KINEMATIC COMPARISONS OF KICK DIRECTIONS DURING THE INSTEP SOCCER PENALTY KICK

By:

Yumeng Li

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Abstract

The purpose of the study was to compare the differences in the kinematics of the instep kicking movement in different kicking directions in a soccer penalty kick. The significant aspects of the joint movements that influence the kick directions were determined. Understanding the relationship of these factors to kick may be useful in preparing goalies to perceive potential directional properties of kicks before the ball is struck, giving them increased time in which to react. Eleven female soccer athletes performed the instep kick in two different directions (left and right posts) on an outdoor field. The kinematic data measured from kicking techniques were collected using three standard video cameras and a high speed camera (80Hz). All the data was analyzed by paired t-test. Two way ANOVAs were used to compare the displacement and velocity curves and post hoc analysis (Tukey's HSD) was used to determine where the differences occurred. Stepwise multiple regression analysis tested how the kinematic variables predicted the kicking direction. There are several variables that are significantly different between the two kick directions, including: peak knee extension angular velocity, peak foot linear velocity, support foot plant orientation and position, pelvis orientation at foot plant, support leg lean in the frontal plane and approach angle. There are only three variables that can predict kick direction significantly: support foot orientation, distance from support heel to the ball center and approach angle. These three variables combined can explain 77.4% of the variance of the kick direction. The support foot may be the most useful cue for goalkeepers to predict the ball direction. It is suggested that if the support foot landed behind the ball and pointed towards the left side, the ball usually went to the left post. If the support foot landed in front of the ball and pointed towards the right, the ball usually went to the right post. Other cues may be less helpful because they are difficult to interpret or too subtle to be detected.

CHAPTER 1

Introduction

Soccer is one of the most popular sports in the world in terms of participation rate. According to Federation International Football (Soccer) Association (FIFA) latest statistics, there are 265 million male and female players in addition to five million referees and officials actively involved in the game of soccer, which is four percent of the world's population (World football: Big Count, n.d.). The soccer game is played by two teams on a rectangular field that is usually grass or artificial turf. The objective of the game is to drive the soccer ball into the opponent's goal. The ball is controlled primarily by using the feet; a goalkeeper can defend the ball by using the hands. The basic skills of soccer include passing and receiving the ball, possession of the ball, attack and defense skill, heading skill, shooting skill and goalkeeping. Team coordination and communication in the game is also very important, because the soccer game requires teamwork.

Scoring goals may be the most difficult task in a typical soccer match, so the player has to use a variety of shooting skills depending on the situation of the ball (Luxbatcher, 1991). To score goals on a regular basis, the player should be able to execute various shooting skills under the game-related pressures of limited time, restricted space, physical fatigue and opponents' interference (Luxbatcher, 1991). Basic shooting techniques include the instep kick, push kick, outside kick and bending kick. In soccer shooting, linear velocity of the ball is the key to goal-scoring. As we know, velocity is a vector, which has both magnitude and direction. There are various research studies focused on the factors that can contribute to kick speed (magnitude of velocity) such as technique and coordination of kicking leg movement, supporting leg position, pelvis and upper trunk movement and foot-ball interaction. However, there are only two studies describing kicking directions (Nagasawa et al., 2011; Lees & Owens, 2011). The present study will compare the kicking movement between two (left and right posts) kicking directions and determine the key factors that contribute to the kicking direction.

Purpose of the Study

The purpose of the study is to compare the differences in the kicking movements between two different kick directions. The significant kinematic factors that influence the kick directions will be determined. Understanding of the relationship of these factors may be useful in preparing goalies to perceive potential directional properties of kicks before the ball is struck, giving them increased time in which to react and stop the ball.

Null Hypotheses

1. There is no difference in the kicking leg movements between the two kick directions.
2. The trunk displacement in the transverse plane and support foot orientation (the angle between the long axis of the foot and the anterior-posterior axis) have no effect on the kick directions.

Rationale of this study

The speed and direction of the ball are two key components in soccer kicking. High speed and cunning directions of the kick give little chance for the goalkeepers to stop the goal. There are various studies (Katis & Kellis, 2010; Nunome, Asai, Ikegami & Sakurai, 2002, Dorge; Andersen, Rensen & Simonsen, 2010) focused on factors that can contribute to kicking speed (magnitude of velocity) such as technique and coordination of the kicking leg movement, supporting leg position, pelvis and upper trunk movement and foot-ball interaction. However, there are few studies (Scurr & Hall, 2009) investigating kicking directions. Most of these studies are focused on the shot accuracy through studying the kick directions. There is only one study that was to describe postural cues in kicking that may be of use to goalkeepers (Lees & Owens, 2011). They compared the movement of three different types of kicks: low side-foot kick to the left corner, low side-foot kick straight ahead and a low instep kick straight ahead. They suggested that the support foot orientation on the ground is the best cue to predict kick direction and type of kick (Lees & Owens, 2011). To date no studies have compared the differences in the instep kick movements involved altering kick direction. As a result, the key factors that contribute to kick direction are still unclear. This study will compare the kicking movement between two kick directions (to the left post versus to the right post) and will determine some key factors that contribute to the kick direction.

Limitations

There are some limitations in this study.

- Even if significant differences are found, it is still not clear whether the goalkeepers have enough time to predict the direction and make the correct movement to successfully defend the penalty kicks.
- This study does not involve studying any kicking movement with deception. However, the deception is commonly used in the real penalty kick.
- The step length during the kicks to the right side may be underestimated because the pathway of the approach was farther from the sagittal camera, which resulted in that the measurement length was shorter than the real length.

Description of the Instep Kick

An instep kick uses the upper medial surface of the foot or the area of the shoe laces to strike the ball. It is often used for maximum force and distance such as a powerful shooting or a long distance pass.

Approach

The approach for an instep kick usually requires 3-5 steps. The approach begins at an angle of approximately 30-45 degrees to the desired direction of the kick (Isokawa & Lees, 1988). The pathway of the approach is usually slightly curved (see Figure 1-1).

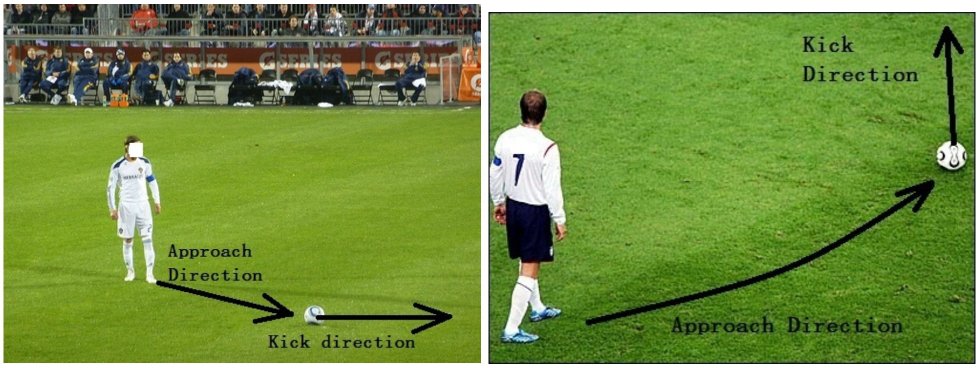


Figure 1-1. The angled approach of a soccer kick. (a) side view, (b) overhead view.

At the end of the approach, the non-kicking side arm should abduct and horizontally extend. The length of the last step should be maximized by the non-kicking leg. The longer the step, the larger the backswing movement that occurs. The maximal backswing (the maximal kicking hip extension) should occur just before the foot contact. In the maximal backswing, the kicking side hip should be extended at about 30 degrees (Levanon & Dapena, 1998). The knee should be flexed at about 90 degrees (Figure 1-2). The right arm should be in neutral position or slightly extended.

The non-kicking side hip is flexed at 50 degrees. The knee is slightly flexed at about 25 degrees. The arm is horizontally abducted. The trunk should be vertical and facing the target directly, while the pelvis is facing slightly sideways. The eyes should be fixed on the ball.

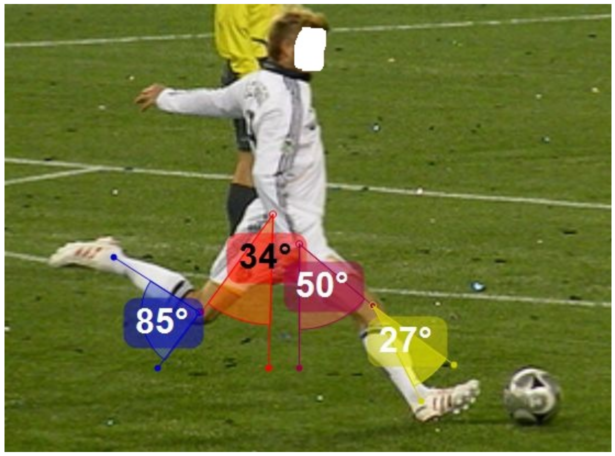


Figure 1-2. Measurement of the segment positions in maximal backswing. His foot plant is slightly behind the ball.

Foot Plant

The non-kicking foot should plant directly beside the ball and about 10-15 cm away from the ball (Luxbacher, 1991). The toe should be pointed directly to the kick direction (Lees & Owens, 2011). The foot plant position can affect the pathway of the ball. If the plant is too far behind the ball, the distance from the ball to the kicking foot is relatively long, so the kicking leg should have more hip flexion to reach the ball, which causes the instep to face upward. Therefore, the force exerted on the ball has more upward component, which will tend to produce a high trajectory of the ball. In the opposite situation, if the plant position is too far ahead of the ball, the kicking leg position and instep direction (face forward) at ball contact will tend to produce a low trajectory of the ball. The non-kicking knee should be flexed at about 25 degrees to absorb the impact force from the ground. However, the knee flexion angle at foot plant should not be over 30 degrees, because a large knee flexion at the non-kicking side will result in a more flexed knee at the kicking side at ball contact, which will reduce the radius of rotation at the kicking leg thus a lower foot velocity.

Force producing phase

After the foot plant, the forward movements occur. The pelvis should rotate forward (to the left). The kicking hip begins to flex, while the knee is flexing more. The kicking foot is plantar flexed; however, the ankle joint should be relaxed. As the leg swings forward, the non-kicking side arm should swing forward as well by shoulder horizontal adduction. This arm movement will help to take up the angular momentum created by the kicking leg (Shan & Westerhoff, 2005). As the kicking leg swings through the neutral position, the thigh will slow down and knee extension will occur. Some of the momentum of the thigh will transfer to the lower leg to increase the angular velocity of the knee extension (Barfield, Kirkendall &Yu, 2002). The ankle joint remains plantarflexed and should be tightened by contraction of calf muscles prior to the ball contact, because a rigid ankle and foot will increase the coefficient of restitution so that it will increase the ball speed (Lees & Nolan, 1998).

Ball contact

In an instep kick, the ball contact should occur on the upper medial surface of the foot (the first and the second metatarsal). The trunk is flexed and relatively upright in the frontal plane. The legs are tilted laterally away from the ball. Orloff et al. (2008) reported the lateral angle to the vertical is 25 degrees. The tilted support leg will help the kicking foot be more able to get under the ball to make better contact (Plagenhoef, 1971). As well, the lateral tilt away from the ball will increase the moment arm for rotation of the foot about the left hip (axis of rotation). An inclined lower body would allow a more extended kicking knee at impact and thus a higher foot velocity (Lees et al., 2011). The eyes should be fixed on the ball.

Figure 1-3. At the ball contact, the trunk is flexed; the legs are tilted away from the ball.

Follow through

After the ball contact, the kicking hip continues to flex and gradually slows down by muscle eccentric contraction. The purpose of the follow through movement is to reduce the risk of joint impingement injury and muscle strain injury, so the athletes should perform a long range of motion.

Figure 1-4. The follow through movement in an instep kick.

Definition of Terms

Approach angle: is the angle between the line of pathway of the approach and the direction of pathway of the ball in a soccer kick (see Figure 1-1).

Anterior-posterior axis: in this study, the anterior-posterior axis refers to the axis that is perpendicular to the goal line.

Center of Mass: is the point around which the body's weight is equally balanced, no matter how the body is positioned (Hall, 2007).

Coefficient of restitution: the coefficient of restitution of two colliding objects is a fractional value representing the ratio of speeds after and before an impact, taken along the line of the impact (Bartlett, 1999).

Ground reaction force (GRF): is the force exerted by the ground on a body in contact with it (Hamill & Knutzen, 1995).

Inertia: Inertia was defined as the property of an object that resists changes in motion. (McGinnis, 1999).

Inertial lag: the lag of distal body segments behind proximal segments is known as inertial lag, which is the trailing of the distal segments due to their inertia (Alexander et al., 2010)

Instep kick: is a type of kick that uses the upper medial surface of the foot to strike the ball, and is mainly used for a powerful shot or a long distance pass.

Kick direction (ball direction): is the angle between the pathway of the ball and anterior-posterior axis (the axis perpendicular to the goal line).

Kinematics: is the study of bodies in motion without regard to the causes of the motion (Robertson, Caldwell, Hamill, Kamen & Whittlesey, 2004).

Kinetics: is the study of the causes of motion (Robertson et al., 2004).

Linear momentum: In classical mechanics, linear momentum or translational momentum is the product of the mass and velocity of an object. P=MV (Robertson et al., 2004).

Overhead view: the view that is above the participants' head. In this study, the view is capturing the kicking movement in the transverse plane.

Pelvic orientation angle: at support foot touch down, the angle between the pelvic girdle and medial-lateral (x) axis (the axis parallel to the goal line). (See Appendix A, Figure 1-2.)

Pelvic retraction/protraction angle: at support foot touchdown, the pelvis is behind the X axis. This position is called pelvic retraction (Lees & Owens, 2011) (see Figure 1-5a). After the ball contact, the pelvis continues to rotate. If the line of pelvis orientation is in front of the X axis, this position is called pelvic protraction (Lees & Owens, 2011)**.**

Support foot orientation angle: at whole support foot touch down, the angle between the long axis of the foot and the anterior-posterior axis represents the support foot orientation (Fig.1-5b)

(a) (b)

Figure 1-5. pelvis and support foot orientation angle (overhead view).

CHAPTER 2

Literature Review

Kicking is the most used skill in soccer, and is used to pass or shoot the ball. There are several types of kicks commonly used. A push kick, also called an inside foot kick, allows a highly accurate and short pass due to the large foot-ball strike area. In a push kick, the ball is stroked with the inside of the foot at the high arch, or the navicular bone. It is called a "push" pass because of the long follow through like pushing the ball. An instep kick uses the upper medial surface of the foot to strike the ball, and is mainly used for powerful shooting and long distance passes. The outside kick uses the outside surface of the foot to strike the ball**.** The strike areas can affect the ball speed and pathway of the ball. In the push kick, the foot has to be angled outwards. The movement prevents the knee from flexing and extending in the same way as it would for an instep kick (Lees & Nolan, 1998). The instep kick can use the large muscle group in the hip joint to accelerate the foot. Therefore, the instep kick is more powerful than a push kick. However, in a push kick, the contact area is made on the firm bones of the medial aspect of the foot and ankle. This leads to a greater ball to foot speed ratio for a push kick (Lees & Nolan, 1998). During the outside kick, the ball is usually stroked at the inside half of the ball, so the shot will curve outward. Though the strike areas are different among different types of kicks, the general pattern of the segment movements are very similar.

As the kicking shot is the major method to score goals, the ball speed is very important. A higher speed shot will give the goalkeepers less time to react and save the ball. There is considerable research (Kellis & Katis, 2007; Dorge et al., 2010; Nunome et al., 2002**)** to determine the factors that contribute to ball speed and how these factors affect ball speed.

The Approach

The approach before the kick is important. Skilled soccer athletes use a curved approach. The curved approach will tend to produce an inclined lower body due to the lean in toward the center of the arc, which would allow a more extended kicking knee at impact and thus a higher foot velocity (Lees et al., 2011). Another reason is that the curved approach will tend to produce an inclined kicking leg and foot that is more able to get under the ball to make better contact with it (Plagenhoef, 1971). Lees, Steward, Rahnama and Barton (2009, p.155) also discussed a third possible reason: "a curved approach provides a stable position for executing the kick, thus contributing to the accuracy and consistency of kick performance."

Soccer players also often approach the ball at an angle when taking the instep kicks (Kellis, Katis & Gissis, 2004). The contribution of the angled approach is quite similar to that of curved approach. The angled approach refers to the angle between the line of the approach pathway and the desired direction of the pathway of the ball; whereas the curved approach suggests that the pathway of the approach is curved rather than straight. An angled approach can position the body to gain greater hip and knee flexion and enables the kicking leg to be tilted in the frontal plane so that the foot can be placed further under the ball, thus enabling better ball contact (Lees and Nolan, 1998). Isokawa and Lees (1988) studied the effects of approach angle on kick kinematics. They found that an approach angle of 30 degrees to 45 degrees is optimal for maximum ball speed. This finding is supported by others who suggested that an approach angle around 43 degrees can generate maximum ball speed (Egan, Vwerheul, & Savelsbergh, 2007). Scurr and Hall (2009) also examined the effects of approach angle on penalty kicking accuracy and kick kinematics. They used seven male amateur soccer players to kick penalties at a 0.6m×0.6m target in a full size goal from their self-selected approach angle, 30 degrees, 45 degrees and 60 degrees. They found that altering an individual's self-selected approach angle at recreational level did not improve kicking accuracy or ball velocity (Scurr & Hall, 2009).

The stride length of the approach should be increased progressively. The length of the last stride should be maximized, because it is important in maximal speed kicking. The longer the last stride, the more backswing movement at the kicking leg can be produced. The maximal backswing is also achieved by "inertial lag". In kicking movement, the right side of the pelvis rotates forward (to the left) first, leaving the kicking leg behind. This lag places the right anterior hip muscles on a stretch (Alexander et al., 2010). It can activate the stretch-reflex of the muscle and store some strain energy at the elastic components of muscles, tendons and ligaments. It will also provide more distance and time for the forward acceleration of the kicking leg. Lees and Nolan (2002) found a large last step length preceded a long range kick, which contributes to high ball speed. Approach speed can also affect ball speed. Players have their own preferred optimal approach speed. When the approach speed is higher or lower than the optimal one, it will decrease the maximal ball speed (Andersen & Dorge, 1999). On the other side, Orloff et al. (2008) suggested that the approach speed can affect the ball speed with a high positive correlation (0.72). They suggested that the higher the approach speed, the higher the ball speed that was produced.

Backswing

The kicking leg technique may be the most important factor in producing a good kick that has high speed. The backswing of the kicking leg occurs during the last stride when the hip begins to extend. Levanon and Dapena (1998) reported that the maximal hip extension is 29 degrees with an angular velocity of 171.9-286.5 degrees/second. The maximal hip extension is achieved due to inertial lag when the pelvis rotates forward and leaves the right thigh behind.

While the hip is extending, the hip is also slowly adducted and externally rotated. Kellis and Katis (2007) suggested that the knee flexes at an angular velocity of 745-860 degrees/second and internally rotates in the backswing phase. The ankle is plantarflexed at 10 degrees, abducted at 20 degrees and slightly pronated (Levanon & Dapena, 1998). The maximal backswing usually occurs just prior to the instant that the support foot touches down on the ground (see Figure 2-1).

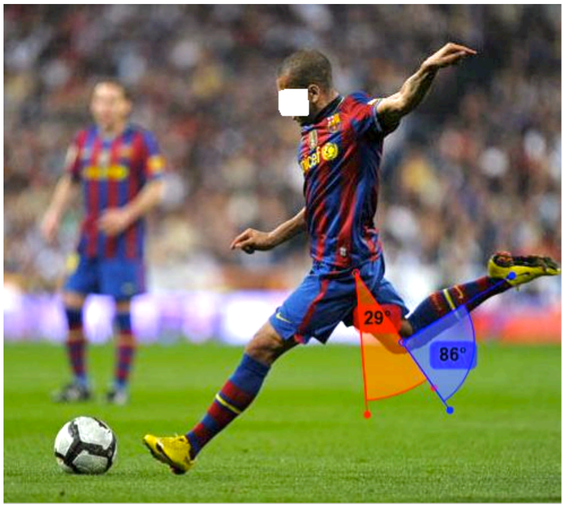


Figure 2-1. The maximal backswing of instep kick performed by an elite player.

Foot plant

After the maximal backswing in the approach, the non-kicking foot should touch down on the ground initially on the heel then the whole foot. The non-kicking foot should be planted directly beside (on the left side, if a right foot dominant player) the ball approximately 10-15cm away (Luxbacher, 1991).

The support leg is very important for kicking, because the support leg acts to stabilize the kicking movement and utilize the ground reaction force directly. The ground reaction force (GRF) can be a predictor of speed of the soccer kick. Dos Anjos and Adrian (1986, p44) have suggested that "skilled players kicked faster than unskilled (25.9m/s vs 23.4m/s) and the GRFs the skilled players exhibited vertically, anteriorly-posteriorly, and laterally were greater than among unskilled." Orloff et al (2008) analyzed ground reaction forces and kinematics of plant leg position during the instep kick in males and females. They reported the general patterns of ground reaction forces in all three primary directions in skilled kicking.

There are three general patterns of vertical force-time curves of the support leg in Orloff's study (2008): decreasing, double peak and increasing. In the decreasing group, the peak vertical force occurred immediately after the foot plant before the ball contact. The peak ground reaction forces in all three directions occurred almost at the same time. The vertical force is decreasing throughout the kicking process. In the increasing group, the peak ground reaction forces in all three directions occurred almost at ball contact. In the double peak group, the two peak vertical forces occurred before and after the ball contact respectively. However, the patterns of the vertical forces were not related to the ball speed (Orloff et al., 2008). They also found the peak medial-lateral force was significantly higher in the women and mean medial GRF was 0.56 body weight units for women and 0.43 for men (Orloff et al., 2008). The higher medial GRF for women might be the result of the trunk lean away from the kicking side in the frontal plane. The males have more upright trunk position, therefore less medial GRF produced by the support foot. In Orloff's study (2008), a correlation (-0.65) was observed between ball speed and peak anterior-posterior GRF. According to Orloff's study (2008), a more upright trunk position with lower anterior-posterior GRF may be related to a higher ball speed.

Besides the forces of the support leg, the movements of the support leg at foot plant are also examined. "The support leg knee is flexed to 26 degrees at foot contact and remains flexed throughout the duration of the kick, being flexed to 42 degrees at ball contact (Lees et al., 2009). Orloff et al (2008) also reported the knee angle: 157 degrees (23 degrees of flexion) at foot plant and 139 degrees (41 degrees flexion) at ball contact. The flexion of the support leg knee may have two major functions: to absorb the vertical impact force and stop the forward movement of the body when the support foot touches down; to stabilize the action (Lees et al., 2009).

Force production

The force production phase is initiated by pelvic rotation which increases hip extension followed by hip flexion. While the hip is flexing, adducting and medially rotating, the knee continues to flex. This is due to inertial lag of the distal segments while the proximal segments rotate forward.

Figure 2-2. The hip is flexing while the knee is flexing more. The maximal knee flexion is 93°.

The knee is medially rotated and ankle is plantar flexed. As the hip continues to flex, the knee starts to extend. The angular velocity of the thigh continues to increase and reaches its peak value (516-573 degrees/second) just before the knee starts to extend (Kellis & Katis, 2007). There is a strong positive correlation between foot linear velocity and the resultant ball velocity (Apriantono, Nunome, Ikegami and Sano, 2006). If athletes want to maximize the ball speed, they should increase foot linear velocity. However, there is some disagreement about the linear and angular velocity of the foot just prior to the ball contact. Many studies reported a reduction in angular velocity of the kicking knee extension and/or linear velocity of the foot immediately before ball impact (Barfield, Kirkendall & Yu, 2002; Katis & Kellis, 2010; Kellis & Katis, 2007). On the other side, Huang, Roberts and Youm (1982) suggested that at ball impact, the thigh angular velocity is almost zero while the knee and the foot reach peak angular velocity and zero acceleration. Nunome, Asai, Ikegami and Sakurai (2002) reported that the knee extension angular velocity was still accelerating until ball impact. This reduction of foot velocity and knee extension angular velocity may have two possible advantages. The athlete decelerates the foot in order to obtain better accuracy of the ball impact. Secondly, the deceleration of the foot as well as the knee extension can reduce risk of the hyperextension injuries at the knee joint.

The maximal hip extension of kicking leg occurs at about 90% of the pre support phase (Katis & Kellis, 2010)**,** which means maximal thigh backswing occurs just prior to foot contact. As the hip flexes, the knee continues to flex. The knee extension of the kicking leg starts from 30% of the support phase (Katis & Kellis, 2010). Then the angular velocity of the knee joint experiences high accelerations and reaches a peak at about 1600 degrees/second. The angular velocity of the knee is slightly decreased just prior to the impact. The angular velocity of the hip is relatively slow (about 200 degrees/second) at impact. The hip reduces velocity in order to transfer the angular momentum to the knee joint and shank (Katis & Kellis, 2010).

The proximal to distal pattern of segmental movement in the sagittal plane is apparent. The kicking leg should follow the principle of throwing and kicking biomechanics, in which the movement starts from the proximal (larger) segment to the distal (smaller) segment (Kellis & Katis, 2007). The reason is that the correct segmental coordination will create the inertial lag that will stretch the muscle connecting the proximal to the distal segments. Kicking is segmental rotation that occurs in multiple planes. Katis and Kellis (2010) reported the joint displacement in the transverse plane, including external and internal rotation of the thigh and lower leg segments.

The hip and knee rotation may help the foot produce a better contact with the ball. However, there is no article describing the role of the hip and knee rotation in the instep kick.

Katis & Kellis (2010) suggested that the kicking hip is slightly externally rotated and the knee internally rotated in the backswing phase. The knee internally rotated rapidly from 5 degrees to 25 degrees just prior to foot plant. In the support phase, which is also interpreted as the force producing phase, the hip continuously internally rotated while the knee slightly externally rotated. Kellis and Katis (2010) observed a higher internal rotation during the outstep kick compared with the instep kick in 30%-60% of the support phase.

Skilled kicking also requires greater hip joint moments (torques). Kawamoto, Miyagi, Ohashi and Fukashiro (2007) compared kinetics of a side-foot kick between experienced and inexperienced players. They observed that the most noticeable difference in the kinetics of the kick was found in the hip flexion moments (Kawamoto et al., 2007). They found the mean peak value of the experienced group (168 $\pm$ 20Nm) was significantly greater than that of the inexperienced group (94 $\pm$ 17Nm) (Kawamoto et al., 2007). Kawamoto et al. (2007) also support the previous study indicating that the critical kinetic factor to increase kicking foot speed during a kick is the hip flexion torque exerted during the early stage of the kicking phase. Nunome et al. (2002) analyzed three-dimensional kinetics of instep soccer kicks of five experienced male high-school soccer players. The average magnitude of the hip flexion moment is 249$\pm$ 31 Nm (Nunome et al., 2002). According to Lyle et al. (2011), the hip flexion moment is the most important for increasing foot velocity, thus increasing ball velocity.

Nunome et al. (2002) demonstrated that the hip adduction torque was continuously generated throughout kicking, even though the adduction motion was not clearly visible during the kick. They suggested that the hip adduction torque acts to control the hip abduction angle in order to control the kicking leg orientation (Nunome et al., 2002). The general pattern of time-hip flexion/extension moment curve is similar to that of Kawamoto et al. (2007). After the hip flexion moment reached its peak value, it deceased continuously. Just prior to the ball impact, the hip flexion moments reduced to zero and became hip extension moments. The hip extension moments can decrease the thigh angular velocity, which can increase the angular velocity of an adjacent distal segment (the shank) due to the angular momentum transferring. However, Nunome et al. (2002) observed that the deceleration of the thigh had been initiated before the hip extension torque was exhibited, so they suggested that the hip extension torque was not the only source to decelerate the thigh during the instep kicking. As the knee is extending, the extensor torque on the proximal shank produces an opposite torque on the distal femur. This torque will tend to extend the thigh thus decelerate the hip flexion.

The Upper Body Movement

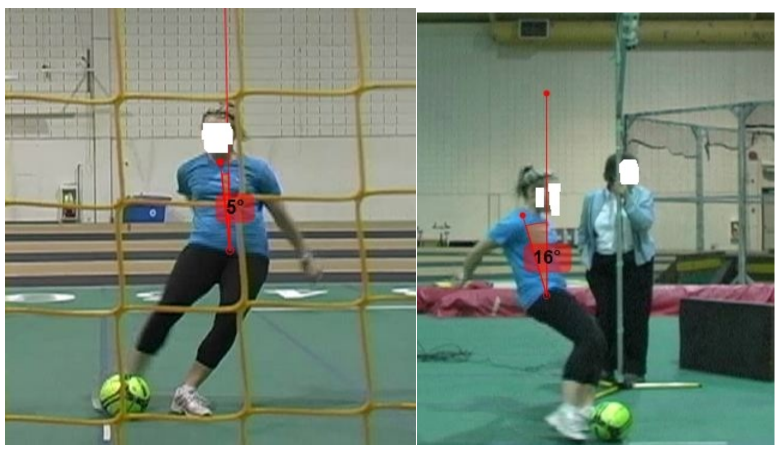
"The upper body demonstrates some important characteristics of technique." (Lees, Asai, Andersen, Nunome & Sterzing, 2010, p809). The non-kicking side shoulder abducted and the arm horizontally extended to maintain the balance of the whole body during the backswing of the kick. The arm rotation about the longitudinal axis (horizontal extension/flexion) will take up some of the angular momentum of the kicking leg and help to control the whole body rotation about the longitudinal axis (Bezodis et al, 2007).

Figure 2-3. The soccer player abducted and horizontally abducted her non-kicking side shoulder.

A large range of motion of the non-kicking side arm will produce a “tension arc” (Shan & Westerhoff, 2005). The theory of the tension arc in soccer kicking is explained by Shan and Westerhoff (2005, p67) as follows: “The tension arc goes across the body from the kicking leg to the non-kicking side arm”. The muscles along this arc including trunk flexors, hip flexors and knee extensors will stretch during the backswing phase and will store the strain (elastic) energy. A great range of motion in the backswing of the right leg and left arm will allow the muscle to store more energy that can contribute to the force production in kicking. Shan and Westerhoff (2005) used a full-body model to compare the kinematic characteristics of the maximal instep kick between a novice and skilled player. They observed that a skilled player would use trunk rotation and shoulder extension and abduction on the non-kick side to form a tension arc at the beginning of the kick step (Shan & Westerhoff, 2005). As well, skilled players had rapid upper trunk flexion and rotation towards the kick side during the release of the tension arc, which was accompanied by a rapid shoulder flexion and adduction on the non-kick side (Shan & Westerhoff, 2005). They also suggested that the distance between the non-kick side shoulder and the kick side hip could be an indicator of the quality of a maximal instep kick (Shan &

Westerhoff, 2005), because this distance is the length of the tension arc. The longer the tension arc, the more strain energy that will be released in the force producing phase.

Orloff et al. (2008) analyzed kinematics during instep kicking in males and females. They found the trunk inclinations viewed from both the sagittal view and the frontal view are significantly higher in females compared with males. In other words, males have a more upright trunk position during kicking. They concluded that the farther the players leaned back, the less ball speed they produced (Orloff et al., 2008).



(a) (b)

Figure 2-4. Side lean (left) and back lean (right) of the trunk at the ball contact.

Foot-Ball Interaction

Besides the technique in kicking, the foot-ball interaction is another major factor in ball speed, which has been studied recently. Ishii and Maruyama (2007) concluded that ball speed was maximized when the area of impact was near the center of mass of the foot (50% of the foot length, close to the intermediate cuneiform bone). It can be explained by the transferred linear momentum in the impact. Lees and Nolan (1998) described the mechanism of the collision between the foot and ball:

$$V_{ball} = V_{foot} \cdot \frac{M \cdot (1 + \ell)}{(M + m)}$$

V_{ball} is velocity of the ball after impact, V_{foot} is velocity of the foot before impact, M is effective striking mass of the leg, m is the mass of the ball, ℓ is the coefficient of restitution. (ℓ =0.575 in soccer, Andersen et al.,1999).

Andersen et al. (1999) used conservation of angular momentum to derive a different equation describing the velocity of the ball after impact.

$$V_{ball} = \frac{I \cdot V_{foot} \cdot (1+\ell)}{I + m \cdot r^2}$$

V_{ball} is the velocity of the ball after impact, V_{foot} is velocity of the foot before impact, I is moment of inertia of the shank-foot segment about the knee joint, m is the mass of the ball, ℓ is the coefficient of restitution, r is the distance between the knee joint and the center of the ball as well as the distance between the knee joint and the point of contact on the foot.

Based on the two equations given above, the velocity of foot before impact and coefficient of restitution are important to ball speed. The higher the speed of the foot before impact, the shorter the foot-ball contact and the higher the ball speed (Kellis & Katis, 2007). $(1+\ell)$ relates to the firmness of the foot at impact (Lees and Nolan, 1998). A rigid foot and ankle can increase the coefficient of restitution and increase the ball speed.

The coefficient of restitution of the foot and ball is a fractional value representing the ratio of speeds after and before the impact (Andersen et al., 1999; Hall, 2007).

$$\ell = \frac{V_{ball} - V_{foot}}{V'_{foot} - V'_{ball}}$$

ℓ is the coefficient of restitution, V_{ball} is the velocity of the ball after impact, V_{foot} is the velocity of the foot after impact, $V_{ball}^{'}$ is the velocity of the ball before impact, $V_{foot}^{'}$ is the velocity of the foot before impact.

A perfectly elastic collision has ℓ =1 and sum of the kinetic energy of the two objects before the collision is the same as the sum of the kinetic energy after the collision (Andersen et al., 1999). They reported the mean coefficient of restitution of the soccer kick in their study is 0.575 (0.463-0.681). A change in the coefficient of restitution from 0.5 to 0.65 will lead to a 10% rise in ball speed (Andersen et al., 1999). The coefficient of restitution depends on the mechanical properties of the ball, the footwear, the ankle and the foot upon impact (Andersen et al., 1999). A more rigid foot is related to a higher coefficient of restitution. The effective striking mass (M) is the mass equivalent of the striking object (in this case, the foot and the shank), also increases as the limb becomes more rigid by muscle activation (Lees and Nolan, 1998). However, the effective mass of the shank-foot segment does not influence the velocity of the ball significantly (Andersen et al., 1999). Footwear can also change the interaction between the foot and ball. Footwear can reduce the ball speed by up to 1.5% compared with barefoot (Sterzing, Kroiher & Hennig, 2008), because footwear has a cushioning function that can reduce the impact force and coefficient of restitution between the foot and ball. Footwear is designed to reduce the impact pain and increase the coefficient of friction between the foot and ground, and the foot and ball in order to kick a curved shot.

Penalty kick and scoring on the goalkeepers

In a penalty kick, the penalty taker shoots a stationary ball located 12 yards (11m) from the goal line. The goalkeeper must stand on the goal line until the ball is struck. The ball speed can be up to 30m/s, therefore it will take only 0.3s-0.4s from ball contact to pass the goal line. Even though the goalkeeper usually guessed at the kick direction in order to gain more time to react, it is hard to stop a penalty kick. Bar-Eli et al. (2006) analyzed 286 penalty kicks in top leagues and championship worldwide. They reported 80% of the penalty kicks result in a goal being scored. They reported the distribution of the direction of goalkeeper jumps and penalty kicker kick directions. The kick directions of the penalty takers are approximate evenly distributed. The goalkeepers tend to jump to the right or the left rather than staying in the center.

They also reported the chance of stopping a penalty kick by the goalkeepers. Most of the kicks are stopped when the goalkeeper jumps to the same direction as the kick direction (Bar-Eli et al., 2007). The probability of saving the penalty kick is the highest (33.3%) when the goalkeeper stay in the center compared to jumping to the left or right. Along with Table 2-1, it seems the goal keepers jump to the side more than they should. Therefore, Bar-Eli et al. (2007) suggested the optimal strategy for goalkeepers is to stay in the center of the goal.

Savelsbergh, Williams, Van Der Kamp & Ward (2002) investigated differences in anticipation and visual search behavior between expert and novice goalkeepers during the penalty kick. They found the experts were more accurate in predicting the direction of the penalty kick and waited longer before initiating a response (Savelsbergh et al., 2002). The novices spent longer fixating on the trunk, arms and hips, whereas the experts fixated on the kicking leg, non-kicking leg and ball areas. Savelsbergh et al. (2002) suggested the ball areas were more informative particularly as the moment of ball contact approached. This finding was also supported by Dicks, Uehara & Lima (2011) in which they suggested the goalkeeper would benefit from learning to ignore early information (eg. approach angle) and use late information (support foot orientation) just before the initiation of the kicking action (about 400ms before ball contact).

Throughout the literature review, most of the research studies are focused on the kinematics and kinetics in kicking and how they related to the ball speed. There are few studies investigating shot accuracy through studying the kick directions (Lees & Nolan, 2002; Nagasawa et al., 2011). There are some sport psychology studies investigating goalkeepers action during penalty kicks (Bar-Eli et al., 2007; Savelsbergh et al., 2002). There is only one biomechanical study (Lees & Owens, 2011) describing postural cues in kicking that may be of use to goalkeepers. They suggested that the support foot orientation on the ground is the best cue to predict kick direction and type of kick (Lees & Owens, 2011). Therefore, the present study was to investigate differences in the kinematics between two kick directions and determine the visual cues that can be used by goalkeepers when defending against penalty shot.

CHAPTER 3

Methods

Participants

The participants were the current members of the University of Manitoba Bison women's soccer team, who volunteered to participate in this study. Based on the sample size calculation, eleven participants participated this study. The average years of experience in soccer training is 13.4 ± 1.9. The average height of the participants is $166 \pm 8.2 cm$. The average weight is $61 \pm 7.1 kg$. All the participants were right foot dominant players without any injuries within the six months prior to the filming. To simplify the data collection and analysis, the study only selected right foot dominant players. Consent forms were signed by the participants prior to filming, following the university ethics protocol. The time of the data collection for each participant was approximately 20 minutes, including warm-up, the ten trials of kicks and data collection. There was no additional risk of injury in this study. The participants wore outdoor soccer cleats and performed skills as they normally perform them in a practice situation. The film and other collected data were confidential, which were viewed only by the researchers in this study and would not be used for any other purpose than this study.

Table 3-1. Subject characteristics

Subject	Height (cm)	Body Mass (Kg)	Years of Experience
1	177.8	68.2	11
2	157.5	54.5	12
3	165.1	54.5	12
4	170.2	54.5	15
5	175.3	75.0	13
6	165.1	55.9	13
7	157.5	65.9	12
8	175.3	68.2	13
9	152.4	55.5	14
10	167.6	61.4	14
11	162.6	59.1	18
Mean value	166.0	61.1	13.4

Soccer kick filming

The kinematic data were collected on the outdoor field at University of Manitoba on two occasions. On April 16, eight participants were filmed. On April 20, three more participants were filmed. The participants performed about ten minutes of warm-up and several instep kicks to adapt to the experimental environment. The warm up included running on the field, dribbling the ball and shot distance passing instructed by the coach. The goal size was standard: 8 yards (7.3m) wide by 8 feet (2.4m) high. The ball was located at the penalty spot, which was 11m away from the goal line. The participants were instructed to shoot at the left/right target using a 2 step run-up, attempting five trials to the targets on each side. The target areas were restricted by the goal post and the vertical axis of a pylon. The pylon was 4 feet (1.2m) beside the post and 25cm high (Figure 3-4).

The participants performed the instep kick as fast and accurately as possible with the right foot. The participants were free to choose their own preferred approach angle. Three trials that place the ball successfully in the target area on each side were selected for further analysis. If the quantity of successful trials was less than 3 on each side, the participant would continue to kick until she reached 3 successful trials. If the quantity of successful trials is larger than 3, only the last 3 trials was selected.

Filming procedure

To simplify the procedure of the study design, the kicking movement was broken down into three phases: approach phase, backswing phase and force producing phase. The approach phase is defined as the phase from the start of the run up to the last step before toe-off of the right foot. The backswing phase is simplified from toe-off of right foot to heel strike of the support foot. The force-producing phase is from the heel strike of the support foot to the ball contact.

Figure 3-1. Approach movement

Figure 3-2. Backswing movement (from kicking side toeoff to support foot touchdown).

Figure 3-3. Force producing phase (from support foot touchdown to ball contact).

Kinematic data of the kicking movement was collected using four digital video cameras. One high speed camera (80 Hz, Fijifilm EXR) was set up three meters beside the ball. Because the participants were all right-foot dominant, the camera was on the right side to capture the movement that occurred in the sagittal plane. Another camera (Canon GL2) was set up behind the net of the goal, which captured the participants' movement that occurred in the frontal plane. The third camera (Canon HV10) was set up above the ball. The camera was mounted on a lightweight tripod that was fixed on the end of a steel pipe. The other end of the pipe was anchored on the ground. The camera was suspended 3.5 meters high from the ground and directly above the ball. This camera captured the movement that occurred in the transverse plane. The fourth camera was behind the ball. This camera captured the pathway of the ball in order to identify which trials were placed in the target area therefore would be included in the analyses. As a result, this four-camera set up provided a three dimensional view of the kick skill being analyzed (see Figure 3-4). The cameras were set up manually. The shutter speed was 1/500 seconds. This camera setup and arrangement ensured the relatively good quality of each frame in the video, so that all movements of interest could be viewed.

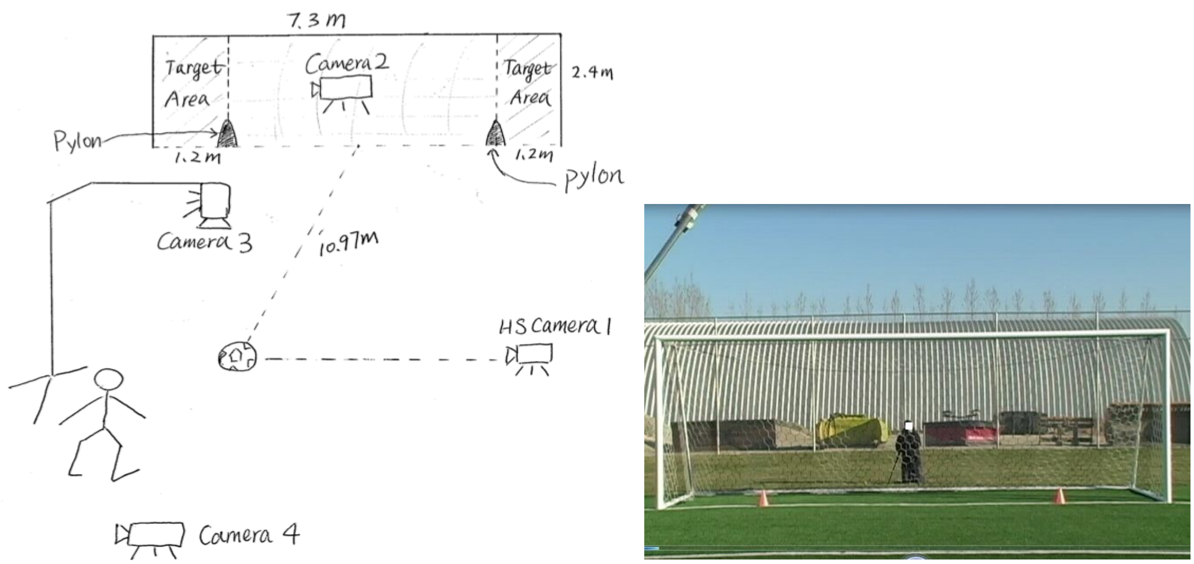
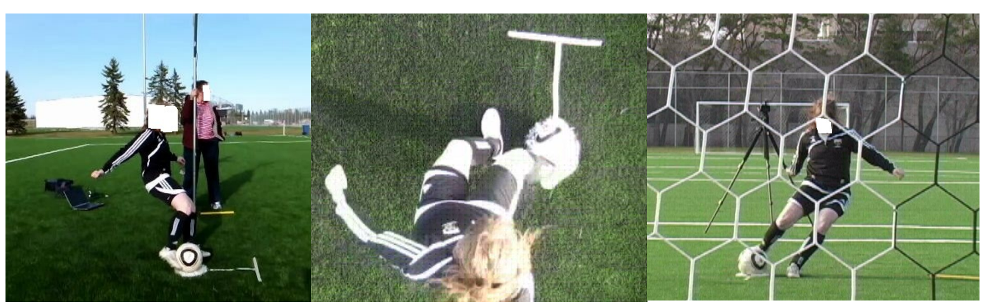


Figure 3-4. The experiment set up and the goal.



(a) (b) (c)

Figure 3-5. Three views from each camera: (a) sagittal view; (b) overhead view; (c) frontal view

Data Analysis

The kinematic data were analyzed by Dartfish team pro 6.0 (Dartfish team pro, 2/14/2012) and Kinovea 0.8.15 (Kinovea, 1/9/2012) for high speed film. These two software programs can import and review video and provide in depth analysis of movement. The displacement of the joint movements was measured through these two software programs and then the velocity was calculated.

The variables measured in the present study are presented in Table 3-2. These variables are also commonly analyzed by the previous studies.

Table 3-2. Variables measured in the present study and previous studies.

Variables measured in the present study	Reported in previous studies	unit
Hip flexion (+)/extension(-)	Katis & Kellis,2010; Scurr&Hall, 2009; Alcock et al., 2012; Lees & Owens, 2011	(˚)
Knee flexion (+)/extension(-)	Katis & Kellis,2010; Scurr&Hall, 2009; Alcock et al., 2012; Lees & Owens, 2011	(˚)
Hip angular velocity	Katis & Kellis,2010; Nunome et al., 2006; Alcock et al., 2012; Lees & Owens, 2011	(˚/s)
Knee angular velocity	Katis & Kellis,2010; Nunome et al., 2006; Alcock et al., 2012; Lees & Owens, 2011	(˚/s)
Foot linear velocity	Katis & Kellis,2010; Nunome et al., 2006; Lees & Owens, 2011	(m/s)
Pelvis orientation	Scurr&Hall, 2009; Alcock et al., 2012; Shan, 2009; Lees & Owens, 2011	(˚)
Trunk lean	Orloff et al.,2008; Alcock et al., 2012	(˚)
Support leg lean	Orloff et al.,2008; Alcock et al., 2012; Brophy et al., 2010	(˚)
Distance from support heel to ball (x)	Orloff et al.,2008; Scurr&Hall, 2009; Alcock et al., 2012	(m)
Distance from support heel to ball (y)	Orloff et al.,2008; Scurr&Hall, 2009; Alcock et al., 2012	(m)
Support foot orientation angle	Lees & Owens, 2011	(˚)
Approach angle	Scurr&Hall, 2009; Shan, 2009	(˚)
Ball direction	Orloff et al.,2008; Lees & Owens, 2011; Lees & Owens. 2011	(˚)
Ball speed	Katis & Kellis,2010; Orloff et al.,2008; Scurr&Hall, 2009; Nunome et al., 2006; Shan 2009; Lees & Owens, 2011	(m/s)
Ball/foot speed ratio	Katis & Kellis,2010; Nunome et al., 2006; Ball, 2011	
Last step length		(m)

The hip and knee flexion and extension angles were measured using relative angles, in which zero degrees is the anatomical position. The hip and knee angular velocity was calculated using angular displacement between two consecutive frames divided by 12.5ms (time between two frames).

The foot linear velocity was measured from the support foot touchdown to ball contact. The center of the foot was used to represent the foot. The velocity was calculated using linear displacement between two consecutive frames divided by 125ms (time between two frames). The foot linear velocity before impact is important to ball speed (Katis & Kellis,2010; Nunome et al., 2006; Lees & Owens, 2011). Lees & Nolan (1998) suggested that the ball should travel at about 1.2 times the velocity of the foot: $V_{ball}=1.2\times V_{foot}$. Zernicke and Roberts (1978) reported a regression equation between foot and ball speed: $V_{ball}=1.23\times V_{foot}+2.72$

The ball speed was measured as the average velocity using three frames after ball contact. Then the ball/foot speed ratio was derived. The ball/foot speed ratio can demonstrate some characteristics of foot-ball impact, which is related to the coefficient of restitution between foot and ball (Katis & Kellis, 2010).

The pelvic orientation and support foot orientation were measured at the instant that the support foot touched down. The support foot orientation angle was measured relative to anterior-posterior axis (y axis). The right side is negative sign (-); the left side is positive sign (+). The pelvic orientation was measured relative the x axis. The support foot orientation and pelvic orientation could be useful cues to predict the kick direction (Lees & Owens, 2011).

The trunk lean and support leg lean were also measured at the instant that the support foot touched down. Both of them were measured relative to the vertical axis. The line that represented the support leg was drawn from the hip joint to ankle joint (see Figure 3-6.)

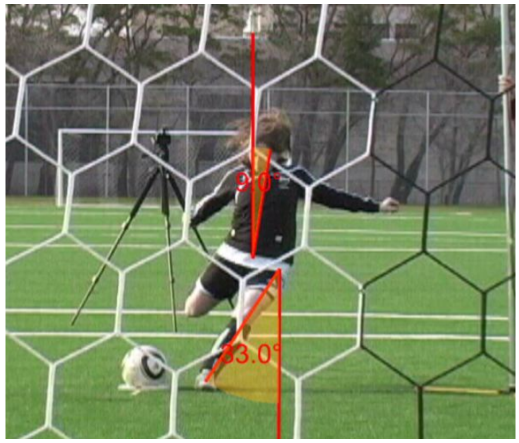


Figure 3-6. Measurement of trunk lean and support leg lean.

The approach angle can affect the kick quality. An approach angle between 30-45 degrees can produce maximal ball speed (Scurr & Hall, 2009). In the present study, it is impossible to track the pathway of approach of the trunk due to the camera setup limitation. Instead the investigator tracked the pathway of the support foot before touchdown. The approach angle measured in the present study was measured between pathway of the support foot and y axis rather than desired ball direction. The reason is that this study is attempting to predict the ball direction. Therefore, all the independent variables should be measured before the ball contact.

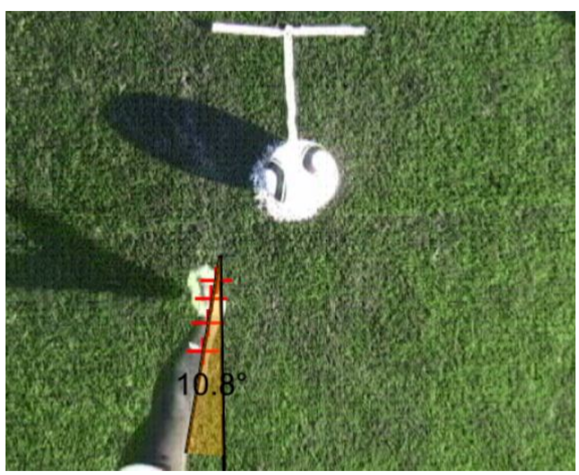


Figure 3-7. Measurement of approach angle

The last step length cannot be measured directly from the sagittal view because the player used an angled approach. The last step length was estimated using projection of the step length measured from the sagittal view divided by cosine approach angle. Usually, the step length was measured from toe to toe or heel to heel. However, it cannot be clearly seen from the sagittal view. Therefore, the distance of the projection was from the right foot toe-off to support foot heel-strike (see Figure 3-8). The last step length was normalized as a percentage of the participant's standing height.

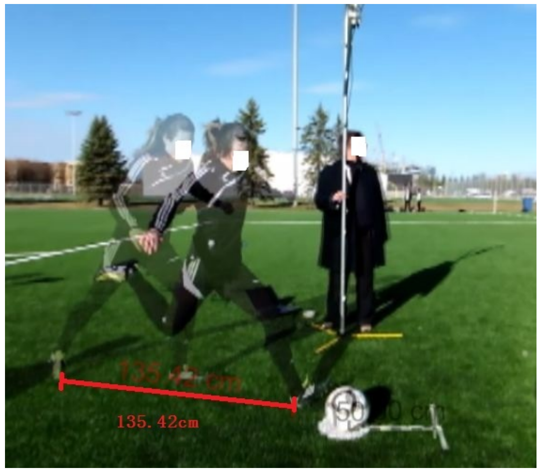


Figure 3-8. Measurement of the projection of the last step.

The distance from the heel to the ball center was measured in two directions (x-mediolateral and y-anteriorposterior). This variable was reported in several previous studies (Orloff et al.,2008; Scurr & Hall, 2009; Alcock et al., 2012).

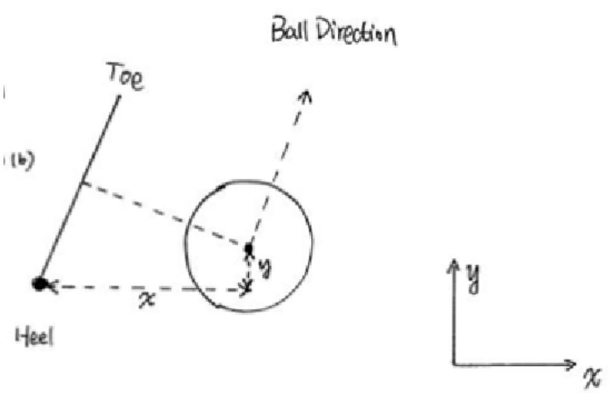


Figure 3-9. Measurement of the distance from the heel to ball center.

Statistical Analysis

Sample size calculation: Power analysis was used to calculate sample size in this study. The statistical power refers to the probability of rejecting null hypothesis when it is false (Jiang, Pepler & Yao, 2010). The statistical power analysis is the main technique to decide how large a sample is needed to enable statistical judgments that are accurate and reliable. It is also used to determine how likely the statistical test will detect an effect given the sample size in a study (Jiang, Pepler & Yao, 2010). In this study, the Type I error Alpha was set as 0.05. The Type II error Beta was set as 0.2. The effect size was also required to calculate the sample size (Jiang, Pepler & Yao, 2010). The effect size is defined as the standardized difference in means under the null and alternative hypotheses. The means and standard deviation were determined from the previous study. Through the calculation, the required sample size was 10 (detailed calculation see Appendix 1). Additionally, based on the previous soccer kick analyses, the number of subjects to determine significance is close to 10 (Lees & Owens, 2011;Katis & Kellis, 2011;Katis & Kellis, 2010). Therefore, ten participants were sufficient for this study. The present study recruited one additional participant for a total sample size of 11, which increased the statistical power by 6%.

Comparison between kick directions

Differences of kinematic data such as pelvic orientation, support foot orientation and hip extension/flexion displacement between two kick directions were examined using paired two-tailed t-test that was conducted by SPSS 20 statistical software for Mac operating system (IBM SPSS statistics, n.d.). Statistical significance was set at $P<0.05$. The two way (side×phase) analysis of variance (ANOVA) was used to compare the hip and knee angular displacement and velocity curves as well as foot linear velocity curves. The post hoc analysis was used to determine where the differences occurred in the curves. The investigator used Tukey's HSD test for the post hoc analysis. Tukey's HSD was designed for a situation with equal sample sizes per group (Stevens, 1999). The formula is critical value $= q \times \sqrt{MS_{error}/n}$, where q is the value of the studentized range statistic and n is the number of observations that went into each point.

Prediction of kick direction

Stepwise linear regression was used to test whether the kinematic variables can predict the kick direction angle. In the soccer kick, the kinematics of the movement were seen as independent variables that can affect and predict the kick direction (dependent variable). As a result, the association between the independent variables and dependent variables was examined using regression analysis also conducted by SPSS 20 statistical software for the Mac operating system. Only the variables that were significantly different between the two kick directions were included in the stepwise regression analysis. A p-value >0.1 was used as a criterion for removal of the independent variables. For example, the pelvis orientation, hip flexion/extension displacement and support foot orientation angle were chosen as three independent variables; the kick direction angles from anterior-posterior axis was chosen as the dependent variables. The multiple regression analysis will test whether these independent variables can significantly predict the dependent variable.

Skill analysis of the kicks

The investigator and his advisor and colleagues performed a kick technique analysis for each of the participants as compensation for their participation in the study. The procedure for the analysis included creating a technique checklist of the instep kick, comparing the skill of the participants with top professional soccer players and making a DVD with their videos and suggestions to improve their skill. There was also a meeting with each of the participants in the biomechanics lab and to present the videos and technique suggestions to them on May 28th, 2012.

Credibility/Generalizability/Reliability

This study uses the scientific method to establish and examine the potential associations between kick movements and kick directions. The instrumentation includes high speed cameras that are one of the most useful techniques to analyze the soccer kicking movement. The internal validity is defined as the extent to which the designers of a study have taken into account alternative explanations for any causal relationships they explore (Huitt, 1998). In this study, the researcher controlled for the factors, which included the athletes' skill level, age, healthy condition and types of kick technique and foot wear. As for external validity, which is defined as the extent to which the results of a study are generalizable and transferable, the participants were selected from a single team. So the findings and conclusions may not actually apply to the whole population of soccer players. However, to some extent, the Bison women soccer players may be representative of the population of young women soccer players in Canada. As such, the findings and conclusions may be generalized for young adult Canadian female soccer players. The word generalizability is defined as the degree to which the findings can be generalized from the study sample to the entire population (Polit & Hungler, 1991).

CHAPTER 4

Results

Sagittal plane kinematics

The kicking side hip and knee angular displacement are presented in Figure 4-1 and Figure 4-2 respectively. The kicking side hip and knee angular velocity are presented in Figure 4-3 and Figure 4-4. The horizontal axis is the percentage of total time (from toe-off in the last step to ball contact). Each unit represents 10% of the total time. The toe-off occurred at 0%. The ball contact occurred at 100%. The support foot touchdown occurred at 43% in the kicks to the right and at 45% in the kicks to the left. Through the two way ANOVA, the kicking direction (right or left) had no effect on the hip angular displacement ($F(1,10)=3.97$, $p>0.05$) , knee angular displacement ($F(1,10)=0.38$, $p>0.05$) or hip ($F(1,10)=3.83$, $p>0.05$) and knee angular velocity ($F(1,10)=1.5$, $p>0.05$). The kicking direction had significant effect ($F(1,10)=314$, $p<0.01$) on the foot linear velocity. The interaction effect of side*phase is significant in hip ($F(9,90)=3.63$, $p<0.05$) and knee angular displacement ($F(9,90)=6.46$, $p<0.01$), knee angular velocity ($F(9,90)=3.71$, $p<0.05$) and foot linear velocity ($F(7,70)=2.4$, $p<0.05$). The post hoc analysis indicated the significant difference in hip angular displacement occurred from 60%-100% of the total time (see Figure 4-1). The significant difference in knee angular displacement occurred at 10%, 40%, 50%, 60%, 80% and 90% (see Figure 4-2). The significant difference in knee angular velocity occurred at 70%, 80%, 100% (see Figure 4-4). The difference in foot linear velocity occurred through all the phases (see Figure 4-7).

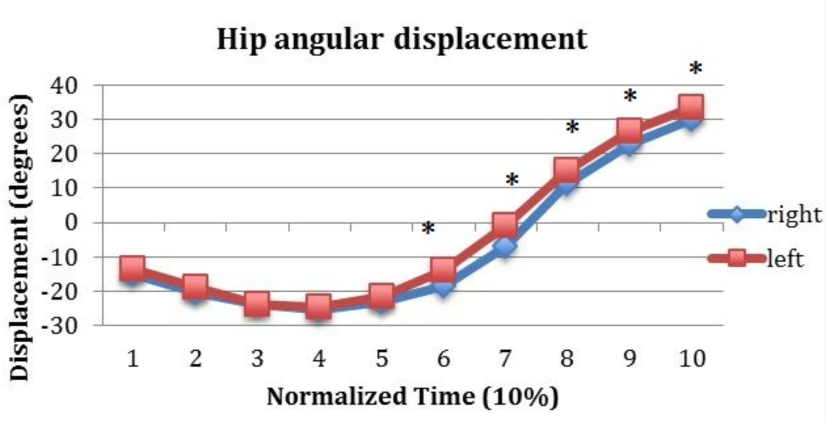


Figure 4-1. Hip flexion (+)/ extension (-) displacement in the kicks to the right and left side. *p<0.05

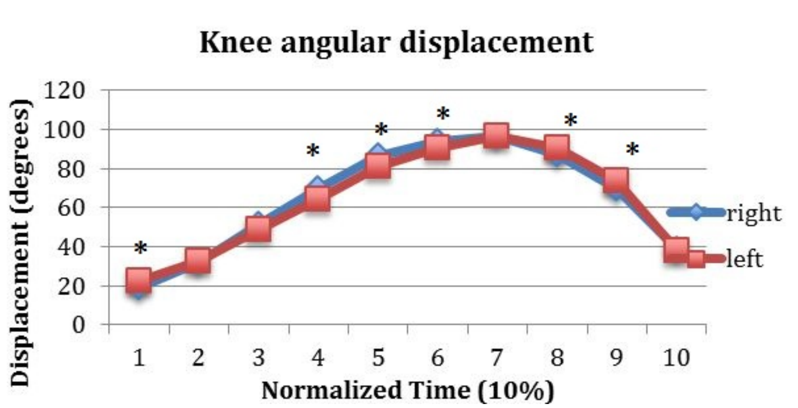


Figure 4-2. Knee flexion (+)/ extension (-) displacement in the kicks to the right and left side. *p<0.05

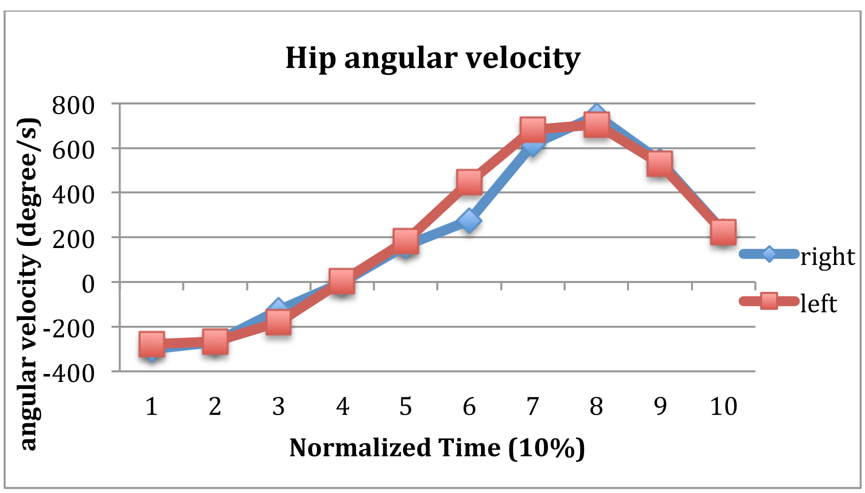


Figure 4-3. Hip flexion (+)/ extension (-) angular velocity in the kicks to the right and left side. *p<0.05

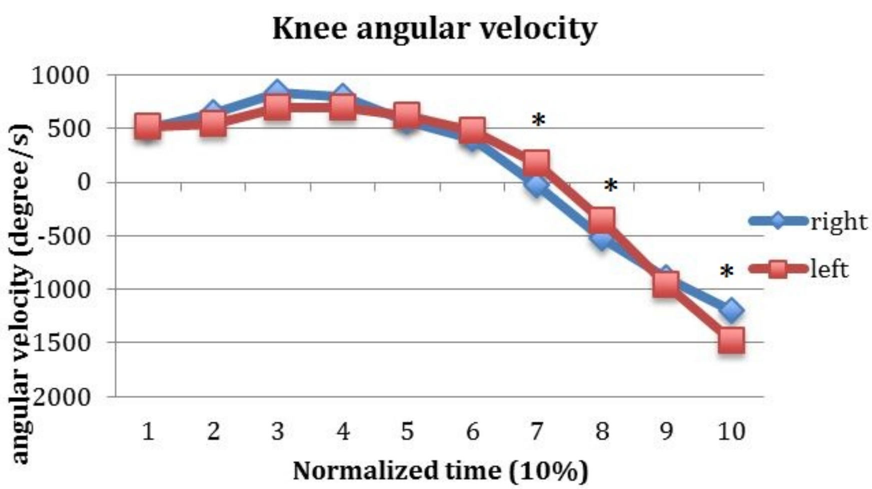


Figure 4-4. Knee flexion (+)/ extension (-) angular velocity in the kicks to the right and left side. *p<0.05

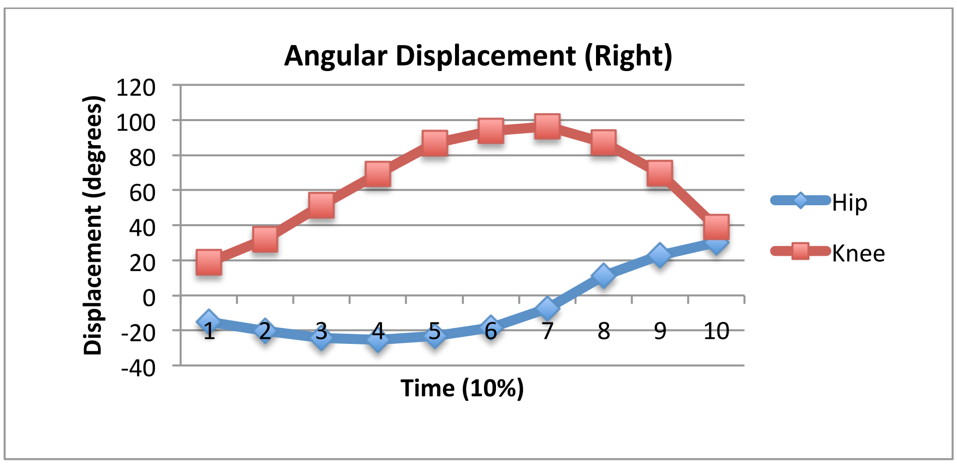


Figure 4-5. Hip and knee angular displacement during the kicks to the right. *p<0.05

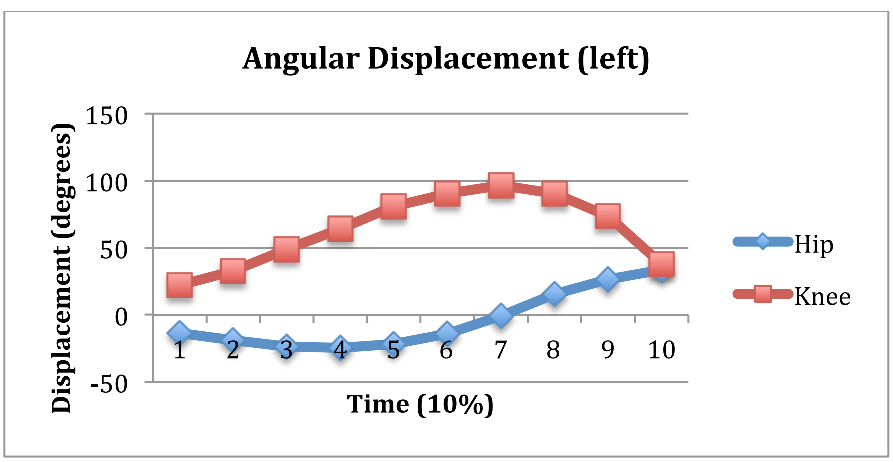


Figure 4-6. Hip and knee angular displacement during the kicks to the left. *p<0.05

The peak hip extension, peak knee flexion, peak flexion angular velocity and peak knee extension angular velocity are presented in Table 4-1. Paired t-tests indicated that there is no significant difference in peak hip extension (P=0.407) nor peak knee flexion (P= 0.884) between two kick directions. There is no significant difference in peak hip flexion angular velocity (P=0.942). The peak knee extension angular velocity is significantly higher in the kicks to the left post compared to the right post (P=0.007). The linear foot velocity from support foot touch down (about 100ms before ball contact) to ball contact is presented in Figure 4-7. The peak foot linear velocity is significantly higher in the kicks to the left post compared to the right post (p=0.001). There is no significant difference in step length (p=0.058).

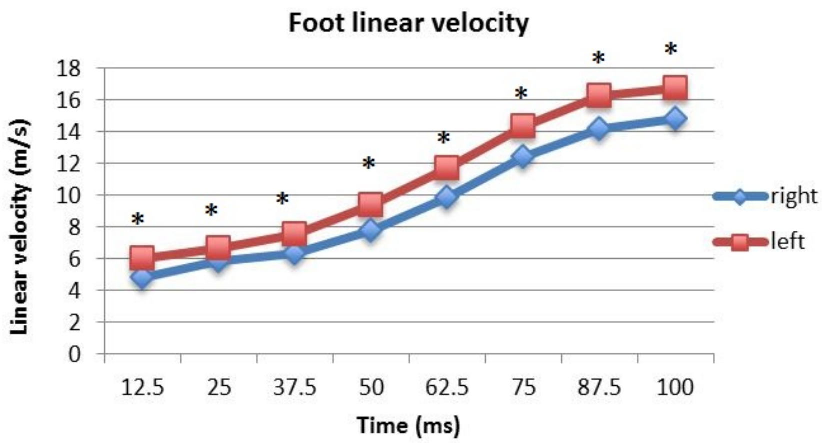


Figure 4-7. Foot linear velocity from touch down to ball contact (0ms is the touch down, 100ms is the ball contact). *p<0.05

Table 4-1. Peak hip and knee angular velocity and displacement values to the right and left sides. (Ex-Extension, Flex- Flexion, ω- angular velocity, V- linear velocity, R-right, L-left.* $p<0.05$, **$p<0.01$.)

Variables	Mean value	N	SD (deg/s)	t-value	Sig.
PeakHipEx R	-26.20 deg	11	6.08		
PeakHipEx L	-25.25 deg	11	6.91	-0.865	0.407
PeakKneeFlex R	96.91 deg	11	16.53		
PeakKneeFlex L	96.65 deg	11	15.59	0.149	0.884
PeakHipFlexω R	819.11 deg/s	11	161.51		
PeakHipFlexω L	821.82 deg/s	11	146.46	-0.075	0.942
PeakKneeExω R	-1208.39 deg/s	11	204.42		
PeakKneeExω L	-1489.92 deg/s	11	320.82	3.389	**0.007
Step length R	69.8%	11	0.08		
Step length L	74.4%	11	0.11	-2.140	0.058
PeakFootV R	15.1 m/s	11	1.61		
PeakFootV L	16.9 m/s	11	1.35	-8.579	**0.001

Transverse plane kinematics

The mean kick direction angle to the right post is -15.12˚±2.8. The mean kick direction angle to the left post is 13.77˚±3.1. Ball speed, support foot orientation, pelvis orientation and support foot position at whole foot touch down are presented in Table 4-2. The positive sign for support foot orientation indicates the support foot pointed to the right relative to the anterior-posterior axis; the negative sign indicates the foot pointed to the left. The positive sign for the distance of the heel behind the ball indicates the heel was behind the ball center; the negative sign indicates the heel was in front of the ball center. There are significant differences in support foot orientation angle and pelvis orientation angle between two kick directions. The support foot landing positions are significantly different between two kick directions. In the kicks to the left post, the support heel is closer to and farther behind the ball compared to that of the kicks to the right post. The approach angle is significantly larger in the kicks to the right side.

Table 4-2. Kinematic variables measured from the overhead view camera. *p<0.05, **p<0.01

Kinematic variables	Right post	Left post	t-value	Sig.
Ball speed (m/s)	17.70±1.9	17.53±2.0	1.061	0.314
Ball direction (degrees)	-15.12 ±2.8	13.77±3.1	-28.584	**0.000
Support foot (degrees)	-2.66±10.5	16.77±8.3	-12.816	**0.000
Pelvis orientation (degrees)	23.64±8.8	10.82±6.1	6.746	**0.000
Distance from support foot heel to ball center (beside the ball) (m)	0.36±0.1	0.30±0.1	6.708	**0.01
Distance from support foot heel to ball center (behind the ball) (m)	0.05±0.1	0.17±0.1	-6.591	**0.001
Approach angle (degrees)	25.5±7.2	7.9±5.8	11.085	**0.000

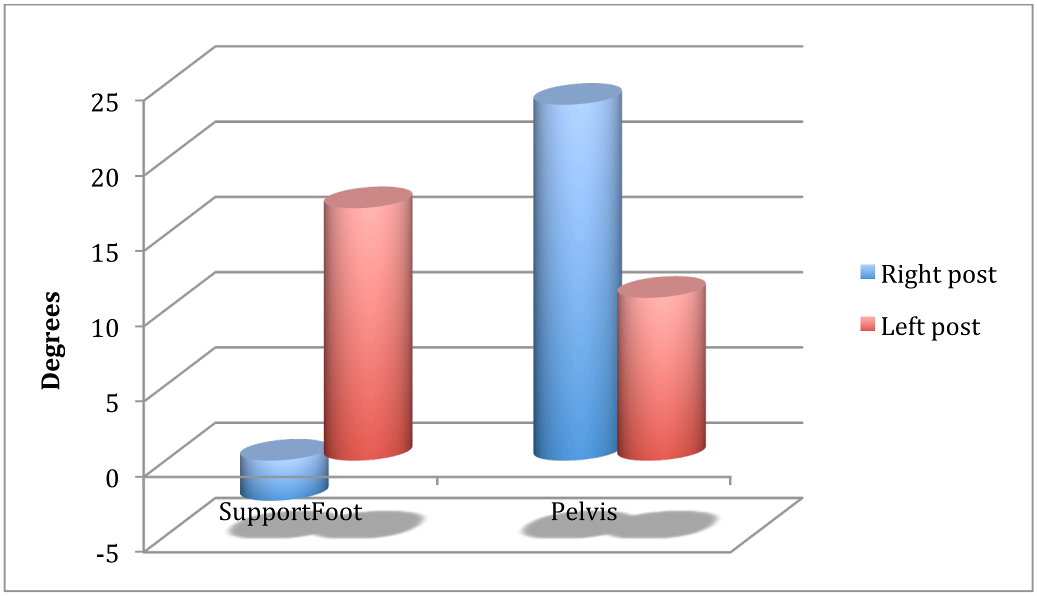


Figure 4-8. Comparisons of support foot orientation and pelvis orientation between left and right sides

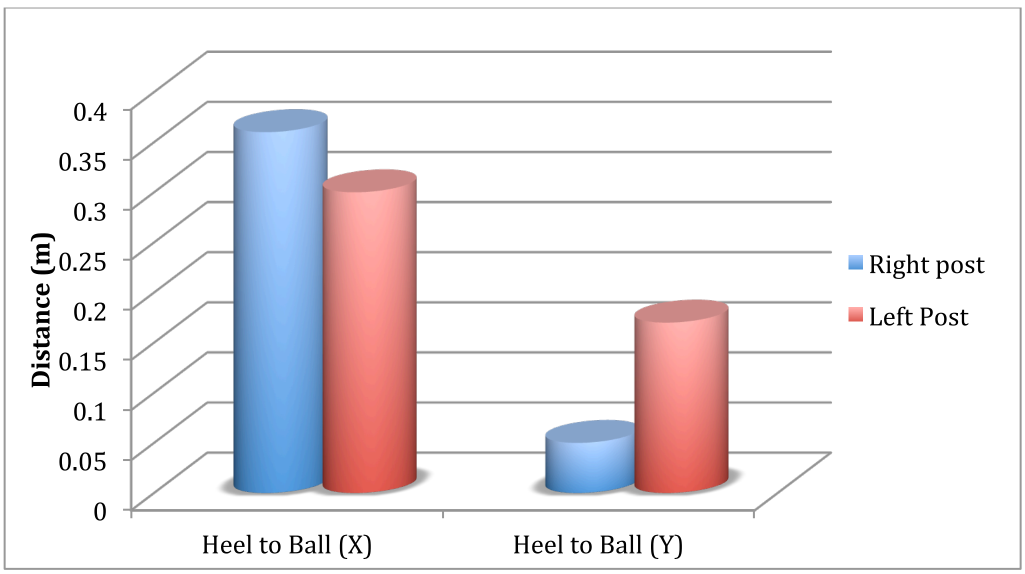


Figure 4-9. Comparisons of distance from support foot heel to ball center between right and left sides.

Frontal plane kinematics

The trunk lean and support leg tilt angle (away from the vertical direction) at the whole foot touch down are presented in Table 4-3. A positive value means leaning away from the ball, negative value means leaning toward the ball. There is a significant difference in support leg tilt angle between two kick directions (p=0.002) (Figure 4-10).

Table 4-3. Trunk lean and support leg lean in the frontal plane. *p<0.05, **p<0.01

Kinematics variables	Right post	Left post	t-value	Sig.
Trunk lean (degree)	8.23±3.3	6.99±2.4	1.691	0.122
Support leg tilt	27.74±7.6	21.79±7.3	4.279	**0.002

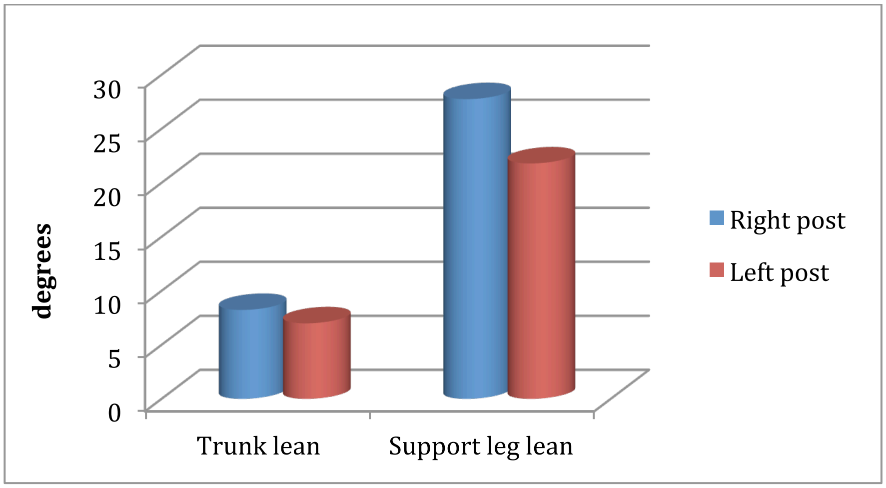


Figure 4-10. Comparisons of trunk lean and support leg lean in the frontal plane.

Linear regression analysis

The kinematic variables that were significantly different between two kick directions included support leg tilt angle in the frontal plane, support foot orientation angle, pelvis orientation angle, peak knee extension angular velocity, peak foot linear velocity, distance of support heel beside the ball, distance of support heel behind the ball and approach angle. The kinematic variables served as the independent variables and ball direction angle served as the dependent variable. Through the stepwise procedure, there are three variables that were included in the final regression model: support foot orientation, distance of support heel behind the ball center and approach angle. These three variables can explain 77.4% of the variance of kick direction angles ($p<0.01$). The regression equation produced is as follows:

Kick direction angle= 0.42×(SuppotFootOrientation)+0.37×(FootBehind)-0.62×(approach angle)+2.47

(See Appendix M for samples of the use of the equation in determining the kick direction)

CHAPTER 5

Discussion

Introduction

The primary purpose of the present study was to compare the differences in the lower extremity movement between two different kick directions in the soccer penalty kick. The study attempted to determine how different kinematic variables predict kick direction. To achieve this purpose, the study analyzed 33 kicks to the right post and 33 kicks to the left post (3 kicks to each side of the goal for each participant, 11 participants in total). The investigator measured lower extremity angular displacement and angular velocity in the sagittal, transverse and frontal plane. Through the statistical analysis, the study determined that support leg tilt angle in the frontal plane, support foot orientation angle, pelvic orientation angle, peak knee extension angular velocity, peak foot linear velocity and approach angle were significantly different between two kick directions. The stepwise linear regression indicated that among the kinematic variables given above, the support foot orientation, approach angle, and peak linear foot velocity can predict the kick direction significantly ($r^2 = 0.77, p < 0.01$). The present findings are consistent with Lees & Owens (2011) suggestion that the support foot orientation angle was considered to be the most valuable variable for a goalkeeper to use for decision making. However, they reported the support leg shank and thigh angles were less clear in their interpretation and so less valuable (Lees & Owens, 2011).

Sagittal plane kinematics

Hip and knee angular velocity

In the sagittal plane, the investigator measured kicking side hip flexion/extension and knee flexion/ extension displacement and angular velocity from the start of the backswing (Figure 5-1) to the ball contact (Figure 5-2). The start of the backswing simplified as the instant when the right toe leaves the ground in the last step. The range of this total time was from 162ms to 275ms in the present study. The mean of the total time was 225ms, which is slightly longer than a previous report (174ms for skilled players and 187ms for unskilled players) (Kawamoto et al, 2007), but similar to the value (221ms) reported by Nunome et al (2002). However, both of these studies used experienced male soccer players. No reported value of backswing duration for female players has been found. The present study may be the first one to report percentage of duration of each phase during kick movement for female players.

Figure 5-1. Start of the backswing.

Figure 5-2. Ball contact

The kicking leg followed the principle of throwing and kicking biomechanics, in which the movement starts from the larger joint (hip) to the smaller joint (knee). The hip reached peak extension first at 40% of the total time, while knee is still flexing. Then the hip began to flex and left the shank behind, which increased the range of knee flexion due to inertial lag. The knee reached peak flexion at 70% of the total time. Figure 5-3 shows the position of the shank and thigh from maximal backswing to ball contact.

Figure 5-3. Hip and knee angular kinematics: the position of shank and thigh in the force producing phase. Note as thigh slows down the lower leg increases angular velocity.

After the hip reached its peak flexion velocity at 80% of the time, the hip began to slow down. This reduction of the angular velocity of the thigh (hip flexion) will help transfer the angular momentum to the linked segment (shank) to increase the knee extension velocity (Barfield et al., 2002). Therefore, the knee extension velocity increased rapidly and reached its peak value at ball contact.

The general pattern of the hip angular displacement and knee angular displacement are identical between the two kick directions. The displacement-time curves are similar to those in Lyle et al. (2011) study that analyzed instep kicks in female players. They collected data from maximal hip extension to ball contact. At the start of the backswing, the hip is extended at 15° and knee is flexed at 20°. After the right foot leaves the ground, the hip continues to extend while the knee is flexing. The hip reaches peak extension (25°) at 40% of the total time. The peak hip extension just occurs before the support foot touches down (45% of the time). The duration of backswing phase is slightly longer than the previous report (36% for skilled players and 17 % of unskilled players) by Kawamoto et al. (2007), but similar to the value (48%) reported by Nunome et al. (2002). Kawamoto et al. (2007) reported that the skilled players and unskilled players share the same amount of the total time in kicks. However, the skilled players had a larger percentage of kick time for the backswing phase and smaller percentage of kick time for the force producing phase than the inexperienced players. They suggested that the skilled players tend to obtain sufficient time to store energy required to perform a high speed kick through the back swing motion (Kawamoto et al., 2007). Compared with the previous studies, the results in the present study suggested that the participants may perform a proper duration of backswing movement.

After the maximal hip extension, the hip begins to flex while the knee is increasing flexion. The knee reaches its peak flexion (96˚) at about 70% of the total time. Lyle et al. (2011) studied female soccer players and reported the peak hip extension was 23.4˚and peak knee flexion was 94˚, which were very close to the values in the present study. However, these values for females are lower than that (29˚hip extension, 110˚knee flexion) for male players reported by Levanon & Dapena (1998). The peak hip extension and knee flexion are highly related to the kicking movement. The larger the backswing movement the larger range of forward swing movement that occurred, which contributed to a high foot linear velocity. This was also due to the greater range of knee flexion that accompanied the increased hip extension. The increased knee flexion range of motion was related to increased angular velocity.

The general pattern of hip angular velocity and knee angular velocity are also similar between two kick directions. Through the two way ANOVA, the kick direction had significant effect on the foot linear velocity, which indicated the foot linear velocity altered depending on the kick direction. The peak knee extension velocity is significantly higher in the kicks to the left than to the right (-1489.9˚/s vs -1208.4˚/s, p=0.007). In the study of Barfield et al. (2002), they reported the peak knee extension velocity for female players is about 22 rad/s (1260.5˚/s). The knee angular velocity curve reported in Barfield et al. (2002) study was very similar to that in the present study.

The knee reached its peak flexion velocity (520°/s in the present study and 11rad/s (630°/s) in the Barfield study (2002)) almost at the support foot touchdown. The flexion velocity decreased progressively to zero then became extension velocity. In the present study, the knee extension velocity continued to increase until ball contact. However, in Barfield's study (2002), the knee extension velocity reached its peak value just prior to the ball contact and decreased slightly to 19.8 rad/s (1134°/s). This decrease of the knee extension velocity just before the ball contact has also been reported in other previous studies (Barfield, Kirkendall & Yu, 2002; Katis & Kellis, 2010; Kellis & Katis, 2007).

The possible reason for this reduction of knee extension can be explained by motor control strategy that is aimed to enhance the accuracy of the ball contact (Lees et al., 2010). Another advantage of this reduction is to reduce the risk of knee hyperextension injury. Based on the result of Barfield's study, the male players had larger reduction in knee extension velocity compared with the female players. They suggested male players tend to perform this protective mechanism to slow the limb prior to the ball contact to reduce potential injury (Barfield et al., 2002). On the other side, Huang et al. (1982) suggested that at ball impact, the thigh angular velocity is almost zero while the knee and the foot reach peak angular velocity and zero acceleration. The results in the present study indicated that the knee extension velocity and foot linear velocity were increasing until ball contact, which agreed with Huang et al. (1982) and Nunome et al. (2002).

Filtering knee angular velocity

Nunome et al. (2002) reported that the knee extension angular velocity was still increasing until ball impact. Nunome, Lake, Georgakis & Stergioulas (2006) used a new filtering process (modified version of a time-frequency filtering algorithm) and high sample frequency (1000Hz) to capture the lower limb kinematics before, during and after ball contact. They also suggested the traditional method (sample frequency between 100 and 400Hz and filtered with a second-order low-pass Butterworth at 6-18Hz) is unable to provide enough data points to adequately describe the curves of both low-frequency (backswing and force producing phase) and high-frequency (ball contact phase). In their study, the high sample frequency with a modified version of time frequency filtering determined that the knee angular velocity still accelerates at ball contact. They also used a traditional method (sample frequency at 250Hz with second-order low-pass Butterworth at 10Hz filtering) to reproduce the knee angular velocity reduction before ball contact reported by the previous studies.

Using the new filtering technique and high sample frequency, the knee angular velocity reached its peak value 35 rad/s (2005°/s) just 2ms after initial ball contact (Nunome et al., 2006). Then the knee angular velocity decreased drastically. Using the traditional filtering technique, the knee angular velocity reached its peak value 32.5rad/s ($1862°/s$) fifteen milliseconds before the ball contact, which was reported in several previous studies (Lees & Owens, 2011; Katis & Kellis, 2010; Barfield et al., 2002). Therefore, Nunome et al. (2006) provided new evidence that the presented reduction of knee angular velocity might be due to the sampling and filtering technique rather than real existence of deceleration. Their findings also agreed with the coaches' suggestion of swinging through the ball (Huang et al., 1982).

Foot linear velocity

The present study analyzed the foot linear velocity from support foot touchdown to ball contact (force producing phase). The foot linear velocity prior to ball contact is highly correlated with ball speed (Lees et al., 2010). In the present study, the kicking side foot velocity is close to 6m/s at support foot touchdown and reached its peak value at close to 16m/s at ball contact. These values are close to those (4m/s and 19m/s, respectively) reported by Barfield et al. (2002). In Barfield's study, the reduction of linear velocity just prior to ball contact has been reported. However, it may be due to the traditional filtering technique they utilized in the study, as discussed in the knee angular velocity section previously. The foot linear velocity probably should reach its peak value until ball contact.

In regards to the kick direction, the kicks to the left post had significantly higher foot velocity compared to that to the right post. The higher foot linear velocity in the kicks to the left side is partially related to the higher knee extension angular acceleration and higher angular velocity at ball contact. However, this high foot velocity did not result in a high ball speed in the present study, as there is no significant difference in ball speed between kick directions.

Ball/foot speed ratio

The ball/foot speed ratio can demonstrate some characteristics of foot-ball impact (Katis & Kellis, 2010). Katis & Kellis (2010) suggested the "soft" collision would attenuate the foot-ball impact, which could reduce the resultant ball speed. In contrast, if the impact was made on the ankle rather than the metatarsal, this ankle more rigid and larger contact area would subsequently increase the ball speed (Katis & Kellis, 2010). They compared the ball/foot speed ratio between an instep and outstep kick and reported that it is significantly higher during instep kick (1.61 ± 0.41 vs 1.48 ± 0.32, $p<0.05$). This result suggested the surface of collision in the instep kicks is more rigid thus can produce higher ball speed (Katis & Kellis, 2010).

In the present study, the ball/foot speed ratios are smaller than those of Katis & Kellis (2010) possibly due to the participants' gender difference and level of skill. The difference in ball/foot ratios between directions indicated the difference in foot-ball collision mechanics. One possible difference is the striking position. In the kicks to the right post, the kicking side foot tended to get below the ball and made better contact at the ankle (see Figure 5-4a). In the kicks to the left post, the striking area often occurred below the ankle (at the metatarsal bones) (Figure 5-4b). However, it is not the case for every participant. In the former situation, the striking area is rigid, which would produce a high ball speed or high ball/foot ratio.

(a) (b)

Figure 5-4. Comparison of contact area between the kick to the right post (a) and left post (b)

Another reason for the difference in ball/foot speed ratio could be the contact area. The contact area is usually larger in the kicks to the right side compared to the left (also see Figure 5-4). Katis & Kellis (2010) suggested a larger surface of collision would lead to a larger striking mass thus a higher ball velocity or ball/foot speed ratio. It can be proved by the ball speed equation based on transferred linear momentum: $V_{ball} = V_{foot} \times \frac{M(1+l)}{M+m}$ (Lees & Nolan, 1998) (calculation see Appendix I).

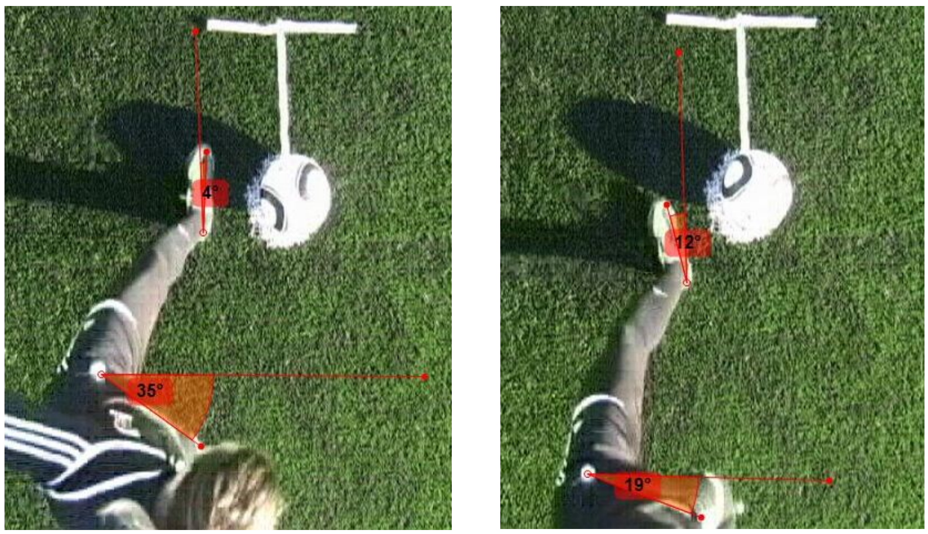
Several kinematic variables measured in the sagittal plane were recorded as significantly different between kick directions, including peak knee extension angular velocity, peak foot linear velocity and ball/foot speed ratio. However, none of these variables can be used as trustable predictors of kick direction for goalkeepers defending a penalty shot, because it may be impossible for goalkeepers to detect the difference in such variables during the penalty kicks from the front view (goalkeepers' view). Moreover, the stepwise linear regression analyses indicated that these values were excluded from the final regression model, which suggests they cannot statistically significantly predict kick direction.

Transverse plane kinematics

Support foot orientation

The results in the present study suggest the support foot tends to point toward the desired kick direction, which agrees with the previous study (Lees & Owens, 2011). Based on the linear regression analysis, the foot orientation angle can significantly predict kick direction angle. The correlation between the support foot orientation and ball direction is positive, which indicates that the ball direction would alter to the same direction as the support foot did. When all other factors were controlled for, every 10° increase in support foot orientation angle can increase kick direction angle by 4.2°. This finding suggested the support foot orientation should be altered when the penalty takers want to change the kick direction. Therefore, this information could be used as a cue for goalkeepers to predict the ball direction during a penalty shot. It can be explained along with the pelvic rotation in the transverse plane. The proper orientation of the support leg will allow proper pelvic orientation thus allow full range of the pelvic rotation to achieve maximal velocity of the kicking leg. Therefore, the pelvis had more retraction angle (relative to the medial-lateral axis) and less support foot orientation angle (more to the right side) in kicks to the right post compared to the left (see Figure 5-5).

An analogy is baseball pitching. Skilled pitchers will point the support foot forward or even slightly sideways to the left (for a right handed player) to allow a large range of hip and trunk rotation. Several sports psychology studies agreed the support foot orientation can predict the ball direction (Franks & Hanvey, 1997; Savelsbergh et al., 2002), but there have been no biomechanical studies investigating the role of the support foot orientation to the kicking movement. The present study may be the first one to discuss how and why the support foot orientation can affect the ball direction.



(a) (b)

Figure 5-5. Comparisons of support foot orientation and pelvis orientation at whole foot touchdown between kicks to the right post (a) and kicks to the left post (b).

The support foot orientation may be the most useful cue for the goalkeeper to predict the direction of the penalty kick. The first reason is that this angle can be easily detected by the goalkeeper from the front view. This angle barely changed after the whole foot touchdown to ball contact (Lees & Owens, 2011), so it is reliable. Savelsbergh et al. (2002) used the eye track system to examine the differences in anticipation and visual search behavior during the penalty kick between expert and novice goalkeepers. They found the expert goalkeepers spent longer fixating on the kicking leg, support leg and ball areas. They suggested these areas may be more informative to predict ball direction (Savelsbergh et al., 2002). Their findings support the suggestion of the present study that the goalkeepers should focus on the support foot as information to predict the ball direction. Another reason that support foot orientation may be the most useful for goalkeepers is that the support foot touch down occurred at about 45% of the total kick time (from kicking side toe-off to ball contact), which leaves about 125ms to the goalkeepers to react. This information may occur early enough for goalkeepers to respond, but not too early so as to be 'fooled' by some element of disguise on behalf of the penalty taker (Savelsbergh et al., 2002).

Pelvic orientation

Pelvic orientation at the whole foot touch down also needs to alter as the desired kick direction changes (also see Figure 5-5). In the force producing phase of the soccer kick, the pelvis should rotate counter-clockwise around a vertical axis through the left hip initially followed by hip flexion. The pelvis needs proper distance to rotate in order to accelerate the distal limbs. The kicks to the right post had a significantly larger pelvic retraction angle compared to the left (23.6° vs 10.82°, $p<0.01$). In the present study, the variables in the kicks to the straight ahead direction were not measured, but the pelvic orientation angle can be estimated between 23.6° and 10.8°. Therefore, the values are slightly smaller than that reported by Lee & Owens (2011) (24° during the instep kick straight ahead).

Support foot landing position

In the present study, the distance from support heel to the ball center at whole foot touchdown was analyzed. This variable has rarely been analyzed in previous studies, except one recent study by Alcock et al. (2012). They compared the kinematics between the curve kick and instep kick. However, they did not find any significant difference in support foot landing position between the two kick types (Alcock et al., 2012). The support foot landing position has been known as a factor that affects the height of the ball trajectory (Luxbatcher, 1999) and swing leg orientation (Lees et al., 2010). To date no other study has investigated the role of the support landing position on ball direction. The distance from support foot heel to ball center in medial-lateral direction (x direction) was 0.36m for the right post and 0.30m for the left post. The distance from support foot heel to ball center in the anterior-posterior (y direction) was 0.05m for the right post and 0.17m for the left post. These values are similar to those reported by Alcock et al.(2012) (0.33m in x and 0.09m in y). The results from the present study indicate that support foot touch down is further back and closer to the ball center in the kicks to the left. The differences in the landing position may be partially because the measurement is relative to the x and y axes rather than the desired ball direction. Figure 5-6 shows the difference in measurement. Figure 5-6(a) presented the support foot and ball position in the kicks to the left post and Figure 5-6(b) is derived from 45 degrees clockwise rotation of Figure 5-6(a). The distance from ball center to foot center remained the same. We also measured the distance from the heel to ball center in both the x and y directions. Apparently, the heel position moved farther beside and ahead of the ball from (a) to (b). Therefore, in the kicks to the left post, the support foot landed more backward and closer to the ball.

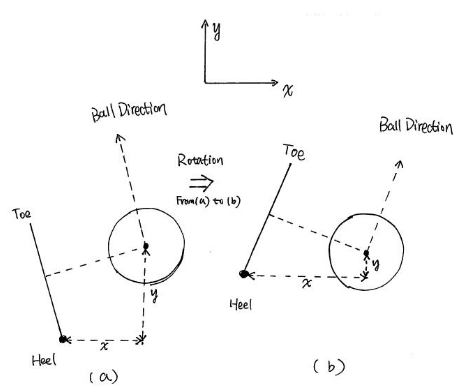


Figure 5-6. Overhead view: support foot landing position during the kicks to the left post (a) and to the right (b).

The linear regression model determined that the foot landing position behind the ball can significantly predict ball direction. The correlation between the landing position and ball direction was positive, which indicates that the more backward the support foot touch down the more toward left side the ball would go. However, the regression model also suggested this landing position slightly affects the ball direction angle. If the player controlled for all other factors, every 1 meter increased in the distance from heel to the ball center (in y direction) will only increase 3.7 degrees of ball direction angle. This support foot landing position may also be easily detected from the frontal view by goalkeepers. Even though the effect of landing position on the ball direction is subtle, along with the support foot orientation, it may be informative for goalkeepers to predict the ball direction. It is likely that if the support foot landed behind the ball and pointed towards the left side, the ball will probably go to the left post. If the support foot landed in front of the ball and pointed towards the right, the ball will probably go to the right post.

However, the support foot position and orientation in the instep kick should be differentiated from those in the curved kick. In a curved kick, the support foot pointed to the right of the desired ball direction (Alcock et al., 2011).

Approach angle

A 30-45 degrees approach angle relative to the desired ball direction would produce maximal ball speed (Isokawa & Lees, 1988). The players altered approach angle relative to the y-axis depending on kick direction. Therefore, the approach angle relative to the y-axis could be a cue to predict the desired ball direction. In the present study, the approach angle relative to the y-axis was significantly larger in the kicks to the right side (25.5° vs 7.9°, $p<0.01$). Based on the linear regression model, the correlation between approach angle and ball direction was negative, which indicates that the larger the approach angle the more to the right side the ball went. If the player controls for the other factors, every 10 degrees increase in approach angle can decrease ball direction angle by 6.2 degrees. However, the goalkeepers should carefully use the approach angle as information to predict the ball direction because as Dicks et al. (2011) argued, the approach angle was an early piece of information that can be used as deception for penalty takers to fool the goalkeepers. Secondly, the desired approach angle varies a lot from player to player. Scurr & Hall (2009) reported that soccer players use a self-selected approach angle of 0 to 60 degrees during an instep kick. Thirdly, the approach angle may be difficult to judge as large or small by goalkeepers due to lack of consistent reference.

Frontal plane kinematics

In the frontal plane, the present study measured the trunk lean and support leg lean at the whole foot contact. The results indicated that the larger the support leg lean the more to the right side the ball would go. There is no previous study that reported the trunk and support leg lean angle at the foot plant. Orloff et al. (2008) reported trunk lateral lean of -3° and 8° and support leg lean of 25° and 26° in males and females respectively at ball contact. The negative sign indicated that males leaned the trunk towards the ball at ball contact.

The trunk lean in the frontal plane is related to the foot speed thus ball speed (Orloff et al., 2008). A more upright trunk in the frontal plane would produce a higher ball speed (Orloff et al., 2008). One possible reason is that the trunk position in the frontal plane is related to the length of the moment arm of the kicking foot. In the kicking movement, the kicking foot has an angular velocity component around the spine. It is possible to measure the moment arm from kicking foot to the axis of rotation (spine) see Figure 5-7. If the trunk is more vertical, or even towards the ball along with the large leg lean, the length of the moment arm will increase. The longer moment arm will result in a larger radius of rotation around the trunk thus faster foot linear velocity.

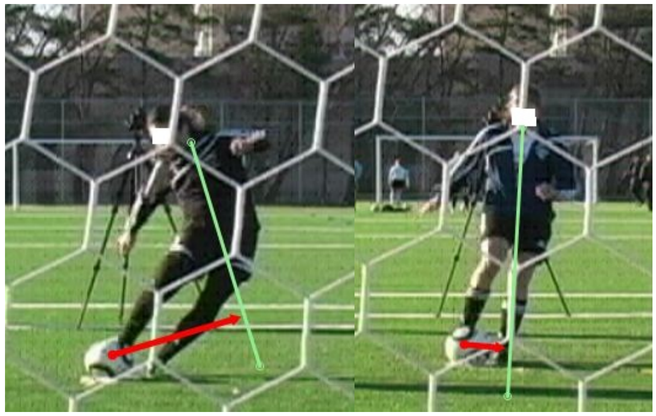
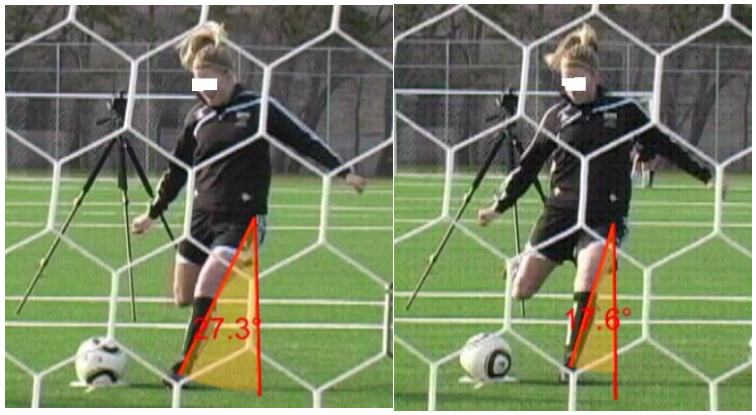


Figure 5-7. Comparisons of the length of moment arm. Red arrow line indicated the moment arm. Green line indicated axis of rotation.

A larger support leg lean would also contribute to a higher ball speed (Lees et al., 2010). The large lean of the support leg would allow a more extended knee at the kicking side, which would result in a longer radius of rotation around medial-lateral axis through the kicking side hip joint. Therefore, a higher linear velocity would occur at the end segment (kicking side foot).

No other studies have desrcibed the role of the trunk and support leg on ball direction. Therefore it is not entirely unclear why the trunk and support leg had a larger lean in the kicks to the right post. One possible reason is that when kicking to the right side, the angle between the approach and ball direction was relatively small (Alexander, personal communication, May 25, 2012). Therefore, it restricted the range of motion of the pelvis rotation. The player has to increase the support leg lean in order to allow a more extended kicking leg thus a higher foot velocity to compensate for this approach angle disadvantage.

Another possible reason could be explained by the measurement plane. In the kicks to the right post, the trunk and support leg were facing the camera slightly sideways. The support leg lean angle consists of both adduction and flexion. In the kicks to the left post, the trunk and support leg were facing the camera squarely. The lean angle only consists of adduction. Therefore, a difference in leg lean angle was measured (see the Figure 5-8)



(a) (b)

Figure 5-8. Comparison of support leg lean in the kicks to the right post (a) and to the left (b).

That said, the support leg lean angle may be difficult for goalkeepers to evaluate due to the lack of a reference to judge. Even though the player performs a large support leg lean, it is still not clear in which direction she would kick. In addition, Lees & Owens (2011) suggested the support leg lean was less valuable because it occurred too late for the goalkeepers to use as a cue regarding direction of kick. Therefore, the support leg lean may be less helpful for goalkeepers to predict kick direction.

In summary, the support foot orientation, support foot landing position in y direction and approach angle combined can explain about 77% of the variance of the ball direction. The effect of support foot orientation and approach angle on ball direction is apparent. The effect of support foot landing position on ball direction is more subtle. The support foot orientation along with the landing position is the most useful cue for goalkeepers to predict ball direction. Other factors such as support leg lean and pelvic orientation could likely account for the unexplained variance (about 23%).

Implications

To the knowledge of the investigator, there have been no studies comparing the differences in the instep kick movements involved altering kicking directions. Therefore, the key kinematic factors that can be used to predict the ball direction during instep kicks were unclear. The present study is the first one that successfully examined the kinematic factors that contribute to kick direction. Because the instep kick is commonly used during a penalty shot (Shan, 2009), the present study provides important information that may benefit the goalkeepers when defending a penalty kick. The present study also provides a direction for future studies that investigate defending penalty shot. Future studies could focus on the kinematics of kicking movement before ball contact to develop more visual cues that may benefit the goalkeepers.

Lees & Owens (2011) analyzed the push kick and instep kick between two kick directions (to the left corner and straight-ahead). Compared with Lees & Owens (2011) study, the present study identified more visual cues that can be used by goalkeepers (eg. support foot landing position and approach angle) and more kinematic variables that are significantly different between kicks to the right and left posts. The present study was also conducted on an outdoor field in which the participants performed the real penalty kicks as they usually perform them in a normal game. Therefore the results and findings may be more representative for the real penalty kicks and more useful for the goalkeepers when defending the penalty kicks.

The findings in the present study suggest that the support foot orientation and landing position at the instant that the support foot touched down may be factors that contribute to kick direction. Moreover, the support leg lean and approach angle were also detected as different between two kick directions. As a result, these indicators should be factors of interest in future studies and emphasized in the goalkeeper's penalty shot defense training. For example, coaches could suggest that goalkeepers focus on the support leg and foot directions of the opponents during their approach. However, the approach angle should be used cautiously by goalkeepers, as it can be used as deception information. This study does not involve studying any kicking movement with deception. Some skilled penalty kickers will deceive the goalkeepers by concealing these movements that can be used for prediction. Diaz (2010), a cognitive scientist at Rensselaer Polytechnic Institute in Troy, N.Y., reported a study to determine the reliable predictors of penalty kicks. He stated that “ if a kicker tried to do something unexpected, such as point his planted foot one way but kick the ball in the opposite direction, the rest of this body could also give him away, such as move his arms in a certain way to keep his balance.” (Diaz, 2010, para. 7). Consequently, future studies should consider of the effects of deception and develop more predictors that can be used for goalkeepers to defend against penalty shots.

CHAPTER 6

Summary, Conclusions and Recommendations

Summary

In a penalty kick, the penalty taker shoots a stationary ball located 12 yards (11m) from the goal line. The goalkeeper must stay on the goal line until the ball is struck. An instep kick is commonly used for penalty kick because it can produce a higher ball speed and give less time for the goalkeeper to react and stop the shot.

The purpose of the present study was to compare the differences in the instep kick movements between two different kick directions during a penalty kick. The visual cues of the kick movements that could be used by goalkeepers to predict kick direction were determined.

The participants in the present study performed a general pattern of the instep kick. The kinematics are similar to those in the previous studies. Several variables were identified that were significantly different between two kick directions, which included peak knee extension angular velocity, peak foot linear velocity, support foot plant orientation and position, pelvis orientation at foot plant, support leg lean in the frontal plane and approach angle. There were only three variables that predicted kick direction significantly: support foot orientation, distance from support heel to the ball center (y-direction) and approach angle. These three variables combined can explain 77.4% of the variance in kick direction.

Of those, support foot may be the most useful cue to predict the ball direction. It is suggested that if the support foot landed behind the ball and pointed towards the left side, the ball probably goes to the left post. If the support foot landed in front of the ball and pointed towards the right, the ball probably goes to the right post. Other cues may be less helpful because they are difficult or too subtle to be detected by goalkeepers.

However, support foot orientation and position may be confused with those in a curved kick.

The goalkeepers should predict the types of kick before the prediction of direction. Therefore, future studies may focus on cues that are helpful to predict the types of kick. The effective prediction of types of kick along with the direction will provide the goalkeepers more information to increase their chances of stopping a penalty kick.

Even though the approach angle can significantly predict kick direction, the goalkeeper should carefully use this visual cue, because the approach occurs too early and can be used as deception for penalty takers to fool the goalkeepers (Dicks et al., 2011). Most of the elite penalty takers would use deception during the penalty kicks. Therefore, the goalkeepers should learn to ignore early information (eg. approach angle) and focus on the late information (eg. support foot orientation).

It should be noted that the correct side prediction doesn't ensure successful penalty kick stoppage. Savelsbergh et al.(2002) reported that the correct side prediction, correct height prediction and penalties stopped are 83.8%, 42.6% and 35.7%, respectively for expert goalkeepers. This result suggested that postural cues relating to the height of the penalty kick are more subtle and difficult to pick up than those to the correct side (Savelsbergh et al., 2002). Therefore, future studies may also investigate the cues that can be used to predict the height of kick.

Conclusions

Based on the findings of this study, the following conclusions have been determined:

1. There is a significant difference in support foot orientation when kicking to the right and left sides, which can significantly predict kick direction.
2. There is a significant difference in support foot placement position (distance behind the ball center) when kicking to the right and left sides, which can also significantly predict

the kick direction.

3. The support foot orientation along with the support foot placement position may be the most useful cues for goalkeepers to predict the kick direction.
4. There is a significant difference in approach angle between two kick directions, which can significantly predict the kick direction. However, goalkeepers should carefully use this cue, because it can be used as deceptive information to fool the goalkeepers (Dicks et al., 2011).

Recommendations

Based on the findings and discussion in the present study, the recommendations for future studies on penalty kick prediction are as follows:

1. Future studies should try to utilize a three-dimensional motion capture system to collect the kinematic data in order to avoid errors in measurement due to being off the primary plane (eg. step length measurement).
2. Future studies may investigate the cues that can be used to predict types of kick and height of the ball placement. Along with the ball direction prediction, it can provide more information and increase the chance for goalkeepers to stop a penalty shot.
3. Future studies may also investigate penalty shots with deception and develop more trustable cues for goalkeepers.

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APPENDICES

Appendix A- Power Calculation

Type I error Alpha is set as 0.05; type II error Beta is set as 0.2. Based on the previous study, the average kicking hip abduction is -7.2 (5.4) degrees (Robert et al, 2010), the pelvic tilt angle is 7.4 (4.8) degrees (Scurr & Hall, 2009). The expected detected difference is seven degrees. So $n_1 = 2(\frac{Z_{1-\alpha/2} + Z_{1-\beta}}{ES})^2$, $n_1 = 2(\frac{1.96 + 0.84}{1.3})^2 = 9.2$. Using the same method, $n_2 = 7.2$. The Effect size is defined as the standardized difference in means under the null and alternative hypothesis. N1is the number of needed subjects to detect five degrees difference of hip abduction. N2 is the number of needed subjects to detect five degrees difference of pelvic tilt.

Appendix B - Sample joint displacement measurement

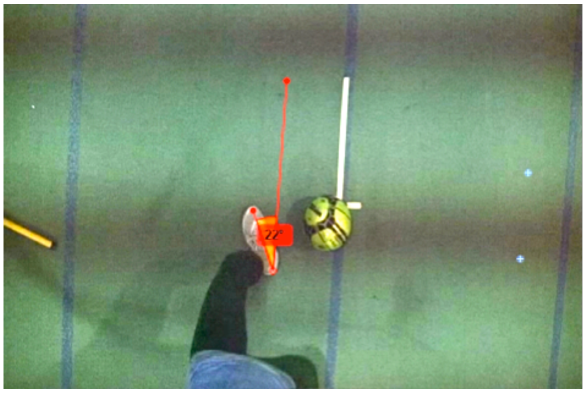

Figure 1. Support foot orientation angle.

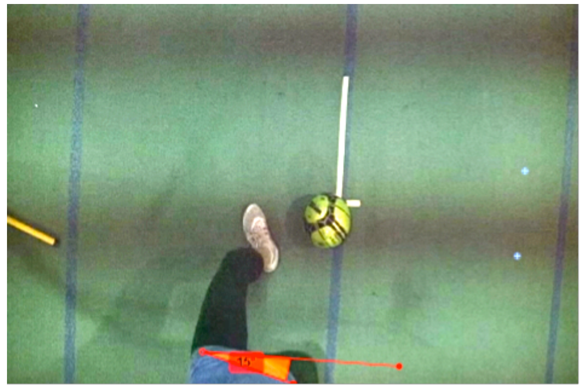

Figure 2. Pelvis orientation angle

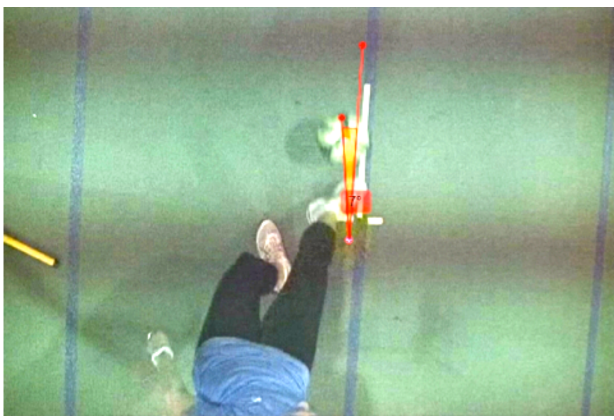

Figure 3. Kick direction

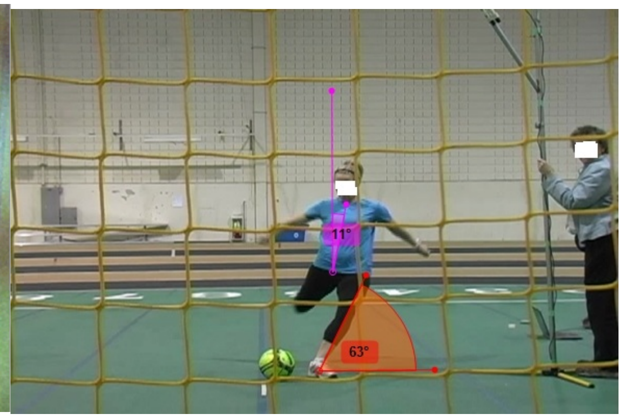

Figure 4. Trunk lean and support leg lean at whole foot touch down.

Appendix C - Pilot study

Introduction

The purpose of the pilot study was to collect video and ground reaction force data from the participants performing the instep kick in different directions. The pilot study provides the investigator an opportunity to test the methods and procedure of the study, and analyze the kinematic and ground reaction force data.

The pilot study took place on two occasions: at Pan Am clinic biomechanics laboratory, February 25th, 2012 and Max Bell indoor field, March 15th, 2012.

Methods

Participants

A skilled male soccer player participated in the force plate data study at Pan Am clinic biomechanics laboratory on February 25th, 2012. A female soccer player from University of Manitoba Bison soccer team participated in the kinematic data collection at the Max Bell indoor field on March 15th, 2012. Informed consent was obtained prior to film data collection.

Procedure

GRF data collection: The force plate is mounted on the ground at the Pan Am clinic biomechanics laboratory. A net sized 2 meters wide and 1.8 meters high was set up as a goal. The ball was 3 meters away from the goal. The ball was placed close to the force plate, which ensured that the support foot of the participant touched down on the force plate directly. The participant shot at the left/right post using a 2 step run-up. There were five trials on each post performed by the participant. The GRF data was collected by the force plate (AMTI, 200Hz). A side view camera (Canon GL2, 30fps) was set up to synchronize the force plate data and define the phase of the kicking movement.

Figure 5. Ground reaction force data collection at Pan Am Biomechanics Lab.

Kinematics data collection at Max Bell field (March 25th, 2012): The participant performed several kicks to adapt to the experimental environment. The goal size in the field was two meters high and three meters wide. The goal was located 4.5 meters away from the ball. The participant was instructed to shoot at the left/right post using a 2 step run-up, attempting five trials on each post. The participant performed the instep kick as hard and accurately as possible with the right foot. The participant chose her own preferred approach angle. Three trials with relative high speed and accurate direction for each participant were selected for further analysis.

The kinematics data was collected by four cameras. One high speed camera (Fijifilm EXR, 80Hz) was set up three meters beside the ball. Because the participant is right-foot dominant, the camera was on the right side to capture the movement that occurred in the sagittal plane. A normal speed camera (Canon GL2, 60Hz) was set up four meters beside the ball to use as reference. Another camera (Canon GL2) was set up behind the net of the goal, which captured the participants' movement occurred in the frontal plane. The third camera (Canon HV10) was set up above the ball. The camera was mounted on a light weight tripod that was fixed on the end of a steel pipe. The other end of the pipe was anchored on the ground. The camera was suspended 3.5 meters high from the ground and directly above the ball. This camera captured the movement occurred in the transverse plane.

Results

Sagittal plane kinematics:

All the kinematic data are from Max Bell testing session. The kicking side hip and knee displacement are presented in Figure 6 and 7 respectively. Independent t-test results indicated the peak hip flexion angle is significantly larger in the kick to the left post compared with the right post (46.3 ± 1.5˚vs 27.4± 3.56˚, p=0.029). It is also indicated the peak knee flexion angle is significant larger in the kick to the left post compared with the right post (102±2˚vs 94±3.46˚, p=0.037).

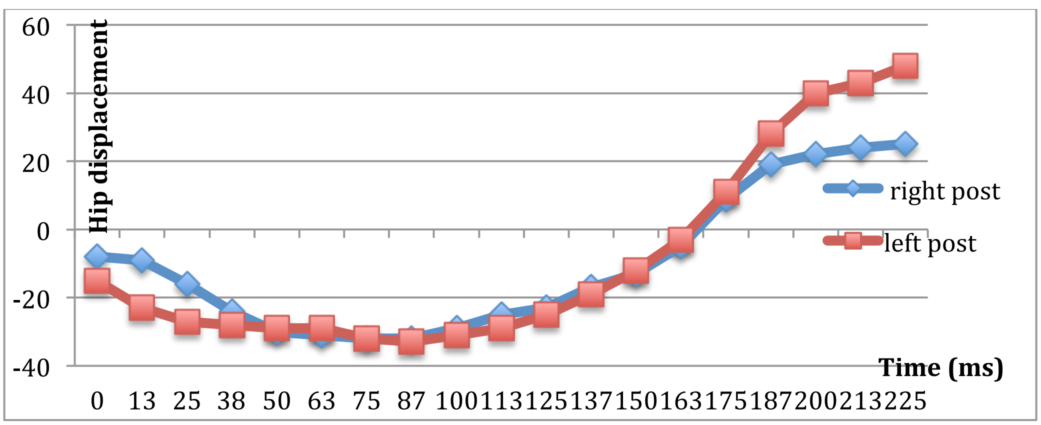

Figure 6. Kicking side hip Flexion (+)/ Extension (-) displacement (degrees) in the two kick directions from swing side toe off (0ms) to ball contact (225ms).

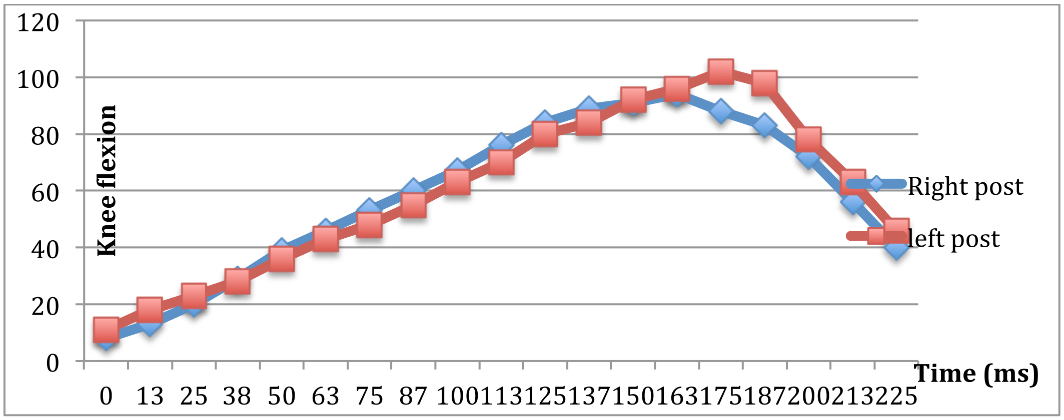

Figure 7. Kicking side knee flexion (+)/ extension (-) displacement (degrees) between toe-off (0ms) to ball contact (225ms).

The hip and knee angular velocity from toe-off to ball contact are presented in Figure 8 and 9 respectively. The peak hip flexion angular velocity is significantly higher in the kick to the left post compared with that to the right post (1360± 17˚/s vs 1120± 40˚/s, p=0.004). The independent t-test indicated there is no significant difference in peak knee angular velocity between two kick directions (p=0.93).

Figure 8. Hip angular velocity (˚/s) in the sagittal plane. Hip flexion (+), hip extension (-).

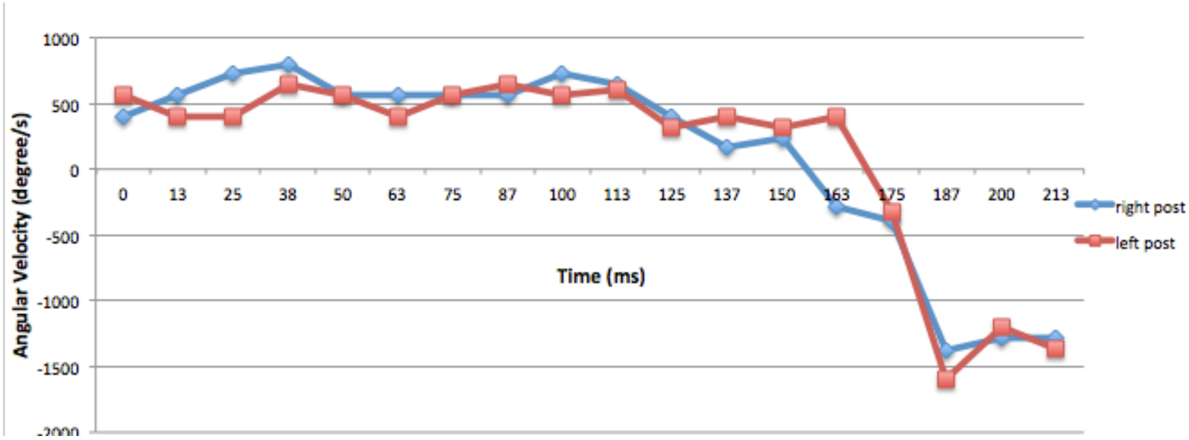

Figure 9. Knee angular velocity (˚/s) in the sagittal plane. Knee flexion (+), knee extension (-).

Linear foot velocities are presented in Figure 10. The peak foot velocity is higher in the kick to the left post than to the right (23.73±1.35m/s vs 19.6±0.77m/s, p=0.017).

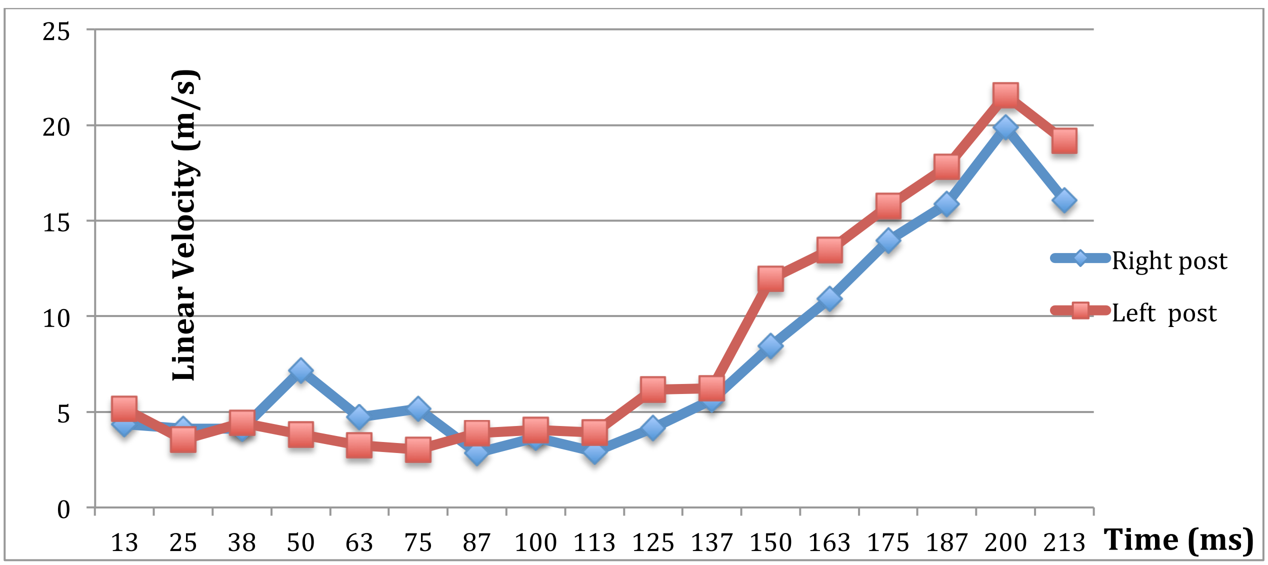

Figure 10. Kicking foot linear velocity from toe-off to ball contact.

Transverse plane kinematics:

The mean kick direction angle in the kick to the right post is -12.2±3.67˚. The mean kick direction angle in the kick to the left post is 5.9±1.01˚.

Ball speed, support foot orientation and the orientation of the pelvis in the transverse plane at whole foot touch down are presented in Table 1. The independent t-test indicated the support foot orientation and pelvis orientation between two kick directions are significantly different. The difference in ball speed between two kick directions is not statistically significant.

Table 1. Ball speed, support foot orientation angle and pelvis orientation angle in the kicks to the right post and the left post. *p<0.05, **p<0.01

	Right post	Left post	Sig.
Ball speed (m/s)	19.67±0.61	19.67±0.56	0.995
Support foot orientation (degrees)	10.2±1.67	22.7±2.29	**0.002
Pelvis orientation (degrees)	33.17±2.65	15.63±2.89	**0.002

Frontal plane kinematics:

Support leg angle and trunk lean in the frontal plane at whole foot touch down are presented in table 2. These variables are not significantly different between diections.

Table 2. support leg angle and trunk lean angle (degrees)

	Right post	Left post	Sig.
Support leg angle	62.17±2.54	61.17±1.37	0.59
Trunk lean	9.8±1.83	7.3±0.58	0.135

Ground reaction forces from touch down to ball contact are presented in Figure 11 (To the right post) and Figure 12 (to the left post). The mean GRF in medial-lateral and vertical directions between two kick directions are not significantly different. The mean GRF in anterior-posterior direction between two kick directions are significantly different (187.98N vs 249.36N, $P<0.01$). There is no significant difference in peak GRF in all three dimensions between two kick directions.

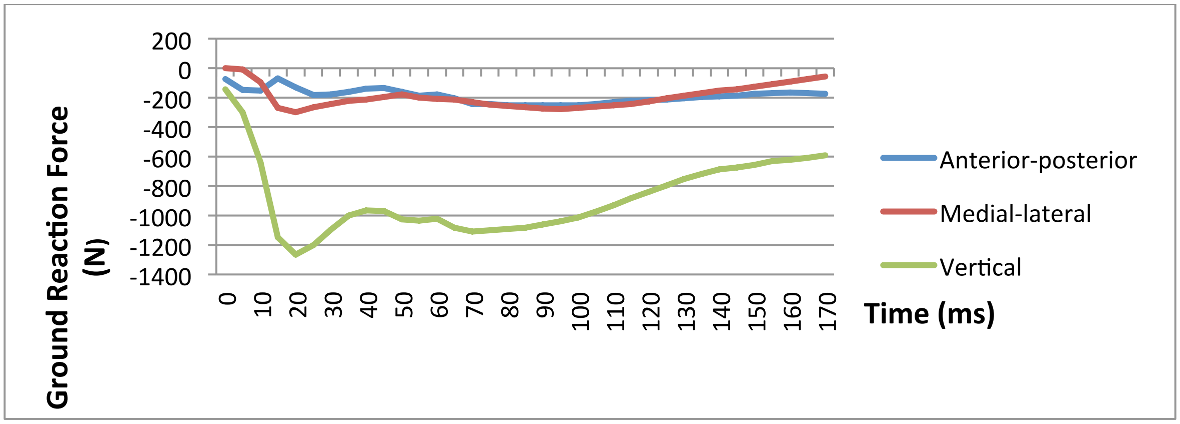

Figure 11. The ground reaction force in three dimensions from touch down to ball contact during the kick to the right post.

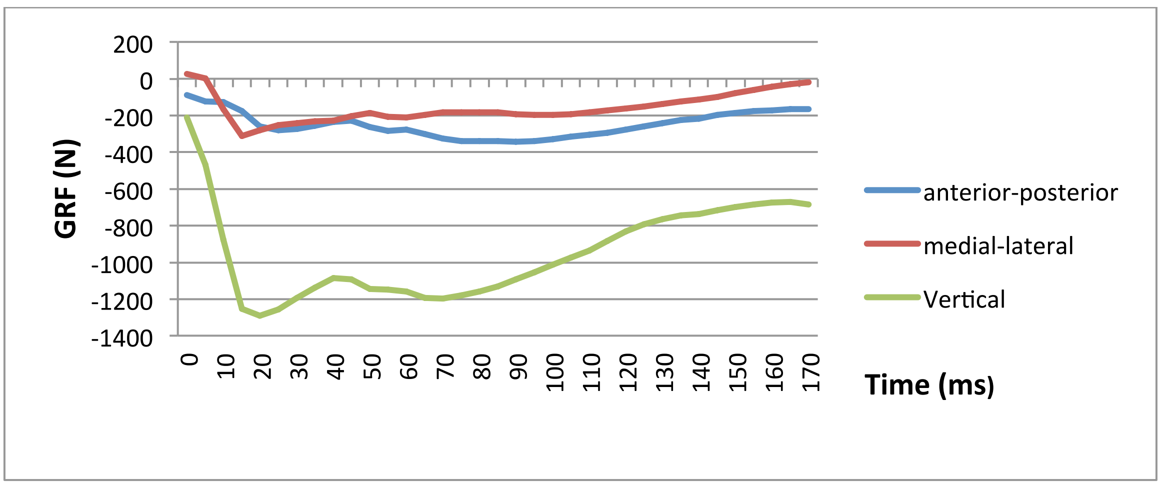

Figure 12. The ground reaction force in three dimensions from touch down to ball contact during the kick to the left post.

From the pilot data analysis, there are four kinematic variables significantly correlated with the kick direction: peak hip flexion (r=0.89, p=0.017), peak knee flexion (r=0.881, p=0.02), support foot orientation (r=0.97, p=0.001), pelvis orientation (r=-0.93, p=0.007). Using the stepwise procedure, only one variable is included in the final regression model: support foot orientation. It can explain 92.7% of the variance in the kick direction angle.

Discussion

There are four kinematic variables that can predict the kick directions significantly: support foot orientation angle, pelvis orientation angle, peak hip flexion and peak knee flexion. However, there are only two variables that can be detected from the frontal view (goalkeepers' view): support foot orientation and pelvis orientation. The angle between the direction of the support foot and direction of the ball travel is approximately 20 degrees. This finding disagrees with the study of Lees & Owens (2011). They suggested the support foot is oriented in the direction of the ball travel. The foot orientation angle would be negative if the player kicks the ball to the right side (Lees & Owens, 2011). However, they did not measure the kick direction (ball travel) and examine the correlation between the kick direction and support foot orientation. They did not investigate an angled kick to the right side due to the restrictions of the laboratory space.

The support foot orientation altered when the kick direction changed. It can be explained along with the pelvic rotation in the transverse plane. The proper orientation of the support leg will allow full range of the pelvic rotation to achieve maximal velocity at the kick leg. An analogy is the baseball pitching. Skilled pitchers will point the support foot forward or even slightly sideways to allow a large range of hip and trunk rotation. However, there have been no studies investigating the role of the support foot orientation to the kicking movement.

The support foot orientation angle can be a useful cue for the goalkeeper to predict the direction of the penalty kick. The first reason is that this angle is easily detected by the goalkeeper. The foot orientation angle barely changed after the whole foot touched down (Lees & Owens, 2011), so it is reliable. Another reason is that it was 125ms from whole foot touch down to ball contact, which is about 56% of the time of the kick event duration (from kick side toe-off to ball contact). The goalkeeper may have enough time to detect and react.

Pelvic orientation at the whole foot contact also needs to alter as the kick direction changes.

In the force-producing phase of the soccer kick, the pelvis should rotate counter-clockwise initially followed by hip flexion. The pelvis needs proper distance to rotate in order to accelerate the distal limbs. Based on the results of this study, it seems that the pelvis is facing the direction of the kick as the whole foot touches down. The hip orientation angle (retraction) is 33.17±2.65 degrees in the kick to the right post and 15.63±2.89 degrees in the kick to the left post, which agree with Lee & Owens (2011) report (24 degrees in the instep kick ahead). For the same reason, the pelvic orientation can also be used as a cue to goalkeepers.

Due to the limitation of the overhead view camera setup, the study cannot capture the path of the approach. Therefore the differences in the approach angle between two kick directions cannot be quantified.

The participant performed a larger range of hip flexion and knee flexion in the kicks to the left post compared with the right post. The hip flexion and knee flexion are two key factors to a powerful instep kick (Kellis & Katis, 2007; Lyle et al., 2011; Barfield, Kirkendall & Yu, 2002). Therefore the peak foot linear velocity is higher in the kicks to the left post (23.73±1.35m/s vs 19.6±0.77m/s). The linear foot velocity before the impact is still higher in the kicks to the left post than to the right post (19.18±1.44m/s vs 16.06±1.59m/s). The linear foot velocity slightly decreased just before the impact. This result agreed with other studies (Barfield, Kirkendall & Yu, 2002; Katis & Kellis, 2010; Kellis & Katis, 2007). It can be explained by a motor control strategy to enhance accuracy, which means the athlete decelerates the foot in order to obtain better accuracy of the ball impact. Another possible reason may be that the deceleration of the foot as well as the knee extension can reduce risk of the hyperextension injury at the knee joint. The peak knee extension angular velocity can be up to 1800 degrees per second (Barfield, Krikendall & Yu, 2011; Katis & Kellis, 2011) (1600 degrees per second in this study). The extraordinarily high velocity of the knee extension needs enough time and distance to decelerate in order to avoid impingement injury. Therefore, the soccer player may have to decelerate knee extension before the ball contact.

Interestingly, even though the linear foot velocity before impact is higher in the kick to the left post, there is no significant difference in the ball speed between the two directions. The possible explanation could be the differences in coefficient of restitution between foot and ball. The coefficient of restitution between foot and ball is 0.51±0.037 for the kicks to the right post and 0.43±0.075 to the left post. This result is close to (0.463-0.681) reported by Andersen et al. (1999). When the player kicked to the right post, the foot contacted the ball with upper part of the foot (first and second metatarsal bone). This contact area of the foot is relatively rigid. However, when the player kicked to the left post, the foot tended to contact the ball with the medial part of the foot. This area is relatively soft, so the coefficient of restitution is smaller. Therefore, the ball speed is reduced. However, the exact contact area cannot be determined due to the limitations of the camera setup.

Appendix D – Participants information

Participants	Sex	Height (cm)	Mass (kg)	Years of experience
1	F	177.80	68.18	11.00
2	F	157.50	54.55	12.00
3	F	165.10	54.55	12.00
4	F	170.18	54.55	15.00
5	F	175.26	75.00	13.00
6	F	165.10	55.91	13.00
7	F	157.48	65.91	12.00
8	F	175.26	68.18	13.00
9	F	152.40	55.45	14.00
10	F	167.64	61.36	14.00
11	F	162.56	59.09	18.00

Appendix E - Standardize time

Because the total kicking time for each trial is different, we need to standardize time to average the kinematic data. For example, if the total time is 162ms, the number of frames is 14. We choose 10 frames evenly from these 14 frames to make each frame 10% of the total time. The first 10% is always from the 2nd frame. 14/10*1=1.4, 14/10*2=2.8, 14/10*3=4.2, 14/10*4=5.6, 14/10*5=7 ……Then we round up these value. We get 3rd, 4th, 6th, 7th…….

Table 1. Original value of standardized time

Total Time	No. of frames										
162	14		1.4	2.8	4.2	5.6	7	8.4	9.8	11.2	12.6
174	15		1.5	3	4.5	6	7.5	9	10.5	12	13.5
187	16		1.6	3.2	4.8	6.4	8	9.6	11.2	12.8	14.4
200	17		1.7	3.4	5.1	6.8	8.5	10.2	11.9	13.6	15.3
213	18		1.8	3.6	5.4	7.2	9	10.8	12.6	14.4	16.2
225	19		1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.2	17.1
237	20		2	4	6	8	10	12	14	16	18
250	21		2.1	4.2	6.3	8.4	10.5	12.6	14.7	16.8	18.9
262	22		2.2	4.4	6.6	8.8	11	13.2	15.4	17.6	19.8
275	23		2.3	4.6	6.9	9.2	11.5	13.8	16.1	18.4	20.7

Table 2. Rounded up value of standardized time

Total Time	No. of frames										
162	14		2	3	4	6	7	8	10	11	13
174	15		2	3	5	6	8	9	11	12	14
187	16		2	3	5	6	8	10	11	13	14
200	17		2	3	5	7	9	10	12	14	15
213	18		2	4	5	7	9	11	13	14	16
225	19		2	4	6	8	10	11	13	15	17
237	20		2	4	6	8	10	12	14	16	18
250	21		2	4	6	8	11	13	15	17	19
262	22		2	4	7	9	11	13	15	18	20
275	23		2	5	7	9	12	14	16	18	21

Appendix F – Kinematic variables (Hip and knee angular displacement and velocity in the sagittal plane)

Subject 1

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-17	21	-136.7521368	805.5555556
2	-19.66666667	40.33333333	-164.5299145	619.6581197
3	-23	75	-134.6153846	1641.025641
4	-23.66666667	101	53.41880342	1029.91453
5	-20.66666667	125.3333333	53.41880342	491.4529915
6	-15.66666667	132	290.5982906	388.8888889
7	-8.666666667	126.6666667	384.6153846	-615.3846154
8	12.66666667	106.6666667	743.5897436	-1025.641026
9	26.66666667	83.33333333	461.5384615	-820.5128205
10	33	53.33333333	205.1282051	-974.3589744
L				
1	-11	16.33333333	-222.2222222	611.1111111
2	-14.33333333	34.33333333	-111.1111111	976.4957265
3	-19	66.66666667	-153.8461538	948.7179487
4	-22.33333333	91.66666667	-132.4786325	978.6324786
5	-21.66666667	115	134.6153846	658.1196581
6	-16	126	282.0512821	435.8974359
7	-3.333333333	131	666.6666667	51.28205128
8	16	118	512.8205128	-621.7948718
9	27	91.66666667	388.8888889	-1250
10	30.66666667	51.66666667	79.05982906	-1549.145299

Subject 2

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-12.66666667	12	-453.3333333	426.6666667
2	-22.33333333	28.33333333	-426.6666667	746.6666667
3	-29.33333333	46.33333333	-266.6666667	773.3333333
4	-32.66666667	74	-106.6666667	1173.333333
5	-34.33333333	99.66666667	53.33333333	693.3333333
6	-36.66666667	109.6666667	-133.3333333	426.6666667
7	-30	108.3333333	426.6666667	-320
8	-14	97.66666667	640	-586.6666667
9	8.666666667	76.33333333	1093.333333	-1013.333333
10	20.33333333	35	400	-1573.333333
L				
1	-9.666666667	14.33333333	-240	506.6666667

2	-19.66666667	25	-373.3333333	320
3	-28.66666667	50.66666667	-293.3333333	1200
4	-31.66666667	73.33333333	-26.66666667	853.3333333
5	-35	91.66666667	-80	800
6	-35	99.66666667	80	453.3333333
7	-23.33333333	110.3333333	720	106.6666667
8	-4.333333333	103.3333333	933.3333333	-506.6666667
9	17.66666667	81.66666667	826.6666667	-1093.333333
10	25.33333333	30.66666667	186.6666667	-2240

Subject 3

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-19.33333333	14.33333333	-293.3333333	426.6666667
2	-29	32.33333333	-373.3333333	800
3	-32.66666667	57.33333333	-80	853.3333333
4	-35.66666667	78.66666667	-133.3333333	773.3333333
5	-34.66666667	92.66666667	106.6666667	293.3333333
6	-30.33333333	99.33333333	186.6666667	213.3333333
7	-20.66666667	101.6666667	560	133.3333333
8	1	89.66666667	933.3333333	-373.3333333
9	17.33333333	65.33333333	506.6666667	-1040
10	23.66666667	31	186.6666667	-1200
L				
1	-22	18.33333333	-240	560
2	-29.33333333	31.66666667	-320	533.3333333
3	-35.33333333	46.66666667	-133.3333333	640
4	-37.33333333	63.66666667	26.66666667	746.6666667
5	-33.33333333	87	133.3333333	880
6	-21.33333333	98	640	480
7	-9.333333333	97	453.3333333	-346.6666667
8	11	89.33333333	826.6666667	-373.3333333
9	26.33333333	71.33333333	560	-853.3333333
10	31	31.33333333	186.6666667	-1893.333333

Subject 4

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-24.66666667	26.33333333	-213.3333333	400
2	-26.33333333	35.66666667	-106.6666667	560
3	-27.66666667	50	-26.66666667	560
4	-25.66666667	65	133.3333333	746.6666667

5	-22.66666667	81.33333333	106.6666667	746.6666667
6	-17.33333333	90.33333333	266.6666667	453.3333333
7	-7.333333333	93.33333333	480	-186.6666667
8	11	81.66666667	773.3333333	-666.6666667
9	20.33333333	71	480	-693.3333333
10	25.66666667	41.66666667	160	-1093.333333
L				
1	-16.66666667	29.33333333	-293.3333333	453.3333333
2	-23.66666667	40	-293.3333333	426.6666667
3	-27.66666667	48.66666667	-240	533.3333333
4	-29	60.33333333	-53.33333333	533.3333333
5	-23.66666667	76.66666667	266.6666667	640
6	-12.33333333	93	560	613.3333333
7	5	94.33333333	1040	26.66666667
8	16	93	693.3333333	-133.3333333
9	26	77	480	-933.3333333
10	34	42.66666667	266.6666667	-1386.666667

Subject 5

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-13.66666667	19.33333333	-346.6666667	373.3333333
2	-18	27	-266.6666667	426.6666667
3	-20.66666667	42.66666667	-80	826.6666667
4	-19.66666667	64	213.3333333	853.3333333
5	-15.33333333	82.33333333	186.6666667	506.6666667
6	-10.66666667	86.66666667	293.3333333	266.6666667
7	2.333333333	87.66666667	693.3333333	-26.66666667
8	16	81	613.3333333	-453.3333333
9	22.33333333	69.66666667	346.6666667	-746.6666667
10	28.33333333	35.66666667	160	-1386.666667
L				
1	-11	25.33333333	-346.6666667	426.6666667
2	-14.66666667	32.33333333	-293.3333333	560
3	-17.33333333	47.33333333	-106.6666667	640
4	-15.66666667	65.33333333	26.66666667	960
5	-7.666666667	85	426.6666667	746.6666667
6	-1.333333333	91	453.3333333	480
7	12	96.33333333	693.3333333	106.6666667
8	21.33333333	85.33333333	320	-453.3333333
9	25.33333333	68.33333333	320	-1360
10	30.33333333	29	133.3333333	-1440

Subject 6

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	0.666666667	15	-320	293.3333333
2	-8	36	-293.3333333	666.6666667
3	-14.66666667	56.66666667	-213.3333333	773.3333333
4	-16	77.66666667	53.33333333	720
5	-13	100.6666667	240	826.6666667
6	-6.333333333	109.6666667	373.3333333	480
7	6.333333333	114	586.6666667	26.66666667
8	25	109.6666667	640	-453.3333333
9	39.66666667	85.66666667	480	-1040
10	46	50.33333333	213.3333333	-1360
L				
1	-6	25	-320	400
2	-13	37.5	-320	640
3	-18.5	52	-160	600
4	-16	69.5	80	800
5	-11.5	87.5	200	680
6	-8	96.5	280	720
7	6.5	107.5	680	320
8	20	109	560	40
9	37.5	94	720	-840
10	48.5	58	320	-1520

Subject 7

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-23	15.5	-280	520
2	-26	21	-240	440
3	-27.5	34	40	720
4	-25	41	200	560
5	-17.5	60.5	400	640
6	-10	69.5	400	520
7	1.5	80	760	400
8	16.5	70.5	800	-520
9	24.5	53	440	-840
10	31.5	34	360	-880
L				
1	-20.33333333	19.66666667	-213.3333333	480
2	-22.33333333	25.33333333	-160	453.3333333
3	-24.66666667	40.33333333	-26.66666667	613.3333333
4	-22.66666667	47	160	533.3333333

5	-16.33333333	61	266.6666667	586.6666667
6	-4.333333333	73	746.6666667	480
7	5	81.33333333	746.6666667	666.6666667
8	20	78.33333333	666.6666667	-293.3333333
9	26.33333333	69.66666667	506.6666667	-693.3333333
10	33.33333333	36	240	-1386.666667

Subject 8

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-14.66666667	22.33333333	-320	533.3333333
2	-19.33333333	38.33333333	-160	666.6666667
3	-21.66666667	60.33333333	-80	960
4	-22.66666667	74.66666667	-80	426.6666667
5	-20.66666667	81.66666667	106.6666667	320
6	-17.66666667	83.33333333	240	133.3333333
7	-6	82	586.6666667	-106.6666667
8	9.666666667	74.33333333	613.3333333	-293.3333333
9	20	55.66666667	293.3333333	-880
10	25	29.33333333	133.3333333	-960
L				
1	-5	32.66666667	-213.3333333	560
2	-10	45.66666667	-213.3333333	506.6666667
3	-14.66666667	58	-240	586.6666667
4	-14.66666667	72.33333333	26.66666667	586.6666667
5	-11.33333333	80.66666667	213.3333333	213.3333333
6	0	85.66666667	613.3333333	213.3333333
7	13.33333333	87.66666667	480	106.6666667
8	22.33333333	80.66666667	453.3333333	-400
9	33	55.33333333	320	-1173.333333
10	36	27.66666667	106.6666667	-1093.333333

Subject 9

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-13.66666667	19	-346.6666667	693.3333333
2	-18.33333333	28	-373.3333333	720
3	-24.33333333	45.66666667	-213.3333333	720
4	-27.66666667	62.33333333	-106.6666667	906.6666667
5	-27.66666667	78	186.6666667	613.3333333
6	-21.33333333	85.66666667	400	506.6666667
7	-3.333333333	98	1066.666667	533.3333333

8	23.33333333	93.66666667	933.3333333	-506.6666667
9	30.33333333	80.33333333	560	-1066.666667
10	40.33333333	50.33333333	240	-1306.666667
L				
1	-16.33333333	20.66666667	-373.3333333	586.6666667
2	-23.33333333	27.66666667	-400	373.3333333
3	-31	41	-346.6666667	613.3333333
4	-32	51.33333333	-53.33333333	586.6666667
5	-32	64.33333333	106.6666667	480
6	-22.66666667	77.33333333	533.3333333	480
7	-13.33333333	84	613.3333333	346.6666667
8	9.333333333	85	1040	-106.6666667
9	19.33333333	78.33333333	613.3333333	-426.6666667
10	32	46	373.3333333	-1386.666667

Subject 10

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-13.33333333	14.66666667	-320	480
2	-18.66666667	27.66666667	-293.3333333	746.6666667
3	-23	40.33333333	-240	586.6666667
4	-26.66666667	58.66666667	-80	720
5	-27	71.66666667	26.66666667	453.3333333
6	-21	77	400	293.3333333
7	-8.666666667	74	666.6666667	-266.6666667
8	9.666666667	66.33333333	906.6666667	-426.6666667
9	18.66666667	50.66666667	533.3333333	-960
10	23.66666667	20.33333333	133.3333333	-1253.333333
L				
1	-14.5	18	-360	680
2	-19.5	30	-280	600
3	-22	39	-80	520
4	-25	50.5	-80	400
5	-26	61	40	320
6	-19	67.5	400	320
7	-4	75.5	680	320
8	12.5	67	880	-520
9	22.5	48.5	520	-1000
10	29	21	280	-1160

Subject 11

Time (%)				
R	MeanHip	MeanKnee	MeanHipW	MeanKneeW
1	-14.33333333	27.33333333	-293.3333333	586.6666667
2	-17.66666667	36.33333333	-266.6666667	720
3	-20.66666667	55.66666667	-106.6666667	800
4	-23	65.66666667	-186.6666667	800
5	-20	80.66666667	320	640
6	-16.33333333	89.33333333	293.3333333	693.3333333
7	-5.333333333	94	560	26.66666667
8	14.33333333	87	586.6666667	-480
9	23.66666667	77	746.6666667	-800
10	35	47	293.3333333	-1253.333333
L				
1	-16	23.66666667	-240	400
2	-18	31.33333333	-160	613.3333333
3	-23	48.33333333	-213.3333333	693.3333333
4	-24.33333333	62	53.33333333	693.3333333
5	-19	79.33333333	293.3333333	826.6666667
6	-15	86.33333333	320	560
7	1.333333333	94.66666667	720	240
8	24	85.66666667	880	-666.6666667
9	31.33333333	74.66666667	586.6666667	-880
10	40.66666667	44	293.3333333	-1253.333333

Appendix G – Sagittal plane peak value

Subejct	RHipEX	LHipEx	RKneeFlex	LKneeflex	RhipExW	LhipExW	RkneeFlW	LKneeExW	RpeakFootV	LPeakFootV
1	-23.67	-22.3	132	131	743.59	666.67	-1025.64	-1549.15	16.67	18.48
2	-36.67	-31.67	109.67	110.33	1093.3	933.33	-1573.33	-2240	18.38	18.86
3	-35.67	-37.33	101.67	98	933.33	826.67	-1200	-1893.33	15.65	18.59
4	-27.67	-29	93.33	94.33	773.33	1040	-1093.33	-1386.67	15.17	16.77
5	-20.67	-17.33	87.67	96.33	693.33	693.33	-1386.67	-1440	16.53	17.68
6	-16	-18.5	114	109	640	720	-1360	-1520	14.29	16.47
7	-27.5	-24.6	80	81.3	800	746.67	-880	-1386.67	14.21	16.43
8	-22.67	-14.67	83.33	87.67	613.33	613.33	-960	-1173.33	12.65	14.28
9	-27.67	-32	98	85	1066.6	1040	-1306.67	-1386.67	15.02	16.24
10	-27	-26	77	75.5	906.67	880	-1253.33	-1160	13.52	16.11
11	-23	-24.33	89.33	94.67	746.67	880	-1253.3	-1253.33	14.43	16.47

Appendix H – Frontal and transverse plane kinematic variables

Subejct	Rtrunklean	Ltrunklean	RLegLean	Lleglean
1	3.07	4	34.37	31.37
2	9.57	5.23	39.1	26.63
3	14.13	7.8	29.77	17.8
4	8.6	9.9	27.07	25.27
5	5.3	4.3	30.03	21.07
6	7.5	8.27	12.4	11.1
7	7.6	6.6	27.77	21.77
8	6.83	8.2	31.37	24.2
9	10.83	9.5	31.8	33.13
10	12.3	9.8	16.43	12.56
11	4.8	3.27	25.06	14.77

Subejct	RsupportFoot	LsupportFoot	Rpelvis	Lpelvis	RballSpeed	LballSpeed	RballDirection	LballDirection	Rfootbeside	Lfootbeside	Rfootbehind	Lfootbehind
1	-5.7	12.73	33.63	9.73	19.49	18.8	-17.57	8.23	0.31	0.24	0.15	0.33
2	4.37	25.3	31.87	12.23	18.96	19.37	-12.97	13.47	0.36	0.29	-0.03	0.13
3	-13.5	10.53	24.97	7.33	17.62	17.62	-14.23	12.7	0.38	0.37	0.03	0.11
4	10.03	33.37	18.2	11.77	17.02	16.33	-20.73	10.97	0.27	0.23	0	0.13
5	11.1	26.63	17.6	3.1	17.42	17.07	-16.07	16.45	0.45	0.41	-0.04	0.09
6	-15.93	8.57	14.07	3.97	15.45	16.16	-11.87	16.2	0.27	0.18	0.32	0.29
7	3.27	16.4	24.8	15.77	15.9	15.45	-16	13.57	0.33	0.24	0.04	0.17
8	-15.1	8.37	41.73	24.5	14.34	13.65	-16.2	19.9	0.37	0.28	0.04	0.2
9	9.23	18.17	16.73	14	19.04	19.28	-10.37	14.63	0.31	0.26	0.05	0.13
10	-6.87	12.63	19.9	10.77	19.74	18.89	-16.17	12.47	0.53	0.44	0.08	0.19
11	-10.16	11.73	16.57	5.87	19.75	20.17	-14.1	12.9	0.4	0.38	-0.06	0.11

Appendix I – ball/foot speed ratio calculation

Based on the ball speed equation developed by Lees & Nolan (1998), the ball/foot speed ratio equals $\frac{M(1+l)}{M+m}$. If the effective striking mass is increased, the new ratio can be written like: $\frac{(M+\Delta m)(1+l)}{M+\Delta m+m}$. To compare the two ratios, we can use the difference (D) between the two ratios.

D=$\frac{(M+\Delta m)(1+l)}{M+\Delta m+m} - \frac{M(1+l)}{M+m} = \frac{\Delta m \times m \times (1+l)}{(M+\Delta m+m)(M+m)}$>0, therefor the new ratio is larger than the previous ratio.

It can be concluded that increase in effective striking mass will lead to increase in ball/foot speed ratio.

Appendix J – Soccer Instep kick checklist

Approach

-The approach usually requires 3-5 steps long.

-The length of the steps should be increased progressively. The length of the last step should be maximized.

-The approach should begin at 30-45 degree angle to the desired direction of the path of the ball. This angled approach will enable the hips to rotate through a larger range of motion before they are square with the shot. This greater range of motion will further increase the velocity of the swing leg.

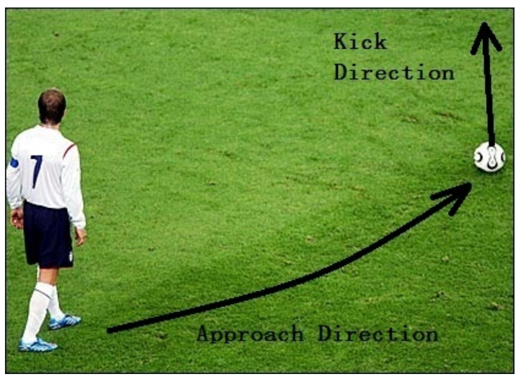

Figure 1. Approach was angled to the desired kick direction.

Foot Plant

-The non kicking foot should be planted directly beside the ball with the toe in line with the desired path of the ball.

-The foot should be about 10-15 cm away in a sideways direction from the ball and directly beside the ball. Other research studies reported the plant foot can be 30 cm away beside the ball.

-The foot can be planted slight behind or in front of the ball depends on the desired trajectory. If the foot is planted behind the ball it will tend to produce a high trajectory. If the foot is planted in front of the ball it will tend to produce a low trajectory.

-The non kicking foot should land with approx. 24-28 degrees of flexion in the knee to absorb the impact force from the ground.

Foot plant is close to the ball in the left picture and even with the ball in the right picture. Toe is pointed in the direction of the kick.

Long Last Step and backswing

-It is crucial that the last step be long and powerful as this will contribute to increasing ball velocity. This long step will leave the hip of the kicking leg in a position of hyper extension allowing for a longer range of motion in the forward direction through hip flexion. Ideal length is close to 2 m for the last step; depending somewhat on the height of the player.

The last step increases the velocity of the player and places his hip in a position of extreme hyper extension.

-This long last step will also ensure the athlete has a high linear velocity going into the kick. Any velocity the athlete has during the shot will be added to the velocity of the kicking foot and transferred to the ball at contact.

- After the toe-off of the kick foot, the kicking side hip continues to extend while knee is flexing.

- As the kick hip is extending, the non-kicking side arm should horizontally abduct. The muscles along the non-kicking side arm to the kicking side hip should be stretched to store energy in the backswing phase.

- The hip should reach peak extension at about 30 degrees. The peak hip extension occurs just before the support foot touches down.
- After the support foot touchdown, the hip begins to flex while the knee is flexing more.

-Knee flexion increases due to inertial lag of the lower leg as the upper leg starts to flex forward, the lower leg has it's own inertia and tends to stay in the same place. This increased flexion angle of the lower leg will increase the range of motion at the knee. This phase (from peak hip extension to peak knee flexion) is usually called leg cocking phase.

-The non-kicking side arm should be adducted and horizontally hyper-extended. This will allow it a full ROM to horizontally flex through the kick. Based on the action/reaction principle this will increase the velocity of the swing leg and produce a harder kick. The action of the arms also serve to keep the trunk balanced through the kick. As the kicking leg is flexed forcefully forward; the opposite arm is also flexed forward forcefully to help take up the angular momentum created by the leg. These two motions help to keep the trunk balanced and facing forward.

-The athlete should be looking directly at the ball at this point in the skill.

Force Producing Movements of the Kick

After the plant foot is planted beside the ball, the kicking leg starts to move forward to impact. The first movement of the kicking leg is hip flexion, which is produced by the powerful hip flexors. The hip flexion occurs from the furthest backward position of the leg, until the knee is pointing towards the ball. During this time period, the knee angle is increasing due to inertial lag.

-When the knee if pointing to the ball due to hip flexion, the thigh is slowed down and the lower leg will increase in speed. It has been suggested that some of the momentum of the thigh is transferred to the lower leg as it slows down, increasing the angular velocity of the lower leg through release. The powerful knee extensors will help to increase lower leg speed through impact.

Notice the sequence of hip flexion, knee extension and ankle dorsiflexion

The ankle joint remains plantarflexed through impact, which is the most rigid position of the leg and foot. In this position the joints are locked and create the most rigid surface from which to contact the ball. The more rigid the ankle and foot at impact, the greater the transfer of velocity from the foot to the ball due to high coefficient between foot and ball.

-The key to a forceful instep kick is segmental rotation of the trunk, hips and knee. This means that max knee flexion should occur after the hip has rotated part way forward. It should occur when the thigh is about vertical. A large range of motion at the knee is also important. Elite athletes achieve a position of about 115 degrees of flexion at it's maximum position. At contact it should have only about 15 degrees of flexion remaining for a range of motion of about 100 degrees at the knee joint.

-The support leg (hip and knee joints) should **not** go through a large range of motion through the kick. This will allow more accurate aiming as it will minimize the downward motion of the pelvic girdle. Some amount of knee flexion is necessary to decelerate the body after the large step forward. This should be no more than 30 degrees.

<u>Contact</u>

-Contact should be made at the medial upper surface of the foot (close to shoe laces).

-Hips and shoulders should be square to the direction of the kick.

-The athlete's legs should be leaning away from the ball at contact. The angle can be up to 50 degrees in top professional players. The lateral lean will allow a more extended kicking leg.

- The trunk should be upright or slightly leaning towards the ball.

-The opposite arm should begin to horizontally adduct just prior to contact in order take up the large forces produced in the lower body.

Ball contact: the legs are leaning away from the ball. The trunk is leaning towards the ball slightly.

<u>Follow through</u>

-The athlete should have a long follow through to ensure proper time and distance with which to decelerate limbs and avoid injury. Many players perform a large trunk flexion in the follow through movement to take up the momentum.

Follow through movement with large trunk flexion.

-A large follow through in which the kicking foot crosses in front of the athlete's body is a good sign of proper hip rotation through the shot.

-Some athletes become airborne and land on the same foot they kick with. This is a good technique for following the ball in anticipation of a rebound as the athlete can maintain a running stride.

Appendix K – informed consent

UNIVERSITY OF MANITOBA | Health, Leisure & Human Performance Research Institute

Faculty of Kinesiology
and Recreation Management
316 Max Bell Center
Winnipeg, Manitoba
Canada R3T3K2
Phone (204) 510-2028
Email umli499@cc.umanitoba.ca

Informed Consent

Research project title: Two Dimensional Kinematics Comparisons during Instep Soccer Penalty Kick to the Left and Right Posts

Principal Investigator and contact information: Yumeng Li, Faculty of Kinesiology and Recreation Management. umli499@cc.umanitoba.ca

Research Supervisor and contact information: Marion Alexander, professor, Faculty of Kinesiology and Recreation Management. alexan@cc.umanitoba.ca

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Outline of the study:

The purpose of the study is to compare the differences in the movement of soccer instep kicking in different kick directions. The significant factors that influence the kick directions will be determined. Understanding of these factors may be useful in preparing goalies to predict the direction of the ball when they defend against a penalty kick.

Study Methods:

The participants will be from the University of Manitoba Bison women soccer team, who volunteered to participate in this study. All the participants should be right foot dominant players without any injuries within the six months prior to the experiment. The total time of the experiment for each participant will be approximate twenty minutes, including warm-up, reflective markers attaching and data collecting.

The participants will be filmed by four digital video cameras. There will be eight reflective markers attached on the participants' joints. However, they won't affect the performance of the kick.

The participants will be instructed to perform the instep kicks for approximate ten trials. Three trials with relative high speed and accurate direction will be used for analysis. The measurement data will be provided to the participants in Microsoft Excel format immediately after the study. The results and conclusions will also be provided.

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Faculty of Kinesiology
and Recreation Management
316 Max Bell Center
Winnipeg, Manitoba
Canada R3T3K2
Phone (204) 510-2028
Email umli499@cc.umanitoba.ca

Risk:

There is no additional risk involved in this study, as the participants will perform the skills as they would normally perform in a practice situation. The cameras will be out of the way, and will not interfere in any way with their performance of the skills.

Confidentiality:

The film will be viewed only by the researchers involved in the study and by the participants filmed in the study. The video film and the data (joint displacement and velocity) derived from the film will not be used for any other purpose than the current study. No one will have access to the films or data except the researchers involved in the study. After the study is completed the films and data will not be used again without the express permission of the athletes. The data will be destroyed before September 2012. If the participants wish to receive a copy of the results, they should contact with the principal investigator directly.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba Research Ethics Board(s) and a representative(s) of the University of Manitoba Research Quality Management / Assurance office may also require access to your research records for safety and quality assurance purposes.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122. A copy of this consent form has been given to you to keep for your records and reference.

Participant's Signature ________________________ Date ___________

Researcher and/or Delegate's Signature __________________ Date _______

Appendix L – Ethics Approval

Human Ethics
208 - 194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Fax 204-269-7173

UNIVERSITY OF MANITOBA | Office of the Vice-President (Research and International)
Research Ethics and Compliance

APPROVAL CERTIFICATE

March 30, 2012

TO: **Yumeng Li** (Advisor M. Alexander)
Principal Investigator

FROM: **Stan Straw, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2012:020**
"Three-dimensional Kinematics and Ground Reaction Forces during Instep Soccer Kick in Different Kick Directions"

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to the Office of Research Services, fax 261-0325 - please include the name of the funding agency and your UM Project number. This must be faxed before your account can be accessed.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

Appendix M – Sample of use of the regression equation

To test the regression equation, the investigator randomly chooses 2 trials from 2 participants and plugs the independent values into the equation.

The regression equation is:

Kick direction angle= 0.42×(SuppotFootOrientation)+0.37×(FootBehind)-0.62×(approach angle)+2.47

Trial	Support foot orientation	Foot behind	Approach angle	Predicted kick direction	Actual kick direction	Difference
1	9.8	-5.81	23.4	-10.07	-13.8	3.7
2	28.3	15.64	5.2	16.93	16.1	0.83

The differences between the predicted kick direction and actual direction are subtle (only few degrees).