calculations listed the velocity of the soccer ball in the x- and y-directions. From the six markers located on the soccer ball, at least three markers remained visible at all times. Therefore, the two markers with distances equal to the diameter of the ball allocated the midpoint between them, accurately determining the center of the ball. This position vector replicated the original location, with the time derivative used to define the velocity of the ball.

Accuracy

Figure 4 displays the setup and the expected path for each shot. To determine accuracy, measurements noted the angle between the expected path and the actual path, with all angles measured clockwise. In processing the statistics, the absolute values from all raw data of the deviation from the target, neglecting the direction of the deviation, totaled a figure in degrees. The analysis of the accuracy for each target consisted of a comparison with the two different outcome calculations, based on results noted within literature and a correlating Pearson statistical test.

Results & Discussion

Table 1 shows the average kicking foot velocities and the average ball velocities of all twelve subjects for side-foot kicks aimed at the left, straight, and right targets. The shots aimed at a straight target exhibited the lowest velocities, whereas the shots aimed at the right target exhibited the highest velocities. Table 1 also shows the average deviation from the left, straight, and right targets for all subject attempts. The shots at the straight target resulted in the lowest deviation from the center of the target, whereas the shots at the left target resulted in the highest deviation from the center.

<table>
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<tr>
<th>Table 1. Kinematic Outcomes of Side-Foot Kicks at Three Targets</th>
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<td><strong>Outcomes</strong></td>
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<td>Kicking Foot Velocity (m·s⁻¹)</td>
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<td>Ball Velocity (m·s⁻¹)</td>
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<td>Deviation from Target (°)</td>
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In the papers reviewed by Kellis, et al., a correlation existed between lower kicking-foot and ball velocities with higher accuracy rates. This appeared correct based on the processed data, revealing the means for all twelve subjects. Subjects aiming for the straight target had the best accuracy (2.8°±1.5° deviation) with the lowest kicking foot and ball velocities, (3.6±1.5 m·s⁻¹ and 8.0±1.6 m·s⁻¹, respectively). Accuracy of a soccer kick seemed to depend on how fast the subject approaches the ball. However, in the same review the mindset of the player also determined shot accuracy [8, 9]. Since subjects in this study began knowing that the goal of the experiment focused on accuracy rather than power, the possibility occurred that this factor influenced their performances. Therefore, the average of all ball velocities (8.5 m·s⁻¹) measured in this study totaled a lower rate than those cited in the literature (16-23 m·s⁻¹), wherein the subjects performed both in-step and side-foot kicks at a non-specific target with maximum force [2, 7, 8, 9].

Although based on the averages, a positive correlation seemed correct. A Pearson product-moment correlation test precisely compared accuracy with the other outcomes of velocity of ball and velocity of kicking foot. The correlation coefficients values, r, equaled 0.146 and 0.252 for ball velocity and velocity of kicking foot, respectively. Since the r value of kicking foot velocity totaled more than the critical value, 0.179, accuracy and kicking foot velocity proved to demonstrate a negative correlation. A faster kick by the subject appeared to increase accurate target aim. Furthermore, a One-Way ANOVA tested for statistical difference of the variance between each of the three targets, for all three outcomes. In this test, p equaled greater than 0.05. Therefore, no statistical difference occurred between the targets for any of the outcomes measured.

**Conclusion**

The sample characteristics defined in this study may have been an influential factor in the variation of the outcome measurements, particularly the ball velocity, the kicking foot velocity, and the ball’s deviation from the target. The selection of participants in soccer-kick studies typically depends on their experience level in the sport. This study excluded the subject’s soccer experience as relevant criteria due to the simplicity of the motion that participants performed. Thus, when compared to the literature, the average outcome calculations all resulted in lower values. Moreover, several of the subjects collected for this study had over five years of soccer experience, where as other subjects had none. The highly experienced subjects demonstrated more consistency with the accuracy of their kicks. Meanwhile, the unexperienced subjects had very large deviations from the targets, subsequently affecting the average deviations. Trends in the data allows for speculation that a faster ball velocity results in more accurate side-foot kicks. There exists a significant correlation between higher foot velocity and higher accuracy.

**References**


