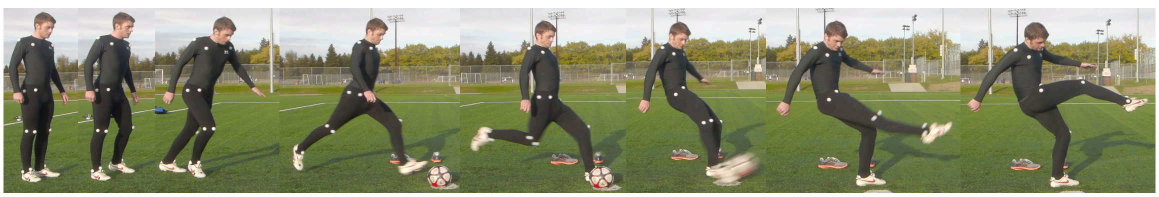
Qualitative Biomechanical Analysis of a Penalty Kick in Soccer



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Introduction

Purpose

To provide a qualitative biomechanical analysis of a top left-hand corner penalty kick in soccer.

Skill Description

The objective of this kick is to get the ball to hit the top left-hand corner of the net (and score a goal) as high, and as hard as possible. In order to do this, several aspects of the skill must be considered.

First, the accuracy of the ball must be considered. This is determined primarily by flight distance, which is further determined by angle of release, relative height at takeoff, velocity at takeoff, air resistance, acceleration due to gravity, and curve of the ball.

Secondly, the speed of the ball is crucial to the perfect shot. This is influenced by the change in momentum of the ball, which is further determined by initial velocity after ball contact, impulse, force, time, and body position.

Finally, the projectile motion of the ball is an important consideration for the penalty kick. Ideally, the projectile motion will allow the apex of the arc to occur right before the crossbar of the net. Thus, the ball will decrease in height just low enough to miss making contact with the crossbar, as desired. This will allow for the highest positioning, and make it most difficult for the goaltender to reach the ball and save the goal. The optimal angle of release for this projectile motion is 13°. The description of the shot will be based on the eight-phase series of frames of Evan's kick (Evan is a 19 year old Male with 16 years of soccer experience).

Limitations

The limitations of the performance of this skill include weather, physique, equipment, and outside distractions. Weather is a limitation for several reasons. Accuracy could be affected by the slightest wind, which could push the ball in a different direction, rain, which could make the ball slippery, or sun, which could affect the player's vision, and not allow them to see the target accurately.

Physique could affect the player's shot because a shorter leg would provide a lower angular velocity, contributing to a weaker shot. Furthermore, the strength level of the player is crucial to how hard the ball can be kicked.

Equipment could be a limitation because if the ball is heavy, it will have greater air resistance, which will cause it to travel slower and lower.

Finally, any other distractions from players, parents on the sidelines, background imagery or other diversions could take away from the player's mental concentration.

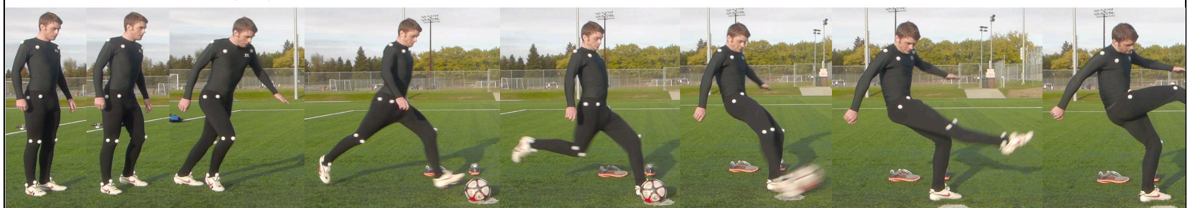
Different Techniques

Although we chose to kick the ball with the inside, front edge of our foot, there are several ways in which contact with the ball can be made. Many players prefer to contact the ball with the "laces" of their foot, or the anterior portion of the foot just above the toes. Depending on the intention of the kick, this technique could be used for greater height, or greater force. Generally, the ball could be kicked lighter for greater accuracy, or harder for greater force.

Qualitative Anatomical Analysis (QAA)

Table 1.1 – QAA of Right Hip (Sagittal View)

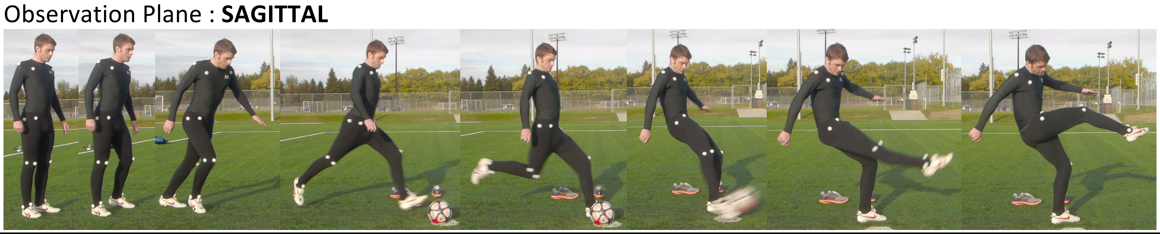
Observation Plane: **SAGITTAL**



Joint: Right Hip	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Extension	Isometric	Extensors		
	2-3	Flexion	Concentric	Flexors		
	3-4	Extension	Eccentric	Extensors	Yes	
	4-5	Flexion	Concentric	Flexors		
	5-6	Flexion	Concentric	Flexors	Impact	
	6-7	Flexion	Concentric	Flexors		
	7-8	Medial Rotation	Concentric	Medial Rotators	Yes	

Table 1.2 – QAA of Right Knee (Sagittal View)

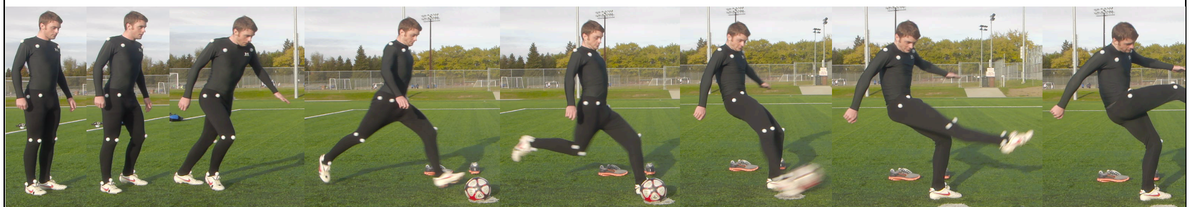
Observation Plane : **SAGITTAL**



Joint: Right Knee	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Extension	Isometric	Extensors		
	2-3	Flexion	Concentric	Flexors		
	3-4	Extension	Eccentric	Extensors		
	4-5	Flexion	Concentric	Flexors	Yes	
	5-6	Extension	Eccentric	Extensors	Yes/ Impact	
	6-7	Extension	Eccentric	Extensors	Yes	Hyperextension
	7-8	Flexion	Concentric	Flexors		

Table 1.3 – QAA of Right Shoulder (Sagittal View)

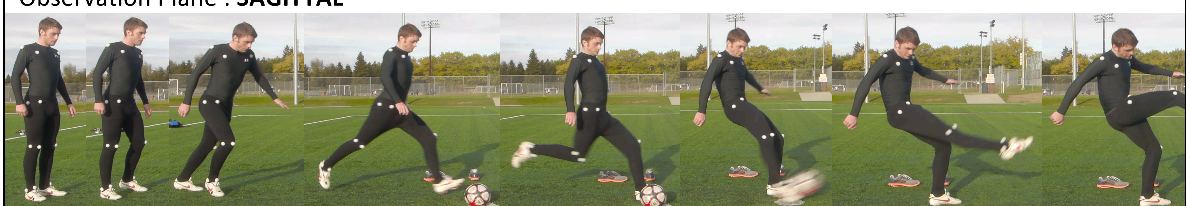
Observation Plane : **SAGITTAL**



Joint: Right Shoulder	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Retraction	Eccentric	Retractors		
	2-3	Retraction	Eccentric	Retractors		
	3-4	Protraction	Concentric	Protractors		
	4-5	Retraction	Eccentric	Retractors		
	5-6	Retraction	Eccentric	Retractors		
	6-7	Retraction	Eccentric	Retractors		
	7-8	Retraction	Eccentric	Retractors		

Table 1.4 – QAA of Left Hip (Sagittal View)

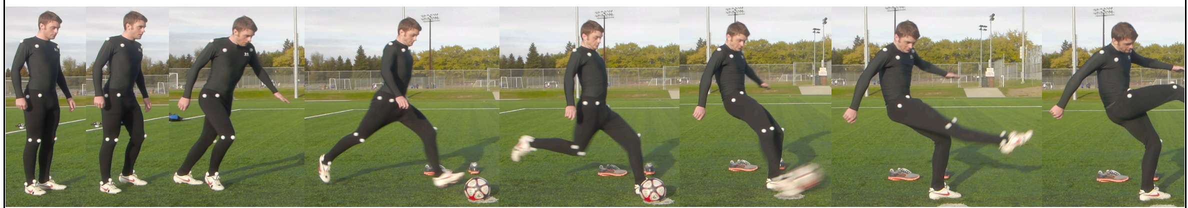
Observation Plane : **SAGITTAL**



Joint: Left Hip	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Flexion	Concentric	Flexors		
	2-3	Extension	Eccentric	Extensors		
	3-4	Flexion	Concentric	Flexors	Yes	
	4-5	Extension	Eccentric	Extensors	Ground Impact	
	5-6	Flexion	Isometric	Flexors		
	6-7	Flexion	Concentric	Flexors		
	7-8	Extension	Eccentric	Extensors		

Table 1.5 – QAA of Left Knee (Sagittal View)

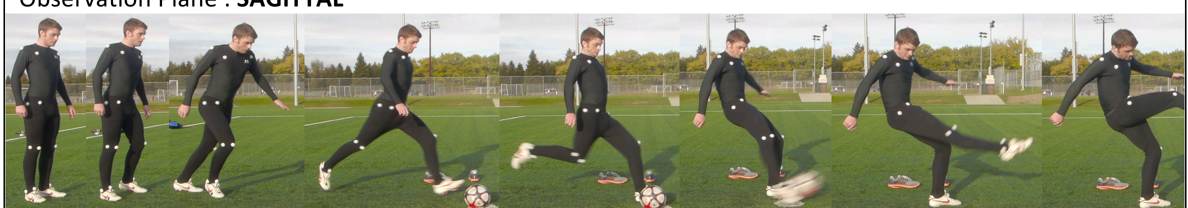
Observation Plane : **SAGITTAL**



Joint: **Left Knee**	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Flexion	Concentric	Flexors		
	2-3	Extension	Eccentric	Extensors		
	3-4	Flexion	Concentric	Flexors		
	4-5	Flexion	Isometric	Flexors	Ground Impact	
	5-6	Flexion	Isometric	Flexors		
	6-7	Flexion	Concentric	Flexors		
	7-8	Extension	Eccentric	Extensors		

Table 1.6 – QAA of Left Ankle (Sagittal View)

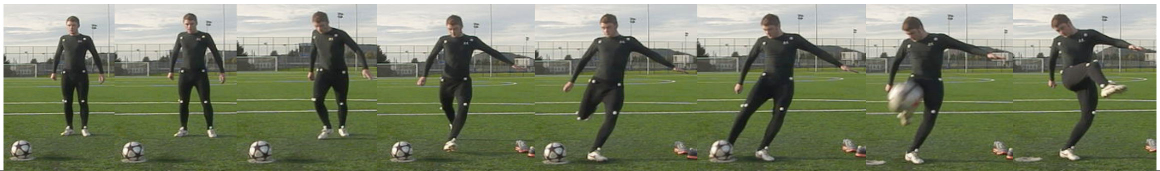
Observation Plane : **SAGITTAL**



Joint: **Left Ankle**	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Plantar Flexion	Eccentric	Plantar Flexors		
	2-3	Dorsiflexion	Concentric	Dorsi Flexors		
	3-4	Dorsiflexion	Concentric	Dorsi Flexors		
	4-5	Plantar Flexion	Eccentric	Plantar Flexors	Ground Impact	
	5-6	Plantar Flexion	Isometric	Plantar Flexors		
	6-7	Eversion	Eccentric	Evertors		
	7-8	Eversion	Isometric	Evertors		

Table 1.7 – QAA of Left Hip (Frontal View)

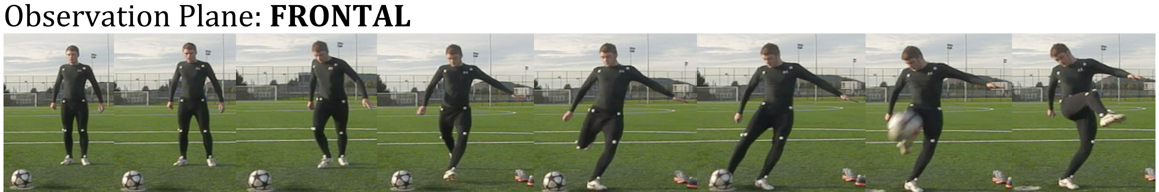
Observation Plane: **FRONTAL**



Joint: Left Hip	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Abduction	Concentric	Abductors		
	2-3	Extension	Eccentric	Extensors		
	3-4	Flexion	Concentric	Flexors	Yes	
	4-5	Adduction	Eccentric	Adductors	Ground Impact	
	5-6	Adduction	Eccentric	Adductors		
	6-7	Adduction	Isometric	Adductors		
	7-8	Lateral Rotation	Concentric	Lateral Rotators		

Table 1.8 – QAA of Left Knee (Frontal View)

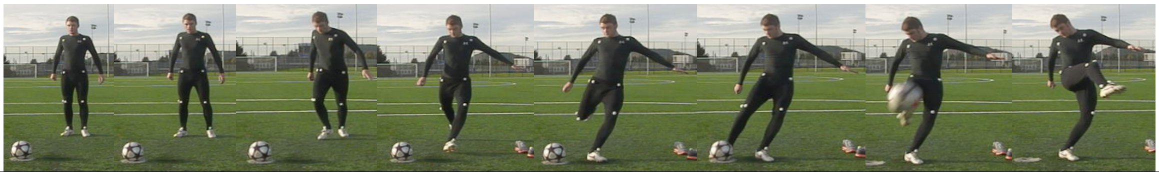
Observation Plane: **FRONTAL**



Joint: Left Knee	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Extension	Isometric	Extensors		
	2-3	Extension	Eccentric	Extensors		
	3-4	Flexion	Concentric	Flexors		
	4-5	Flexion	Concentric	Flexors	Ground Impact	
	5-6	Extension	Eccentric	Extensors		
	6-7	Extension	Isometric	Extensors		
	7-8	Flexion	Concentric	Flexors		

Table 1.9 – QAA of Left Ankle (Frontal View)

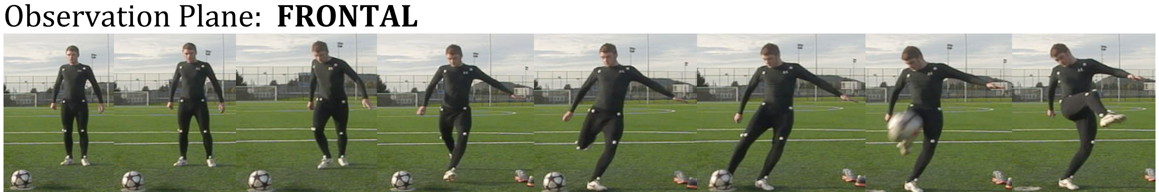
Observation Plane: **FRONTAL**



Joint: Left Ankle	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Plantar Flexion	Isometric	Plantar Flexors		
	2-3	Dorsiflexion	Concentric	Dorsi Flexors		
	3-4	Inversion	Concentric	Invertors		
	4-5	Eversion	Concentric	Evertors	Yes Ground Impact	Full Eversion
	5-6	Inversion	Eccentric	Invertors		
	6-7	Inversion	Eccentric	Invertors		
	7-8	Dorsiflexion	Concentric	Dorsi Flexors		

Table 1.10 – QAA of Left Shoulder (Frontal View)

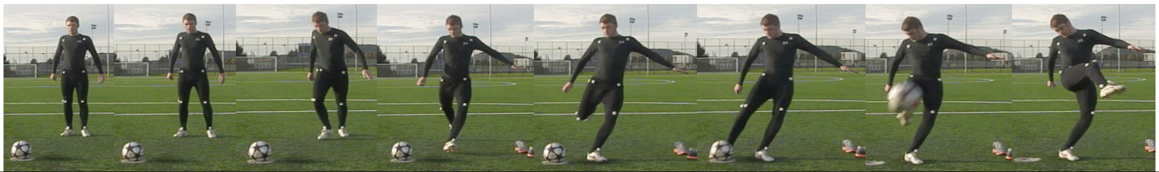
Observation Plane: **FRONTAL**



Joint: Left Shoulder	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Abduction	Eccentric	Abductors		
	2-3	Lateral Rotation	Concentric	Lateral Rotators		
	3-4	Abduction	Eccentric	Abductors		
	4-5	Abduction	Eccentric	Abductors		
	5-6	Adduction	Concentric	Adductors		
	6-7	Abduction	Eccentric	Abductors		
	7-8	Abduction	Eccentric	Abductors		

Table 1.11 – QAA of Right Hip (Frontal View)

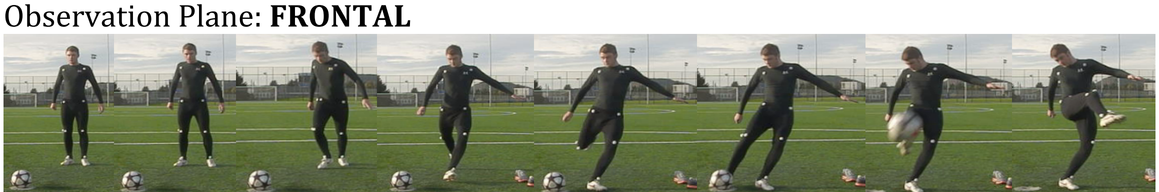
Observation Plane: **FRONTAL**



Joint: Right Hip	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Extension	Isometric	Extensors		
	2-3	Lateral Rotation/ Flexion	Concentric	Lateral Rotators/ Flexors		
	3-4	Extension	Eccentric	Extensors	Yes	
	4-5	Abduction	Eccentric	Abductors		
	5-6	Medial Rotation/ Extension	Eccentric	Medial Rotators/ Extensors	Ball Contact	
	6-7	Flexion	Concentric	Flexors		
	7-8	Medial Rotation/ Flexion	Concentric	Flexors	Yes	

Table 1.12 – QAA of Right Knee (Frontal View)

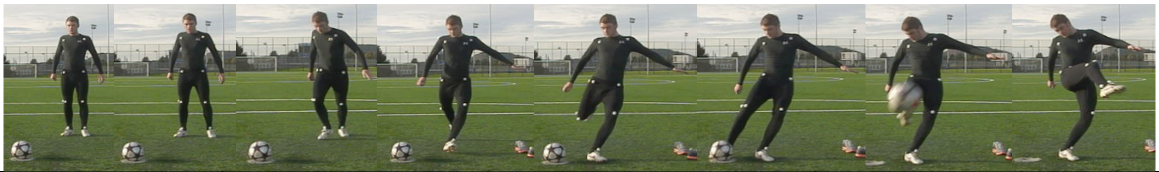
Observation Plane: **FRONTAL**



Joint: Right Knee	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Extension	Isometric	Extensors		
	2-3	Flexion	Concentric	Flexors		
	3-4	Extension	Eccentric	Extensors		
	4-5	Flexion	Concentric	Flexors		
	5-6	Extension	Eccentric	Extensors	Ball Contact	
	6-7	Extension	Eccentric	Extensors		
	7-8	Flexion	Concentric	Flexors		

Table 1.13 – QAA of Right Ankle (Frontal View)

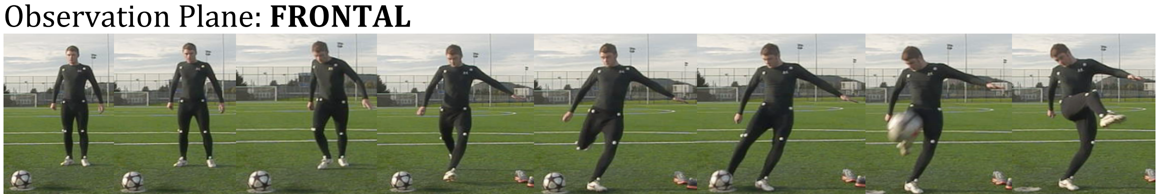
Observation Plane: **FRONTAL**



Joint: Right Ankle	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Plantar Flexion	Isometric	Plantar Flexors		
	2-3	Dorsi Flexion	Concentric	Dorsi Flexors		
	3-4	Plantar Flexion	Eccentric	Plantar Flexors		
	4-5	Dorsi flexion	Concentric	Dorsi Flexors		
	5-6	Plantar Flexion	Eccentric	Plantar Flexors	Ball Contact	
	6-7	Dorsi Flexion	Concentric	Dorsi Flexors		
	7-8	Plantar Flexion	Eccentric	Plantar Flexors		

Table 1.14 – QAA of Right Shoulder (Frontal View)

Observation Plane: **FRONTAL**



Joint: Right Shoulder	Frames	Joint Motion	Muscle Contraction	Active Muscle Group	Rapid Acceleration or Impact	Extreme Range of Motion
	1-2	Horizontal Extension	Eccentric	Extensors		
	2-3	Horizontal Flexion	Eccentric	Flexors		
	3-4	Horizontal Extension	Concentric	Extensors		
	4-5	Horizontal Extension	Isometric	Extensors		
	5-6	Horizontal Extension	Isometric	Extensors		
	6-7	Horizontal Flexion	Eccentric	Flexors		
	7-8	Horizontal Flexion	Eccentric	Flexors		

Key Phases

Legend

Force of Gravity –
Movement Vectors –
Force Vectors –
Net Force Vector –
Centre of Gravity –

Phase 1: Preparation

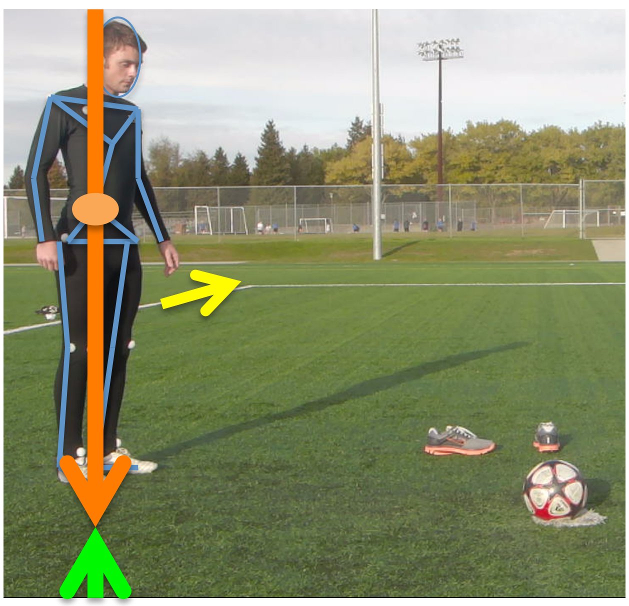


Figure 1.1 - Preparation Phase with Free Body Diagram and Force/Movement Vectors

In the preparation phase, feet are shoulder width apart, which allows for a fairly wide base of support, and the hips and knees are fully extended, which allows for an upright position that is square to the target. Both of these factors contribute to an optimal balance between stability and mobility, and an ideal centre of gravity. This will allow for the performer to complete an accurate run-up to the ball before contact. Also, there is limited muscle activity during this stage.

Phase 2: Load Phase

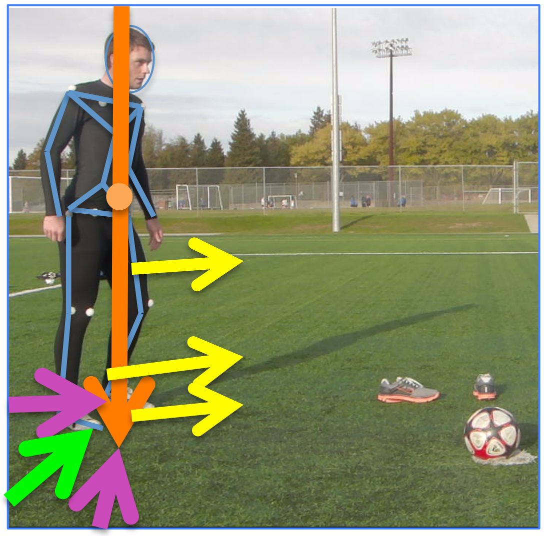


Figure 1.2 - Load Phase with Free Body Diagram and Force/Movement Vectors

In the load phase, the left knee and the left hip both begin to flex. This initiates the shift of centre of gravity, and the forward momentum leading up to the ball contact. The even distribution of weight shifts to the right foot, and the extensors of the ankle cause plantar flexion in the left foot, and the left heel to be lifted off the ground.

Phase 3: Transition Phase

Figure 1.3 - Transition Phase with Free Body Diagram and Force/Movement Vectors

In the transition phase, the left ankle is dorsiflexed, and most of the weight is on it. However, the right ankle is plantar flexed, and is about to have the weight shifted onto it in order for the left foot to take the final lead-up step. Because of the plantar flexion, the right heel is lifted off the ground, and will not make ground contact for the rest of the performance. The right shoulder is protracted, which contributes to evening out the distribution of weight in order to keep optimal balance. Also contributing to balance is the further shift forward of centre of gravity. This is caused by flexion of the hips, and flexion of the right knee, along with the weight distributed to the right ankle.

Phase 4: In Air Phase

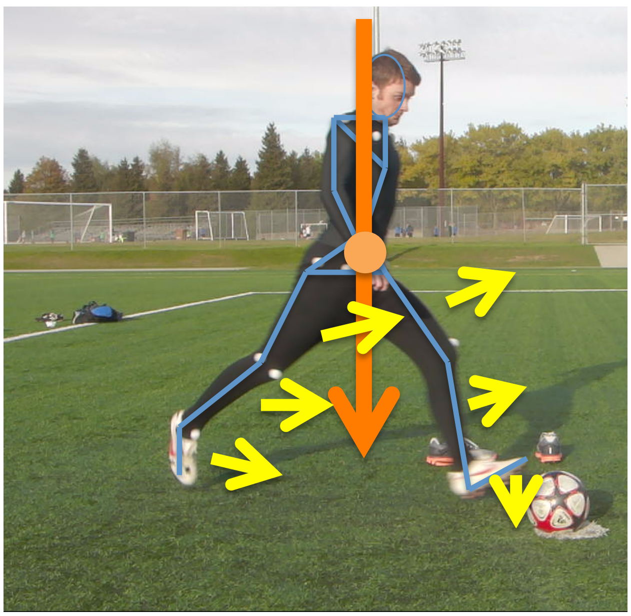


Figure 1.4 - In Air Phase with Free Body Diagram and Force/Movement Vectors

During the in air phase, the right hip is in full extension, allowing for maximum force to be exerted upon the ball during contact. The more extended the right hip is, the greater the angle of velocity will be for the contact phase. Inversely, the left hip is flexed in order to position the left foot for ground contact during the plant-foot phase, an important aspect of the skill that contributes to accuracy and angle of release. The left knee is also flexed, in order to absorb the reaction forces during the plant-foot phase. Finally, the right shoulder is protracting, again to distribute the weight, and adjust to the centre of gravity, which has moved back significantly from the transition phase.

Phase 5: Plant Foot Phase

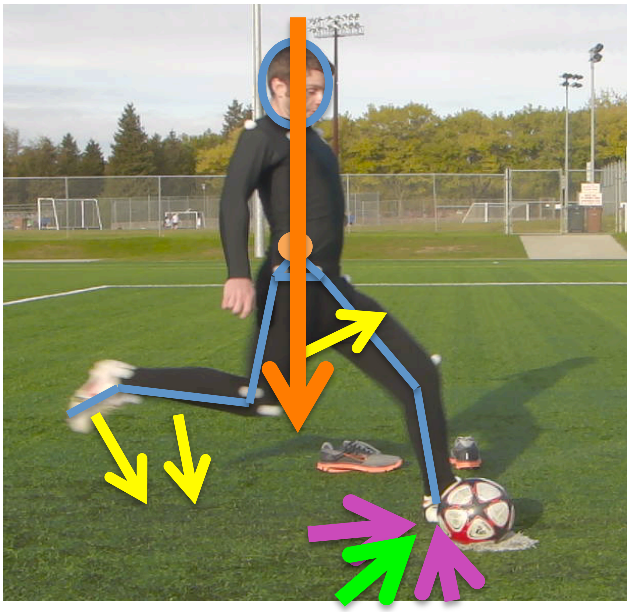


Figure 1.5 - Plant Foot Phase with Free Body Diagram and Force/Movement Vectors

In the plant foot phase, the left ankle is plantar flexed upon ground contact, and is now the bearer of the total weight of the body. The positioning of the left foot is crucial for an optimal angle of release, and force production. The left knee is slightly more flexed because of the absorption of ground contact. The right knee is significantly flexed, as the right hip begins to flex, which allows for an optimal angular velocity of the knee. The right hip is also laterally rotating, which will ultimately contribute to the Magnus effect. Again, the centre of gravity has shifted back even further, and the arms have retracted, and abducted to evenly distribute the weight. The right ankle is plantar flexing to prepare for contact with the ball.

Phase 6: Contact With Ball Phase

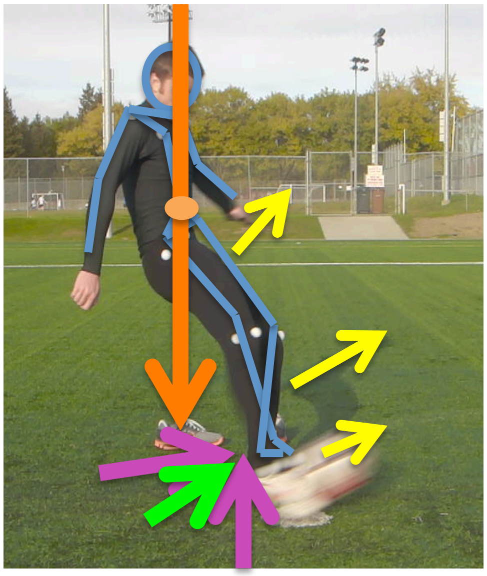


Figure 1.6 - Contact with Ball Phase with Free Body Diagram and Force/Movement Vectors

In the contact with ball phase, the right knee is significantly extended because of the velocity of the "swing", and in turn, the velocity of the ball. The right hip flexes to produce the angular velocity, and the right ankle further plantar flexes to make contact with the ball in the bottom, right corner. The plantar flexion of the right ankle increases the angle of release is because the performer is able to get their foot underneath the ball rather than through the centre. The shoulders are abducted, and the opposition of flexion and extension of the arms and legs controls the angular momentum of the body.

Phase 7: Hyperextension of Knee Phase

Figure 1.7 - Hyperextension of Knee Phase with Free Body Diagram and Force/Movement Vectors

The right knee is hyperextended in this phase, because of the maximal force the right leg is producing from the contact with ball phase. The right hip continues to flex, and medially rotates. Because of this, the torso needs to rotate in the opposite direction to counter the medial rotation, and maintain a stable centre of gravity. The arms continue to retract, as well as abduct to maintain balance during this rotational shift.

Phase 8: Full Extension of the Thigh Phase

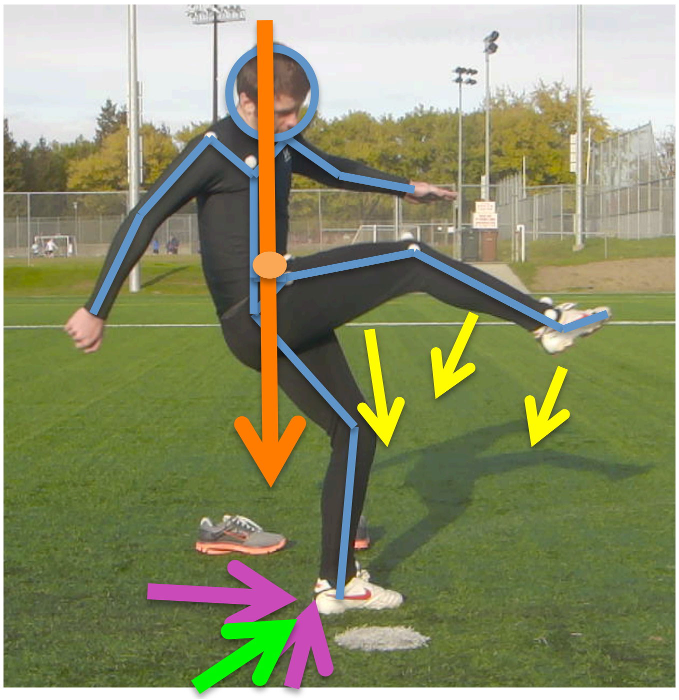


Figure 1.8 - Full Extension of Thigh Phase with Free Body Diagram and Force/Movement Vectors

During the full extension of the thigh phase, there is rapid acceleration with the medial rotation of the right hip. This rotation in turn causes extension of the left hip, which in turn causes extension of the left knee. Arms are further abducted in order to decrease the angular velocity of the body, rotating about the left foot. Even though the rest of the body is rotating, the left foot stays stable, and continues to point towards the target.

Description of Expert Performance

Characteristics of the Most Effective Technique

To effectively and consistently score a soccer goal in the top-left corner of the net from a penalty kick, there exist 6 important elements that are linked to the aforementioned phases of the skill. They are: Preparation, Run-Up, Location of Foot Placement, Location of Ball Contact, Body Position and Posture During Ball Contact, and Follow-Through.

Preparation

The Preparation is limited to Frame 1: the Preparation Phase. During the start phase, it is extremely important for the player to align himself in the direction of the target. The optimal start position (for a right footed player) is to the left of the ball and approximately 5 yards behind the ball. The position to the left of the ball allows for a curved run up allowing for a greater curve on the ball during contact (as discussed in the "Location of Ball Contact" Characteristic). The distance behind the ball is of the utmost importance; this gives the player time to accelerate their body through space and reach a high-velocity at the time of contact with the ball (as discussed in the "Run-up" Characteristic). Stability is extremely important during Preparation, with the player's weight evenly distributed on the balls of their feet, with a wide base of support. Not only will this stable nature ensure a balanced run-up, but it will also give the player an opportunity to clear his mind of any distractions in the environment and attend to the task at hand.

Run-Up

The Run-Up ranges from Frames 2-4: the Load Phase, Transition Phase, and In-Air Phase. During the Load phase, it is extremely important for the player to begin his Run-Up with a sudden burst of force to initiate his forward momentum. As the player's location is to the left of the ball, the player makes a curved run during his acceleration. During the Transition Phase and In-Air Phase, speed maintenance is paramount. In order for the ball to travel the required distance (11.005 metres), enough force must be exerted on the ball to ensure that its apex of flight is located in close proximity to the top-left corner of the net. By extending the distance of his run, a greater velocity can be placed on the ball at impact to achieve the desired result. It is also important to note that, an increase in ball velocity results in a decrease in the amount of time the goalkeeper has to react, thus increasing the chances of scoring a goal.

Location of Plant Foot Placement

The Location of Plant Foot Placement is limited to Frame 5: the Plant Foot Phase. Accuracy is one of the most fundamental determinants of scoring a goal in the top-left corner of the net. During a penalty kick (or any other shot on net), foot placement beside the ball is the most influential aspect in determining accuracy; a good plant foot placement establishes a good foundation for the rest of the body to follow (through kinetic linking). The determining body movement for foot placement is medial/lateral rotation at the hipbone. The ideal placement for the player's plant foot is with their toes pointed towards the target; this can be achieved by rotation at the hip (as described above). In the context of this skill (where we are trying to score in the top-left corner), the right-footed player's left foot should be pointing towards the left side of the net upon contact with the ground. Although this is the typical description of the Location of Foot Placement, some expert soccer players (in the autonomic stages of learning) can actually release the degrees of freedom in their lower body, and point their plant foot in the opposite direction as they want their shot to go. This deceiving tactic can "trick" goalkeepers into diving a certain way, thus increasing the player's chances of scoring a goal.

Location of Ball Contact

The Location of Ball Contact is limited to Frame 6: the Contact with Ball Phase. Foot-to-ball contact is crucial in determining the height of the ball, spin on the ball, and parabolic path that the ball will travel. As we are trying to score in the top-left corner of the net, a significant amount of height on the ball is needed. To achieve an upward flight of the ball, the player's foot must make contact with the bottom portion of the ball. This upward force, exerted through rapid acceleration of the foot at the ankle joint, causes a lift in the ball, as desired. However, a ball with solely good height might not be able to "beat" the quick reaction time ability that goalkeepers have. This is where spin on the ball is necessary to deceive the keeper. As described above (in the Preparation Characteristic), a curved run is the first step to putting an effective spin on the ball. Secondly, contact with the right outside edge of the ball is extremely important (i.e. not the centre of the ball) when trying to curve the ball left. This will create a torque on the ball as it spins about its own axis. While in flight, this angular motion will create an effect known as the Magnus Effect (Cayzac, Carette, Denis, & Guillen, 2011). In a rotating frame of reference, there exists a boundary layer around the ball created by its angular velocity. The angular acceleration at the front of the ball is greater than the angular acceleration at the back of the ball. This imbalance in acceleration causes a perpendicular force (Magnus Force) to be exerted on the ball. This force (though quite minor), in combination with a centrifugal force that acts outwards in a radial direction from the ball's axis, creates a curved movement through space, or "spin" on the ball (Cayzac et al., 2011). This curved projectile motion will not only allow us to perfectly score the ball in the top-left corner, but also deceive the goalkeeper as his or her reaction time cannot beat the effects of the Magnus Effect. Now it is finally clear how we can "Bend it Like Beckham". (Please note: due to insufficient camera speed, we were unable to capture the perfect moment of foot-to-ball contact in Frame 6 of our key phases: most expert performers remain in contact with the ball for a very short amount of time – approximately 0.01 seconds)

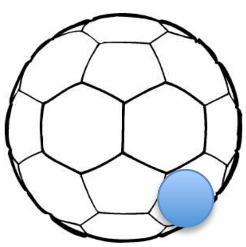


Figure 2 - Ideal Location of Contact with Ball

Figure 3 - Ideal Location of Contact on Cleat

Body Position and Posture During Ball Contact

Body Position and Posture During Ball Contact are limited to Frame 6: the Contact with Ball Phase. In order to effectively shoot the ball into the top-left corner of the net, control and stability during contact with the ball is a necessity. As described above (in the Location of Ball Contact Characteristic), contact with the ball should be somewhat underneath the ball, or at least on the bottom portion of the ball. In order to effectively do this, expert players increase the angle of our body by leaning backwards. To account for this change in body position and trunk posture, soccer players use their arms to distribute the mass in their body, thus increasing their ability to stay balanced during a shot. The body stability will allow for a smooth, consistent motion as the right leg swings and makes contact with the ball. Ultimately, the more stable (and controlled) you are during a penalty kick, the less error is made; and when taking a penalty shot, every inch makes a difference.

Follow-Through

The Follow-Through ranges from Frames 7-8: the Hyperextension of Knee Phase and the Full Flexion of Thigh Phase. After contact with the ball is made, all expert soccer players' striking legs follow through in the direction of the ball. This helps guide the ball in the desired direction. However, contrary to popular belief, a big follow-through where you are running forward after you kick the ball actually inhibits your performance. During a big follow-through where there are a lot of other body movements, energy that could have been put towards the ball is being wasted. Thus, it is important to focus all of your energy on the ball and let the follow-through happen naturally.

Deterministic Model

Mechanical Explanation

Rationale for Deterministic Model

Scoring a goal on a penalty shot is dependent on both speed and accuracy. The final speed of the ball when it crosses the goal line is dependent on several biomechanical concepts relating to force production. Furthermore, the accuracy of the shot is dependent on several other concepts, which control the actions of the forces created. Both of these components will be discussed biomechanically in the later. Only the final determinants can be optimized by the performer. However, these determinants are responsible for optimizing their superior biomechanical categories, which ultimately control the speed and accuracy of the ball.

Speed

Change in Momentum of the Ball

A change in momentum is due to the impulse imparted onto the ball from the performer, and the initial velocity of the ball immediately after contact with the performer. The force imparted from the player onto the ball can change the velocity of the ball, and changes in force occur because momentum is dependent on velocity and the mass of the ball is constant. Initial velocity of the ball is determined from the collision of the ball with the foot (conservation of momentum). Mass of the ball is constant; momentum is therefore dependent on velocity. Thus, the force applied can change momentum by causing a change in velocity of the ball.

Initial Velocity of Ball After Contact

The initial velocity of the ball after contact is a result of the momentum of the player before and during contact with the ball, and the type of collision that occurred. The momentum of the player was determined by the increasing velocity at which the player ran an optimal distance in the least amount of time possible, while overcoming their mass (inertia) at rest to begin the run up. The player can overcome their own mass (inertia) to stop themselves from moving by producing a force that could be transferred in the kinetic chain to exert a greater force onto the ball. The performer can effectively change their distribution of mass with the swing through of the striking leg to reduce the moment of inertia at the hip joint. This allowed for an easier swing through of the striking leg because less force is required to overcome the distribution of mass of the leg if the mass is less spread out amongst the entire leg. An increase in the angular velocity of the foot occurred during the swing through because of the decrease in the moment of inertia of the hip joint produced at the same angular momentum. Reduced inertia of the leg and thigh by flexing the striking leg at the knee required less force (torque) to make the lower limb accelerate; Therefore higher angular momentum, angular velocity and thus greater force imparted on the ball. The collision of the ball after contact with the players striking foot was dependent upon the combined masses of the ball and the kicking leg. An inelastic collision occurred briefly between these two objects while the forces exerted from the foot were transferred onto the ball. The original momentum of the foot was conserved in this system as the contact with ball phase rapidly changed from an inelastic to an elastic collision to impart a greater velocity onto the ball. Based on Newton’s third law, the force exerted by the player’s foot against the ball was equal in kind to the force exerted by the ball against the player’s foot to cause it to accelerate in the same direction as the foot.

Momentum of Player

The goal of this mechanical principle was to increase the velocity of the player to cause a relative increase in their momentum; therefore a greater force can be imparted onto the ball. The whole body angular momentum of the player is dependent upon the sum of the angular momentum of all the limbs. Starting from the load phase and carried on until the end of full flexion of thigh phase the player flexes and extends the arms in opposition to the flexion and extension of the contra lateral thigh. Each contra lateral movement performed in opposition to an opposing limb acts to balance the angular momentum of the opposing limbs and thus balance the angular momentum of the whole body. This is vital for producing a successful penalty shot because a properly balanced curvilinear run up enables the perform to conserve the energy that would have been required to regain balance of their overall angular momentum if any limb was out of sync with any of the other limbs. Therefore this energy can be effectively used in the kinetic linking phase to exert as much force as possible onto the ball.

Inertia of Player

The angular momentum of the player's limbs and the linear momentum of the curvilinear run up rely on the moment of inertia affecting the joints involved in the movement of the player and the mass (inertia) of the player that must be overcome to change momentum, respectively. Newton's law of Inertia states that an object (player in this case) will stay at rest unless acted on by a net external force and the player will stay in uniform motion unless acted on by a net external force. The mass (inertia) of the player must be overcome by a force produced by the torque of our limbs to initiate the run up from a resting position and to stop the player from accelerating forward after landing from the in air phase. The moments of inertia among the player's joints that are involved in this skill can be altered to change the angular velocity of the limbs because the human body is a non-rigid object. Changing the moment of inertia at specific joints will alter the angular velocity which can produce more force that will be exerted on the ball or to overcome the angular momentum of the entire body during the follow through phases.

Inertia of Player (Optimization)

To perform the curvilinear run up to the ball the player has to overcome his own mass at rest by applying a net external force on the ground from the load phase to the transition phase by extending the thigh and knee of the push off leg while plantar flexing the ankle. Based on Newton's third law, the reaction force from the ground pushing back against the player's foot enables the performer to overcome his or her own mass (inertia) to initiate a change from rest to motion. Producing a force or torque at the hips by flexing the torso can also overcome the mass (inertia) of the player by changing the position of the center of gravity to lie in front of the base of support to increase mobility and provide a toppling moment. This increase in mobility allows a greater acceleration in the run-up; the greater the acceleration, the greater the force we can apply on the ball. Thus, flexing the torso is paramount during the load phase. The mass (inertia) of the player must be over come again to stop the player from continuing to accelerate towards the net. This can be achieved by positioning the weight of the performer above the plant leg during the in air phase; this is done by changing the position of the center of gravity to be in line with the plant leg. The plant leg will then exert a greater net external force upon the ground. Thus, the net reaction force acting in opposition to the direction of the plant foot prevents the player from accelerating any further towards the net. The player can efficiently save energy that would have been used to create a force or torque of the thigh (lever) about the hip joint (axis of rotation) by decreasing the distribution of mass of the lower limb before striking the ball. Flexing the leg at the knee and extending the thigh at the hip of the striking leg along the sagittal plane can be better applied to the overall velocity of the

Distribution of Mass

Also known as radius of gyration, the distribution of mass is measured as the distance of the mass from the axis of rotation. The equation for moment of inertia states that inertia is dependent on the mass of the object and the radius of gyration squared; therefore the mass of an object doesn't have as great of an influence on the angular inertia as distribution of mass does. How the player distributes the mass of their limbs after landing on the plant foot and during the follow through phases has a considerable effect on the efficiency of the shot and overcoming the momentum of the whole body after the shot, respectively. Flexing the striking leg at the knee as close as possible to the thigh before swinging through to contact the ball decreases the radius of gyration of the striking leg at the hip. By doing so the mass of the lower limb is closer to the hip joint (axis of rotation) which makes it easier for the player to extend the leg at knee because a decrease in the distribution of mass and a constant limb mass effectively decreases the moment of inertia about the hip joint based on the equation for defining moment of inertia. As previously stated, the equation for defining angular momentum is determined by the moment of inertia and the angular velocity. By decreasing moment of inertia about the hip joint, the swing through of the striking leg will produce a greater angular velocity at the hip, thus, greater angular acceleration and linear velocity of the foot at the same angular momentum because the foot is the farthest distance away from the relative angle on the arc length of the hip. A greater linear velocity produces a larger force onto the ball which increases the speed of the shot. As a practical example, when you compare an expert performer with a longer lower limb (Christiano Ronaldo) to an expert performer with a shorter lower limb (Lionel Messi) a trade-off between momentum and force occurs. Although each performer performs full flexion of the knee before the swing through, the longer lower limb of Christiano Ronaldo will require more torque or force produced from the hip joint to compensate for the increased distribution of mass among the limb. This situation is reversed for Messi who won't need as much force to begin the swing through of his lower limb due to less distribution of mass in his leg. It's harder for Ronaldo to begin his shot in comparison to Messi, but Ronaldo will produce a greater momentum of his foot this way because the resistance to change in a state of motion is greater for Ronaldo. It all depends on the situation where the skill is performed, either use more energy to produce a shot with greater momentum or use less energy to produce a faster shot with less momentum. Raising and abducting the arms can effectively alter the moment of inertia at the shoulder joints by increase the radius of gyration of the performer. Increasing the moment of inertia of the player by abducting the arms acts to reduce the angular velocity of the entire body along the plant legs hip joint (axis of rotation) during the follow through phases while maintaining the same angular momentum.

Distribution of Mass (Optimization)

To effectively reduce the amount of torque required by the hip to initiate the swing through of the striking leg, the performer can begin to extend the thigh at the hip and flex the leg at the knee at the beginning of the in air phase until the end of the plant-foot phase. The transition between the end of the plant foot phase and the beginning of the contact with ball phase occurs when the hip begins to flex and the knee beginnings to extend to strike the ball. Decreasing the relative angles formed between the limbs of these joints as much as possible during the in air and plant foot phases effectively reduces the moment of inertia about the hip joint to make for an easier strike at the ball. This also increases the distance from the foot of the striking leg to the point of application on the ball; therefore a greater linear velocity and acceleration of the foot can occur because of the greater arc length. The angular velocity of the whole body along the plant legs hip joint (axis of rotation) during the hyperextension of knee phase and full flexion of thigh phase can be reduced by increasing the moment of inertia about this joint while maintaining the same angular momentum. Initiating abduction of the arms while flexing and extending the arms in opposition to the player's thighs at the ball contact phase can increase the radius of gyration at the shoulder joints. Further abduction of the arms during both follow through phases aids in increasing the moment of inertia at the shoulder joints and the plant legs hip joint with the negative rotation of the torso to overcome the angular momentum of the entire body by reducing angular velocity.

Distribution of Mass (Expected Errors)

<u>Plant Foot Phase</u>

1. Not enough flexion at the knee of striking leg → Corrected by initiating flexion of the knee during the in air phase and continuing with flexion at the knee during the plant foot phase to decrease radius of gyration until extension occurs when striking the ball.

Full Flexion of Thigh Phase

1. Not enough abduction and flexion and extension of arms in opposition to flexion and extension of thighs → Corrected by flexing the torso at the hips in the hyperextension of knee phase to allow for a greater need for balance by abducting and raising the arms in opposition to the thighs, which also increases radius of gyration.

Mass

It is neither ethical nor practical to instruct a performer to change their mass in practice to have an effective run up.

Mass (Optimization)

The mass of the player can be easily overcome (without regard to the size of mass) at rest and in uniform motion by flexing the torso at the hips during the load phase to increase mobility, and flexing the knee of the plant leg during the plant foot phase to increase stability, respectively.

Mass (Expected Errors)

Load Phase

1. No flexion of torso at hips → Corrected by initiating flexion of torso at hips after shifting the weight and likewise center of gravity of the player over to the push off leg. This enables the performer to begin the transition phase unbalanced so a step is required to catch the fall and overcome inertia at rest.

Plant Foot Phase

1. Not enough flexion of leg at knee → Corrected by flexing the leg at the knee during the in air phase.

Velocity of Player

Determined by time it takes to run up to the ball and the subsequent velocities of the limbs. A greater distance allows for more time to increase the acceleration and therefore velocity of the player during the run up phase. Displacement is inversely proportional to time. A change in displacement over a shorter time span would effectively increase the velocity of the player. The player runs in a non-linear motion in the form of curvilinear motion. Observed centripetal force from the leaning of the body directed in wards-towards the center of the curve. Leaning is due to the centripetal force acting on the player. The distance from the center of the curve proportionally effects the centripetal acceleration of the player and therefore the amount of leaning towards the center of the circle. Moment of inertia is proportional to the angular momentum. However, moment of inertia is inversely related to angular velocity. Therefore, there is a trade off between angular velocity and moment of inertia. Furthermore, angular velocity is related to the change in time and the change in angular displacement.

Velocity of Player (Optimization)

Decreasing the amount of time spent in the run up from the preparation phase to the transition phase proportionally increases the velocity of the player.

Velocity of Player (Expected Errors)

<u>Preparation Phase</u>

Taking too long to initiate run up → Corrected by initiating the run up as quickly as possible.

Time

The time it takes the performer to begin the run up from the preparation phase to the plant foot phase is one of the final determinants of this skill. The time spent during the run up to the ball can be readily changed by the performer to effectively increase the velocity of the player. Since time is inversely related to velocity, the velocity of the player during the run up to the ball can be increased by covering the same distance to the ball in less time.

Time (Optimization and Expected Errors)

Same as velocity of player.

Distance

The total distance of the run up to the ball can be readily changed by the performer to effectively increase the velocity of the player. The rules of the game allow the player to begin the run up at any distance or angle relative to the penalty spot. It was determined that the optimal distance to take a penalty shot was approximately 5 meters behind the ball because a greater distance allowed for more time to correctly accelerate and increase the velocity of the player before imparting this force onto the ball. The player's start position allowed for an effective curvilinear run up, a curved path where all point on the player (object) move the same distance without changing orientation, which naturally set the player up for contact at the optimal height. Distance is proportionally related to velocity, so the velocity of the player during the run up to the ball can be increased by covering the same distance to the ball in less time or by covering a greater distance in the same amount or less time.

Distance (Optimization)

The location of the player during the preparation phase was key to optimizing the distance of the run up to the ball. As long as the performer continues to face the ball while constantly changing the direction of motion (curvilinear motion) during the run up phase the curvilinear path can be maintained effectively.

Distance (Expected Errors)

Preparation Phase

1. Improper distance from the penalty spot → Corrected by ensuring the performing is approximately 5 meters away when stepping back from the penalty spot.
2. Improper distance to begin an effective curvilinear run up → Corrected by facing the left goal post at the beginning of run up

Impulse ("Equation of Velocity")

Determined by time forces interact and the extent of the forces excreted by the shoulders, hips, knees, ankles. Where the body is positioned from the run up to the shooting phase has an effect on the angular momentum and impulse of the limbs imparting a linear velocity, acceleration and impulse from the foot onto the ball.

The Time at Which Forces are Exerted

Torque is created by the player to cause rotation of the body about the hip of the plant leg due to kinetic linking. Increasing the time at which the forces or torques are created and exerted by the pulling of contracting muscles on the limb segments (levers) as long as possible to produce a greater force. Transferring the torques and forces produced by the shoulders, hips, knees, ankles can invoke the kinetic chain to increase the impulse that can be exerted onto the ball

The Time at Which Forces are Exerted (Optimization)

During the plant foot phase, the forces at the plant foot can cause a positive rotational torque that is transferred from the feet to the hips while the plant leg remains stationary to allow the hips to positively rotate during the contact with ball phase. This increases the extent at which the upper arms rotate about the shoulders while the torso rotates allows for an optimal transfer of torque to the hip, knee, and ankle of the striking leg to produce a larger force onto the ball.

The Time at Which Forces are Exerted (Expected Errors)

<u>Plant Foot Phase</u>

1. Not enough hip extension and knee flexion of striking leg → Corrected by flexing the knee and extending the hip at a greater extent during in air phase ensure a greater time at which forces can be exerted onto the ball.

<u>Contact with Ball Phase</u>

1. Lack of flexion and extension of each arm in opposition to the flexion and extension to the contra lateral thigh → Corrected by initially flexing and extending each arm in opposition during the transition phase, which enables the player to naturally produce the skill in sync with the angular momentum of whole body.

Body Position

Beginning the run up properly with a stable starting position allows for an optimal run up with less chance of being thrown off balance. This can be achieved by widening the base of support to approximately shoulder-width apart and keeping the position of the center of gravity to 55-57% of standing height. A performer cannot readily change their physique in practice. The ready position at shooting is a modified staggered stance where the plant-foot is the only base of support at which the player rotates about the z-axis of the transverse plane.

Body Position (Optimization)

A stable starting position in the preparation phase can be achieved by abducting both thighs to produce a widened base of support where the centre of gravity will be equally balanced along the sagittal midline of the player. A balanced ready position for shooting at the plant foot phase can be achieved by flexing the thigh and knee of the plant leg while flexing the knee of the striking leg to balance the center of gravity of the player equally along the mid-sagittal plane.

Body Position (Expected Errors)

<u>Preparation Phase</u>

1. Reduced base of support → Corrected by widening the base of support to approximately shoulder width apart. This ensures proper weight distribution and stability before run-up.

<u>Plant Foot Phase</u>

1. Improper landing of plant foot → Corrected by emphasizing dorsi flexion of the plant foot during the in air phase; therefore, the plant foot will land on the heel instead of the toes to reduce the possibility for injury.

<u>Accuracy</u>

As seen in the deterministic model the main branches off of accuracy are the size of the net, the distance from the top left corner, deception, flight distance, and speed.

The Size of the Net

Net size is a constant in adult soccer games. Only in children's soccer games does the size of the net ever vary, depending on age and skill level (see Figure 6).

The Distance from the Top Left Corner

Distance from the top left corner is also constant if the penalty kick is taken at exactly the same distance from the center of the net every time (see Figure 6).

Deception

Deception is another key determinant accuracy, which is optimized by physical cues and the curve of the ball. We define deception as the ability of the performer to kick the ball into a corner of the net that is virtually impossible for a goalkeeper to predict. Expert performers in the autonomic stage of learning can actually release degrees of freedom, to accomplish the same goal (Magill, 2011).

Eye Fixation

By looking away from the corner of the net the shooter intends to shoot for, the shooter is able to deceive the goalkeeper. This type of eye fixation results in unpredictable performance, which lengthens reaction time of the goalkeeper.

Eye Fixation (Optimization)

The performer must first be aware of where they will be shooting. In this case the top left corner. Therefore, the player may want to fixate on the right side of the net to trick the goalkeeper.

Eye Fixation (Expected Errors):

Preparation Phase and In Air Phase

1. Eyes are fixed on the side of the net that the performer is shooting for, allowing the goalkeeper to predict the outcome of the shot. Corrected by fixating eyes on the ball or on another target, irrelevant to the net itself.

Body Position

Plant foot direction determines overall body position. Whichever way the plant foot is facing, the ball tends to follow the same path. The direction of the shoulders and hips also determine accuracy. By facing the body towards the target and following through in the same direction, the performer can ensure accuracy. However, expert performers are able to change these optimal positions of their plant foot, shoulders and hips, yet still maintain accuracy.

Body Position (Optimization)

Plant foot, and shoulders and hips positioning allow the goalkeeper to predict the direction of the ball. Expert performers are able to point their plant foot in a direction opposite of the intended target, reducing the time a goalkeeper has to act. Hips rotation can be delayed to the last second, and shoulder abduction and torso rotation can cause a goalkeeper to misconceive a performance. In order to score in the top left corner the player may face the plant foot, hips and shoulders towards the right side of the net and rotate about the left hip to change the direction of projection at the last second.

Body Position (Expected Errors)

Preparation Phase

1. Standing too far away from the ball can result in improper step count and timing. Corrected by stepping backwards from the ball before preparation phase, in order to ensure proper step count and timing.

Transition Phase

1. Improper takeoff direction. The force-motion principle states that whichever direction force is applied, motion of the body will follow. Corrected by facing the take off foot towards the target and directing force towards the target.

In Air Phase

1. Pointing plant foot away from target can result in improper foot placement. Corrected by pointing plant foot towards target and timing landing properly.

Plant Foot Phase

1. Plant foot is unstable and too far away from ball. Corrected by timing the run up as seen in the correction for the preparation phase.

Magnus Effect

This principle explains the phenomenon of the curved projectile of any object in flight rotating about its own axis. When an object is projecting through the air, there is an angular acceleration at the front of the ball that is greater than the angular acceleration at the back of the ball causing the ball to curve in through its projectile (Cayzak, Carette, & Guillen, 2011). This perpendicular force is affected by point of contact on the ball, run up and lateral to media rotation of the foot from the hip. Different points of contact create different torques on the ball. By contacting the ball on the left side or right side, one can create a respective negative or positive rotation of the ball, which will be displayed upon its projectile path to the net. The curvilinear run up to the ball also helps create this torque on the ball. By running in a quarter circle before hitting the ball, the performer is able to transfer centripetal acceleration of the body into the limbs creating angular momentum. Momentum of the player will be directed around this curvilinear path and transferred into the ball through an elastic collision. According to the conservation of momentum, the ball will cause the leg to negatively accelerate and the foot will cause the ball to positively accelerate towards the target. Furthermore, by rotating the hip from a lateral to medial position the player can create apply angular momentum to be summed with the initial linear momentum of the body. In combination, these factors cause the ball to curve throughout flight, which can deceive the goalkeeper.

Magnus Effect (Optimization)

In order to precisely control the point of contact and initiate proper torque on the ball, a right-footed performer should run a quarter circle from the left side of the ball and contact the ball on the bottom right side of the ball. Theoretically, the ball should consistently curve out of the reach of the goalkeepers hands until it reaches it reaches the top left corner of the net.

Magnus Effect (Expected Errors)

<u>Preparation Phase</u>

1. Standing directly perpendicular to the net and ball. Corrected by a curvilinear run up, by standing at an angle to the ball.

<u>Plant Foot Phase and Contact Phase</u>

1. Planting the foot too far away from the ball reduces the area of the optimal point of contact on the ball. Corrected by placing the plant foot adjacent to the ball.

2. Contacting the ball above the center of gravity. The center of gravity of the ball lies in the midline within the core. Corrected by contacting the ball below the center of gravity, on either the right or left side of the ball.

Projectile Motion/Flight Distance

The projectile motion determines the vertical accuracy of the penalty kick, including relative take off height, angle of release, acceleration due to gravity, air resistance, and velocity at takeoff**.**

Relative Takeoff Height

Relative takeoff height is important in determining the final position of the ball relative to the net. The projectile path of the ball is dependent on the balls initial position. Considering our skill is scoring in the top left corner, the ball must follow a projectile path from a lower relative height to a higher relative height. Therefore, by the time the ball crosses the goal line, a fully symmetric parabola will not yet be achieved. The ball will only begin to project downwards due to gravity.

This component is also a constant in a penalty kick, but varies in an actual soccer game.

Angle of Release

Angle of release is important in determining the projectile height of the ball. An angle of release of 90 degrees will optimize vertical distance of the ball and an angle of release of 45 degrees will optimize horizontal distance of the ball. This component is important in determining linear displacement from the penalty spot to the net.

Angle of Release (Optimization)

Using trigonometry, the optimal angle of release for scoring a goal in the top left corner from the penalty spot was found to be approximately 13 degrees (see Figure 5). This angle will allow the ball to reach an apex height just before it crosses the goal line. At the apex the vertical velocity is zero. The ball will begin to accelerate downwards due to gravity at this very moment. It is important that the ball reaches apex just before the net because if it were to contact the bottom of the cross bar on its way down from apex, it can still cross the goal line.

Angle of Release (Expected Errors)

Contact Phase

1. Contacting the ball above the midline or center of gravity, which reduces the angle of release. The ball will accelerate downwards and hit the ground well before it crosses the goal line. Corrected by contacting the ball on the lower right hand side of the ball for a right-footed performer.

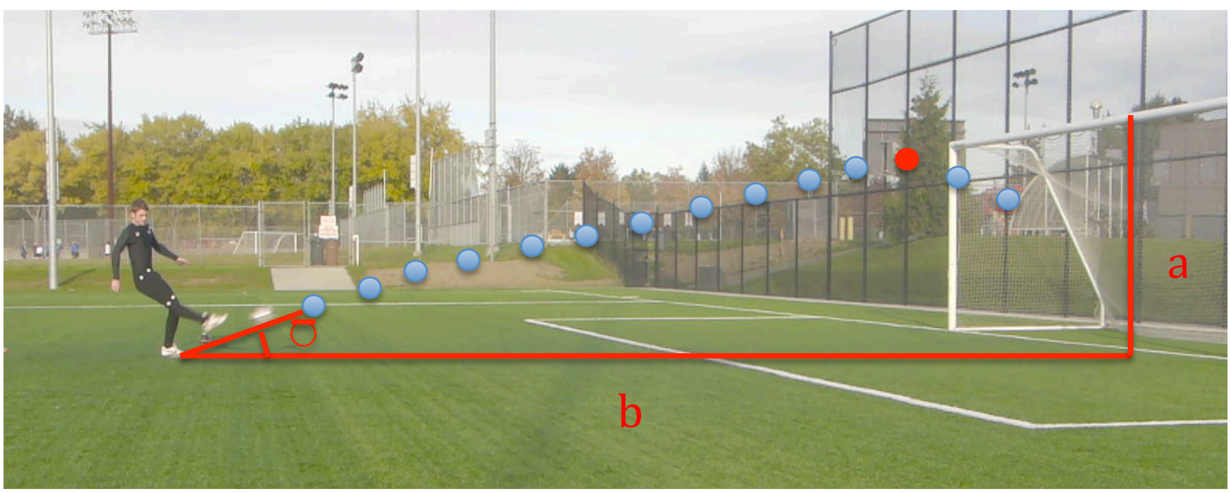


Figure 5 - Optimal Angle of Release and Parabolic Flight Path

a = Height of Net = 2.54 m

b = Distance From Net = 11.005 m

Angle (ϴ) of Release = $\tan^{-1}$ (a/b) = $\tan^{-1}$ (2.54/11.005)

= ≈ 13°

Acceleration of the Ball Due to Gravity

Acceleration due to gravity is controlled by the mass of the ball, which cannot be controlled by the performer. Once the ball leaves the foot, the only vertical force acting on the ball is gravity, neglecting air resistance. Therefore the ball will uniformly accelerate downwards throughout its projectile. Theoretically, at the apex height, the ball will have a net vertical velocity of zero, until it begins to accelerate downwards.

Air Resistance

In a soccer penalty kick, only the ball being used can affect air resistance. This is generally a constant for all match balls but can be controlled depending on the stitching in the ball and the air pressure within the ball.

Air Resistance (Optimization)

Increasing air pressure to 10.4-13.6 pounds per square inch (psi) makes the ball more aerodynamic (Fédération Internationale de Football Association [FIFA], 2011).

Velocity at Takeoff

Velocity at takeoff is mostly dependent on an impulse-momentum relationship. However, we only focus on change in velocity since mass of body and ball are constant. Furthermore, change in velocity can be broken down into forces exerted on the ball and the time these forces are exerted. Kinetic linking of these bodily forces is important in optimization of projectile motion. Along with the angle of release, kinetic linking of forces exerted can determine the linear displacement of the ball. Kinetic linking occurs at the shoulders, hips, knees and ankles. By rotating the shoulders negatively, the performing can transfer force from the shoulders into the hips. This rotation initiates a negative rotation of the hips to load for the shot in the plant foot phase. The performer than reduces their radius of gyration by bending their knee. This allows them to produce more force by reducing the moment of inertia by decreasing the distribution of mass. Next the right hip rotates positively rotates as flexion occurs. The force created by right hip flexion causes the right knee to extend, increasing the radius of gyration. Plantar flexion of the ankle occurs as soon as the right knee begins to extend. By locking the ankle in plantar flexion the forces exerted by the rest of the leg are maximized. The addition of these forces is responsible for determining the net force at ball contact. Acceleration is a vector quantity that determines the change in velocity over time. Furthermore, acceleration is related to force exerted on a given mass. Since mass of the ball remains constant, we can assume that as the net force applied on the ball increases, the velocity of the ball will increase from a resting position to a position crossing the goal line. Therefore, if we consider the velocity of takeoff to be the velocity immediately after contact, acceleration of the ball will increase the velocity before it reaches the goal line. In summary, as velocity of takeoff increases, final velocity of the ball increases.

Velocity at Takeoff (Optimization)

As joint flexion and extension velocities increase, the precision point of contact between the foot and the ball decreases. Therefore, an optimal velocity of contact must be issued to create the perfect shot. In further, the velocity at takeoff is determined by the conservation of momentum from leg to ball. By increasing take off velocities of the ball the flight distance of the ball will be increased greatly. However, accuracy is inversely related to speed (Magill, 2011). Therefore moderate take off velocities will allow the ball to reach the top left corner immediately after the apex height. This will prevent the ball from going over the net, and increase vertical acceleration downwards, making the ball harder to save for a goalkeeper.

Velocity at Takeoff (Expected Errors):

Plant Foot Phase

1. Creating too much force from kinetic linking in the loading phases, which can reduce accuracy. Corrected by producing less force in the loading phases.

Contact Phase

1. Producing too much force in the striking leg throughout the plant foot phase can result in force application outside of the optimal area of contact. This can cause torque in the wrong direction, which can either reduce the final accuracy or final velocity of the ball. Corrected by reducing forces in the striking leg, to allow for precision force application within the optimal contact area.

Concluding Points

Although speed and accuracy are separate determinants, they are also inversely related. As speed increases, accuracy tends to decrease (Magill, 2011). The performer must find a way to balance speed and accuracy to score a goal in a penalty shot. Finding this optimum performance range is dependent on force production and manipulation.

Observation

Skill Level of Athlete and Evaluation Technique

The skill level of the athlete will have a direct influence on how the observation of the penalty kick will be made. In analyzing the penalty kick of a novice performer, we should look for major mechanical flaws, such as lack of flexion/extension at the hips, knees, and ankles. Also, during initial practice, it is important that the novice performer "keep their eyes on the ball". Ultimately, when observing a novice performer, focusing on gross movements as opposed to fine movements is advantageous; many times, errors in these large movements cause other deficiencies in performance. Although there is a difference in the evaluation that we provide to novice and skilled performers, there is no difference in terms of the description of the skill. Fundamentally, all of the elements of an expert performance are necessary for the successfulness of the penalty kick at any level. Thus, there is generally no simplified method for novice performers. We could, however, adjust the target (i.e., change the target from the top-left corner of the net) to make it easier to successfully achieve the goal.

Feasible Observation Conditions

With some preparation, we were able to attain nearly perfect observation conditions. We were able to observe both the expert and novice performers on a regulation size soccer pitch (that had clear, accurate markings according to FIFA Laws of the Game: Law 1 – The Field of Play) (FIFA, 2011). Also, the nets were of regulation quality and size and the penalty mark was an accurate distance away from the end line. Soccer cleats were worn (as required by FIFA Law 4 – Player's

Equipment) to simulate an actual game or practice scenario (FIFA, 2011). For observation purposes, we were restricted to our choice of equipment (normally a uniform, shin guards, etc. must be worn). For easy viewing purposes, tight black clothes and white balls were worn instead. The weather was also ideal for our observation. All observation conditions and measurements are depicted in Figure 6 below.

*Note: there is a difference in surface area between Grass Fields and Turf Fields; however, they are both legal playing surfaces according to FIFA.

**Note: Due to the concave shape of the camera lenses used for observation, measurements will not be exactly accurate (when measuring distances on the periphery of the image, due to slight distortion of the image).

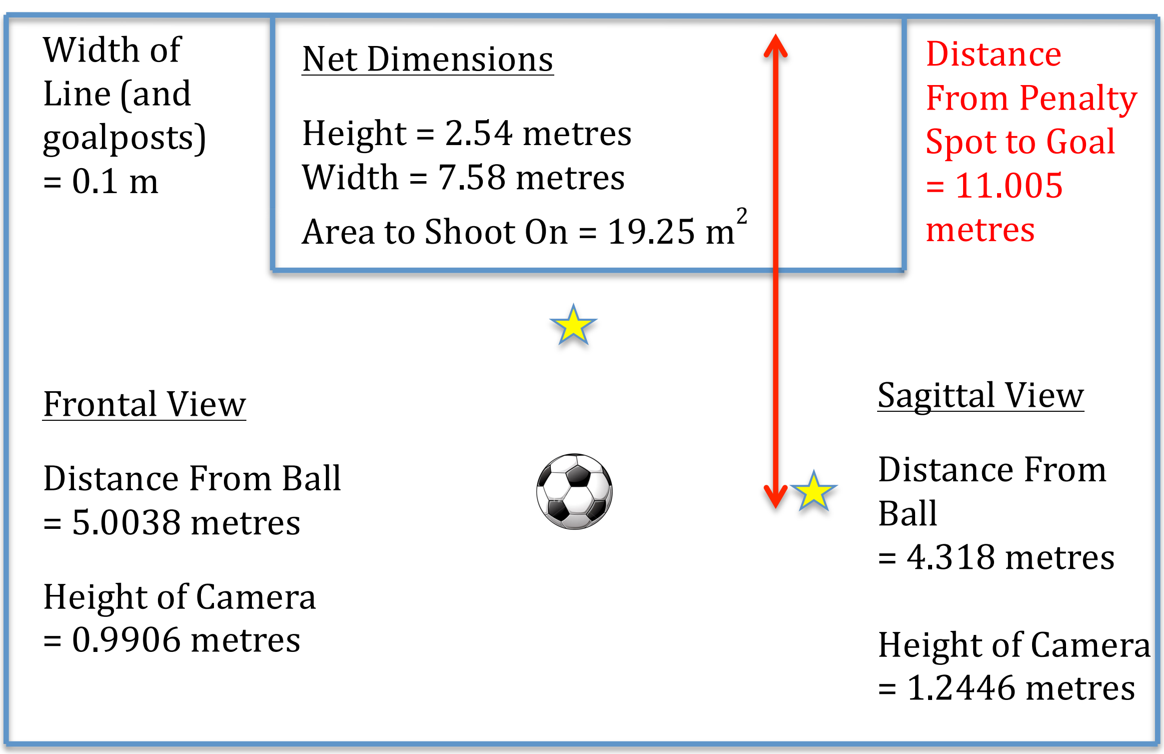


Figure 6 - Observational Methods and Important Measurements

Evan's Body Measurements

Sagittal Plane →	Right Shoulder to Right Hip = 49.5 cm Right Hip to Right Knee = 45.7 cm Right Knee to Right Ankle = 42.4 cm
Frontal Plane →	Left Shoulder to Left Hip = 50.8 cm Left Hip to Left Knee = 44.5 cm Left Knee to Left Ankle = 41.9 cm
	Right Hip to Left Hip = 27.9 cm Right Shoulder to Left Shoulder = 36.8 cm
Shoe →	1 Foot (to use as basis for measurement)

Positioning for Effective Observation

Planes of Movement for Each Phase

The penalty kick is a complex set of movements that moves through all three planes. The principal plane(s) of movement for each phase are included in Table 2.

Table 2 - Principle Planes of Movement for Key Phases

Phase	Principal Plane(s) of Movement
Preparation Phase	No Movement
Load Phase	Sagittal
Transition Phase	Sagittal, Frontal
In-Air Phase	Sagittal, Frontal, Transverse
Plant Foot Phase	Sagittal, Frontal, Transverse
Contact With Ball Phase	Sagittal, Frontal, Transverse
Hyperextension of Knee Phase	Sagittal, Frontal, Transverse
Full Flexion of Thigh Phase	Sagittal, Frontal, Transverse

Distance from Athlete for Each Phase

When observing a novice soccer player taking a penalty kick, viewing from distance is initially best to get a full kick perspective. Observation would be best made from further back as you examine more gross motor skills. When observing an expert soccer player taking a penalty kick, we want to look for very fine motor deficiencies in performance (as they consistently perform successfully); at this stage, we are just trying to fine-tune performance This would likely require a variety of viewing angles from closer up. Subtle changes in the rotation of hips and plantar flexion/dorsiflexion in the ankle require closer scrutiny; even a slight change in these elements can send the ball soaring over the net. Also, the area of contact with the ball is extremely important and a closer view would also be useful. Some potential viewing angles are depicted in Figure 7 below.

Figure 7 – Optimal Observation Angles, Sagittal (Left) and Frontal (Right)

Observational Strategies

The following are examples of observational strategies that could be used to assist in the observation of performance:

1) Novice performers of a skill will exhibit errors that are easily recognized but may not be repeated from one performance to another. As discussed earlier, observations of these performers should be directed at identifying their gross errors in each performance. Alternatively, observers of expert

performers should direct their attention to identifying errors that are repeated from performance to performance.

2) Observation should take place in a controlled environment. Also, an environment that is duplicated as closely as possible to the actual environment in which the subject performs their skill is best. However, this has its limitations; a game scenario may be hard for the observer to get the best angle of performance. Also, a group practice session is not beneficial either as other students may “distract” the performer from achieving his or her full potential. Ultimately, we want to observe performance in an ideal environment with the least amount of distractions.

3) Determining you vantage point as an observer is one of the most critical observational strategies. By identifying the principle plane(s) of movement, and based on the skill level of the performer, the observer can easily choose where to view the performance from. With specific interest for our penalty kick, refer to Table 2 - Principle Plane(s) of Movement.

4) Viewing a performance several times is advantageous. We are all human, and can only deal with so much information from the external environment. Setting up video cameras in various key locations will not only be useful for viewing the same trial of the skill from different angles, but also for reviewing the recordings over and over again. This footage can also be used to show to the performer as a visual aid for evaluating his or her performance.

5) Many activities have specific rhythms. Listening to this pattern can tell you things about the performance that vision might not be able to help you with. Generally, we can rely on our other senses during observation as well.

INSERT OBSERVATIONAL CHECKLIST ON SEPARATE PAGE!

Description of Checklist Elements

Preparation Phase

- Wide Base of Support → allows for stability to prepare for the run-up
- Eyes Fixated on Ball → concentration on the ball and psychologically planning out what needs to be done (i.e., where are you going to shoot)

Load Phase

- Hips Flex → to initiate the beginning of the run-up
- Eyes Fixated on Target → two uses: 1) Imagine where you want to shoot 2) Can focus on an area of the net to "deceive" the goalkeeper
- Transfer Centre of Gravity In-Front of Body → allows for a change from stability to mobility during the initiation of the run-up (i.e., increases mobility)

Transition Phase

- Hips Flex/Extend → allow for powerful run-up with an increasing velocity (change in acceleration). The more powerful and forceful the run-up, the more force the player can exert on the ball.
- Shoulders Abduct and Flex/Extend → during the run-up (where the player is trying to increase mobility), the player still wants to have a certain degree of stability in doing so. Thus, the shoulders abduct to distribute the mass over a greater space (increasing the player's stability), and the arms flex/extend in opposition to the player's legs for balance (to account for the change in centre of gravity).

- Knees Flex/Extend → flexing and extending the knees allows the angular force necessary to move the legs to decrease. Thus, moving the legs is easier, and a greater force can be exerted on the ball (as the radius of gyration is smaller).
- Ankles Plantar Flex/Dorsiflex → when in contact with the ground, the ankles fully plantar flex and dorsiflex to increase the impulse of the movement. Thus, there will be more time to exert a force, and ultimately, a greater force exerted on the ball.
- Eyes fixated on Ball → it is necessary to know where the ball is at all times to plan your run-up accordingly.

In-Air Phase

- Hips Flex/Extend → in this case, the hips flex and extend the thighs as the performer is in the process of ("winding up") his kick. This will increase the amount of force that the player can apply on the ball.
- Knees Extend → extending the knees allows the angular force necessary to move the legs to decrease. Thus, moving the legs is easier, and a greater force can be exerted on the ball
- Ankles Plantar Flex/Dorsiflex → when in the air, the ankles fully plantar flex and dorsiflex to increase the impulse of the movement. Thus, there will be more time to exert a force, and ultimately, a greater force exerted on the ball.

Plant Foot Phase

- Hip Lateral Rotation → lateral rotation in the left hip allows for the foot to be pointed in the direction of the target, as desired. Lateral rotation in the right hip allows for the foot to be turned outward which, when it comes in contact with the ball, will cause the ball to spin (as the player hits the ball on the right side).

- Knee Flexion (Right) → flexing the right leg at the knee (kicking leg) allows the angular force necessary to move the legs to decrease. Thus, moving the legs is easier, and a greater force can be exerted on the ball
- Plant Foot Right Beside Ball → the most important element. A plant foot right beside the ball is necessary for a player to apply the most force on the ball. Also, our stability is increased as the player comes in contact with the ball, and he can follow-through in a smooth, continuous motion (without losing balance which would affect the kick).
- Plant Foot Pointing Towards Target → the plant foot should point towards the target. This will allow for a follow through that will naturally guide the ball in the direction of the plant foot.

<u>Contact With Ball Phase</u>

- Shoulders Abduct and Flex/Extend → during contact (where we are trying to increase stability), the player's shoulders abduct to distribute the mass over a greater space (increasing the player's stability), and his arms flex/extend in opposition to his legs for balance (to account for the change in centre of gravity).
- Leaning Back → leaning back helps distribute the player's mass over a greater area, and increase his stability. When shooting the ball in the top left corner of the net, leaning back helps the player get under the ball, as desired.

- Contact With Ball Made on Bottom Half (Right) → in order for a goal to be scored in the top-left corner of the net, the foot must contact the ball on the right side (to spin left) and on the bottom half of the ball (to give the ball lift).

Hyperextension of Knee Phase

- Shoulders Abduct and Flex/Extend → during the follow through (where we are trying to increase stability), the player's shoulders abduct to distribute the mass over a greater space (increasing the player's stability), and his arms flex/extend in opposition to his legs for balance (to account for the change in centre of gravity).
- Kicking Leg Extend at Knee → by fully extending his leg at the knee (in this case, hyperextension -- which is not common), the player is generating the most force possible on the ball in order to increase the initial velocity of the shot.

Full Flexion of Thigh Phase

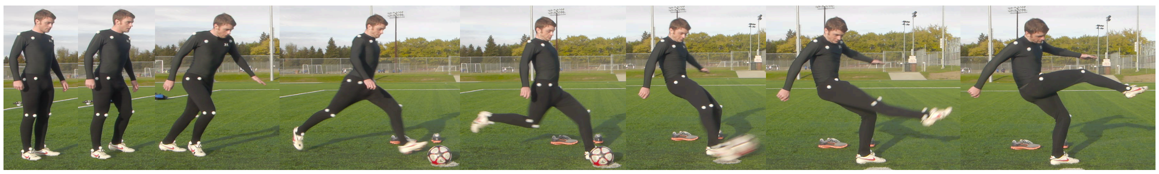
- Shoulders Abduct and Flex/Extend → during the follow through (where we are trying to increase stability), the player's shoulders abduct to distribute the mass over a greater space (increasing the player's stability), and his arms flex/extend in opposition to his legs for balance (to account for the change in centre of gravity).
- Kicking Leg Flex at Hip → by fully flexing his thigh at the hip, the player is generating the most force possible on the ball in order to increase the initial velocity of the shot.

Evaluation/Diagnosis

Novice

vs.

Expert



Determinants that Can Be Changed by the Performer

- Distribution of mass
- ~~Mass~~
- Distance away from ball in run up
- Time of run up
- Forces at the shoulders, hips, knees, and ankles (Speed and Accuracy)
- Time forces act at the shoulders, hips, knees, and ankles
- Ready position for shooting
- Ready position for run up (Speed and Accuracy)
- ~~Physique~~
- ~~Size of net~~
- ~~Distance from top left corner~~
- Speed
- Flight distance
- ~~Air resistance~~
- ~~Acceleration due to gravity~~
- Angle of release
- Eye fixation
- Direction of hips, plant foot and shoulders
- Point of contact with the ball
- ~~Relative height at takeoff~~

Priority

1. Preparation: estimate time to contact of ball (tau) (i.e., number of steps before contact.
2. Widen base of support at ready position.
3. Arms in opposition to legs.
4. Include another step off of the right foot before in air phase to ensure (ensures plant foot placement to be adjacent to the ball).
5. Flexing both knees at the in air phase to prevent injury in the plant foot phase.
6. Flex torso before plant foot phase and extend after plant foot phase.
7. Contact ball with the inside (front) of foot rather than toes. (See Figure 3)
8. Keep plant foot steady throughout follow through.
9. Follow through towards the target with striking leg.

1st Phase (Preparation)

- Before the run up, the ideal performance should include a widened base of support to increase stability. By keeping the players eyes fixed upon the ball they are increasing attention towards the task. By keeping the feet in a squared stance, shoulder width apart, the player is able to maximize stability before the player initiates movement in the load phase and transition phase. Having static balance in this preparation phase allows for optimal dynamic balance throughout the performance. This position is important for planning the number and spacing of steps before contacting the ball.

- The novice has a narrow base of support, which maximizes mobility over stability. This lack of static balance in the preparation phase may lead to poor dynamic balance throughout the performance. The lack of eye fixation on the ball takes away from concentration of the skill.

Improvements:

- Widen base of support
- Eye fixation on ball

2nd Phase (Load Phase)

- The load phase is another stable position of this skill. The stance moves to a slightly staggered position transferring weight to the left foot. The trunk and left hip are flexed due to this weight transfer from right leg to left. By flexing the trunk, the performer is beginning to shift the center of gravity in front of the body. In the novice performance, base of support is narrow and feet are not moving towards a staggered position. This is the initial mobility phase, which determines the effectiveness of the run up and transferring of weight to the next phase in the run up.
- The novice is moving their center of gravity too far forward in this stage by leaning forward by flexing ankles rather than flexing the torso at the hip. She is still in an entirely mobile position, which decreases the balance required for the ready position of the run up. Reducing balance in this stage can affect the entire performance.

Improvements:

- Flexion of torso at hips rather than flexion at the ankles
- Widen base of support

3rd Phase (Transition Phase)

- The transition phase involves transferring of weight from the left foot back to the right foot. Expert performers always take their last step off of their kicking foot. This is another important phase of mobility throughout the skill. Dynamic balance is essential to overall performance. By abducting the shoulders and flexing or extending the arms and legs in opposition (right arm flexed, right leg extended), the performer is preventing the center of gravity from shifting to one side or another by controlling the angular momentum of the body.
- The novice performer is not as balanced as the expert. The feet are not staggered enough in this position, reducing the base of support. Center of gravity is not being pushed as far in front as needed. The arms remained adducted, which prevents her from being able to control her angular momentum throughout the rest of the performance. Therefore, her shoulders will be absent in kinetic linking throughout the performance. Due to an improper preparation phase, the performer is stuck between taking one or one and a half steps before kicking the ball.

Improvements

- Flex right knee 90 degrees
- Completely extend left knee

- Abduct shoulders
- Flex left shoulder and extend right shoulder

4th Phase (In-Air phase)

- The performer is now a projectile. There is a uniform acceleration due to gravity on the performer. Arms and legs are in opposition, and the torso is extending from flexion. Center of gravity is moved further away from the ball due to this torso extension. Both knees are beginning to flex, for different reasons. The striking knee is flexing to allow maximal force production and the planting knee is flexed to absorb the reaction forces from landing. The dorsiflexion of the left ankle allows the performer to absorb the force through the heel first instead of the toes, which prevents injury. The striking ankle is locking into full plantar flexion to prevent injury and a loss of force production.
- The novice has not moved the torso at all from the preparation phase. Her legs are extended or flexed the same distance from the z-axis while her trunk and center of gravity lie directly through her z-axis. The novice is not flexing the left knee, which may cause injury upon landing. The right knee is not flexing either, which reduces the load for force production. No force is produced at the shoulders. Improper timing of load for force production at the right knee reduces the overall magnitude of force exerted on the ball.

Improvements

- Increase flexion at left knee to absorb shock when landing on ground
- Flex left shoulder and extend right shoulder

5th Phase (Plant foot phase)

- The plant foot position is extremely important for angle of release and maximal force production. The expert performer places the plant foot directly adjacent to the ball, facing the net, allowing for full extension of the kicking leg towards the net immediately before contact with the ball. The left knee is slightly flexed to lower the position of the player, and therefore lower the center of gravity, increasing stability throughout the contact phase. Both arms are abducted and swinging in opposition because of leg movements in the in air phase. The right knee is flexed at approximately 90 degrees, which allows for a controlled, yet powerful leg extension. Lateral rotation occurs at the right hip, which ultimately contributes to the extent of the Magnus effect.
- The novice performer plants their foot approximately 2 feet behind the ball, which limits the opportunities for an optimal angle of release. Torso is still aligned with the z-axis. The right knee is only slightly flexed, which limits overall force application on the ball. Her arms are still adducted, not contributing to rotation of the performer at the left hip. No lateral rotation occurs at the right hip, which restricts the degree of the Magnus effect.

Improvements

- Plant foot beside ball
- Flex right knee
- Flex left shoulder and extend right shoulder

6th Phase (Contact With Ball Phase)

- The plant foot remains in the same position pointing towards the left side of the net during ball contact. The Magnus Effect is largely due to the point of application of the foot on the ball. The performer remains balanced with an increased mobility on the plant foot, which allows the performer to rotate the striking leg to make contact on the bottom right corner of the ball. By contacting the bottom right corner of the ball the performer can curve the ball to the left, inducing the Magnus Effect. By extending the torso about the y-axis the center of gravity is shifted behind the performer, which increases angle of release by allowing the performer to get their foot underneath the ball instead of striking through the center of gravity of the ball. By abducting the shoulders and flexing or extending the arms and legs in opposition (right arm flexed, right leg extended) the performer is capable of controlling the angular momentum of the entire body more precisely.
- As seen previously in the plant foot phase, the novice performer has their plant foot further away from the ball, thus reducing the angle of release and heightening the point of application of the foot on the ball. The novice is extending both of her arms and her torso. This occurred to compensate for the greater distance of the plant foot from the ball, which increases her angle of release. Although this angle of release is optimized for her position, the point of application is above the center of gravity of the ball, which prevents the ball from becoming a projectile.

Improvements

- Abduct shoulders
- Flex left shoulder
- Make contact on lower, right side of ball

7th Phase (Hyperextension of Knee Phase)

- Balance is maintained in this position by negatively rotating of the torso to counter the positive rotation of the hips and full flexion of the striking leg. The center of gravity of the performer remains behind the plant foot but is raised due to abduction of the shoulders.
- The novice performer is supporting their weight on the front of the plant foot because the center of gravity of the performer is in front of the plant foot. Therefore she is leaning forward to produce as much force as possible on the ball from a restricted body position and point of application. This restriction is due in part to improper placement of the plant foot in the plant foot phase. The novice performer does not abduct their arms to raise the center of gravity because they are already off balance after striking the ball. She is not flexing her left arm at the shoulder to counter the positive rotation of the hips

Improvement

- Abduct shoulders
- Increase flexion at left shoulder

8th Phase (Full Flexion of Thigh Phase)

- The striking leg is at full flexion while the right arm is in full extension. The performer abducts arms further to increase distribution of mass to decrease angular velocity of the body about the plant foot. Further negative rotation of the torso occurs to counter balance the positive rotation of the hips. Center of gravity is raised directly above his plant foot to maintain balance in a mobile position.
- In the novice performance, arms are fully adducted and neutral increasing angular velocity about the plant foot. She is not counteracting the positive rotation of the hips by negatively rotating her torso and lacking flexion of left arm. She conserves angular momentum by rotating about her plant foot. Therefore, her plant foot is not facing the target, and her right leg is following through away from the target.

Improvement

- Abduct shoulders
- Increase flexion at left shoulder
- Ground left foot
- Follow through with foot towards target
- Increase left knee flexion

Correcting Errors/Implementation

When correcting errors of a novice performer, gross errors are the most important to tackle first. A good observer would view the skill as a whole, meaning they would watch everything together, rather than focusing on specific aspects of the skill. Many of our "priority" determinants that can be changed by the novice performer, according to the evaluation, are gross errors. Preparation, number of steps before making contact with the ball, a wider base of support, and flexing knees are all essential changes that need to be made to improve the novice's performance.

In order to communicate this with the performer, it is important to understand that each aspect needs to be taught separately, so that the performer understands the importance of each one. Once one error has been identified, the performer should try again, and the analysis should be repeated.

After all of the gross errors have been corrected, the observer can then begin to focus on the specific errors, such as those involving specific motor skills, such as flexing the torso at the hips rather than flexing the ankles in the second phase, or specific areas of the body, such as hitting the ball with the inside of the foot, rather than the toes.

Again, the specific errors should be corrected individually, and the analysis should continue to repeat.

Conclusion

The main intent of any penalty kick is to get the ball past the goaltender, and score a goal. In a situation with so much pressure, a player must consider the most important aspects of a kick, and perform them as smoothly as possible. For our specific kick those main aspects were accuracy, and speed of the ball. Each of these aspects can be broken down further into complicated details, but overall, they are the most important points of the kick.

Our project is useful in helping to evaluate and correct a novice performer, because we have the most important features of the eight key phases laid out in the simplest way possible. Comparisons of the expert and novice performance show simple errors that can be corrected, and may be details the player was not even aware of. The easiest way for any observer to correct a novice performance is for them to look at the gross errors first, and then slowly start to focus on the fine, and specific errors of different aspects of the skill. Specificity is what our project takes into account.

Each performer is different, but the guidelines we supply are a foundation for implementations that can be applied to any player's performance.

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