THE UNIVERSITY OF MANITOBA

TRADITIONAL ARCTIC SPORTS: A BIOMECHANICAL ANALYSIS OF THE ONE FOOT AND TWO FOOT HIGH KICK

By:

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ABSTRACT

Traditional Arctic Sports have been an important part of the Northern culture for as long as Northern inhabitants have existed on Earth. Games were played to build the strength, the endurance, and the resistance to pain that the harsh winters would test. Two of the most extraordinary games played are the one foot and two foot high kick. Both high kicks require the athlete to jump and kick a hanging target, making them a very difficult and physically demanding skill to perform at a high level. Neither of the two has been biomechanically analyzed, and thus, the purpose of this study was to provide a biomechanical analysis of the one foot and two foot high kick, Additionally, the study compares the kinematics of male and female athletes in these events. Nine males and four females were videotaped (60 Hz) performing the one foot high kick and 12 males and six females were videotaped (60Hz) performing the two foot high kick. The Dartfish analysis system was used for kinematic analysis of the one and two foot high kick for both genders. Fifty seven independent variables were compared between subjects for the one foot high kick and 47 variables for the two foot high kick. Vertical velocity of the center of mass at takeoff was used as a criterion for vertical jump performance. The male subject group showed significantly greater vertical velocities at takeoff in both the one and two foot high kick ($p < 0.01$). Several additional differences between variables measured were found to be significant between groups. Correlations and a stepwise regression analysis were also performed on the data set for each of the subject groups in order to determine the variables that best relate to and predict vertical velocity. The male two foot high kick showed that trunk extension angular velocity at takeoff was the best predictor of vertical velocity at takeoff. The analysis of the remaining three groups all

concluded that the horizontal approach velocity was the main predictor of vertical velocity at takeoff, thus confirming the importance of the approach phase in the outcome of a successful kick.

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To my fellow students, Adrian and Carolyn, I am thankful for their assistance and willingness to help. I especially thank them for putting up with me and keeping me under control when I got frustrated.

I thank my family for the support that they have given me throughout my education and this project. As well, I am grateful for my friends who stuck with me through these years. They were always there to keep me sane by reminding me that you need to have fun and not to be too serious.

DEDICATION

I would like to dedicate this thesis to the athletes that celebrate their heritage and traditions by competing in these games. Even with little acknowledgement of their athletic abilities in the rest of the sporting world, their spirit and dedication is immeasurable. I thank you all for reminding me what sport is really about.

“Traditional Arctic Sports: A Biomechanical Analysis of the One Foot and Two Foot High Kicks”

CHAPTER 1

INTRODUCTION

Traditional arctic sports have been an important part of the Northern culture for as long as the Inuit inhabitants have existed on Earth. The way the games are played today closely resembles the description given in traditional stories of the early Inuit (Heine, 2002). In this study, the term ‘Inuit’ is used as a general term for individuals living in the Arctic region. It must be noted that not all the indigenous groups of the Arctic region are referred to as ‘Inuit”.

The games played by the Inuit are not merely recreational activities. To the Inuit, they served a greater purpose than fun. According to the Arctic Sports Resource Manual (Heine, 2002) the games served three different purposes. First of all, the games prepared the Inuit for survival on the land. The harsh winters demanded much physical strength of the Inuit. Games were played to build the strength, endurance and resistance to pain that these harsh winters would test. From these attributes, survival skills were maintained and honed. The second purpose games served, was for the education of life on the land. The Inuit were taught traditional games at a young age so as to better prepare them to battle with the demanding northern environment as well as being nomadic. The games developed discipline and respect for not only the elders but for the land as well. The final purpose traditional games served was for sharing and celebrations. The Inuit, historically, were known for their many gatherings of tribes. They would gather together for several weeks or even months in a celebration of their culture and play these traditional games. It was a form of friendly competition and a way to share their culture with other tribes.

The Arctic Winter Games, Northern Games, and World Eskimo Olympics now carry on the tradition of gathering, sharing, celebrating, and friendly competition. The Arctic Winter Games were actually a result of poor performance at the Canada Winter Games, where the southerners often outperformed the northern athletes. Representatives from the northern regions decided to organize a competition where the northern athletes could compete at a high level without being overpowered (Heine, 2002, www.awg.ca). In 1970 the first Arctic Winter Games were held in Yellowknife, NWT, but traditional games were only demonstrations and not yet part of the games. These demonstrations became quite popular at the games as was seen by the fact that then Prime Minister Pierre Trudeau attended the games and asked specifically to watch these traditional games (Heine, 2002). The demonstrations then became part of the Arctic Winter Games and are now known as arctic sports. Since then, the arctic sports have become a major part of the games and tend to attract a large number of spectators (www.awg.ca). Today, at the Arctic Winter Games, the values of the traditional athlete (e.g. overall athleticism) can still be seen, as competitors must participate in a multitude of arctic sports events. For example, a male in the "open" category (> 17 yrs old), must participate in a minimum of six events. Along with the arctic sports, the sharing of traditions through cultural performances has been quite central to the gathering. The Arctic Winter Games, like the traditional gatherings, are more than just about winning alone, "they provide a display of the traditional culture as well as a meeting place for friendly exchange and sharing by athletes and cultural delegates" (Heine, 2002, p. 3-7). The games logo, three interlocking rings, serves as a symbol for these three functions: sharing, cultural exchange and friendly meetings (www.awg.ca) (Figure 1-1).

Figure 1-1 Arctic Winter Games logo.
(www.awg.ca)

A quote from the World Eskimo Indian Olympics website offers this explanation for the games:

"To better appreciate the background of these games, envision yourself in a community village hut three hundred years ago with the temperature outside at 60 degrees below zero, and everybody in attendance celebrating a successful seal hunt. While the young men are demonstrating their athletic prowess and strength, the umialiks, or whaling captains, are on the perimeter of the hut looking with great interest at the young adults - one or more of these young men would be incorporated into their whaling and hunting crews - the fastest, the strongest, the one showing great balance and endurance to pain would be the top pick." (www.weio.org)

The Inuit competed in a variety of interesting ways, but perhaps two of the most extraordinary games played by the Inuit are the one foot and two foot high kick. These games were played traditionally indoors during the long winters of the north and often during large gatherings. These two contests were often viewed as the most important games of a celebration in the western regions of the Arctic. Competitors in these events were young men in the prime of their strength who were quite anxious to perform well (www.weio.org). In these events, a target, often in the shape of a seal, is hung from a string that is attached to a support stand. The athletes attempt to kick the target according to the various rules of the two events. Today, these events are still quite popular at the Arctic Winter Games and continue to keep the traditions alive. The one foot version of the high kick is considered one of the most difficult of traditional games, whereas the two foot kick is considered to be one of the most demanding (Heine, 2002). In the one foot version, the competitor is required to kick the target with one foot only and to land on the same leg that performed the kick. It is because of the landing that it is considered among the most difficult. The two foot kick is much like the one foot kick, however, the competitor is required to kick the target with both feet and return to a landing position on both feet. It is a very demanding skill, as it requires the athlete to be very flexible and strong enough to bring both legs up and place the body in a pike position to kick the target.

The one foot high kick begins with the athlete choosing a spot within the designated playing area for an appropriate approach. The athlete then uses a walking or running approach toward the target, consisting of approximately 3-5 steps (Figure 1-2a&b). The feet are firmly planted close to each other on the final step of the approach (Figure 1-2c) and the athlete jumps off both feet (Figure 1-2d&e). It is noted that the high kick may be played using no approach at all, but this should be a separate competition as the heights achieved will be lower. Once airborne, the athlete attempts to kick the hanging target with one foot (Figures1-2f-i). Following contact with the target, the athlete must land only on the leg that contacted the target (Figures 1-2j-l). A successful attempt in this event is characterized by the athlete contacting the target and by demonstrating a controlled landing on the kicking leg.

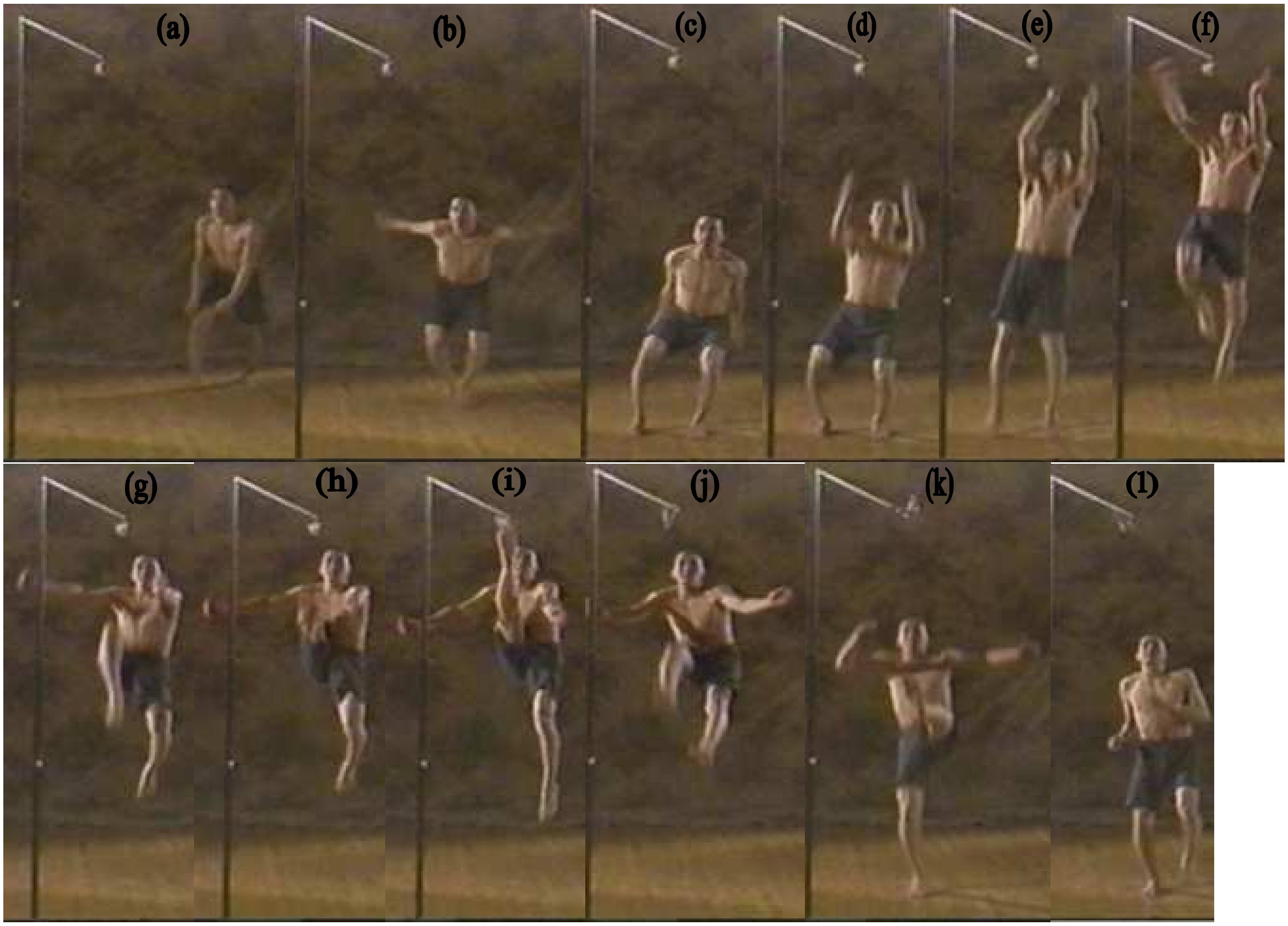


Figure 1-2 (a)&(b) approach phase, (c) backswing phase, (d) force producing phase of the jump, (e) critical instant of the jump, (f)–(h) force producing phase of the kick, (i) critical instant of the kick, (j)–(l) follow through (Heine, 2002)

The two foot high kick displays the same approach as the one foot high kick (Figures 1-3a-e), but differs in the kicking portion of the skill. A version of this event utilizing only a standing jump is not played due to the complex nature of the skill. Once the athlete leaves the ground in the two foot high kick, they attempt to kick the target using both feet simultaneously as opposed to only foot seen in the one foot version of the high kick (Figures 1-3f-i). After contact has been made with the target, the athlete must then land with both feet together (Figures 1-3j-l). The athlete contacting the target with both feet together and demonstrating a controlled landing on both feet characterizes a successful attempt. As well, the athlete’s feet must remain together or very close (within the judges discretion) throughout the duration of the jump, kick and landing.

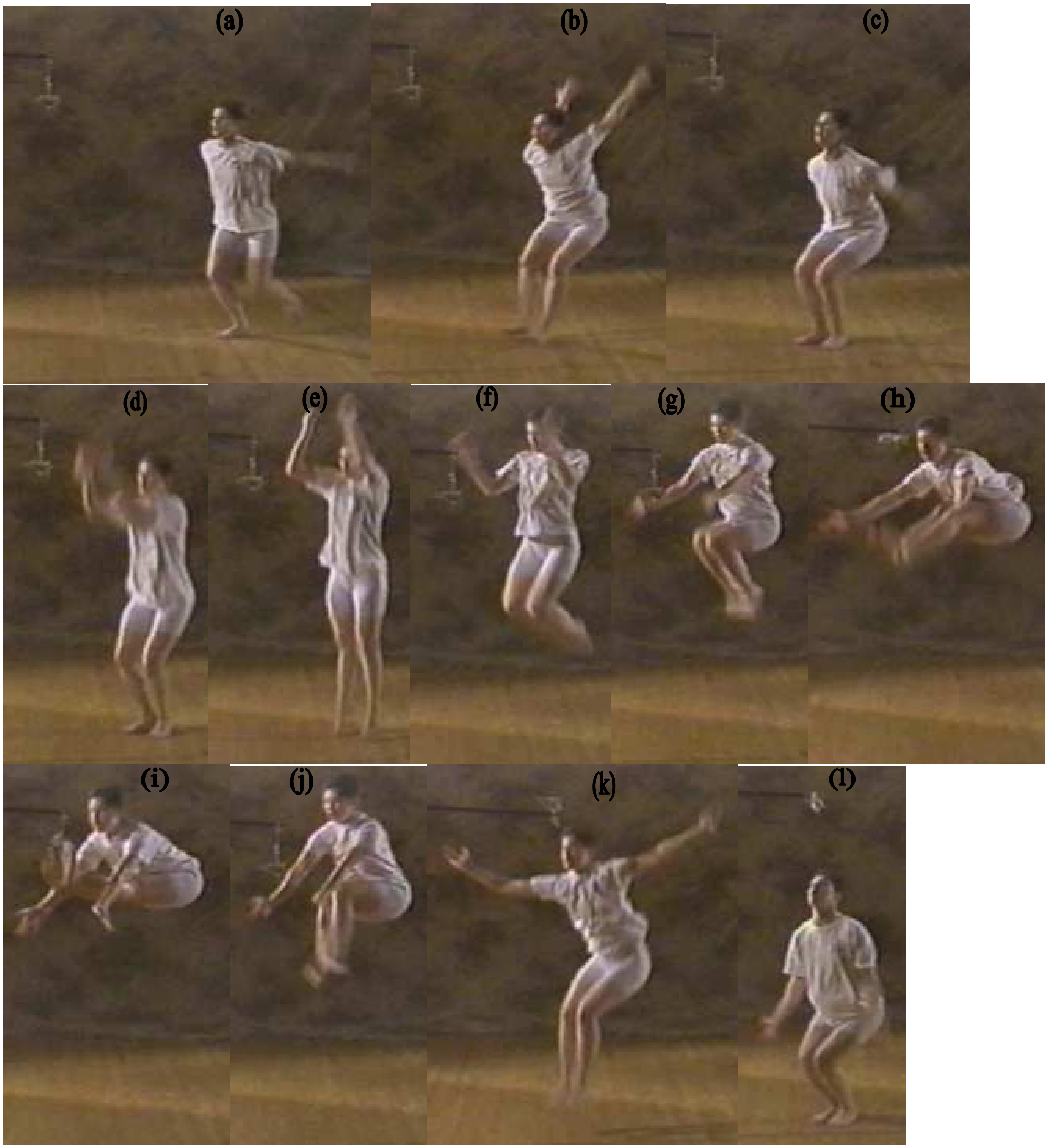


Figure 1-3 (a)&(b) approach phase, (c) backswing phase, (d) force producing phase of the jump, (e) Critical instant of the jump, (f)–(h) force producing phase of the kick, (i) critical instant of the kick, (j)–(l) follow through. (Heine, 2002)

The games are judged based on the height of a successful kick. The competitor with the greatest height of a successful kick is declared the winner. The world records for open male and female one foot high kick are 2.95m (9’8”) and 2.24m (7’4”) respectively. Typically, for the one-foot high kick, an elite male athlete will spend approximately 0.6-0.8sec in the air. The world records for the two foot high kick are 2.64m (8’8”) and 1.96m (6’5”) for males and females respectively. The two foot high kick records are slightly lower than those of the one foot version because of the more demanding position the athlete must achieve to kick the target. An elite male athlete in the two foot high kick will spend approximately 0.6 - 0.8sec in the air, as well. As the approach and jump between the two kicks are the same, the vertical velocity at takeoff and the time spent in the air are almost identical.

As there is no previous literature on the subject of the biomechanics of high kicks, there is a need for some comparison of the high kicks to similar sports skills. As previously mentioned the high kicks are complex and unique movements, therefore there may be several skills that are required for comparison. The approach and jump of this skill was compared to the volleyball spike approach. The one foot kick was compared to martial arts kicks, both standing and jumping. The two foot kick airborne position was compared to the pike position that is common in diving.

The approach and jump of the high kicks are very similar to that of the volleyball spike approach and jump. They both consist of a few steps for an approach and a two foot jump with an arm swing. The topic of the volleyball spike approach and jump has been a topic of interest of many research articles and was therefore a strong comparison for the high kicks.

The one foot high kick technique is very unique in the respect that the athlete must land on the same leg as he/she has kicked the target with. With this in mind, there are very few skills that are similar to the one foot high kick. The martial arts do however, have skills in which the athlete performs a jump with a kick, but the take off is from one foot, the landing is on two feet and it does not emphasize height. Although not as strong of a comparison as the volleyball approach and jump, the martial arts kicks were used in order to draw some comparisons with the one foot high kick (Figure 1-4).

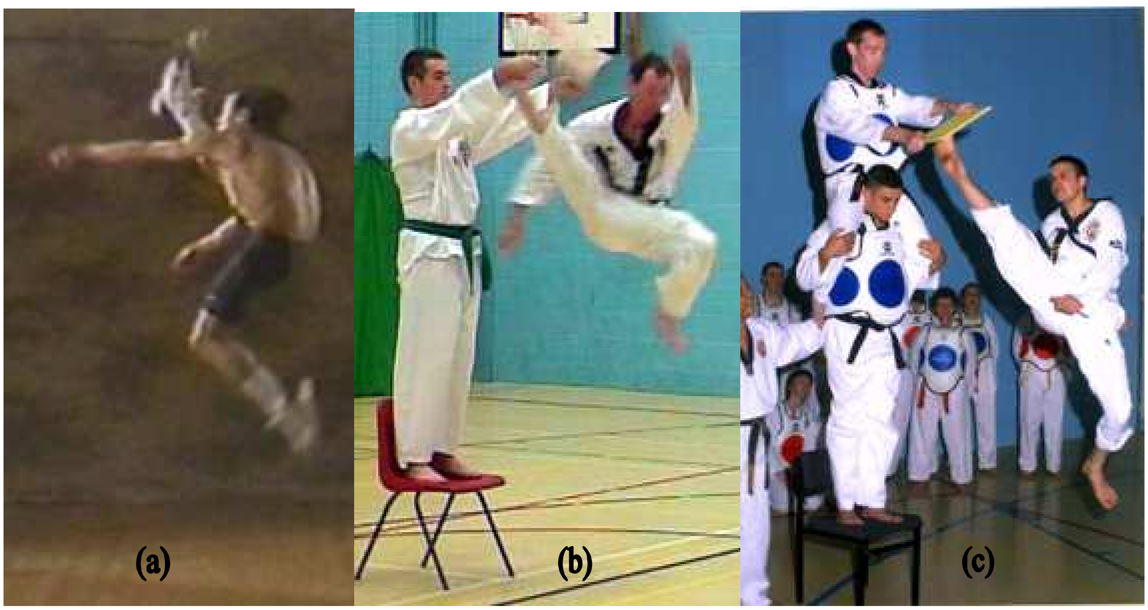


Figure 1-4 a comparison of the one foot high kicker with martial artists (a) One foot high kick (Heine, 2002), (b) & (c) martial arts high snap kick (www.uktaekwondo.co.uk, 2005)

The two foot high kick is a very unique skill and possibly even more unique than the one foot version of the kicks. The uniqueness of the skill comes from the fact that the athlete must touch the target with both feet together and land together as well. It is because of these characteristics; that finding a skill to compare it to is quite difficult. The position that a high kicker is in, upon impact of the target, is a similar position to that of the pike position in diving (Figure 1-5). Both skills require a huge amount of trunk and hip flexibility. Abdominal strength is a requirement in order to bend the body into the pike position. Although the skills are used in different contexts, some comparisons were made.

Figure 1-5 a comparison of a two foot high kicker with an elite diver (a) pike position of the two foot high kick (Heine, 2002) (b) pike position of a diver (Alexander, 2005)

Both high kicks are very difficult and require many physical attributes to perform at a high level. Power, flexibility, body control and timing are all key factors in the success of the skill. These attributes make performing these skills an amazing feat, and worthy of greater understanding. Yet, they have never been scientifically analyzed or researched in detail.

Purpose of the Study

The purpose of this study was to provide a biomechanical analysis of the one foot and two foot high kicks from the Arctic Winter Games and the World Eskimo Indian Olympics using film analysis techniques. An additional purpose of this study was to compare the kinematics of male and female athletes in these events to determine possible gender differences in technique and strategies used in these events.

Hypothesis

1. An optimal technique for the one foot and two foot high kicks will be obtained from the results of the study.
2. Males will have higher values for the measured angles and angular velocities as well as linear velocities throughout the skill.

Rationale for the Study

The analysis of the one foot and two foot high kick will be useful in many situations, such as coaching strategies and use in the sport community in general. When training a beginning athlete, coaches often compare their athletes to elite competitors to identify similarities and differences in technique. An optimal technique for the one foot and two foot high kicks would be beneficial for arctic sports coaches, as it would serve as a basis of comparison for competing athletes. This study will also provide insight into the mechanics of the kicks and suggest differential training techniques. By knowing the most important joint movements to emphasize and the velocities associated with the joints, coaches will be able to use this information to aid them appropriately. A basis for further biomechanical research on the one foot and two foot high kick is another outcome of this study. By creating a base knowledge of the biomechanics of the two kicks, researchers can continue to build on what has already been found from this study. From a technical standpoint, the differences in physical attributes and techniques between genders are also important features. “Males are, on average, 10 cm taller and 10 kg heavier than the average female; males are 30 percent stronger in the lower body and up to 50 percent stronger in the upper body than females; males have faster movement time and reaction time; males have only one-third to one-half of the percent of body fat of females; males have wider shoulders and a higher center of gravity than females" (Alexander, 2001, p. A9). The skill level of males and females may not differ, but the bodies of the two may lead to differing outcomes in the skill. Gaining more exposure to the traditional arctic sports and perhaps traditional games of any culture in general is of great importance. Traditional games are often the basis of many of our major sports and all too often major sports are the topic of interest for biomechanical research and lesser-known games are overlooked.

From a biomechanical perspective, the value of gathering information on performance in these skills is very important. It can act as archival data to be examined later for reference and review of these events. The information may be transferable to other similar sports skills or even across genders. However, possibly the most important aspect is that because these athletes can perform these skills, it challenges our understanding of human limits.

Limitations

1. Selection of athletes is limited to those competing at the Arctic Winter Games and World Eskimo Indian Olympics, which limits the number of subjects and may decrease the generalizability of the results.
2. Due to the lack of literature on the high kicks, there is no data available in which to base the results. Therefore, comparisons must be drawn from past research conducted on similar skills.

Definition of Terms

Anatomical reference position: erect standing position with all body parts, including the palms of the hands facing forward; considered the starting position for body segments. (Hall, 2003)

Angular displacement: change in angular position (Hall, 2003)

Angular impulse: change in angular momentum equal to the product of torque and the time interval over which the torque acts (Hall, 2003)

Angular momentum: quantity of angular motion possessed by a body that is equal to the product of moment of inertia and angular velocity (Hall, 2003)

Angular velocity: rate of change of angular position (Hall, 2003)

Axis of rotation: imaginary line perpendicular to the plane of rotation and passing through the center of rotation (Hall, 2003)

Balance: ability to control equilibrium (Hall, 2003)

Displacement: change in position (Hall, 2003)

Impulse: the product of an applied force and the time over which the force is applied (Hall, 2003)

Momentum: the product of the mass of a body or object and the velocity at which the body or object is traveling (Hall, 2003)

Moment of inertia: inertial property for rotating bodies that increases with both mass and the distance the mass is distributed from the axis of rotation (Hall, 2003)

Torque: rotary effect of a force (Hall, 2003)

Velocity: change in position with respect to time (Hall, 2003)

CHAPTER 2

REVIEW OF LITERATURE

Skill Analysis

Skill analysis is the basis for many biomechanical research studies. When analyzing athletes or any skill, there are five basic phases in which the movements are categorized (Hay, 1993). Each phase has its unique characteristics and its own set of variables to be analyzed. In complex skills, such as the high kicks, there may be multiples of a particular phase, or possibly an overlapping of phases. However, these phases are the basis for most skill analyses. The five phases of skill analysis along with a brief description of the phases are displayed in Table 2-1.

Table 2-1. Skill analysis phases and descriptions

Phase	Description
Preparation/Approach Phase	Movements that occur before the Backswing phase, usually consist of focusing on the target or movements for approaching the target area.
Backswing Phase	These movements are used to prepare the athlete for optimal force producing movements. (e.g. flexing of the hips, knees and ankles prior to a jump)
Force Producing Phase	These movements are performed to produce force for the skill. (e.g. extension of the hips, knees and ankles during a jump)
Critical Instant	This is the instant that is purely a result of previous phases. It is the moment in which the movements of the skill can no longer be changed. (e.g. the instant an athlete leaves the ground in a jump, he/she can no longer change their path of flight)
Follow-Through Phase	The follow-through is any movement following the critical instant. These movements serve mainly to slow down the body to prevent injury. However, they can also be quite important as determinants of success in a controlled landing of the high kicks. The airborne and landing phases act as the follow through in these skills.

(Hay, 1993)

The high kicks are complex movements and therefore should be broken down beyond the five basic phases of analysis. For the two skills, there are actually two force producing phases and two critical instants. The skill should then be divided as follows: Approach, Force Producing (jump), Critical Instant of the Jump (occurs the instant the feet leave the ground), Force Producing (kick), Critical Instant of the Kick (occurs the instant the foot strikes the target) and the Follow Through (landing of the jump). However for the purpose of ease in discussing the skills, the following phases will be used for this study; approach, backswing, takeoff, touch and follow through

High Kick Approach and Jump

The approach and jump for both the one foot and two foot high kicks are exactly the same and will therefore be described together. The similarities between the approach and jump of the kicks and the volleyball spike approach and jump are very strong and will serve as a good basis for comparison.

Preparatory Movements - Approach

The athlete will first identify an appropriate starting position to begin the skill. This position is usually marked out ahead of time, as time constraints become an issue during the competition. Once in the starting position, the athlete uses a running or walking approach to the target. This approach is usually about 3-5 steps and its purpose is to generate horizontal velocity (Figure 2-1). This horizontal velocity will aid in increasing the vertical velocity at take-off. Dapena (1988), states that, at the end of the run up, the planting leg tries to resist flexion, but the forward momentum of the body forces it into flexion. This causes the knee extensors to stretch and produce a stimulation of the muscle that will aid in forceful extension of the knee.

As the athlete moves forward, it is suggested by many researchers that lowering the center of gravity gradually during the approach will greatly increase the distance over which force can be a applied during the jump (Coleman et. al., 1993, Sampson and Roy, 1976). By gradually lowering the center of gravity, the athlete reduces the amount of work that he/she must do to minimize the downward vertical velocity at foot plant. Prior to the last step of the approach the athlete's arms begin to extend.

Figure 2-1 Frontal view of the approach phase
(Heine, 2002)

Backswing Phase

After the last step of the approach, the athlete completes a hop onto both feet, with the feet no greater than shoulder width apart. The hips and knees flex while the ankles dorsiflex to lower the center of gravity; in this position it appears as if the athlete is sitting in an imaginary chair (Figure 2-2). Along with these movements, the arms are extended back behind the athlete and slight trunk flexion is evident. Alexander & Seaborn (1980) suggest that the hips and knees should be flexed to ideally 90 degrees from the anatomical (Figure 2-2b). As well, the movements of these joints are controlled by the eccentric contractions of the hip and knee extensors and the ankle plantar flexors. These eccentric contractions will put the muscles on a stretch and produce a stretch reflex in the muscle that will ultimately generate greater force output. The athlete is now in a position to produce a greater upward vertical force and begin the jump phase of the skill.

(a)

(b)

Figure 2-2 (a) Sagittal view of the backswing movements. (b) Sagittal view of max knee (103.9degrees) and hip (108.2degrees) angles. (Heine, 2002)

Force Producing Phase of the Jump - Takeoff

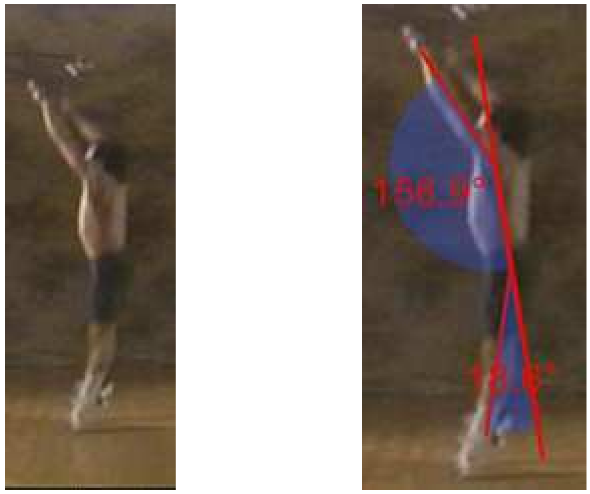
The force producing movements of the jumps are initiated when the backswing phase has ended. In order to create maximal height on the jump, the upward vertical velocity must be maximized during the force-producing phase. It is critical that the force producing movements be initiated immediately after backswing, in order to utilize the stretch reflex in the legs. In this skill the athlete forcefully extends their hips and knees, and plantarflexes the ankles (Figure 2-3) in order to generate more force to increase their upward vertical velocity. This is an application of the impulse momentum relationship, which states that when an impulse acts on a system, the result is a change in the system's total momentum. Or in other words, an impulse (J) is equal to the change in momentum (mv_i – mv_f). An impulse (J) is described as a force (f) multiplied by the time over which it is applied (t). Momentum (M) is the product of the object's mass (m) multiplied by the velocity (v) of the object. When an athlete performs a vertical jump, the greater the impulse applied to the floor, the greater the momentum change and therefore, a higher resulting jump. During the jump it has been proposed that there is a summation of forces from larger muscle joint movements to smaller ones to increase velocity of the limb. Therefore, there would be an adding of forces generated from the hip extension to the knee extension and then to the ankle plantar flexion (Vergroesen et. al., 1982). This summation of forces would also serve to increase the impulse applied to the ground.

The arms may also have an effect on the outcome of the jump. As the arms forcefully flex from behind the body to a position above the head (Figure 2-3), they create a vertical force downward which helps create greater ground reaction forces, which push the athlete off the ground (Hall, 2003). This is according to Newton's third law that states, when a body exerts a force on a second body, the second body exerts a reaction force that is equal in magnitude and opposite in direction on the first body (Hall, 2003). The athlete continues to watch the target in order to make any corrections needed before the critical instant.

Figure 2-3 Sagittal view of force producing phase
(Heine, 2002)

Critical Instant of the Jump - Takeoff

The critical instant is the point during the jump where vertical velocity is maximal and it is this velocity that will determine the height of the jump. At this instant, the body is almost completely vertical (Figure 2-4a). The hips, knees and elbows are in maximum extension (anatomical position), the ankles are plantarflexed, and the shoulders are flexed to approximately 150 –170 degrees (Figure 2-4b). This position suggests that the athlete has extended their joints maximally and has produced a maximal force from all the limbs.



(a) (b)

Figure 2-4 (a) Sagittal view at critical instant. (b) Max hip extension is 18.6 degrees in a flexed position, max shoulder flexion is 156.9 degrees. (Heine, 2002)

Once the athlete is airborne, they become a projectile and are therefore subject to the laws of gravity. Their center of gravity will follow a parabolic path that is predetermined by the vertical and horizontal velocities at take off (Hall, 2003). The vertical velocity of the athlete is maximal at takeoff, but will decrease during flight by the downward acceleration of gravity. At the peak of the jump, the athlete's velocity will be zero and then begin to continually increase with the acceleration of gravity in a downward direction. Nothing the athlete does while airborne will be able to change their set path, and it is therefore important for the athlete to create as much vertical velocity as possible and minimize the horizontal velocity to obtain higher kicks.

The One Foot High Kick

As previously mentioned, the one foot high kick is a relatively unique skill. The martial arts jumping kicks, along with grounded martial arts kicks, will be the closest basis of comparison for the one foot high kick and may help to suggest any possible conclusions about an optimal technique.

Force Producing Phase of the Kick - Touch

At the time of toe off, the athlete must initiate the kick immediately (less than 0.04sec), in order to have enough time to kick the target and land on the same foot. In the martial arts kick it is also essential to initiate the kick quickly, but in order to strike the opponent (Healy, 2000, Hickey, 1997, Park & Seabourne, 1997, Shroeder &Wallace, 1976).

Angular momentum (H) is the quantity of angular motion and is the product of the moment of inertia (I) multiplied by angular velocity (ω). Any change in either the moment of inertia or the angular velocity will have a direct impact on the other in order to keep angular momentum constant. The moment of inertia (I) is the inertial property for rotating bodies that increases with both mass (m) and the distance the mass is distributed from the axis of rotation (k), ($I=mk^2$). For example, an increase in the moment of inertia, will lead to a decrease in the angular velocity. The angular analogy to Newton's first law states that a rotating body will continue to turn about its axis of rotation with constant angular momentum, unless an external couple or eccentric force is exerted upon it (Hay, 1993). Therefore, with an airborne athlete, there are no external forces being applied to him/her, so the angular momentum of the body must be constant.

In the one foot high kick the force producing movements of the kick begin with hip and knee flexion of the kicking leg to about 90degrees, rotation of the arms in a downward direction (shoulder flexion) and flexion of the knee in the non-kicking leg (Figure 2-5). The flexion of the hips and knees are both caused by internal torques produced by the hip and knee flexors about the hip and knee joint, respectively. The rotation of the arms is caused by a torque, which is produced from the shoulder flexors. A torque (T) is defined as a rotary effect of a force and is equal to a force (f) multiplied by the moment arm ($d\perp$), or, the perpendicular distance from the force's line of action to the axis of rotation. A Torque may also be described by Newton's second law as being the product of the moment of inertia (I) multiplied by angular acceleration (α), $T = I\alpha$. According to the angular analogy of Newton's third law, in airborne bodies for every torque exerted by one body on another, there is an equal and opposite torque exerted by the second body on the first. In the airborne athlete, as the kicking leg is rotated in a clockwise direction, the extension of the arms and flexion of the knees are rotated in a counterclockwise direction. These actions are likely used to counterbalance the effects of the kicking leg.

The high kicker will continue to flex the hips and knees until they have reached 90 degrees, at this point, they should be at, or just prior to, the peak vertical height (Heine, 2002). The hip of the kicking leg then flexes past ninety degrees and there is a forceful extension of the knee and plantar flexion of the ankle in order to reach the target. As the lower leg is extended, the arms continue to rotate downward and the trunk may slightly flex to take up the angular momentum produced by the kicking leg.

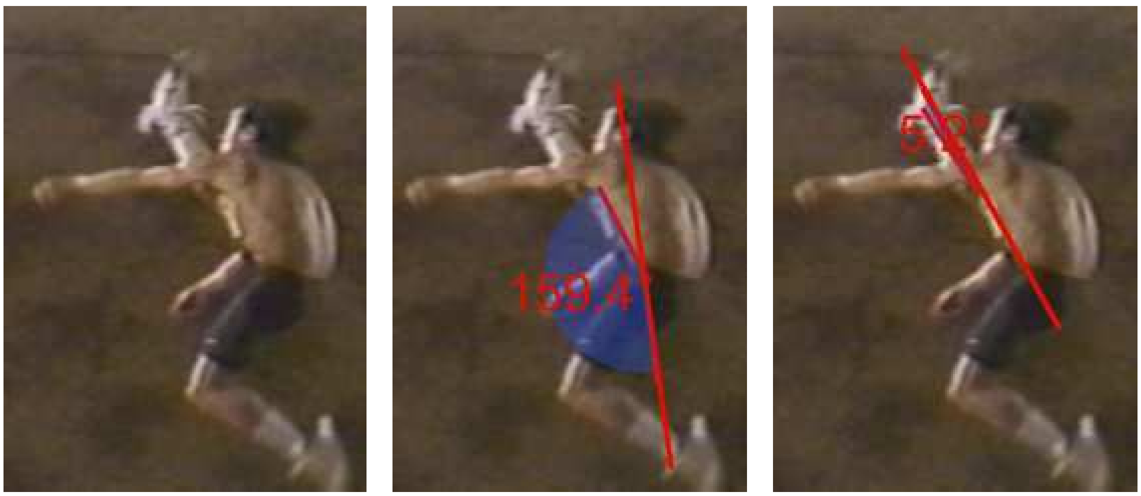
The flexion of the knee in the front snap kick in karate is greater than ninety degrees in order to generate a greater range of motion for force production (Healy, 2000, Shroeder &Wallace, 1976). This is again an application of the angular impulse momentum relationship ($Tt = I\omega_f - I\omega_i$), where the amount of time the torque is applied is lengthened in order increase the momentum of the lower leg. In studies reported by Sorenson et al. (1996), it was indicated that a flexed leg could cause faster kick velocities, as it would decrease the moment of inertia. This information is beneficial to the high kick, as the athlete in the air has little time before landing and must perform a high velocity kick to reach the target. The initial knee flexion will aid in the foot reaching the target faster.

The Chinese jumping front kick is supposed to be a straight leg swing, but is often illustrated and used by elite athletes as a flexed leg swing, (Kan, 1991). In the study conducted by Chen & Huang (1998), it was found that there was no difference in lower leg velocities between the two styles of kick when there was no target. However, Hwang (1987) indicated that when kicking at a target, the velocities of the toes of elite athletes were faster than those of beginners due to the flexed leg and decreased moment of inertia.

Figure 2-5 A sagittal view of the force producing phase of the kick (Heine, 2002)

Critical Instant of the Kick - Touch

As the target is contacted, the athlete's hip is fully flexed (approx. 160degrees), knee fully extended (approx. 5degrees) and ankle fully plantar flexed (Figure 2-6). The snap kick in karate also emphasizes pointing the knee to the target and forcefully extending the knee, but the difference is that while the ankle is plantar flexed, the toes are in an extended position for a better striking surface on the ball of the foot (Sorenson et al., 1996). Peak velocity of the foot in a front kick is between 9.9 –14.4m/s.



(a) **(b)** **(c)**

Figure 2-6 (a) A sagittal/posterior view of the critical instant. (b) Max hip flexion (159.4 degrees). (c) Max knee extension (5.2 degrees) (Heine, 2002)

Follow Through

Once contact has been made with the target, the athlete is required to perform a controlled landing on the kicking leg. In order to do this, the hip of the kicking leg is forcefully extended with slight flexion of the knee and dorsiflexion of the ankle to anatomical position. The arms begin to rotate upward using shoulder flexion and abduction and the hip of the non-kicking leg flexes while the knee extends (Figure 2-6). These movements are, again, to counteract the rotation of the kicking leg. Dissimilar to that, in the snap kick and jumping snap kick, the knee flexes via forceful contraction of the knee flexors. This is taught for a quick recovery to a ready position (Healy, 2000, Hickey, 1997, Park & Seabourne, 1997, Shroeder &Wallace, 1976). By decreasing the moment of inertia of the hip by flexing the knee, the hip should extend faster than if the knee was extended because there is less resistance to rotation. With regard to the high kick, the athlete may benefit from a flexed knee during recovery but it could also put them in an awkward position for landing. Since the athlete is attempting to land on the same leg as they kicked with, flexing the knee during recovery may not be optimal, as they would have to again extend the knee for landing.

Upon contact with the ground, the hip, knee, and ankle of the kicking leg perform a controlled flexion via eccentric contractions in the hip and knee extensors as well as the ankle dorsiflexors. These movements create an impulse in order to decrease the downward momentum of the athlete. The arms continue to counterbalance the rotational effects while the non-kicking leg is flexed at the hip and knee in order to avoid contact with the ground (Heine, 2002) (Figure 2-7). The bouncing of the athlete during landing is also considered part of the exercise.

Figure 2-7 a sagittal/posterior view of the follow through (Heine, 2002)

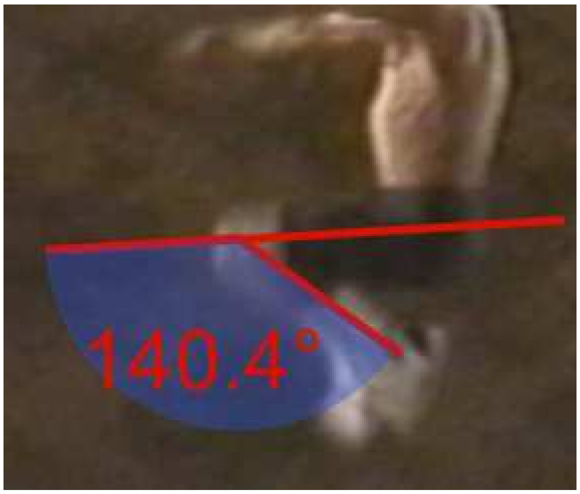
The Two Foot High Kick

Similar to the comparison of the one foot kick and martial arts kicks, the comparison between a pike position in diving the two foot kick is not as valid as the volleyball comparison. However, again, some comparisons must be drawn to help understand this newly analyzed skill.

Force Producing Phase of the Kick - Touch

Just as in the one foot high kick, once the athlete is airborne, the path of the center of gravity cannot be altered. The athlete must initiate the kick almost immediately after the jump, as the time that they are in the air, again, is quite minimal (approx. 0.8sec). Similarly, the competitive diver initiates his/her pike position immediately. However, the diver flexes their trunk forward prior to the take off (O'brien, 2003). This is done in springboard diving to cause a torque for rotation. As the athlete leans forward they move the axis further from the force of the springboard (Hay, 1993).

To initiate the kick, the athlete must flex the knees to near maximum flexion (Figure2-8a). It is noted that in divers, there is no flexion of the knees, the knees are fully extended at take off and continue to stay in an extended position (O'brien, 2003). It is possible that due to the fact that the skills have different outcomes, the flexing of the knees is beneficial for the kicker as they decrease the moment of inertia of the hips in order to flex faster. As the knees of the kicker flex, the hips begin to forcefully flex and the arms rotate downward to oppose the rotation of the legs (Heine, 2002). The hips continue to flex to a position where the knees are almost touching the chest and pointing toward the target (Figure 2-8b). From here, the knees are extended to reach the target and the trunk is flexed to counterbalance the angular momentum of the kicking legs.



(a)

(b)

(c)

Figure 2-8 (a) Max knee flexion (140.4degrees). (b) Hip flexion angle where knee extension begins (115.2degrees). (Heine, 2002)

Critical Instant of the Kick - Touch

When the target is contacted, the body is in a pike position. It is this position that is very similar to the pike position of a diver (Figure 2-9). The position of a diver in a pike position is characterized by a maximal flexion of the hips and trunk, in which the chest of the athlete is pressed against the legs of the diver. The knees are fully extended with the ankles plantar flexed. The arms of the diver are used to pull the legs closer to the body to create what is called a “closed” pike (O’brien, 2003).

A major difference between the two skills in this position is that; whereas the kicker is using the trunk flexion to oppose the rotation of the kicking legs, the diver is actually trying to rotate, so this position is used for more aesthetics as well as to decrease moment of inertia around an axis through the center of gravity to increase the angular velocity (Hall, 1999).

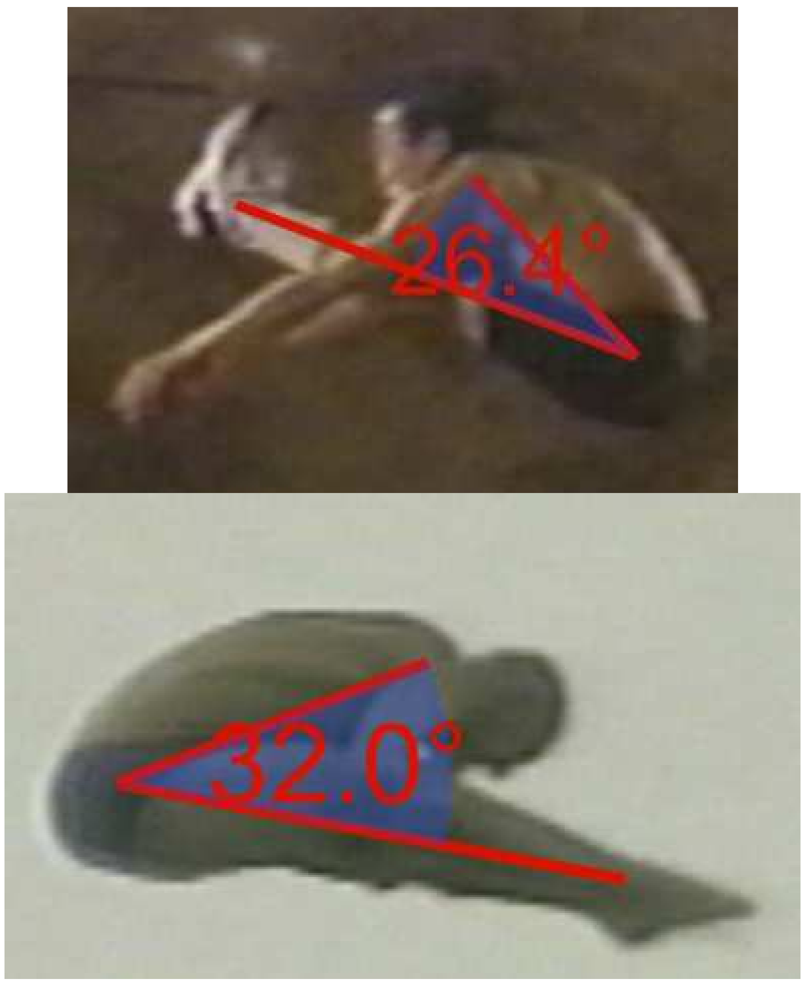


Figure 2-9 sagittal views comparing the “tightness” of the pike

Follow Through

After the target is contacted, the athlete must land on the ground with both feet either touching, or very close to each other. To perform the landing, the knees of the athlete must flex and the arms rotate upward, using flexion and abduction, to counterbalance. When the knees reach about ninety degrees, the hips are then extended and contact with the ground is ready to be made (Figure 2-10). This landing sequence is quite different from both the one foot kick and the opening of a pike dive. In the latter two skills, the knees stay extended as the hips extend. When the athlete contacts the ground, the downward vertical forces are taken up by the eccentric contractions of the flexing hips and knees.

Figure 2-10 Sagittal view of the follow through (Heine, 2002)

Video Analysis

Digital video analysis will be used in this study to investigate the biomechanics of the one foot and two foot high kick. Many researchers use video or film as a main source of insight in order to study athletes in motion. Many movements completed by athletes during particular skills are very fast and observations of fine detail with the naked eye are impractical. By recording the skill on video or film, the researcher is able to slow down the video/film and observe the skill one frame at a time. This is much more useful, as the skill can be broken down into its components and analyzed more effectively.

Biomechanical research has used video for kinematic measurements for many years (Knudson & Morrison, 2002). This trend can be attributed to the fact that video is much more efficient than film. Video is less costly, easier to adjust filming procedures and readily available to watch. By contrast, the overall quality of video is inferior to film, and thus provides a disadvantage. However, the introduction of digital video has improved on this disadvantage significantly. According to Dr. Ron Whittaker, digital video has a much better quality than that of regular video and has been compared to the quality of film under certain situations (www.cybercollege.com/filmtap.htm).

Unfortunately, the problem with video still lies in the speed at which the video is recorded. While digital video is recorded at 30 frames per second, high-speed film cameras can record at speeds in excess of 200 frames per second. There are in fact digital video cameras with high-speed capabilities that provide the same benefits as regular digital video cameras, but the cost is comparable to that of the high-speed film cameras. However through the use Dartfish, the video can be enhanced to 60 fields per second, which is adequate for analysis of most sports skills. As well, according to Knudson and

Morrison (2002), the most important feature for movement analysis is the shutter speed. Although a high shutter speed will not increase the number of frames per second, it will limit the exposure time that each field is scanned (Knudson & Morrison, 2002). This will create less blurred images, but still at a rate of 30 frames per second. Adequate light is needed for higher shutter speed, as there is less time for the film to be exposed. A typical shutter speed for a fast movement would between 1/500 and 1/1000.

Dartfish

"In 1997, after extensive research in image and video processing, SimulCam™ technology was created and developed at the Swiss Federal Institute of Technology in Lausanne, Switzerland" (www.dartfish.com/en/company/history.jsp). A company called InMotion Technologies Ltd. was formed and began to commercially develop digital imaging applications. In 2001, the company quickly expanded and became known as Dartfish, and continues to distribute software packages including, DartTrainer and DartGolfer. Dartfish has been used by many sporting associations around the world for athlete analysis and has received many awards for its innovative technology (www.dartfish.com/en/company/history.jsp). In a statement by Doug Beal, Head Coach, USA Men's National Volleyball Team, "The DartTrainer is the perfect training tool for skill development and technical analysis in volleyball. It's an invaluable tool for coaches at all levels" (www.dartfish.com/en/sport_community/community/feedback.jsp). At a clinical level, Podiatrist Dr. Lou Pack believes the Dartfish software helps patients visualize and understand their progress, provides an improved way to study his patients problems and progress and provides an efficient way of documenting his work with patients to share with other physicians (www.dartfish.com/en/sport_community/community/home.jsp).

The Dartfish DartTrainer is software used for the analysis of sporting techniques, but more accurately the comparison of athletes' techniques. This software makes use of many tools for the biomechanical analysis of sport skills. The SimulCam™ technology that Dartfish was based on is the process of taking two videos and superimposing them over each other and being able to compare the athletes with minimal background interference. The later technology developed by Dartfish was the StroMotion™ analysis tool. With this tool, the analyzer is able to select certain portions of the skill throughout the video and display them on the panoramic background. The ability to zoom in on the image and draw on the film is also very useful. The researcher has the ability to draw lines, circles, text, place markers, and use the spline function when analyzing the video. The spline tool is used to trace the path of a curve, for example, the path of a swinging foot. Perhaps the two most valuable tools for this study are the angle measuring tool and the frame counter. The angle tool is used for measuring angles on the video and can be done in either acute or obtuse form. The frame counter simply displays the time on the film and is accurate to 0.017sec. From these two items, angular displacement, and velocity may be determined. A summary of the key tools to be utilized for this study is shown in table 2-2.

Table 2-2 Summary of key Dartfish Analysis tools

Tool	**Function**
SimulCam^{TM}	Superimposes athletes over top of each other to compare techniques.
StroMotion^{TM}	Provides a single frame view of several key points chosen from the sequence of video.
Angle Tool	Allows the researcher to measure angles of various joints on the body.
Zoom Tool	Allows the researcher to view an enlarged image for closer investigation.
Drawing & Spline Tool	Allows the researcher to draw different shapes or text on the video as well as trace the path of a curved line.
Frame Count	Displays the duration of time for certain segments of the film. (Hours:minutes:seconds:milliseconds/or number of frames)
Distance Tool	Measures distances accurately with its automatic calibration measurement. For example: if one actual distance is known on the video it can convert the length of any other distance measured on the film.

CHAPTER 3

METHODS

One and Two Foot High Kick Analysis

The main purpose of this study was to determine an optimal technique and compare gender differences for the one and two foot high kick. In order to accomplish these goals, three-dimensional filming of the athletes was conducted in competition at the Arctic Winter Games (AWG) as well as the World Eskimo Indian Olympics (WEIO) and later analyzed through video analysis. The athletes were also observed in competition at both the Arctic Winter Games as well as the World Eskimo Indian Olympics. The biomechanics of the athletes' technique was investigated using the high kick film analysis. The data from this analysis was used a measure to evaluate the effectiveness of the kicks as well as obtain an optimal technique for the event. A comparison of gender data was also used to obtain comparison of the different techniques and strategies between the male and female athletes.

Subjects

This study included 12 male and 6 female skilled athletes for the two foot high kick and 9 male and 4 female skilled athletes for the one foot high kick. The athletes were of various ages and from various countries, including Canada, Alaska, Greenland, and parts of Russia. The first filming session took place during the Arctic Winter Games competition at the Fort McMurray Composite High School in Fort McMurray, Alberta. The second filming session took place during the World Eskimo Indian Olympics at the Big Dipper Ice Arena in Fairbanks, Alaska.

While filming these competitions the placement of the camera was directly at the side of the athlete for a sagittal view. The athletes in this study were considered elite as they were competing at the highest level in their events in the Arctic Winter Games as well as the World Eskimo Indian Olympics. All athletes for which ideal camera angles were obtained were used as the subjects for this study. With limited entrants into the competitions and poor camera angles, ten subjects were not available for both female events. The athletes included were free of any medical conditions that could affect skill performance. Prior to the filming of the competition, written informed consent from each participant was obtained. The University of Manitoba's Education/Nursing Research Ethics Board provided the ethical approval for this study.

Filming Technique

Two Canon digital video cameras (Canon Optura 200MC® and Canon GL2®) were used for the filming of the competition, each filming at 3/4ips (18.8mm/sec). As both male and female competitions occured at the same time, one camera was used to film the female competition, while the other was used to film the male competition. The cameras were set outside the designated competition area so as to not interfere with the competition. The cameras were placed in a position such that during the approach and jump, the camera had a direct sagittal view of the athlete. This view was chosen as the primary view because most of the movements performed by the athlete occur in the sagittal plane.

Camera 1 was secured to a tripod approximately 3 - 4.5m from the target and facing perpendicular to the approach of the female athlete. Camera 2 was perpendicular the approach of the male athlete and secured to a tripod approximately 3 – 4.5m from the target as well (Figure 3-1). The researcher adjusted camera positions when needed, to obtain a sagittal view, as different competitors prefer different starting positions and approach paths. The cameras were manually focused with a shutter speed set to 1/500 to ensure that there are no blurred images on the film. The shutter speed for each camera was set the same but the dependency on poor available light forced lower shutter speeds of 1/300 for some portions of the competition at the World Eskimo Indian Olympics.

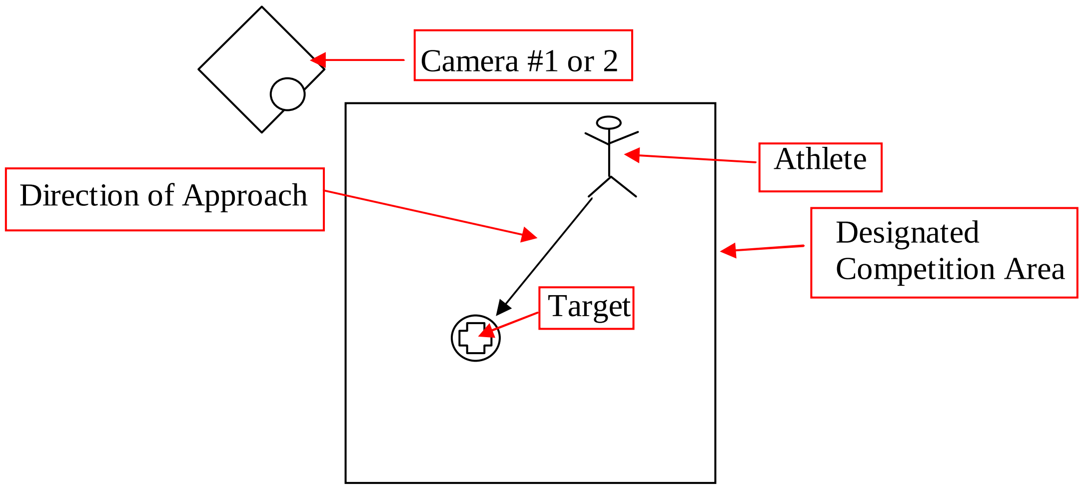


Figure 3-1 *Overhead view of the camera set-up*

Prior to competition, a piece of white tape was placed on the shaft of the target stand 1m from the base at the Arctic Winter Games and 1.03m from the base at the World Eskimo Indian Olympics. This tape was used as a known distance for calibrating measurements from the film during analysis.

Filming Protocol

During filming of the athletes, no instructions were given to them at any time. They were observed only in competition. Athletes were filmed on all of their trials for the two events being analyzed. Due to variations in the starting positions and approach angles of each athlete, the cameras were repositioned accordingly for each individual. This was done by moving the camera in a line perpendicular to the path of their approach in order to observe a sagittal view. The tape on the shaft remained in the same position and was always used as a known distance for calibration.

Video Analysis

As the one foot and two foot high kicks are poorly described skills, the key variables that determine their effectiveness are relatively unknown. However, the high kicks are similar to other sports skills and the known data on these skills were used to identify some of these key variables. For example, it is known that a greater vertical velocity at the instant of takeoff in high jump or in a volleyball spike will yield a greater height jumped by the athlete. It was from these comparisons and several other measurements that the key variables were determined. The variables measured have been broken up and divided into the basic phases previously described.

Preparation/Approach Phase

- Footwork and step pattern
- Horizontal velocity of the athlete prior to the last step and at take-off
- Length of last step
- Foot position in the forward/backward direction
- Shoulder position
- Trunk and head position

Backswing Phase

- Arm position
- Maximum Knee/Hip/Ankle flexion angles
- Trunk/Head flexion angles

Force Producing Phase (jump) - Takeoff

- Arm angular velocity
- Knee/Hip/Ankle angular velocity
- Trunk angular velocity

Critical Instant of the Jump (instant feet leave the ground) - Takeoff

- Maximum Knee/Hip/Ankle extension angles
- Angular velocities of Knee/Hip/Ankle during takeoff
- Arm Position and angular velocity about the shoulder
- Trunk/Head position
- Vertical and horizontal velocity at takeoff
- Height of Jump

Force Producing Phase (kick) - Touch

- Knee/Hip/Ankle angular velocity
- Arm position
- Trunk position and movement description

Critical Instant of the Kick (when foot/feet contact target) - Touch

- Maximum Knee/Hip/Ankle angles
- Angular velocities of Knee/Hip/Ankle
- Arm position description

- Trunk and head position and movement description

Follow Through

- Knee/Hip/Ankle angular velocity
- Arm position description
- Trunk position and movement description

The film analysis for this study was conducted using the Dartfish DartTrainer® software that was installed on a Sony Vaio® laptop computer. The software as well as the data was transferred and the analysis was completed on a Toshiba Qosmio® laptop computer due to technical problems with the Sony Vaio® . Only one trial for each athlete in each of the competitions was selected for analysis. The trial chosen was determined by the kick that produced the greatest height for each athlete. In the case where the camera angle was not ideal for the trial that produced the highest kick, the trial containing the best camera view was used even if the athlete did not successfully kick the target. The best camera view was determined as the video with an unobstructed sagittal view of the athlete

Each trial was copied into the Dartfish program and analysis was conducted. Measurement of the angles of joint movements was recorded by manual placement of the cursor. The entire body was not completely digitized, but rather selected joints were used as a marking system where one mark was placed at the joint center of the axis of rotation, one mark at the joint center of the distal portion of the segment and one mark in line with the joint segment's anatomical position (Figure 3-2). This is consistent with the anatomical reference method of joint angle measurement. However, the measurement of the trunk angle was measured using a point at the hip, a point at the shoulder and then referenced to a directly vertical line (Figure 3-3). The ankle angle was measured as the angle between anatomical position of the ankle and the position it was currently in. Anatomical position for the ankle is a line 90degrees (perpendicular) to the line of the lower leg.

With this, the angle tool from the Dartfish software was used to connect the points and graphically display the angle (Figure 3-2). The video was advanced to the next phase of the skill and the angle measurement was performed again in the same manner. From these two measurements the range of motion (angular displacement) was be found by subtracting the minimum value from the maximum value. If the segment was measured and then moved through a range past the anatomical position, the two angles were added together to obtain the accurate range of motion. The time between the two events was measured using the time indicator in the Dartfish software. The video is viewed at 60 fields per second and therefore the time was measured in 0.017 second increments. Angular velocities of the joint segments were derived from dividing the angular displacement (Ø), measured from the subtraction or addition of joint angles between phases, over the change in time (t), measured from the time indicator as the time between each phase.

Figure 3-2 *Measurement of angles using anatomical reference method*

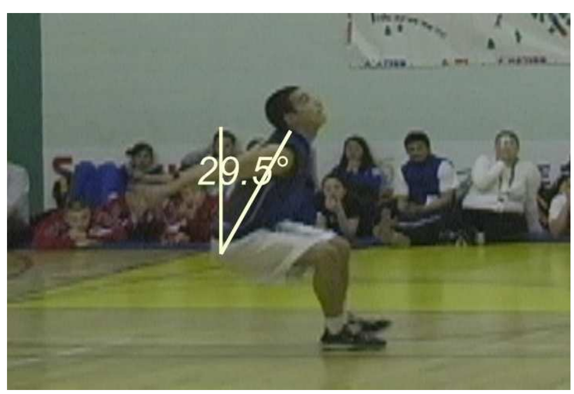


Figure 3-3 *Measurement of trunk angle referenced to vertical*

The horizontal and vertical velocities as well as the height of the jump are three of the most important variables of the high kicks. This is because the higher the athlete is able to jump, the higher the target the athlete will be able to kick. Throughout the skill, linear displacement of the athlete in the horizontal and vertical direction was determined by marking a point on the hip joint and using the calibrated measuring tool from the Dartfish program to measure its displacement. Linear velocity of the athlete was derived from dividing the linear displacement (d), in the vertical or horizontal direction, measured using the measurement tool in Dartfish, over the change in time (t), measured using the time indicator from the software. The length of the last step is also an important part of the skill, as this step will help create a "braking" force to slow the athlete during the approach. The measurement tool from Dartfish was used to determine the length of the last step during the approach phase, by measuring the distance from toe off of the trail leg, to the heel strike of the lead leg. (Figure 3-5)

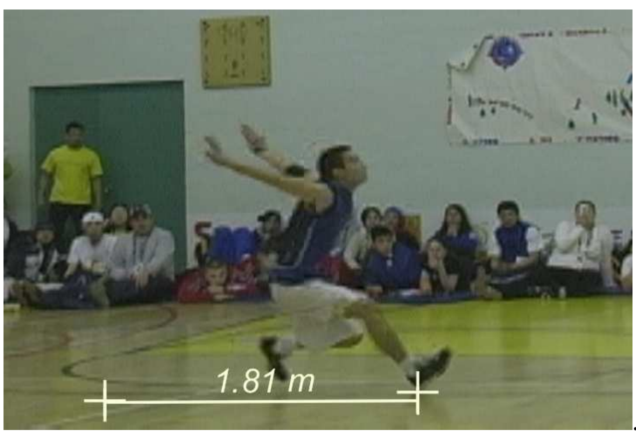


Figure 3-5 *Measurement of step length*

The measured variables were then taken and used to obtain an optimal technique for the two skills. Calculation of descriptive statistics was performed on selected variables by measuring and recording the angles, angular velocities, linear displacements and linear velocities. Qualitative analysis was used for movement descriptions such as approach path. This data was measured and recorded, and then subjected to statistical analysis for further description of these unique skills.

Statistical Analysis

For all the measured variables of the athletes, means and standard deviations were calculated. Male and female data was also compared between the high kick variables to determine any gender differences in physical attributes or techniques. A t-test was used to compare the differences in means between the male and female participants, jump height and biomechanical attributes. Correlation analysis was used to identify any correlations between the measured variables and the jump height for the whole group and for males and females separately. Forward stepwise regression analysis was used determine independence and relative importance of kinematic predictors of performance. The stepwise regression analysis itself not only determines the relationships between the independent variables and the dependent variable, it takes into account interrelationships between independent variables and eliminates them accordingly. The analysis gives you a regression equation that consists of the most important variables in order to predict the vertical velocity at takeoff.

CHAPTER 4

RESULTS

The Dartfish Analysis system was used for video capture and video analysis of the one foot and two foot high kick. Upon collection of data from the Dartfish system, over 50 individual variables were analyzed for 12 male and 6 female subjects of the two foot high kick, and 9 male and 4 female subjects of the one foot high kick.

All means and standard deviations of the variables were calculated to aid in the determination of an optimal technique. Correlation analysis was performed in order to determine the effect of various independent variables on the dependent variable (vertical velocity at takeoff). Regression analysis was used to determine independence and relative importance of kinematic predictors of performance of both skills.

Upon completion of the statistical analysis several significant findings were apparent. This chapter will report the findings of the statistical analysis conducted and give insight into the optimal technique of both the male and female, one foot and two foot high kick.

Two Foot High Kick Analysis

Approach

Three variables were measured during the approach phase of the skill in order to obtain optimal approach technique. The results of the variables measured along with mean values and standard deviations are shown for both male and female athletes in table 4-1. Significant differences were found in both horizontal velocity and foot position in the approach.

Table 4-1 Measured variables and comparison of the approach phase for the two foot high kick

Variables	Males N = 11		Female N=6		p value
	Mean	**SD**	**Mean**	**SD**	
Horizontal Velocity (m/s)	3.62	0.70	2.28	0.39	0.01**
Step length (m)	1.34	0.45	0.79	0.11	0.01*
Foot position (m)	0.15	0.11	0.08	0.05	0.14

***** $p < 0.05$
****$p < 0.01$**

Ten males approached with a straight path towards the target, one approached with curved path, and one athlete's approach was not recorded on video. All six female athletes observed in the two foot high kick approached the target using a straight path. Table 4-2 shows a summary of the approach paths of both male and female athletes.

Table 4-2 Number of athletes per approach path for the two foot high kick

Variable	**Male N=12**	**Female N=6**
Approach Path		
Curved	10	0
Straight	2	6

The t-test showed that there was a significant difference between the approach horizontal velocities of male and female competitors (Figure 4-1). There was almost a 1m/s difference on the horizontal velocities between males and females.

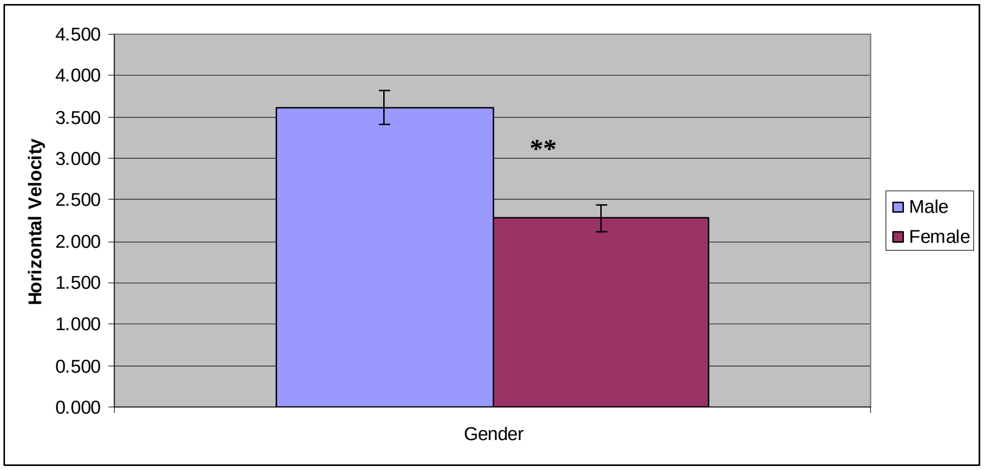


Figure 4-1 *Mean horizontal velocities of male and female athletes during approach of the two foot high kick* ** $p < 0.01$

When comparing the male athletes to the female athletes, a significant difference was found between the step lengths, as males had a much larger step length than females (Figure 4-2). The value for males was 1.34m and 0.79m for females.

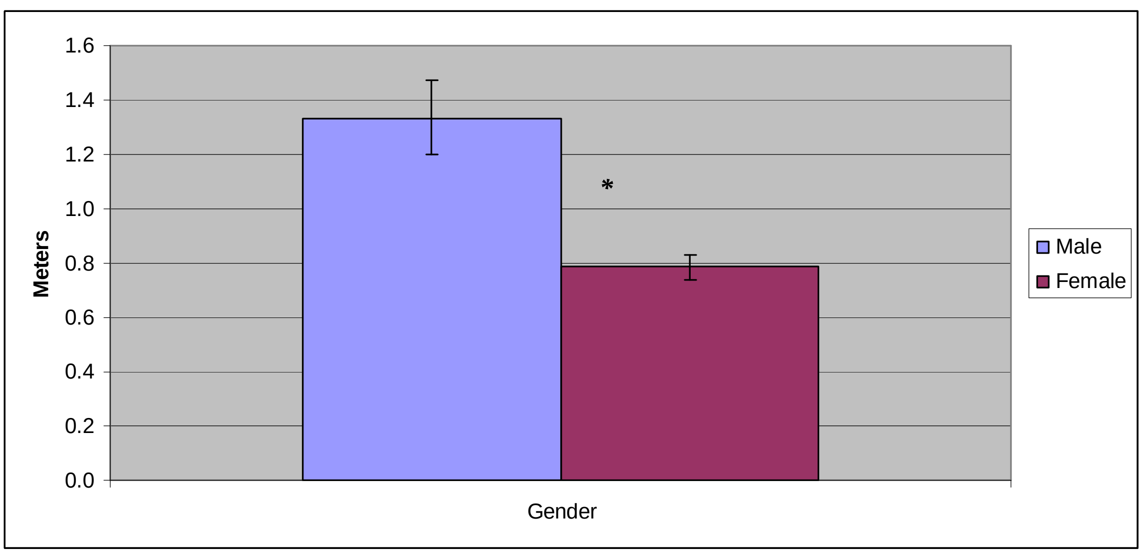


Figure 4-2 *Mean step lengths of male and female athletes during approach of the two foot high kick* *$p < 0.05$

Shown in table 4-3, nine of the male athletes entered the final step of the approach with the left foot forward, whereas only one entered the last step with the right foot. For the females, only two athletes entered the last step with the left foot forward and four entered the last step with the right foot forward.

Table 4-3 Foot placement preference for the two foot high kick

Variable	**Male N=10**	**Female N=6**
Foot Placement		
Right forward	1	4
Left forward	9	2

Backswing

The results for the variables measured for the backswing are detailed in table 4-4 along with the means and standard deviations.

Significant differences were found for two variables in this phase of the skill between male and female athletes. The mean maximum hip flexion by males was 99.68 degrees compared to 86.13 degrees for females (Figure 4-3). The mean for maximum trunk flexion attained by males was also significantly larger than females measuring 30.06 degrees and 23.6 degrees respectively (Figure 4-4).

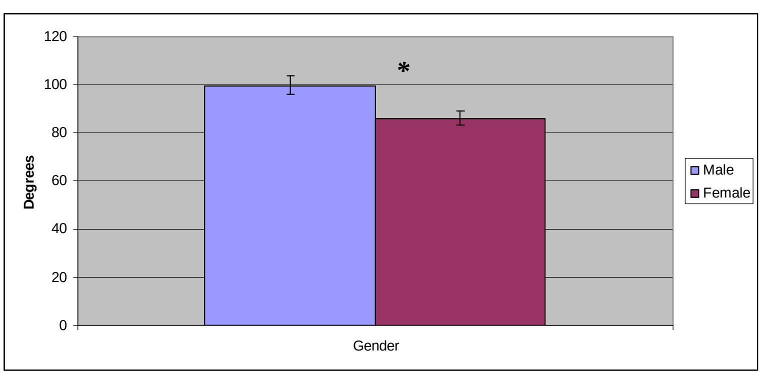


***Figure 4-3** Mean max hip flexion angle of male and female athletes during backswing of the two foot high kick $*p < 0.05$*

Table 4-4 Measured variables and comparison for the backswing phase of the two foot high kick

Variables	**Males N=12**		**Female N=12**		**p value**
	Mean	**SD**	**Mean**	**SD**	
Max Shoulder Extension (degrees)	91.06	12.63	85.75	9.24	0.38
Max Hip Flexion (degrees)	99.68	13.30	86.13	7.59	0.04*
Max Knee Flexion (degrees)	85.29	10.40	85.48	11.08	0.97
Max Ankle Dorsiflexion (degrees)	19.23	7.48	18.10	9.52	0.79
Max Trunk Flexion (degrees)	30.06	6.36	23.60	4.27	0.04*

* $p < 0.05$

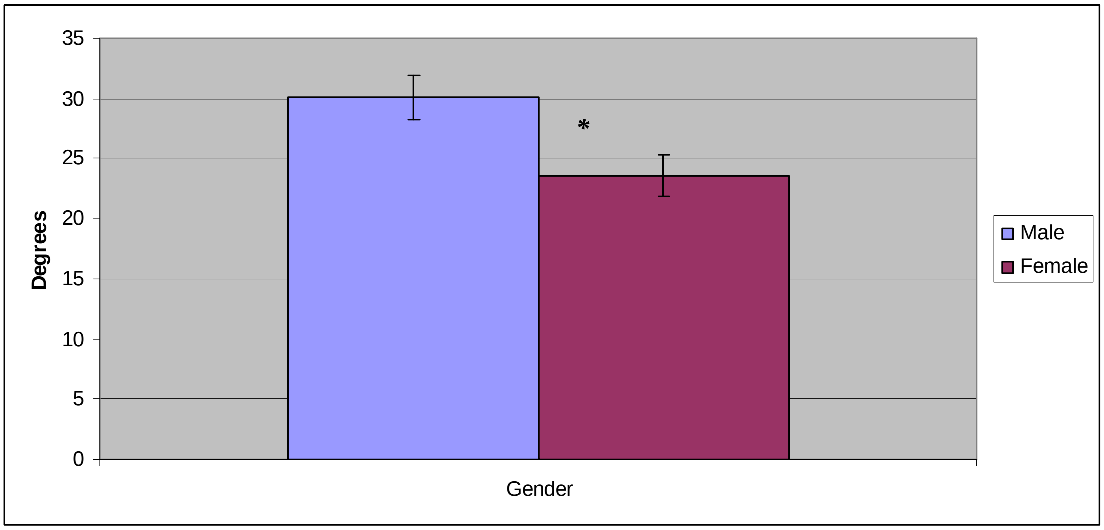


Figure 4-4 *Mean trunk flexion angles of male and female athletes during backswing of the two foot high kick* * $p < 0.05$

Takeoff

A summary of the means and standard deviations of the measured variables are shown in table 4-5. Standard t-tests did not reveal any significant differences for shoulder, knee, ankle, trunk or neck takeoff angles. However, males recorded a significantly larger hip angle at takeoff, 9.35 degrees (hyperextension), when compared to females, 4.117 degrees (hyperextension), suggesting that males had a greater hip extension at takeoff (Figure 4-5).

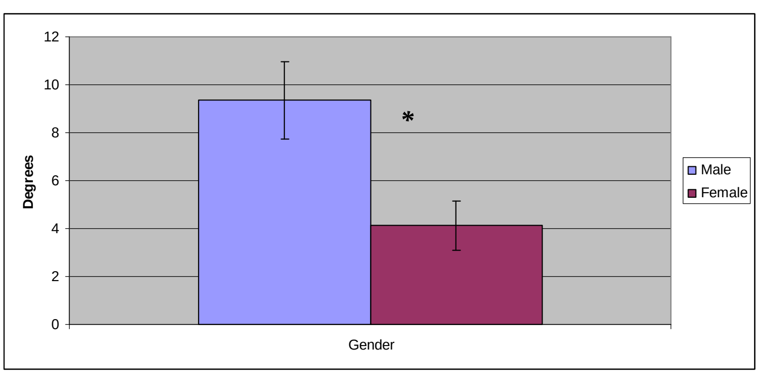


Figure 4-5 *Mean hip hyperextension angles of male and female athletes during takeoff of the two foot high kick* *$p < 0.05$

The angular velocities of shoulder, hip, knee and ankle did not produce any significant difference. The trunk velocity at takeoff for males, however, was significantly larger than for females, 139.45 deg/sec compared to 62.24 deg/sec (Figure 4-6).

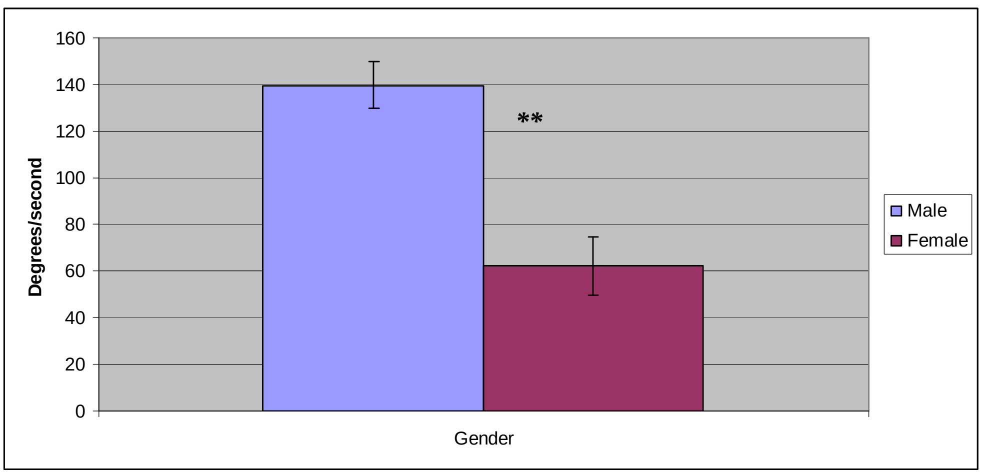


Figure 4-6 *Mean trunk velocity of male and female athletes during takeoff of the two foot high kick* $^{**}p < 0.01$

Table 4-5 Measured variables and comparison for the takeoff phase of the two foot high kick

Variables	Males		Female		p value
	Mean	**SD**	**Mean**	**SD**	
Shoulder Flexion (degrees)	135.83	30.00	126.97	20.03	0.53
Hip Hyperextension (degrees)	9.35	5.58	4.12	2.51	0.05*
Knee Flexion (degrees)	7.53	5.39	11.53	4.78	0.14
Ankle Plantarflexion (degrees)	34.61	24.13	52.93	7.96	0.09
Trunk Hyperextension (degrees)	7.06	9.96	6.60	6.48	0.92
Neck Flexion (degrees)	24.92	11.17	19.65	13.57	0.39
Shoulder Angular Velocity (deg/s)	655.60	118.74	569.95	102.23	0.15
Hip Angular Velocity (deg/s)	396.11	60.49	347.15	18.37	0.07
Knee Angular Velocity (deg/s)	488.45	87.82	494.11	55.91	0.89
Ankle Angular Velocity (deg/s)	498.40	103.52	524.36	119.82	0.64
Trunk Angular Velocity (deg/s)	139.45	34.48	62.24	30.24	0.01**
Vertical Velocity (m/s)	3.66	0.24	2.69	0.21	0.01**

* $p < 0.05$
**$p < 0.01$

As vertical velocity is the main determinant of jump height and one of the most important variables, the vertical velocities of each athlete for both males and females are displayed in Figure 4-7. The most significant difference between male and female athletes in this phase of the skill was seen in the vertical velocity at takeoff.

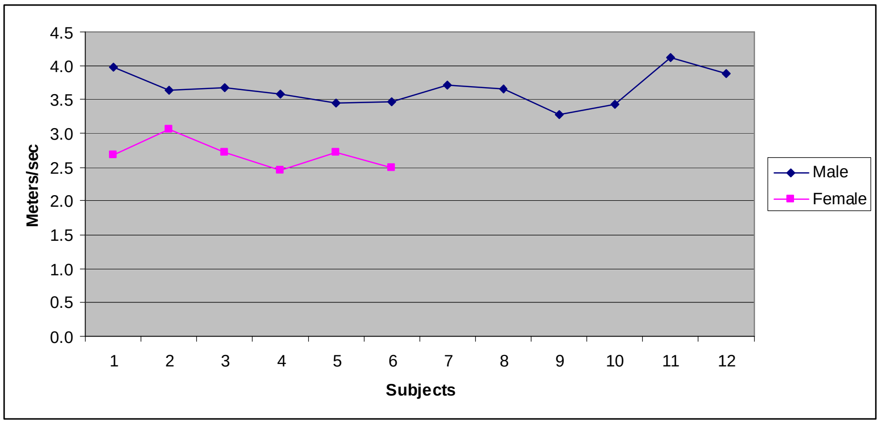


Figure 4-7 *Vertical velocities of male and female athletes at takeoff of the two foot high kick*

Males recorded a mean vertical velocity of 3.66 m/s whereas females recorded a mean vertical velocity of 2.69 m/s. This equals a mean difference of 0.966m/sec which was significant to a p-value of <0.0001 (Figure 4-8).

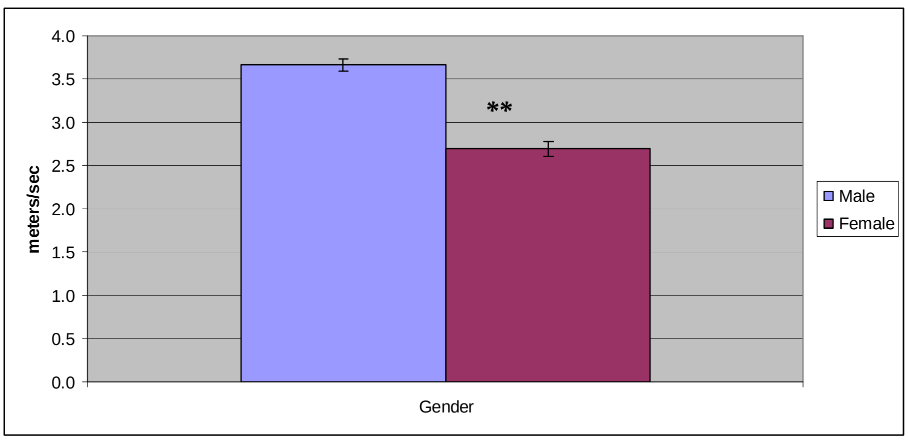


Figure 4-8 *Mean vertical velocities of male and female athletes at takeoff of the two foot high kick* ** $p < 0.01$

Touch

The touch phase of the two foot high kick is the position the athlete obtains when the knee is in full extension/hyperextension. The athlete should make contact with the target in this position. The angular velocities of the body segments were measured from the takeoff position up to the touch position. Results of the angles and velocities measured from this position are shown in Table 4-6.

When comparing the angles achieved by male to female athletes at touch, hip flexion, knee extension, ankle flexion, and neck flexion yielded no significant differences. Females obtained a significantly greater shoulder flexion than male athletes, 122.12 degrees versus 91.37 degrees (Figure 4-9). Figure 4-10 shows that males obtained a significantly greater knee flexion angle of 138.86 degrees compared to 121.52 degrees.

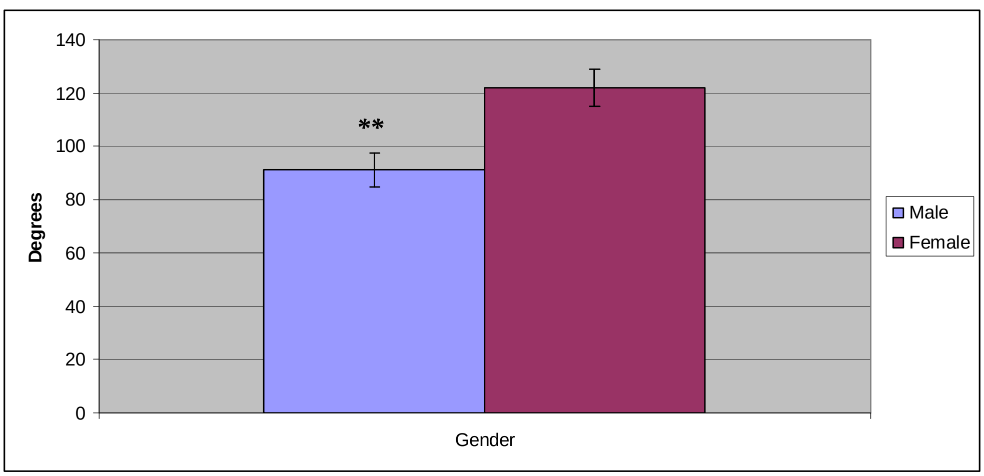


Figure 4-9 *Mean shoulder flexion of male and female athletes at touch of the two foot high kick ** p <0.01*

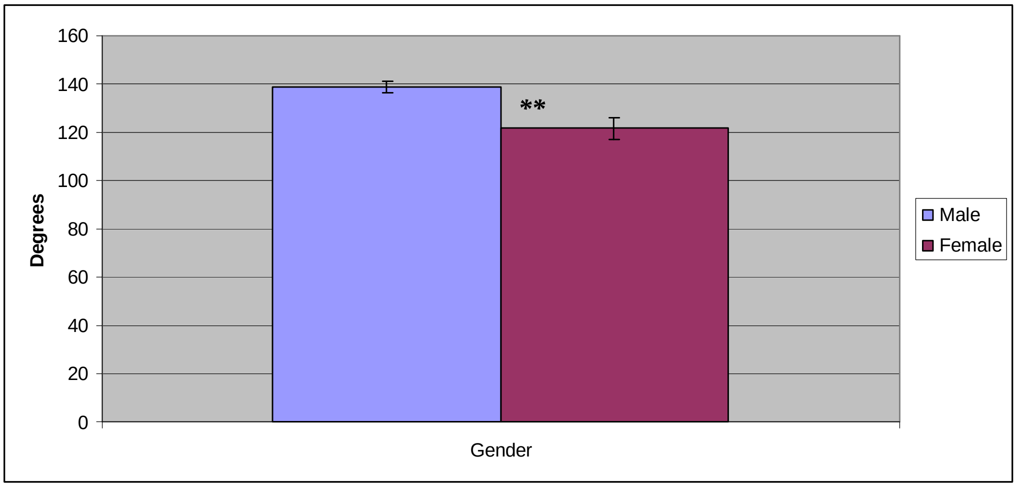


Figure 4-10 *Mean knee flexion of male and female athletes during knee flexion phase of the two foot high kick   * p <, 0.01*

As well, the trunk flexion angle at touch was significantly larger for females, 52.72 degrees, than for males, 43.03 degrees (Figure 4-11).

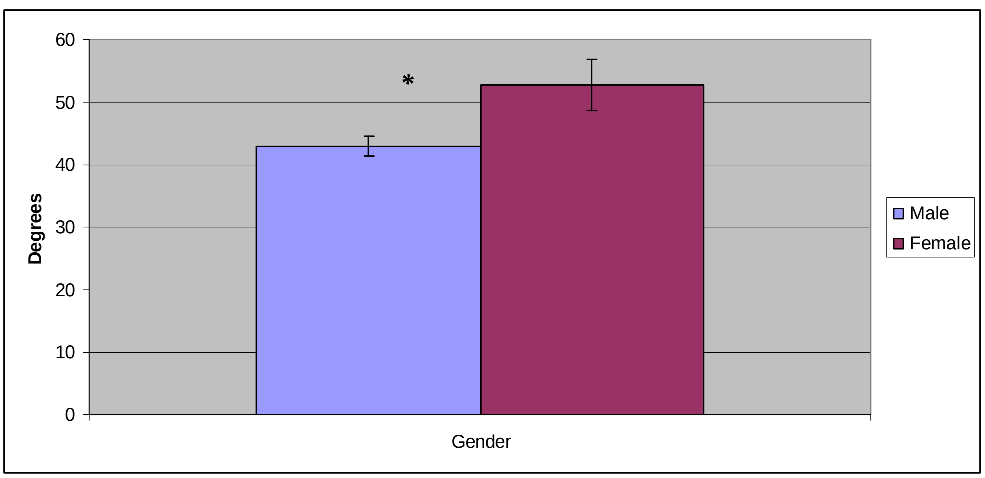


Figure 4-11 *Mean trunk flexion of male and female athletes during touch of the two foot high kick   * p < 0.05*

Table 4-6 Measured variables and comparison for the touch phase of the two foot high kick

Variables	Males N=12		Female N=6		p value
	Mean	**SD**	**Mean**	**SD**	
Shoulder Flexion (degrees)	91.37	22.28	122.12	16.93	0.01**
Hip Flexion (degrees)	164.40	10.72	163.10	6.65	0.79
Knee Flexion (degrees)	138.86	9.11	121.52	10.80	0.01**
Knee Extension (degrees)	-0.18†	10.91	1.45	7.63	0.75
Ankle Flexion (degrees)	-6.27††	12.84	1.63	9.35	0.18
Trunk Flexion (degrees)	43.03	5.43	52.72	9.82	0.01*
Neck Flexion (degrees)	33.28	13.20	29.02	26.40	0.65
Shoulder Angular Velocity (deg/s)	130.72	82.67	78.69	48.97	0.32
Hip Angular Velocity (deg/s)	452.86	65.43	466.60	18.35	0.63
Knee Flexion Angular Velocity (deg/s)	681.85	63.08	608.85	53.48	0.03*
Knee Extension Angular Velocity (deg/s)	829.82	120.34	715.94	64.37	0.05*
Trunk Angular Velocity (deg/s)	137.25	41.65	132.53	29.22	0.81

**p value <0.05*
***p value <0.01*
† hyperextension
†† Dorsiflexion

Angular velocities for shoulder, hip and trunk yielded no significant differences between male and female athletes during the touch phase. However, both knee movement velocities, knee flexion and knee extension, yielded significant differences. A velocity of 681.85 deg/sec was measured for males and 608.86 deg/sec for females during knee flexion (Figure 4-12).

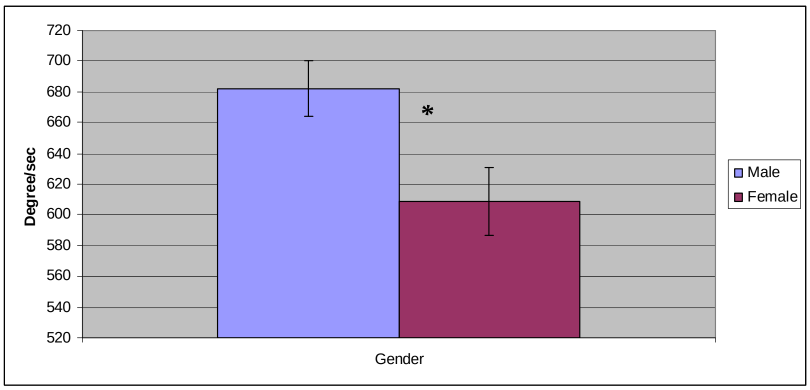


Figure 4-12 *Mean knee flexion velocity of male and female athletes during knee flexion phase of the two foot high kick* * $p < 0.05$

As well, males had a significantly higher knee extension velocity, 829.82 deg/sec, when compared to the female knee extension velocity, 715.935 deg/sec (Figure 4-13).

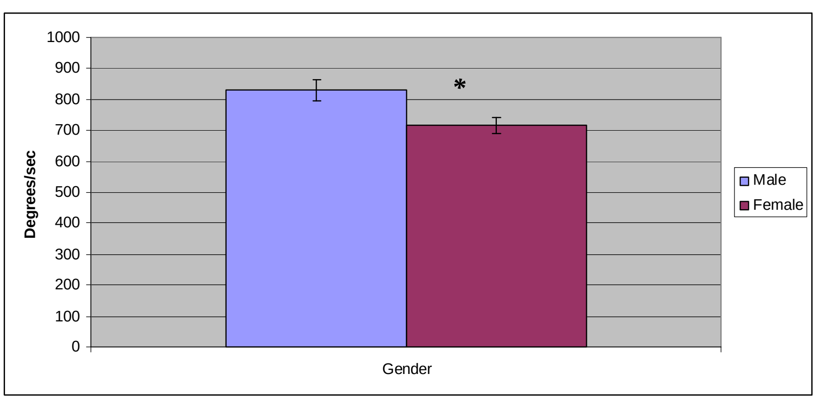


Figure 4-13 *Mean knee extension velocity of male and female athletes during touch of the two foot high kick* * $p < 0.01$

Follow through

The follow through is the phase of the skill that includes all movement after the touch, up to the point of contact with the ground. Angles were measured at point of contact with the ground, whereas angular velocities were measured from the position of touch to contact with the ground. The variables measured and the results of the follow through are shown in Table 4-7.

Of the twelve variables measured in this phase, five were found to be not different. These five variables include; shoulder angle, ankle angle, shoulder velocity, hip velocity, and trunk velocity. During this phase of the skill males had a significantly greater knee flexion angle (114.0 deg vs. 80.68 deg). Figure 4-14 shows the significance.

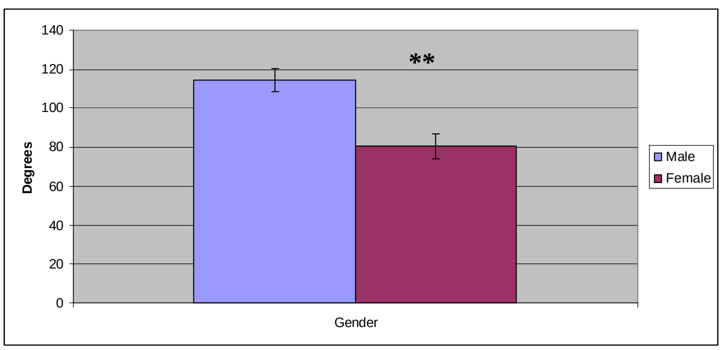


Figure 4-14 *Mean knee flexion of male and female athletes during knee flexion phase of the two foot high kick*
** $p < 0.01$

Mean trunk angle for males, 23.19 deg, was significantly larger than the females' trunk angle of 0.62 deg (Figure 4-15.)

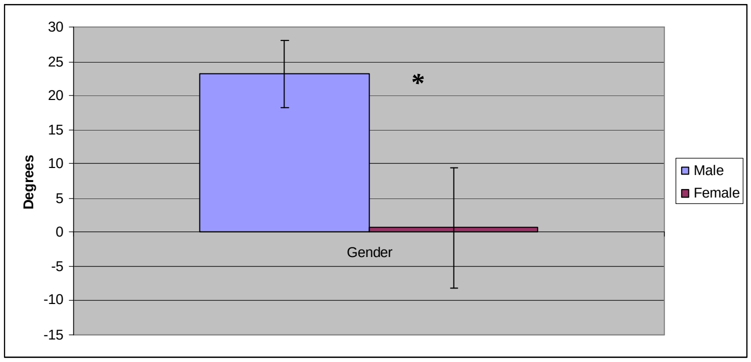


Figure 4-15 *Mean trunk extension of male and female athletes during follow through of the two foot high kick*
** p < 0.05*

Mean knee flexion velocity (526.73 deg/sec vs. 388.40 deg/sec) and mean knee extension velocity (507.46 deg/sec vs. 192.42 deg/sec) were also found to be significantly different (Figures 4-16 and 4-17).

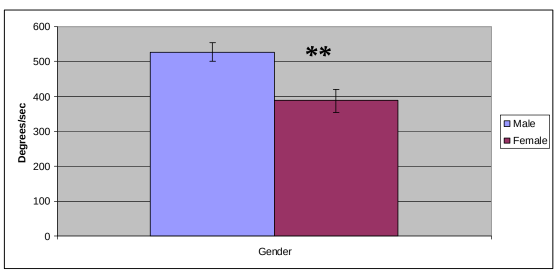


Figure 4-16 *Mean knee flexion velocity of male and female athletes during knee flexion phase of the two foot high kick*
*** p <0.01*

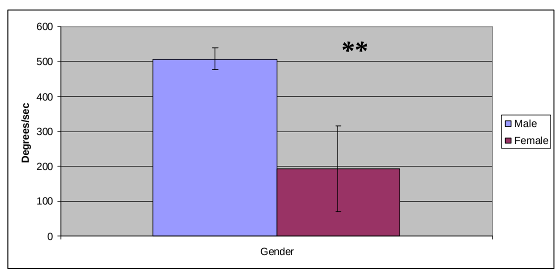


Figure 4-17 *Mean knee extension velocity of male and female athletes during follow through of the two foot high kick*
** p < 0.01

Table 4-7 Measured variables and comparison for the follow through phase of the two foot high kick

Variables	**Males**		**Female**		**p value**
	Mean	**SD**	**Mean**	**SD**	
Shoulder (degrees)	90.80	26.41	74.30	96.81	0.58
Hip Flexion (degrees)	1.67	12.11	50.18	32.92	0.01**
Knee Flexion (degrees)	114.70	20.11	80.68	15.89	0.01**
Knee Extension (degrees)	37.73	9.89	64.30	21.20	0.01**
Ankle Flexion (degrees)	21.85	10.58	30.43	13.701	0.16
Trunk Hyperextension (degrees)	23.19	16.86	0.62	21.67	0.02*
Neck Flexion (degrees)	-5.53†	16.04	22.16	24.49	0.02*
Shoulder Angular Velocity (deg/s)	476.31	51.26	396.07	176.72	0.16
Hip Angular Velocity (deg/s)	437.41	49.04	407.52	116.83	0.45
Knee Flexion Angular Velocity (deg/s)	526.73	93.30	388.40	80.66	0.01**
Knee Extension Angular Velocity (deg/s)	507.46	105.09	192.42	300.76	0.01**
Trunk Angular Velocity (deg/s)	189.86	22.12	188.27	44.01	0.92

**p value <0.05*
***p value <0.01*
† hyperextension

Conversely, females had a significantly greater hip flexion angle (50.18 deg vs. 1.67 deg), knee extension angle (64.30 deg vs. 37.73 deg) at contact with the ground, and neck flexion angle (22.16 deg vs. -5.53 deg). Figures 4-18 through 4-20 show the significant differences of the variables.

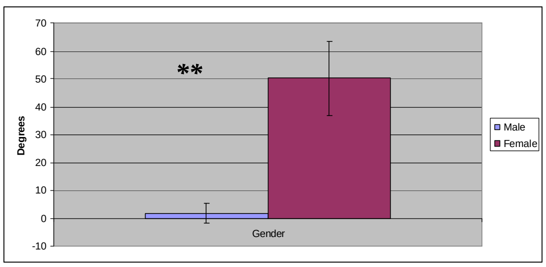


Figure 4-18 *Mean hip flexion of male and female athletes during follow through of the two foot high kick ** p < 0.01*

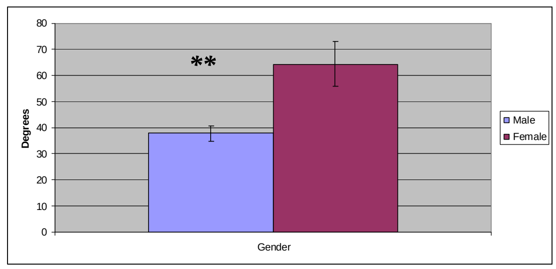


Figure 4-19 *Mean knee extension of male and female athletes during follow through of the two foot high kick ** p <0.01*

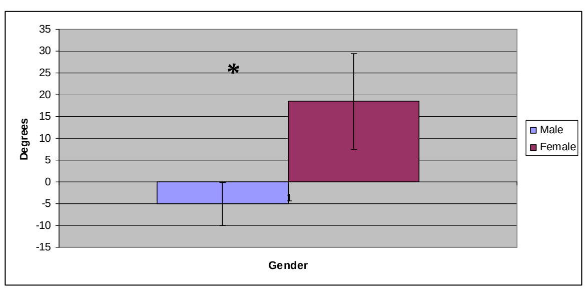


Figure 4-20 *Mean neck flexion of male and female athletes during follow through of the two foot high kick * p <0.05*

One Foot High Kick Analysis

Approach

The approach for the one foot high kick is almost identical to the two foot high kick and therefore the same variables were measured and recorded in order to find optimal technique. Table 4-8 shows the three quantitative variables along with their means and standard deviations, and the significance level for male and female athletes.

During the approach, five of the male subjects approached with a curved path whereas three approached straight on. As for the females, all measured approaches were from straight on. Table 4-9 summarizes the approach paths for both male and female athletes.

Table 4-8 Measured variables and comparison of the approach phase in the one foot high kick

Variables	**Males N = 8**		**Female N = 3**		**p value**
	Mean	**SD**	**Mean**	**SD**	
Horizontal Velocity (m/s)	3.04	0.36	1.99	0.26	0.01**
Step length (m)	1.08	0.20	0.66	0.06	0.01**
Foot position (m)	0.14	0.12	0.07	0.09	0.36

*****p value<0.01***

Table 4-9 Number of athletes per approach path for the two foot high kick

Variable	Male N= 8	Female N=3
Approach Path		
Curved	5	0
Straight	3	3

A standard t-test revealed that both horizontal velocity, during the approach, and step length of the last step were significantly different between males and females. Figure 4-21 shows the horizontal velocities to be 3.04 m/s for male athletes and 1.99 m/s for females. This is over a 1m/s difference in vertical velocity at takeoff.

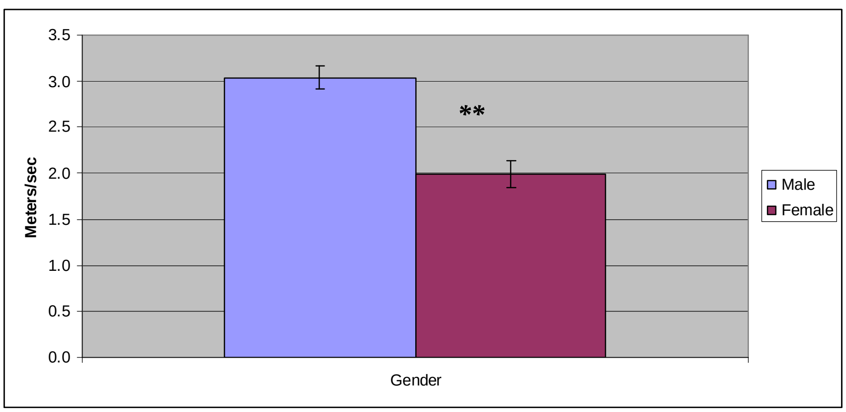


***Figure 4-21** horizontal velocity of male and female athletes during the approach of the one foot high kick* ** $p < 0.01$

Figure 4-22 displays the significance between step lengths for males and females. Males recorded a mean value of 1.08 m whereas females were only 0.66 m

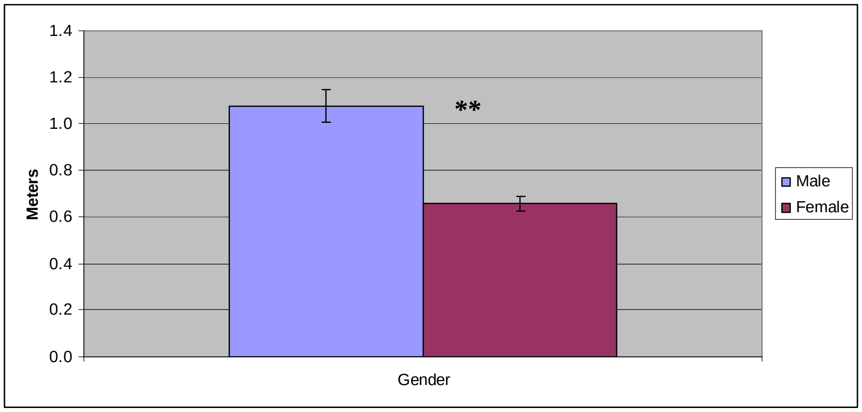


Figure 4-22 Step length *of male and female athletes during the approach of the one foot high kick* ** $p < 0.01$

No significant differences were found for the foot placement distance during the approach. However, athletes did have a preference for which foot was planted ahead of the other. Of the male subjects, seven planted the left foot ahead of the right, compared the one that preferred the right foot ahead. All female subjects planted with the right foot forward. Table 4-10 shows a summary of the foot placements for the one foot high kick.

Table 4-10 Foot placement preference

Variable	**Male N=8**	**Female N=3**
Foot Placement		
Right forward	1	3
Left forward	7	0

Backswing

The variables for the backswing phase of the one foot high kick are the same as for the two foot high kick. However, the results of the measured variables were quite different. The recorded means and standard deviations are shown in Table 4-11.

The t-tests for the gender comparison yielded significant differences in maximum hip flexion and maximum ankle dorsiflexion. Males had a significantly higher hip flexion angle during the backswing phase, 96.68 degrees compared to 80.83 degrees (Figure 4-23).

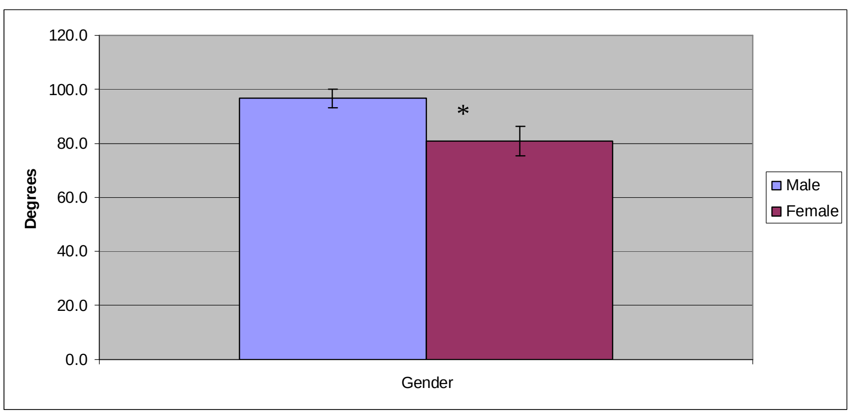


***Figure 4-23 Max hip flexion angle** of male and female athletes during the backswing phase of the one foot high kick *p value<0.05*

Table 4-11 Measured variables and comparison for the backswing phase of the one foot high kick

Variables	Males N = 9		Female N = 4		p value
	Mean	**SD**	**Mean**	**SD**	
Max Shoulder Extension (degrees)	91.67	17.43	88.13	9.85	0.75
Max Hip Flexion (degrees)	96.68	10.08	80.83	10.81	0.03*
Max Knee Flexion (degrees)	96.01	12.19	87.13	8.56	0.22
Max Ankle Dorsiflexion (degrees)	32.69	5.91	23.55	7.55	0.04*
Max Trunk Flexion (degrees)	33.23	11.39	21.75	5.08	0.08

** pvalue <0.05*

Maximum ankle dorsiflexion also produced significant differences between males (32.69 degrees) and females (23.55 degrees) (Figure 4-24).

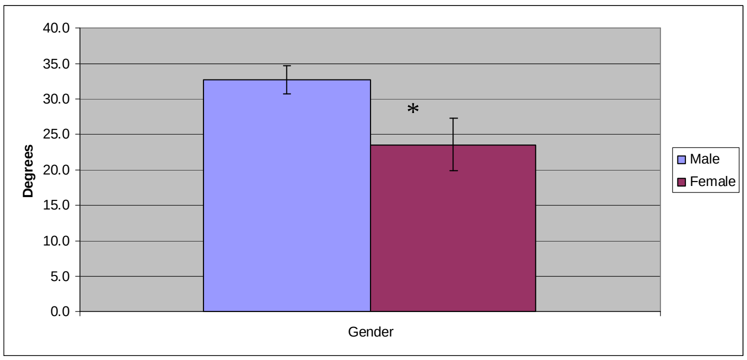


Figure 4-24 Max ankle dorsiflexion angle *of male and female athletes during the backswing phase of the one foot high kick *p value<0.05*

Takeoff

The results of the measured angles and angular velocities of the one foot high kick are listed in table 4-12. The results of the comparison tests between males and females for this phase of the skill indicated that of the twelve measured variables only one was found to have a significant difference. Vertical velocity at takeoff for males was recorded at 3.45 m/s compared to the female mean takeoff vertical velocity of 2.83 m/s (Figure 4-25).

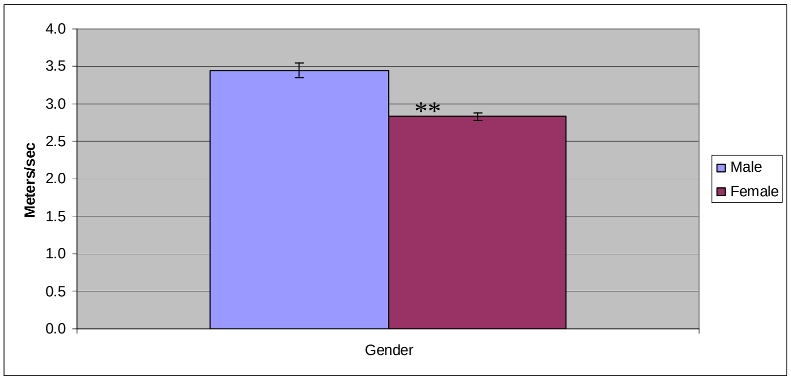


Figure 4-25 Vertical velocity *of male and female athletes during takeoff phase of the one foot high kick* ***p value<0.01*

Just as in the two foot high kick, vertical velocity is the main determinant of jump height and the most important variable, the vertical velocities of each athlete for both male and female are charted in figure 4-26.

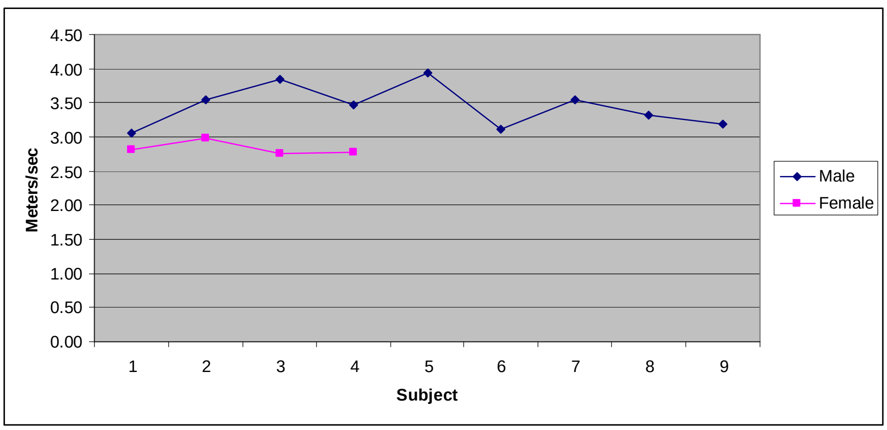


Figure 4-26 *Vertical velocities of male and female athletes at takeoff of the one foot high kick*

Table 4-12 Measured variables and comparison for the takeoff phase of the one foot high kick

Variables	**Males N = 9**		**Female N = 4**		**p value**
	Mean	**SD**	**Mean**	**SD**	
Shoulder Flexion (degrees)	140.51	16.61	128.63	31.83	0.39
Hip Hyperextension (degrees)	5.41	6.38	1.98	11.51	0.50
Knee Flexion (degrees)	6.79	5.50	13.08	11.21	0.19
Ankle Plantarflexion (degrees)	41.44	4.39	44.78	7.28	0.32
Trunk Hyperextension (degrees)	-8.58	5.30	-7.05	8.48	
Neck Flexion (degrees)	33.22	10.21	20.33	20.23	0.15
Shoulder Angular Velocity (deg/s)	592.39	88.58	558.80	119.98	0.58
Hip Angular Velocity (deg/s)	411.93	58.73	374.19	39.473	0.27
Knee Angular Velocity (deg/s)	607.62	96.82	560.47	69.35	0.40
Ankle Angular Velocity (deg/s)	535.89	127.98	578.01	117.50	0.57
Trunk Angular Velocity (deg/s)	140.99	43.87	132.53	30.03	0.74
Vertical Velocity (m/s)	3.45	0.31	2.83	0.10	0.01**

***p value <0.01*

Touch

The touch phase of the one foot high kick included 18 measured variables. The results of these measurements, means and standard deviations, are given in Table 4-13.

The variables identified as being significantly different for joint position during the touch phase were; right shoulder flexion and right knee flexion during the knee flexion phase of the skill. Figures 4-27 and 4-28 show the differences in these two variables.

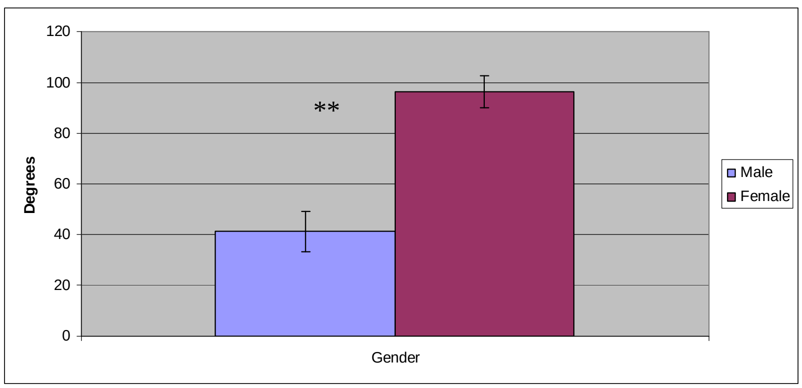


***Figure 4-27 Right shoulder flexion angle** of male and female athletes during the touch phase of the one foot high kick* ***p value<0.01*

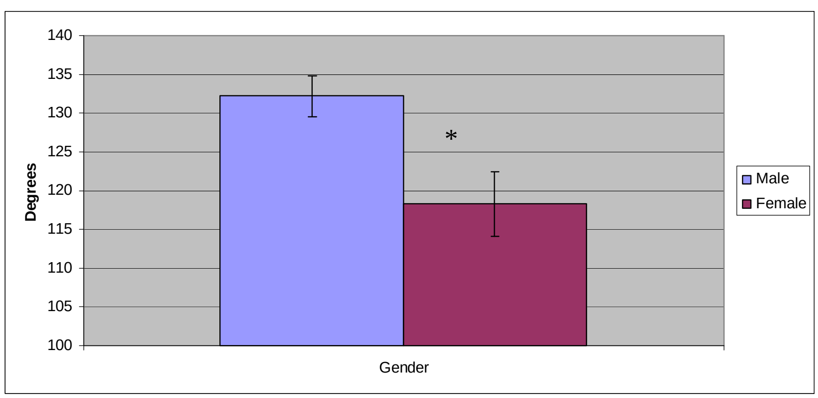


***Figure 4-28 Right Knee flexion angle** of male and female athletes during the knee flexion phase of the one foot high kick* **p value<0.05*

Table 4-13 Measured variables and comparison for the touch phase of the one foot high kick

Variables	Males N = 9 Mean	SD	Female N = 4 Mean	SD	p value
Left Shoulder Flexion (degrees)	78.83	35.73	100.35	8.16	0.23
Right Shoulder Flexion (degrees)	41.22	23.53	96.40	12.79	0.01**
Left Hip Flexion (degrees)	33.83	19.03	48.60	3.02	0.16
Right Hip Flexion (degrees)	148.38	20.72	154.60	9.59	0.58
Right Knee Flexion (degrees)	132.22	7.98	118.30	8.28	0.02*
Left Knee Extension (degrees)	64.95	18.53	89.65	27.41	0.09
Right Knee Extension (degrees)	7.24	9.47	4.20	8.29	0.59
Left Ankle Plantarflexion (degrees)	34.08	9.47	40.15	16.26	0.42
Right Ankle Flexion (degrees)	24.90	26.16	13.35	21.42	0.46
Trunk Flexion (degrees)	14.24	13.22	22.30	7.58	0.29
Neck Flexion (degrees)	14.02	18.05	19.70	13.42	0.59
Left Shoulder Angular Velocity (deg/s)	163.08	105.634	84.41	105.16	0.24
Right Shoulder Angular Velocity (deg/s)	266.74	72.33	97.06	66.79	0.01**
Left Hip Angular Velocity (deg/s)	90.59	53.50	153.53	28.47	0.05*
Right Hip Angular Velocity (deg/s)	412.25	57.35	474.83	52.86	0.09
Right Knee Flexion Angular Velocity (deg/s)	673.03	88.49	587.14	84.21	0.13
Knee Extension Angular Velocity (deg/s)	638.22	56.53	777.04	94.39	0.01**
Trunk Angular Velocity (deg/s)	60.25	37.77	88.87	39.06	0.24

**p value <0.05*
***p value <0.01*

Significant differences in angular velocities for this phase were found in the right shoulder angular velocity, left hip angular velocity and right hip extension angular velocity. Males had a much larger right shoulder angular velocity, 266.74 deg/sec, versus 97.06 deg/sec for females (Figure 4-29).

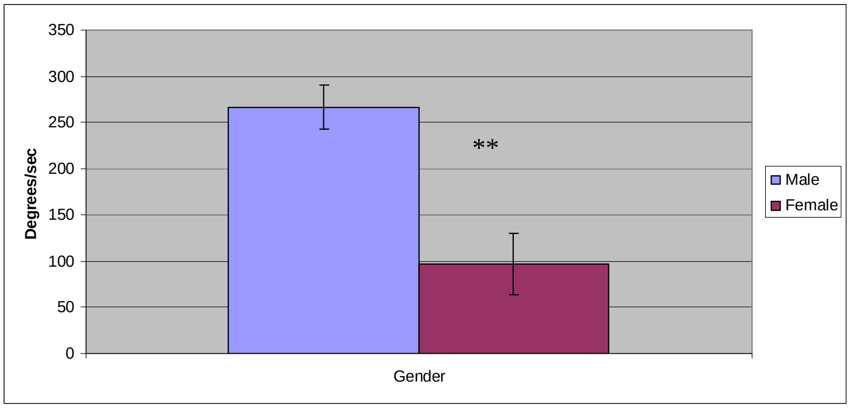


Figure 4-29 Right shoulder angular velocity *of male and female athletes during the touch phase of the one foot high kick *p value<0.01*

However, females recorded a significantly higher left hip angular velocity (Figure 4-30), 153.53degrees/sec versus 90.59 degrees/sec, and knee extension angular velocity (Figure 4-31), 777.04 degrees/sec compared to 638.22degrees/sec.

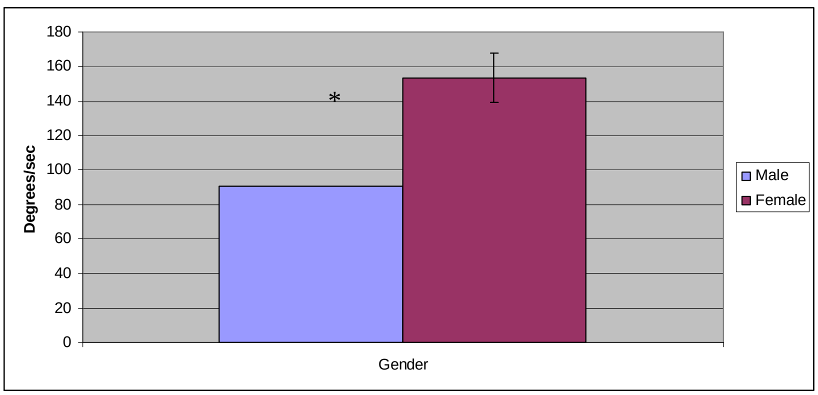


Figure 4-30 Left hip angular velocity *of male and female athletes during touch phase of the one foot high kick *p value<0.05*

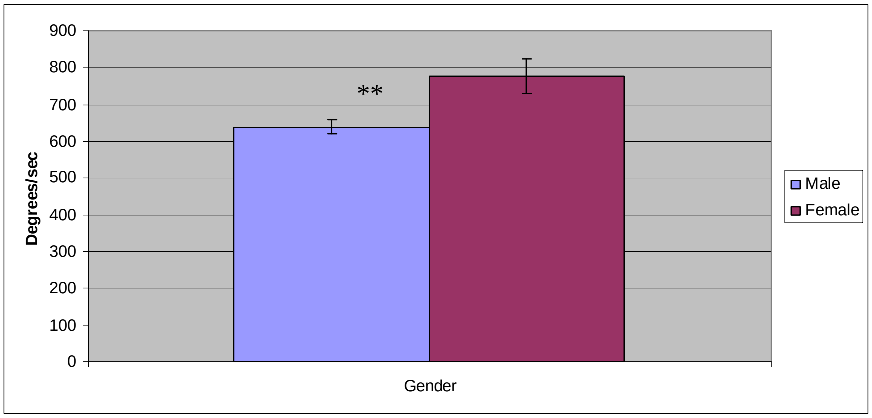


***Figure 4-31 Right knee extension angular velocity** of male and female athletes during the touch phase of the one foot high kick **p value<0.01*

Follow through

The follow through results, including the means and standard deviations of all the variables for this phase are listed in Table 4-14. The joint angles for this phase of the skill had a large number of differences between males and females. Both left and right hip flexion resulted in significant differences with males having a larger left hip flexion angle, 123.27 deg vs. 91.38 deg, (Figure 4-32) and females having a larger right hip flexion angle, 55.30 deg vs. 21.59 deg (Figure 4-33).

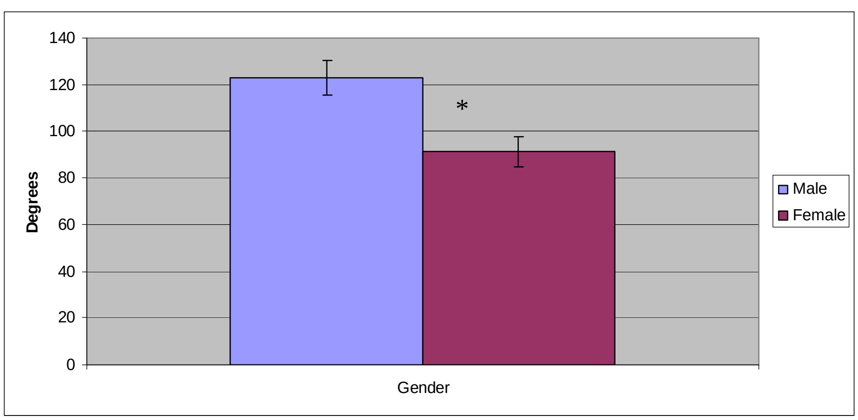


***Figure 4-32 Left hip flexion angle** of male and female athletes during the follow through phase of the one foot high kick *p value<0.05*

Table 4-14 Measured variables and comparison for the follow through phase of the one foot high kick

Variables	Males N = 9 Mean	SD	Female N = 4 Mean	SD	p value
Left Shoulder Flexion (degrees)	85.25	31.72	100.10	33.04	0.47
Right Shoulder Flexion (degrees)	136.214	20.29	n/a	n/a	n/a
Left Hip Flexion (degrees)	123.27	22.25	91.38	12.83	0.02*
Right Hip Flexion (degrees)	21.59	17.96	55.30	20.33	0.01*
Left Knee Flexion (degrees)	37.43	17.41	47.23	53.10	0.61
Right Knee Flexion (degrees)	26.19	6.38	41.38	10.54	0.01**
Left Ankle Flexion (degrees)	8.56	9.29	11.70	24.09	0.73
Right Ankle Flexion (degrees)	35.20	10.16	29.05	7.13	0.30
Trunk Flexion (degrees)	2.72	12.95	20.75	12.07	0.04*
Neck Flexion (degrees)	12.89	21.52	23.58	21.13	0.43
Left Shoulder Angular Velocity (deg/s)	615.16	109.65	651.59	134.50	0.62
Right Shoulder Angular Velocity (deg/s)	595.00	142.20	n/a	n/a	n/a
Left Hip Angular Velocity (deg/s)	290.25	107.21	178.053	67.95	0.08
Right Hip Angular Velocity (deg/s)	407.54	123.38	400.15	52.92	0.91
Left Knee Extension Angular Velocity (deg/s)	85.46	82.46	n/a	n/a	n/a
Right Knee Extension Angular Velocity (deg/s)	58.58	24.84	153.75	58.28	0.01**
Trunk Velocity (deg/s)	31.72	64.12	3.47	39.62	0.44

**p value <0.05*
***p value <0.01*

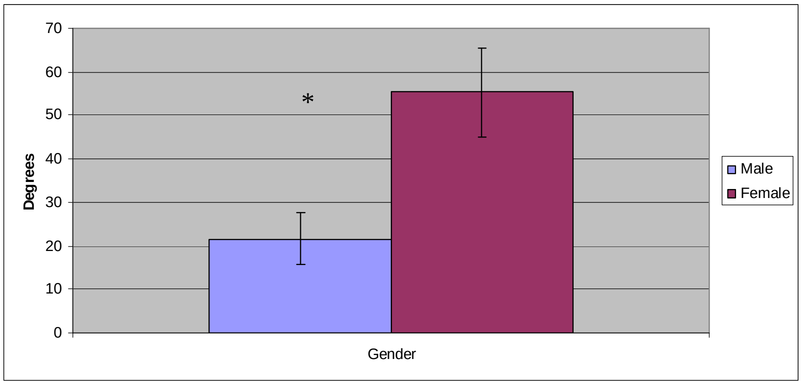


***Figure 4-33 Right hip flexion angle** of male and female athletes during the follow through phase of the one foot high kick* **p value<0.05*

Females also had a significantly greater right knee angle, 41.38 degrees versus 26.19 degrees (Figure 4-34), and trunk angle, 20.75 degrees compared to 2.72 degrees for males (Figure 4-35), during the follow through.

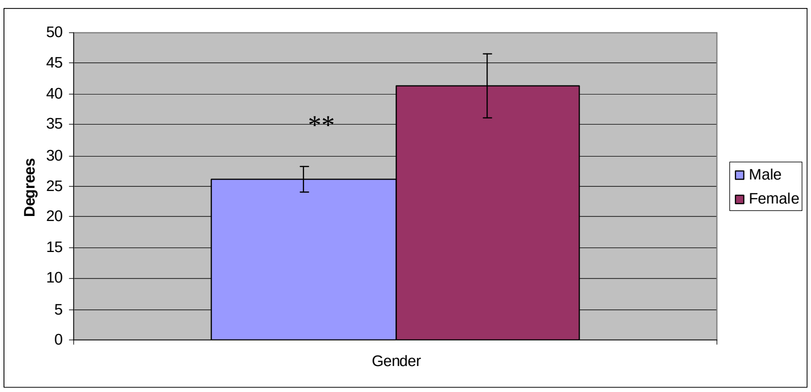


***Figure 4-34 Right knee angle** of male and female athletes during the follow through phase of the one foot high kick* ***p value<0.01*

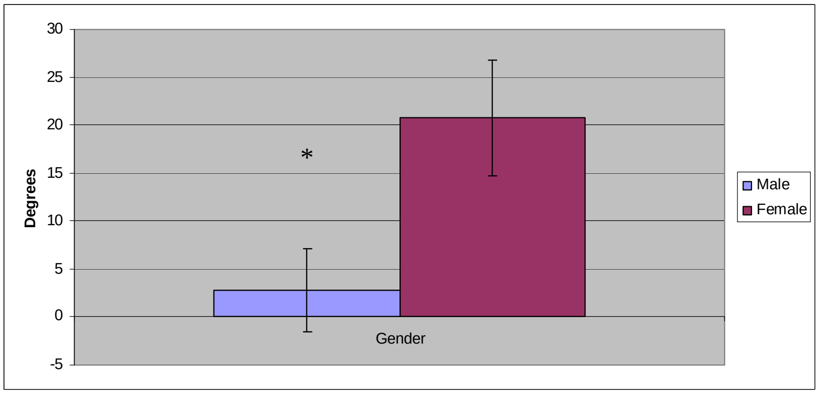


Figure 4-35 Trunk angle *of male and female athletes during the follow through phase of the one foot high kick *p value<0.05*

With regard to the angular velocities in this phase, only right knee extension angular velocity recorded a significant difference. The female athletes recorded a mean angular velocity of 153.75 degrees/sec whereas male athletes had a mean angular velocity of 58.58 degrees/sec (Figure 4-36).

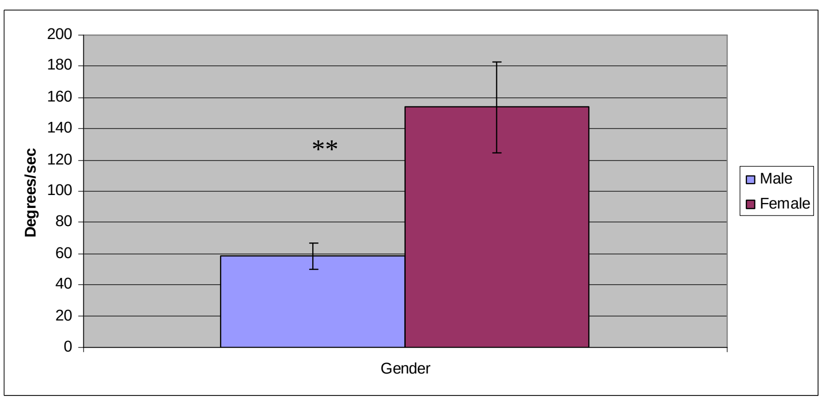


Figure 4-36 Right knee extension angular velocity *of male and female athletes during the follow through phase of the one foot high kick **p value<0.01*

Kinematic Predictors of Vertical Velocity of the One and Two Foot High Kick

As comparison between male and female subjects was a subproblem, it was important to find the variables that had a significant impact on the outcome of the skill in order to describe an ideal technique. A listwise correlation test was done to find relationships between variables and vertical velocity at takeoff. After correlations were completed, a stepwise multiple regression analysis was used to determine the most important variables that would predict vertical velocity at takeoff.

Correlation Analysis

Table 4-15 shows a list of variables that had a strong correlation to male/female takeoff vertical velocities of the one foot high kick. The variables showing the strongest correlations for the male one foot high kick were (Figures 4-37 and 4-38); horizontal velocity of the approach (r = 0.764, p value = 0.024) and ankle takeoff velocity (r = 0.708, p value = 0.031). There were no statistically significant results for the correlation data of the female one foot high kick.

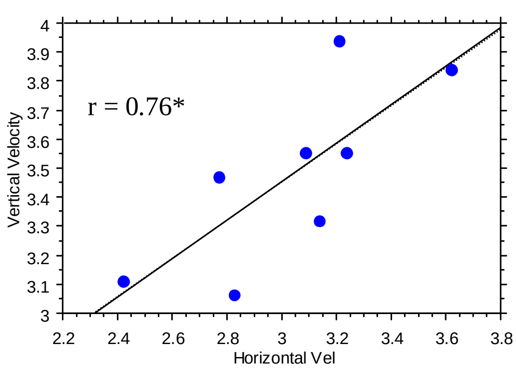


Figure 4-37 Correlation between approach horizontal velocity and vertical takeoff velocity for male one foot high kick r = 0.76 *p value < 0.05

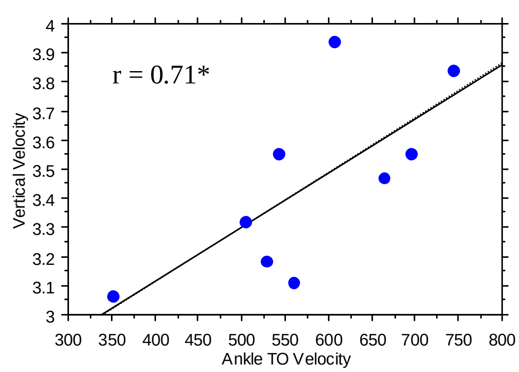


Figure 4-38 Correlation between ankle takeoff velocity and vertical takeoff velocity for male one foot high kick r = 0.71 *p value < 0.05

Although not statistically significant but still correlated, horizontal velocity for approach, step length, foot position, max hip flexion, max knee flexion, shoulder flexion at takeoff, hip extension at takeoff, shoulder takeoff velocity, knee takeoff velocity and trunk takeoff velocity all had relationships with vertical velocity for female one foot kickers. Foot position, max knee flexion, max ankle dorsiflexion, knee flexion at takeoff and ankle plantarflexion at takeoff were correlated with vertical takeoff velocity for male one foot high kick athletes, but not significantly.

The correlations of various variables and takeoff vertical velocity for the two foot high kick are listed in table 4-16. The variables with strong correlations and significance for male athletes were; knee takeoff velocity ($r = 0.644$, p value $= 0.022$) and trunk takeoff velocity ($r = 0.647$, p value $= 0.021$). The plots for these two significant variables are shown in figures 4-39 and 4-40.

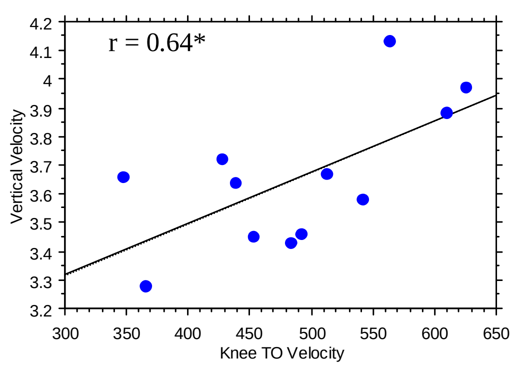


Figure 4-39 Correlation between knee takeoff velocity and vertical takeoff velocity for male two foot high kick
$r = 0.64$ *p value < 0.05

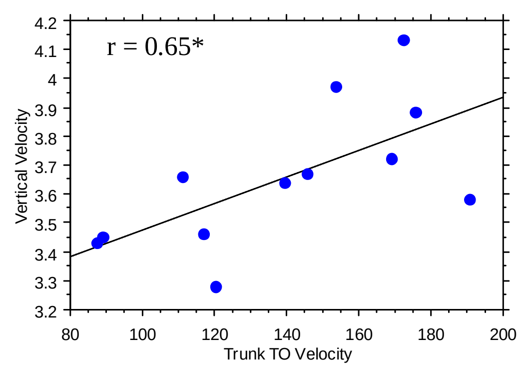


Figure 4-40 Correlation between trunk takeoff velocity and vertical takeoff velocity for male two foot high kick
$r = 0.65$ *p value < 0.05

Table 4-15 Correlation of selected variables to vertical velocity at takeoff for male/female one foot high kick   *p <0.05

Variable	Correlation (r value)	p value
Male (N=8 for Approach, N=9 for Backswing and Takeoff)		
Approach/Backswing		
Horizontal velocity	0.76	0.02*
Foot position	-0.53	0.19
Max knee flexion	0.57	0.11
Max ankle dorsiflexion	0.54	0.14
Takeoff		
Knee flexion	-0.56	0.12
Ankle plantarflexion	0.60	0.09
Ankle angular velocity	0.71	0.03*
Female (N=3 for Approach, N=4 for Backswing and Takeoff)		
Approach/Backswing		
Horizontal velocity	1.00	n/a
Foot position	-0.81	n/a
Max hip flexion	0.76	0.32
Max knee flexion	0.53	0.56
Takeoff		
Shoulder flexion	0.94	0.08
Hip extension	0.62	0.47
Shoulder angular velocity	0.93	0.09
Knee angular velocity	0.66	0.43

Table 4-16 Correlation of selected variables to vertical velocity at takeoff for male/female two foot high kick *p <0.05

Variable	Correlation (r value)	p value
	Male (N=11 for Approach, N=12 for Backswing and Takeoff)	
	Approach/Backswing	
Max shoulder extension	-0.53	0.07
Max knee flexion	0.53	0.08
	Takeoff	
Knee angular velocity	0.64	0.02*
Trunk angular velocity	0.65	0.02*
	Female (N=6)	
	Approach/Backswing	
Horizontal velocity	0.87	0.02*
Step length	0.69	0.15
Foot position	0.67	0.16
Max shoulder extension	0.58	0.25
Max hip flexion	0.68	0.16
Max trunk flexion	0.75	0.09
	Takeoff	
Shoulder flexion	0.66	0.17
Hip extension	0.64	0.19
Knee flexion	0.51	0.33
Ankle plantarflexion	-0.50	0.34
Trunk extension	0.55	0.28
Shoulder angular velocity	0.52	0.32
Hip angular velocity	0.86	0.02*
Knee angular velocity	0.52	0.32
Trunk angular velocity	0.81	0.05

As for the female two foot high kick, horizontal approach velocity (r = 0.869, p value = 0.021) and hip takeoff velocity (r = 0.862, p value 0.024) were both significantly correlated (Figures 4-41 and 4-42).

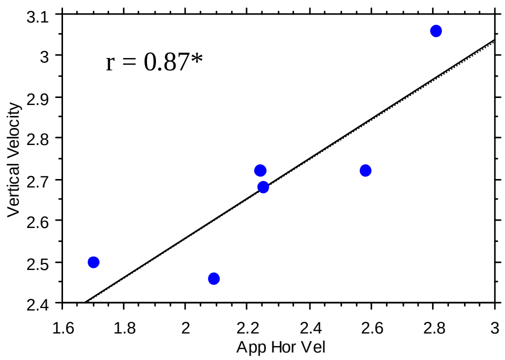


Figure 4-41 Correlation between horizontal approach velocity and vertical takeoff velocity for female two foot high kick
r = 0.87 *p value < 0.05

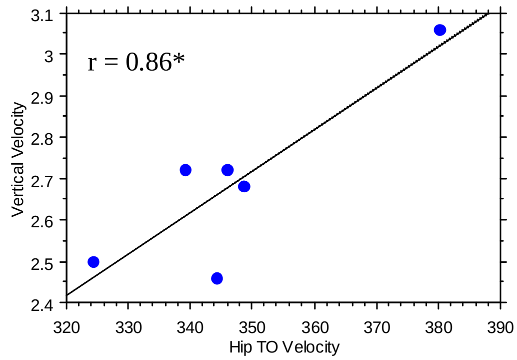


Figure 4-42 Correlation between hip takeoff velocity and vertical takeoff velocity for female two foot high kick
r = 0.86 *p value < 0.05

Stepwise Multiple Regression

The final step of this statistical analysis was the stepwise multiple regression. The analysis was used to determine the variables found to be most important in predicting vertical velocity at takeoff.

The stepwise regression model for the male two foot high kick showed that the four most important variables useful in predicting vertical velocity include; trunk takeoff velocity, max shoulder extension, max knee flexion and hip takeoff velocity respectively. The regression equation along with the summary of this model is shown in Table 4-17.

Table 4-17 Stepwise regression results for male two foot high kick

	Coefficient	Std. Error	Std. Coeff.	F-to-Remove
Intercept	3.573	0.256	3.573	194.053
Trunk velocity at takeoff (TV)	0.007	0.001	0.998	27.656
Max shoulder extension (MSE)	-0.010	0.002	-0.518	24.752
Max knee flexion (MKF)	0.012	0.003	0.536	23.364
Hip angular velocity at takeoff (HVT)	-0.003	0.001	-0.572	7.613

Predictive Equation: y = 3.573+0.007TV-0.10MSE+0.012MKF-0.003HV
r^2 = 0.943

For the female two foot high kick, the stepwise regression indicated that the most important variables to predict vertical velocity at takeoff were; horizontal approach velocity, max trunk flexion, max knee flexion and ankle velocity at takeoff, respectively (Figure 4-18).

Table 4-18 Stepwise regression results for female two foot high kick

	Coefficient	Std. Error	Sts. Coeff.	F-to-Remove
Intercept	1.657	0.007	1.657	59985.644
Max knee flexion (MKF)	-0.007	6.564E-5	-0.372	11948.880
Max trunk flexion (MTF)	0.026	1.265E-4	0.522	42525.239
Ankle angular velocity at takeoff (AV)	-1.148E-4	5.136E-6	-0.064	499.508
Horizontal approach velocity (HV)	0.479	0.002	0.866	73058.414

Predictive Equation: y = 1.657+0.479HV+0.026MTF-0.007MKF-1.128E-4AV
r^2 = 1.00

Turning to the one foot high kick, results of the stepwise analysis conducted on the male one foot high kick are located in table 4-19. The two variables that were selected for the male one foot high kick model were horizontal velocity of the approach and step length of the approach.

Table 4-19 Stepwise regression results for male one foot high kick

	Coefficient	Std. Error	Sts. Coeff.	F-to-Remove
Intercept	2.115	0.550	2.115	14.804
Horizontal approach velocity (HV)	0.729	0.163	0.841	20.022
Step Length (SL)	-0.790	0.298	-0.499	7.042

Predictive Equation: y = 2.115+0.729HV-0.79SL
r^2 = 0.827

Stepwise regression for females of the one foot high kick showed only one variable as being the most important, horizontal velocity of the approach. The summary of the model along with the equation are shown in table 4-20.

Table 4-20 Stepwise regression results for female one foot high kick

	Coefficient	Std. Error	Sts. Coeff.	F-to-Remove
Intercept	1.939	0.020	1.939	9106.545
Horizontal approach velocity (HVT)	0.457	0.010	1.000	2019.343

Predictive Equation: y = 1.939+0.457HVT
r^2 = 1.00

CHAPTER 5

DISCUSSION

Arctic sports are an uncommon topic in the field of biomechanics research with no known studies completed. The movement skills involved in the one and two foot high kick are similar to other skills, yet very unique in their own right. The movements involved the one and two foot high kick are very dynamic and require a high degree of skill to perform correctly. A running approach, followed by a jump and an intricate series of airborne movements make up these unique sport skills. Therefore, it is incorrect to assume that these skills could be compared to other similar skills like volleyball, diving and martial arts. The purpose of this study was to provide a biomechanical analysis of the one foot and two foot high kicks of elite athletes from the Arctic Winter Games and World Eskimo Indian Olympics using video analysis techniques. An additional purpose of this study was to compare the kinematics of male and female athletes in these events to determine possible gender differences in technique and strategies used in these events.

It was the researcher's intent to design a study that would allow for the understanding of the high kick skill as well as investigate through the use of kinematics the difference in genders performing the skills. In order to understand this unique skill, video footage was filmed and imported into the Dartfish analysis system. Multiple variables were measured in the Dartfish analysis system and the values were recorded for later statistical analysis. Statistical analysis was conducted in order to obtain mean values of these variables from elite athletes, then to identify key variables as predictors of vertical velocity and finally to compare variables between male and female athletes to identify mechanical differences.

One and Two Foot High Kick Analysis

Vertical Velocity at Takeoff

In order for an athlete to succeed in the two kicks, a maximum height must be achieved with the kicking leg(s). This height achieved, kicking height, is the determinant of great kickers. However, due to inadequate camera angles, this height could not be measured. Although this is a limitation, vertical velocity is almost an equivalent. Therefore, for this study's purposes, the current researcher chose vertical velocity as the determinant of jump performance. This was done because vertical velocity at takeoff is closely related to jump height of the center of mass. This is described by the following relationship{$s = 1/2g(t)^2$ }, where the height jumped by the athlete (s) is equal to one half of gravity (g) multiplied by the square of the time (t), where time is equal to (Vv/g), vertical velocity (Vv) divided by gravity (g). So for example, if the vertical velocity of an athlete is equal to 3m/s the athlete will in turn jump 0.46m according to the relationship.

$$\mathbf{s = 1/2(9.81)(3/9.81)^2}$$

$$\mathbf{s = 0.46m}$$

According to the equation, the higher you jump, the higher you will be able to kick, assuming your jump technique is adequate, thus, vertical velocity at takeoff is used here as the determinant of jump performance. It is noted here that the highest vertical velocity at takeoff does not always produce the highest kick height.

When measuring the vertical velocity of these elite athletes, the mean result for the male and female one foot high kick were, 3.45 m/s and 2.83 m/s, respectively. There was also a significant difference between male and female vertical velocity at takeoff.

Figure 5-1 shows the two highest vertical velocities achieved for the one foot high kick. The two foot high kick yielded similar results to the one foot high kick with male vertical velocities recorded at 3.66m/s and females at 2.69m/s. These results also showed significance in the mean difference of 0.97m/s.

Figure 5-1 Highest vertical velocities for one foot high kick

Approach

For the approach phase, the one and two foot high kicks are almost identical and serve the same purpose, create an ideal sequence of movements for an optimal jump. Figure 5-2 shows the movements associated with the approach. The male athletes approached the target with two different styles, the first being the straight approach and the second, a curved approach. Of the 12 male athletes analyzed in the two foot high kick, 10 utilized a curved approach and only 2 used a straight approach. For the one foot high kick, 5 used curved approaches and 3 of the athletes used a straight path. Contrary to these approaches, the females all used a straight approach for both events. The similarity between the female approaches may be due to the fact that the majority of females observed were from the same region and trained together.

The use of the straight run up (Figure 5-3) suggests that there will be a greater chance of having no rotation about the long axis of the spine during the airborne phase of the skill. This is because the body is moving in a linear direction toward the target with the body segments all moving linearly as well. However, a straight approach limits the length of the run up due to the size of the competition area. In turn, this small distance will affect the horizontal velocity that athlete can achieve.

Figure 5-2 Sequence of approach movements for the one and two foot high kick

Figure 5-3 Straight path approach

A curved approach much like that of the high jump is beneficial for a few reasons. First of all, the curved path enables the athlete to cover a greater approach distance in a smaller area. If the competition area is limited to a specific size, the athlete using a curved approach is able to utilize more of the area during the run up to create a greater horizontal velocity. A curved path for a right footed kicker also focuses the weight of the body on the left side (Figure 5-4). This will aid in keeping the right side un-weighted into the plant phase.

Figure 5-4 The curved path focuses the weight on the left side

As well, an athlete using a curved path will tend to lean into the inside of the arc created by the curved path. This is beneficial as it creates a more vertical position at takeoff (Figure 5-5). In the high jump study conducted by Dapena (1988) it is suggested that with the inward lean toward the center of the arc, the center of mass of the athlete moves through a larger vertical range of motion than the straight run up, thus permitting a greater lift. This being said, the athlete with too much trunk lean may not be able to recover from this leaning position and vertical velocity would suffer as a result.

Figure 5-5 The curved path creates a more vertical takeoff position

As the athlete approaches the target, he/she takes a long last step into the plant to with a fairly high of horizontal velocity. Males entered this last step with a horizontal velocity of 3.04m/s and 3.62m/s for the one and two foot respectively. Whereas, females had a lower velocity entering the plant with a velocity of 1.99m/s and 2.28m/s for the one and two foot high kicks respectively.

The horizontal velocity of the athlete is important as it will enable a larger force on the ground (Figure 5-6). This is explained in Dapena's (1988) article who states that as the athlete plants the front foot out in front of the body the knee extensors try and resist flexion but cannot due to the forward momentum of the athlete. This forced flexion creates a stretch on the quadriceps that stimulates the muscles causing a forceful extension of the takeoff leg. This stretch reflex is a concentric contraction of a muscle that is stretched at a given rate. The rate at which a muscle is stretched determines the magnitude of the contraction. The faster the muscle is stretched, the faster the contraction and the greater the force output (Chu, 1998). Therefore, a faster stretch of knee extensor muscles during this the plant will cause a stronger contraction to force the athlete upwards during the force production phase of the jump.

Figure 5-6 The momentum of the athlete forces knee flexion causing a stretch in the knee extensors

As a result of greater horizontal velocity, the length of the last step for males of the one foot high kick were found to be 1.08m for the one foot high kick and 1.34m for the two foot high kick. These lengths were significantly larger than those found for female athletes 0.66m and 0.79m for the one and two foot high kick. The females were found to have less horizontal velocity and consequently, a smaller last step length. As mentioned in the previous paragraph, the planting of the front foot causes a “braking” force for the athlete that elicits the stretch reflex. As well, the longer this last step is, the greater this “braking” force will be. As the foot is further out in front of the body, the horizontal component of the ground reaction force becomes larger and the horizontal velocity can be decreased more effectively.

During the plant, the distance between the feet in the forward/backward direction, foot position, will have an impact on the vertical forces during the takeoff. The further the feet are apart in this forward/backward direction, the less vertical and symmetrical the upward forces will be. If the feet are staggered slightly, the resultant force of the takeoff for each leg will be at different angles. As a result of these angled forces, there is not only a vertical component, but also a horizontal component. If the resultant force stays the same and a horizontal component is added, the vertical component is decreased. Figure 5-7 shows the effects of a staggered plant. Both male and female athletes in these events showed only small separation in the foot position, ranging from 0.07m for female one foot and 0.15m for male two foot. It is also noted that a staggered stance is not allowed according to the rules of the game.

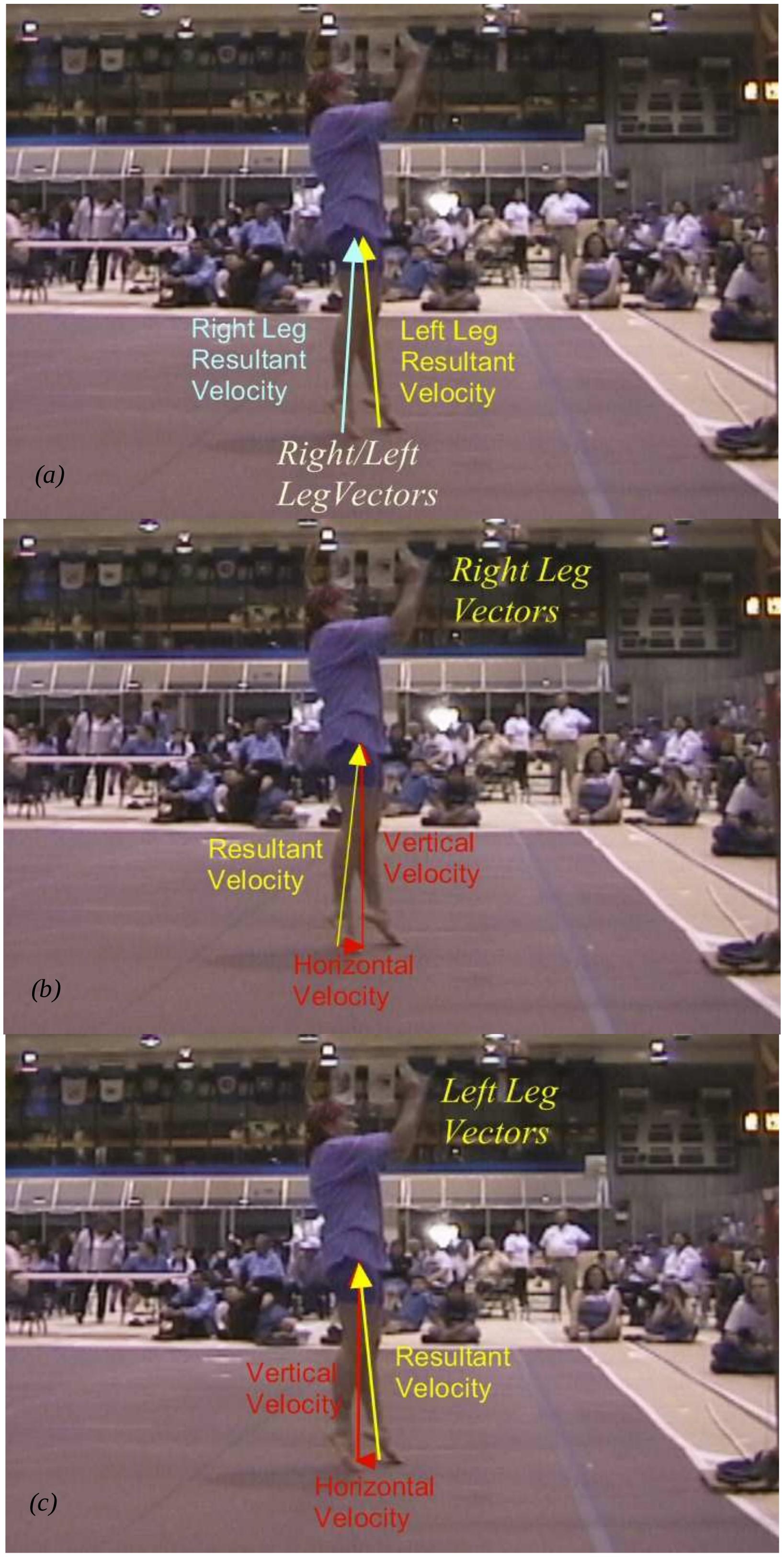


Figure 5-7 The effect at takeoff from a staggered plant in the approach. (a) Resultant velocities of both legs (b) Right leg components of the resultant velocity (c) Left components of the resultant velocity

The final portion of the approach for this discussion is the choice of plant foot for the athletes. Right handed/footed volleyball players and individuals jumping for height, tend to lead into the last step of the approach with their right foot. However, the majority of the male athletes observed in these two skills entered the last step with the left foot, whereas none of the females entered left foot forward. The females entered right foot forward producing the plant with a hop rather than a complete right foot plant.

Using the left foot forward approach along with a curved approach is actually more effective than the regular foot approach in that it is easier to kick with the right foot if the left foot is planted first. During the force producing portion of the jump, the body may be leaning to the left; this means the right leg is less weighted than the left again. This will cause the right leg to leave the ground first and effectively have a quicker initiation of the kick. If the right leg were to lead into the last step, it would be weighted by the body and cause a later kick as it would be contributing more to the jump takeoff than the left leg.

It is common among the females that although the right foot is forward, a hop is used instead of one foot planting then the other. This is more than likely due to the coaching and mimicking of other successful female athletes. The top Alaskan kicker uses a hop and trains younger athletes, therefore teaching them the two foot hop. Another factor for the use of the two foot hop would be quadriceps strength. As the athlete possesses a certain amount of momentum into the plant, the athlete must be able to support the body as it moves into deep flexion preparing for the jump. A two foot hop rather than a one foot plant should help the deceleration of the athlete into deep flexion as there is twice the strength compared to a one foot plant. However, in the one foot kick, the athlete must land on one foot, bearing the weight of the body accelerating downward. This would then suggest that the females would have enough strength in the quadriceps to utilize a one foot plant in the approach. Figure 5-8 shows a comparison of left foot forward and the hop approach.

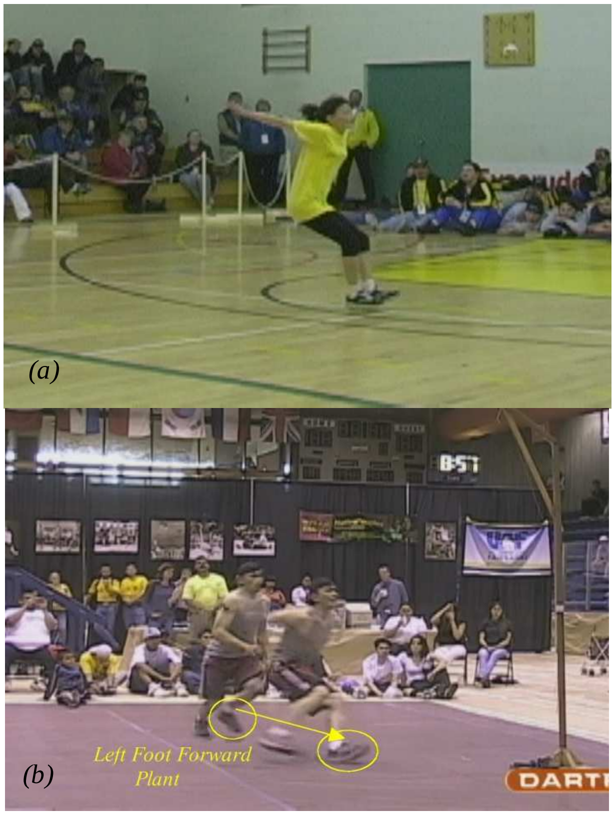


Figure5-8 (a) The hop approach (b) Left foot forward approach

Backswing

Backswing movements occur at the end of the approach and are all movements directed away from the direction of the force production (Figure 5-9). The backswing serves the purpose to prepare the body for an explosive force production. It aids in creating a large range motion through which the body segments can move. It also serves the purpose of creating a stretch on the muscles that contract during force production.

Figure 5-9 Sequence of backswing movements for the one and two foot high kick

Five variables were measured for the backswing phase of these two skills; maximum shoulder extension, maximum trunk flexion, maximum hip flexion, maximum knee flexion, and maximum ankle dosrsiflexion.

Maximum shoulder extension for males and females of both skills were quite similar and ranged from 85.75 degrees (female two foot high kick) to 91.67 degrees (male one foot high kick). Having a higher amount of shoulder extension allows the arms to move through a greater range of motion to aid in force production. As well, the movements of the arm backward into hyperextension, tends to force the trunk into more flexion. According to Dapena (1988), the acceleration of the arms in the upward direction exerts a force downward through the trunk that is transmitted to the takeoff legs.

Having a large amount of trunk flexion in the backswing is important as it creates a larger range of motion in which the trunk can accelerate during force production. The trunk in this study was measured referenced to a vertical line. Significant differences were found between males and females of the two foot high kick, with males having a higher trunk flexion with a mean difference of 6.46degrees. The males and females had similar trunk angle for the one foot high kick, 33.23degrees and 21.75degrees respectively and they were not significantly different.

In order to achieve maximum force production during jump, Alexander and Seaborn (1980) suggest hip and knee angles of 90degrees. The results for hip and knee angles of male athletes in this study showed that only the mean knee flexion angle in the two foot high kick (85.29degrees) did not exceed the optimum of 90 degrees. Contrary to this, females did not exceed this ideal angle (90 degrees) for hip and knee flexion in either event. Males had a significantly larger hip flexion angle in both the one and two foot events as well, 96.68degrees vs. 80.83degrees in the one foot high kick and 99.68degrees vs. 86.13degrees in the two foot high kick. These results do not seem surprising to the current researcher as males are 30 percent stronger in the lower body than females on average (Alexander, 2001). It is noted that it would be quadriceps strength that limits females from obtaining these deep crouch positions.

Ankle dorsiflexion is the most inferior pivot point in the deep crouch position. The measured mean dorsiflexion angle ranged from 18.10degrees (female two foot high kick) to 32.69degrees (male one foot high kick). Although no test for significance was done between the one and two foot high kicks, the angles recorded for the one foot high kick were higher than the two foot high kick.

Takeoff

The two parts of this discussion include the takeoff position of the athlete as well as the angular velocities of the segments involved. Trunk extension and shoulder flexion, followed by hip, knee and ankle extension make up this explosive portion of the skill (Figure 5-10). The movements in this phase, also considered the force producing phase of the jump, are used in order to drive the athlete upward for an effective takeoff. The purpose of the phase is to apply as much force to the ground as possible in order to increase the vertical velocity of the center of mass.

With the one and two foot high kick all groups measured mean trunk angles past the vertical into a hyperextended position (-8.58degrees for male one foot, -7.05degrees for female one foot, -7.06degrees for male two foot, and -6.60degrees for female two foot).

Figure 5-10 Sequence of takeoff movements for the one and two foot high kick

The current researcher believes that this hyperextended position is used in order to allow for a higher kick. As mentioned previously, while an athlete is in the air, the total angular momentum (H) of the system must be constant. This stated as the angular analogy to Newton's first law states that a rotating body will continue to turn about it's axis of rotation with constant angular momentum, unless an external force is exerted upon it (Hay, 1993). In order for momentum to remain constant, there must be equal and opposite reactions of the body segments. During the airborne phase of the jump, the trunk must take up most of the angular momentum of the legs. As flexion of the hip occurs in a counter clockwise wise direction, the trunk must also flex forward in a clockwise direction keeping the total angular momentum of the body constant, allowing the body to stay in balance. With the trunk being extended past the vertical at takeoff, it allows the same amount of flexion of the hips and trunk at touch, while a higher peak height of the feet can be achieved. This is able to occur as the entire body is rotated back, so that the line of the legs is more vertical rather than horizontal (Figure 5-11)

Figure5-11 (a) Hyperextended trunk and high leg position (b) Vertical trunk and low leg position

This hyperextended position may also benefit the kicker in another way. The purpose of the skill is a kick for height; therefore speed of the leg is very important as the athlete must kick in the air and then land on either one or two feet. The benefit in the hyperextended trunk may come from the fact that as the trunk extends past a vertical position, the hip flexors become stretched. When these muscles become stretched it will produce a faster contraction of the hip flexors, therefore benefiting the athlete with a faster kick overall.

However, as the athlete extends the trunk past vertical, the center of gravity moves behind the point of force application, in this case, the feet in contact with the ground. By doing this, the athlete will create a moment about the center of gravity causing the body to leave the ground with a certain amount of angular momentum not equal to zero, causing it to rotate in a counterclockwise direction (Figure 5-12).

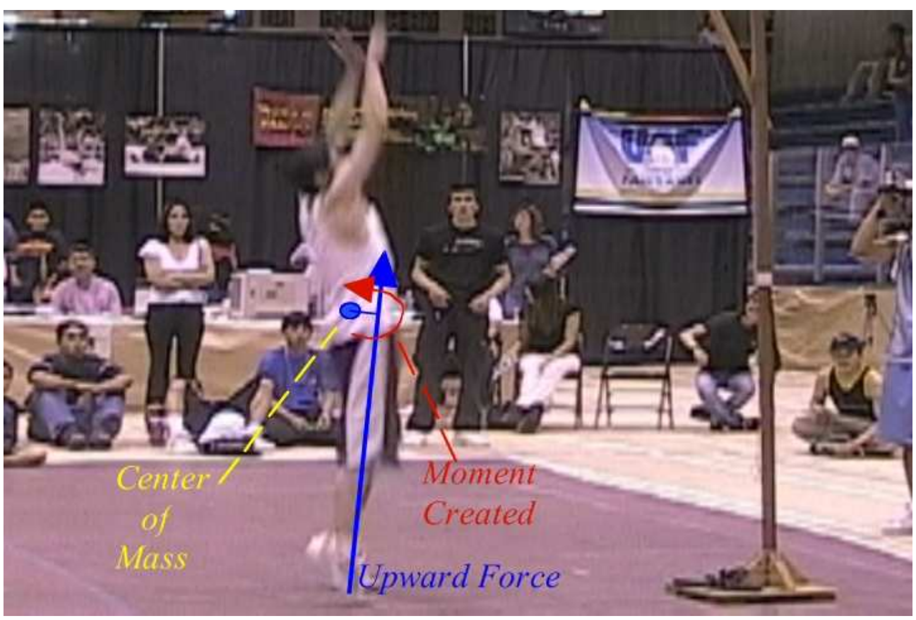


Figure5-12 The center of mass is behind the upward force creating a counterclockwise moment about the center of mass

Once airborne, this angular momentum must be conserved; therefore the athlete will continue to rotate about an axis with the same amount of angular momentum throughout the airborne phase. The problem lies in the fact that if the athlete leans back too far at takeoff, he/she will have a large amount of angular momentum and incur too much backward (counterclockwise) rotation and therefore not be able to land on their feet. Although the athlete can control the velocity at which the body rotates by altering the positions of body segments, and their moments of inertia, it could be quite counter productive in this skill. The athlete must kick as fast as they can as they are in the air for only a short period of time. Therefore, they must decrease the moment of inertia of the knee(s) to be able to flex the hips faster. As a result, a decrease in the moment of inertia of the entire body is observed, causing the system to rotate backward with a faster angular velocity.

The shoulder position at takeoff is maximized toward the vertical (180degrees of shoulder flexion) in order to raise the center of gravity in the body. Males recorded values of 140.52degrees and 135.83degrees for one and two foot kicks respectively. Female values for the one and two foot kick were 128.63degrees and 126.97degrees. Dapena (1988) suggests that a higher center of mass at takeoff is indicative of more talented high jumpers, and is related to greater shoulder flexion and hip flexion at takeoff.

The hip, knee and ankle positions of the jumpers should all be extended as much as possible in order to use the greatest range of motion as possible. There were no significant differences between any of these variables for male and female one and two foot kickers. All athletes mean hip extension was past anatomical position and into a hyperextended position. This hyperextension was noted to the hyperextended position of the trunk at takeoff as hip angles are referenced to the trunk. Mean knee angle during takeoff did not reach full extension for any of the groups observed. This indicates that the fullest range of motion was not used to produce maximal force. The mean angles for knee extension ranged from 6.79degrees for male one foot to 13.08degrees for female one foot. Ankle plantarflexion (extension), showed a large angle at takeoff with means for females of the two foot measuring 52.93 degrees and the lowest measured means being 34.61degrees for male two foot. The numbers shown for the angles reflect by which that the angle was measured. The angle was measured as the angle between anatomical position of the ankle and the position at takeoff. Anatomical position for the ankle is a line 90degrees (perpendicular) to the line of the lower leg (Figure 5-13).

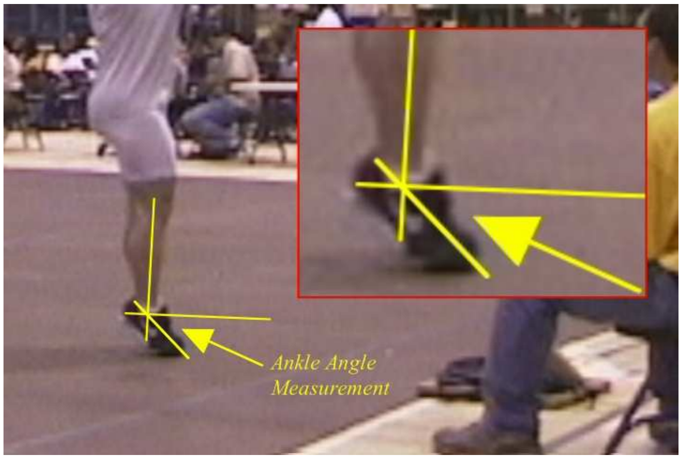


Figure5-13 Determination of ankle plantarflexion

In order to jump higher, the athlete must have higher angular velocities of the body segments in order to accelerate the body to increase the ground reaction forces that will help the athlete accelerate from the ground. According to Newton's second law, F=ma, the athlete applies a force to the ground, the force then produces an acceleration of the center of mass of the athlete. The bigger the force, the greater the acceleration. Also, Vergroesen et al. (1982) proposed that, there is a summation of forces from larger muscle joint movements to smaller ones to increase velocity of the limb. Therefore, an addition of forces generated from the hip extension to knee extension and then to ankle plantar flexion would help in increasing the vertical velocity at takeoff.

Angular velocity of the shoulder joint is a very important movement in creating a larger vertical velocity. In a study done by Feltner, Fraschetti and Crisp (1999), the arm swing was found to slow the rate of counterclockwise trunk rotation during the force production phase. As this trunk rotation was slowed, the arm swing placed the hip joint into a favourable position for a large tension in the muscles.

The angular velocities for all body segments between male and female kickers were not significantly different except for the trunk angular velocity of the two foot high kick. The male athletes of this skill recorded a mean value of 139.45 deg/sec, whereas females measured a mean value of 62.24 deg/sec. Males of the one foot kick recorded a higher mean value of trunk velocity with 140.99 deg/sec although not tested for significance. Females of the one foot high kick, recorded a similar mean value (132.53deg/sec) to that of the male athletes. This finding leads the current researcher to believe that due to the larger sample size of the female two foot high kick, the mean value of the female two foot high kick is representative of most jumpers, with a value of approximately 6 feet. As the trunk accounts for fifty percent of the body's overall mass, being able to move the trunk faster is very beneficial to the athlete at takeoff. The more force applied by the trunk extensors to accelerate the trunk, the greater the force on the ground to accelerate the body, F=ma.

Although the angular velocities of all body segments at takeoff were not significantly different between male and females, the vertical velocities at takeoff were significantly different to a p value <0.0001. The current study looked only at average angular velocities of the body segments and not the peak velocities or the accelerations of these segments. The fact that the vertical velocities were so different was more than likely due to the difference in mass of the athlete, as well as the accelerations of these segments. As males tend to have more muscle mass than females do, the contractions of the muscles would be more forceful and result in higher accelerations of the segments. The greater force that is used to accelerate the larger masses, the greater the force applied to the ground to accelerate the body's center of mass.

Touch

Although only vertical velocity was used as the determinant of jump performance in this study, it is very important to discuss the airborne phase in order to fully understand these unique and difficult skills.

Touch - One Foot High Kick

A total of eighteen variables were measured for this portion of the kick. The sequence of movements is shown in Figure 5-14. This phase of the skill is begins with knee flexion of the right knee in order to bring the leg up to a position for kicking the target. The right knee of the athletes should be as flexed as possible in order reduce the moment of inertia for hip flexion. By reducing the moment of inertia, the hip is able to flex faster as angular momentum must remain constant (Figure 5-15). Sorenson et al. (1996) indicated that a flexed leg could cause faster kick velocities, as it would decrease the moment of inertia. In the study conducted by Hwang (1987) it was indicated

Figure 5-14 Sequence of Touch movements for the one foot high kick

that when kicking at a target, the velocities of the toes of elite athletes were faster than those of beginners due to the flexed leg and decreased moment of inertia, thus suggesting that the hip angular velocity should be greater for a flexed knee. Males exhibited a significantly larger knee flexion angle for this phase with a mean difference of 13.92 degrees. However, the angular velocity of the right hip for females was larger, this is a contradiction to the point that more knee flexion will aid in the velocity of the right hip. This finding was not significantly different but it does warrant some mention as the female athletes did measure higher velocities of the right hip.

Figure5-15 Reduction of the moment of inertia in order to flex the hip faster

As the hip flexes to a maximal position the right knee will extend and attempt to contact the target. The position of the hip and knee extension at touch is a crucial part of the skill. Flexibility is a major part of this position as it will determine the amount of flexion that the athlete will be able to achieve. The more flexible the athlete is, the higher the leg can kick. Males measured mean values of hip flexion and knee extension to be 148.38degrees and 7.24degrees, whereas females recorded means of 154.60degrees and 4.20degrees for hip and knee angles. The implication of these positions is that the more flexion in the hip and the more extension of the knee the athlete can obtain, the more vertical the leg becomes, therefore the higher they will be able to kick. Flexibility is a key feature of highly skilled athletes in this sport as it allows the hamstrings to be lengthened and obtain these maximally flexed positions, especially for movements in the touch phase.

As this is an airborne skill, the athlete must be able to put the leg in this position quickly, as they are only in the air for less than one second. This is determined by the velocity at which the hip flexes and the knee extends. As stated earlier, the hip flexion should be partially determined by the flexing of the knee. As the knee flexes, the moment of inertia about the hip decreases and the velocity will then increase. Females, however, exhibited a larger, yet not significant, hip flexion velocity of 474.83deg/sec compared to 412.25deg/sec. Females also had a significantly larger right knee extension angular velocity compared to the males, 777.04deg/sec vs. 638.22deg/sec. The current researcher believes that this difference may be due to the time that the athletes are in the air. Females will spend less time in the air, approximately 0.03 sec less, due to the lower vertical velocities at takeoff, therefore they will have to produce much faster velocities of the right hip and knee in order to kick the target and then recover for landing. As males were found to have a much higher vertical velocity at takeoff, the need for such a high velocity of these joints is much less as they would have slightly more time in the air to produce these movements and then recover. As well, in the study conducted by Chen &

Huang (1998), it was found that there was no difference in lower leg velocities between the straight leg and flexed knee kick when there was no target present.

As the kicking leg moves into a position to touch the target, the trunk and shoulders along with the non kicking leg move accordingly in order to take up the angular momentum of the kicking leg (Figure 5-16). The trunk position during the touch is affected by the takeoff position of the trunk. As mentioned in the takeoff section of the discussion, a hyperextended trunk at takeoff enables the trunk to move through the same range of motion as a vertical trunk, however it allows the trunk to remain more vertical at touch, thus allowing the kicking leg to be more vertical as well. Although not significant, males had less trunk flexion at touch (14.24degrees vs. 22.30degrees). This implies that males will be able to kick higher, even though hip flexion angles and knee extension angles are similar, the more vertical trunk allows kicking leg to be in a more vertical position as well.

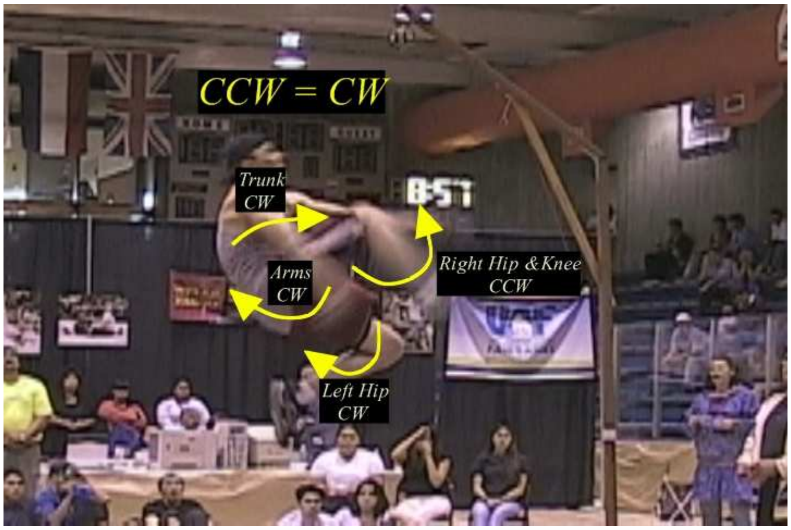


Figure5-16 Clockwise and counterclockwise angular momentums must balance. The trunk, arms and non kicking leg balance the angular momentum of the kicking leg

The shoulder movements of this portion of the skill are very different for male and female athletes. Female shoulder movements were quite symmetrical as the foot contacted the target. As the trunk flexed forward, both arms extended down together at the same time. This was contrary to the movements of the male athletes. As the kicking leg contacted the target, the right arm of the male athletes extended down past the hip of the kicking leg whereas the left arm extended down, but not to that degree. Therefore, there was a large asynchrony between the shoulder positions of the male athletes at contact.

The non kicking leg of the athlete remains in a position of hip and knee flexion in order for the kicking leg to utilize full flexion of the hip and extension of the knee. If the hip and knee of the non kicking leg extends at touch, it will tilt the pelvis downward and limit the range of motion of the kicking leg. The trunk and arm should take up as much of the angular momentum of the kicking leg as possible in order for the non kicking leg to remain in this flexed position. Mean hip and knee flexion angles for male athletes were 33.83degrees and 64.95degrees compared to 48.60degrees and 89.65degrees for females.

The right ankle, although only a small movement, can play an important role in the outcome of the one foot high kick. The mean right ankle plantarflexion angle was 24.90degrees for males and 13.35degrees for females. A positive number indicates a plantarflexed angle, whereas, a negative number would indicate a dorsiflexed position. In this skill it is very important to ensure that a plantarflexed angle is seen, as it may add that extra length to the foot in order to touch the target. In fact, the athlete that obtained the world record had missed the target due to a dorsiflexed ankle, but quickly plantarflexed at the right instant in order to contact the target.

Touch - Two Foot High Kick

The two foot high kick is similar to the one foot high kick, however, movements of the right and left sides are symmetrical. Figure 4-17 shows the movements associated with the touch portion of the two foot high kick. As in the one foot high kick, the first movement going into the touch phase is the flexing of the knees into a tuck position. Again, this will decrease the moment of inertia for the hip joint and allow a faster angular velocity at the hips. Males again had a significantly larger knee flexion angle (138.86 degrees) and knee flexion velocity (681.85 deg/sec) during this phase which indicates a more tucked position and should imply a faster hip flexion velocity. However, as in the one foot high kick females measured a larger mean hip velocity, although not significantly different from males (466.60 deg/sec vs. 452.86 deg/sec).

Trunk flexion velocity of male and female athletes for this portion of the skill was similar, 137.25deg/sec vs. 132.53deg/sec, however trunk position differed significantly. The trunk angle at touch was significantly more vertical for male athletes (43.03degrees vs. 52.72degrees), suggesting that the legs were able to become more vertical at touch. As trunk flexion increases, it limits the height that the legs can achieve, even though the same range of motion may be seen. Unlike the one foot high kick where the non kicking leg can take up some of the angular momentum of the kick, only the trunk and arms can take up the kicking leg’s momentum (Figure 4-18)

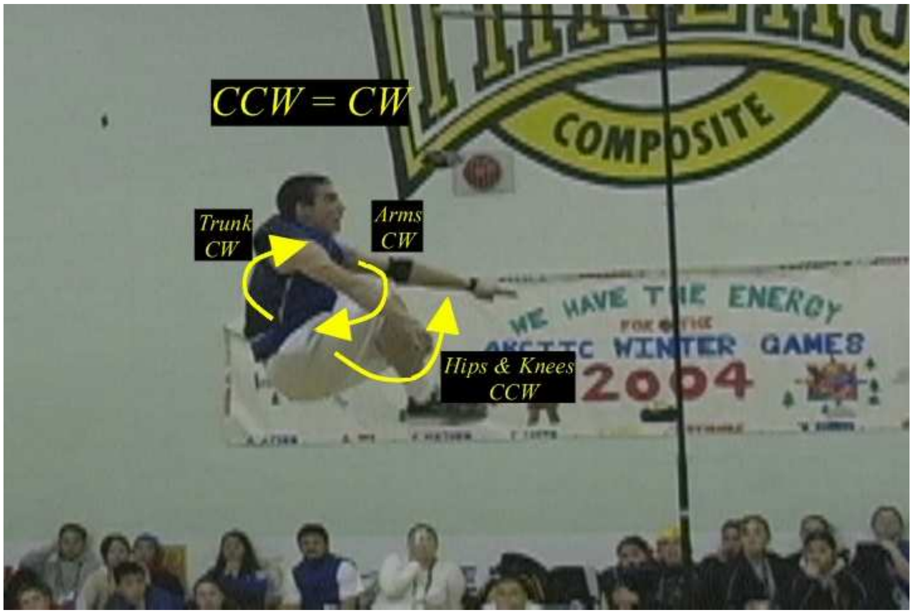


Figure5-18 Clockwise and counterclockwise angular momentums must balance. Only trunk and arms balance the angular momentum of the kicking legs

Females in the two foot high kick event had similar shoulder movements to that of the one foot high kick. However, during the two foot high kick, it was observed that the females extended the shoulders to certain point and then began flexing them again as if they were reaching out for their toes. This explains the high shoulder flexion angles at touch (122.12degrees) and the low shoulder velocity (78.69deg/sec). The left and right shoulder movements of the male athletes were quite symmetrical, as would be expected due to the symmetry of the leg movements.

Figure 5-17 Sequence of Touch movements for the two foot high kick

Knee extension and hip flexion velocities of this portion of the skill indicate how fast the athlete is able to touch the target. Faster movements in this phase will allow more time for recovery as the time in the air is predetermined by the vertical velocity at takeoff. Therefore the less time spent trying to touch the target, the more time that can be spent during recovery. Hip velocity between genders was not significantly different with females recording a mean value of 466.60deg/sec and males 452.86deg/sec. This is somewhat surprising to the current researcher as the male athletes had a significantly larger knee flexion velocity (681.85 deg/sec vs. 608.85 deg/sec) and angle, 138.86 degrees compared to 121.52 degrees, leading up to the touch. This should again suggest that due to these greater angles and velocities of knee flexion, the moment of inertia about the hip joint would decrease and therefore hip velocity increase, assuming torques remain constant.

The angles of the hip and knee at touch are rather interesting. Male athletes measured a mean angle close to zero for knee extension. This implies that the knee extension velocity of many male athletes at touch forced the knee into a hyperextended position. This may be beneficial to the athlete as it would increase the range of motion and possibly the height achieved. However, forcing the knees into a hyperextended position could be damaging as it places the knee joint under a great deal of stress and possible injury could occur to the surrounding structures of the knee. The mean knee extension angle was 1.45degrees, which suggests that some female athletes may enter this position of hyperextension as well. The hip positions of both male and female athletes are quite high, 164.40degrees and 163.10degrees respectively. These large hip angles suggest that the athletes are in a very tight position similar to divers. O’Brien (2003) characterizes this “closed” pike position as full extension of legs with the arms pulling the trunk closer to the legs. The two foot high kick position is similar but differs in the fact that the arms of the athlete are not used to pull the body closer. Thus, a need for extreme flexibility in the extension of the hips is an asset to the athletes (Figure 5-19).

Figure5-19 Athletes of the two foot high kick need to be extremely flexible at the hips

Follow Through

The follow through movements of these two skills are used in order to place the body in an optimal position for landing. From the peak of the jump to the landing, the body is accelerating downward from gravity. This increasing velocity creates a larger momentum, as momentum (M) is the product of the mass (m) and velocity (v). The legs upon contact with the ground are important as they must slow the body’s downward momentum to zero by producing an impulse equal to the change in momentum.

Follow Through - One Foot High Kick

The most difficult task in the one foot high kick is that the athlete must land on the leg that they attempt to kick the target with. This means that the kicking leg that is supposed to be fully flexed at the hip and extended at the knee in an almost vertical

Figure 5-20 Sequence of Follow through movements for the one foot high kick

position at touch, must move through a range of motion such that it is in a position to land on. The hip must therefore move through an angle of close 180 degrees in order to be in a position to take the weight at landing. As well, the athlete is utilizing a one foot landing which means that only one leg will be able to accept the downward momentum of the body. Figure 5-20 shows the sequence of follow through movements

During a snap kick martial artists will forcefully flex their knee to aid in quick recovery to a ready position (Healy, 2000, Hickey, 1997, Park & Seabourne, 1997, Shroeder &Wallace, 1976). By flexing the knee, the moment of inertia is decreased and the hip should be able to extend faster.

By comparison, the results of this study showed that the athletes did not utilize this flexed position during recovery. Instead, there was an almost straight leg recovery using only hip extension (407.54deg/sec for males and 400.15deg/sec) and slight knee flexion (58.58deg/sec for males and 153.75deg/sec for females). However, this may be optimal for high kickers as it may prove to be an awkward position to fully flex the knee and then extend again for landing. Females competing in this event landed on the right leg with a mean right knee flexion angle of 41.38 degrees. This flexed position could suggest that female athletes are trying to, although somewhat unsuccessfully, flex the knee and extend during recovery.

The rest of the body, shoulders, trunk and left leg all react by rotating opposite to that of the kicking leg to counterbalance the effect of the rotation of the kicking leg Figure 5-21. Focus during this phase should be directed toward the kicking leg as it is the limb that must accept all the body weight at landing.

Figure5-21 Clockwise and counterclockwise angular momentums must balance. The trunk, left/right arms and non kicking leg balance the angular momentum of the kicking leg

Follow Through - Two Foot High Kick

In diving, the athlete exits the pike position by extending the hips with straight knees (O'Brien, 2003). This straight legged extension of the hips to exit a pike position is used in diving as it is a sport based on aesthetics. Two foot high kick is not based on score and the main focus of the recovery is to ensure a balanced landing. It is in this aspect that the two skills differ. The movement sequence of the follow through is presented in Figure 5-22. During the recovery of this skill, the legs are flexed after touch (114.17degrees for males and 80.68degrees) to decrease the moment of inertia to enable a faster hip extension (Figure 5-23). Unlike the one foot high kick, where the straight approach to recovery was used, it would seem very beneficial to this skill to flex the knee for recovery. This is because after the touch the athlete must attempt to extend both legs, rather than one leg, down underneath them to land. When you add more mass away from the axis of rotation of the hip joint the moment of inertia is greater, therefore the velocity will decrease as angular momentum must remain constant.

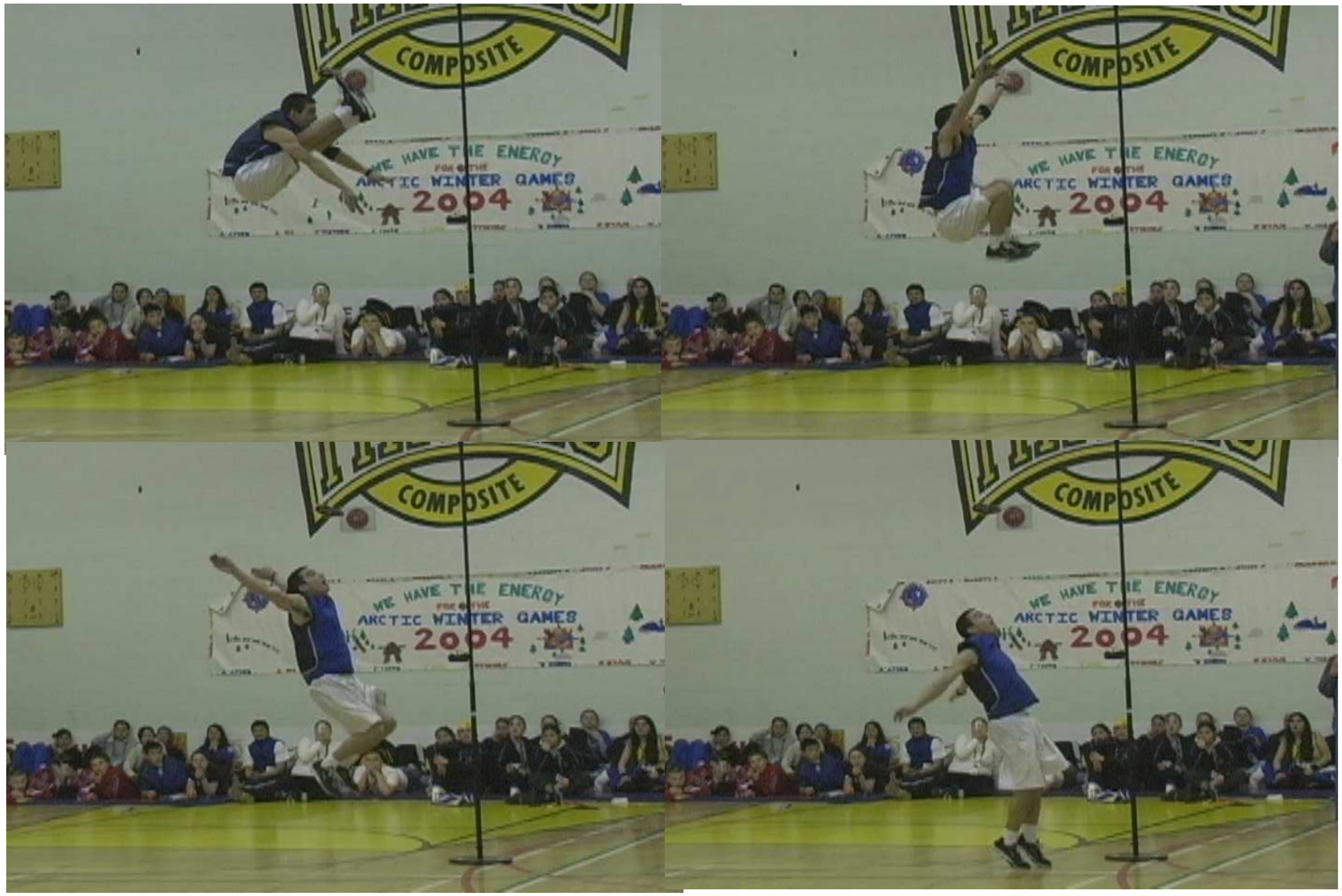


Figure 5-22 Sequence of Follow through movements for the two foot high kick

The athletes of this two footed skill have twice the mass to move, to reach the floor, so they must increase the velocity by flexing the knees and decreasing moment of inertia, in order for them to attain a balanced landing.

Figure5-23 Reduction of the moment of inertia in order to flex the hips faster

With this double legged recovery, more angular momentum is generated and must be counterbalanced. This angular momentum is taken up by the extension of the trunk and the flexing of the arms according to Newton's third law of angular motion (Figure 5-24). There is more focus on trunk extension in this skill than there is in the one foot recovery. With the one foot high kick, the non kicking leg is used to take up some of the momentum along with the trunk. With the two foot high kick, both legs are kicking, creating more angular momentum that must be taken up solely by the trunk and arms.

Figure5-24 Clockwise and counterclockwise angular momentums must balance. The trunk and arms balance the angular momentum of the kicking leg

Kinematic Predictors of Vertical Velocity

Correlation Analysis

One Foot High Kick – Male

Two variables were shown to have a statistically significant correlation to the vertical velocity at takeoff in male one foot high kick athletes, horizontal approach velocity and ankle velocity at takeoff.

Horizontal approach velocity showed a strong positive correlation to the vertical velocity at takeoff (0.76). A strong correlation indicates that as horizontal approach velocity increases so will vertical velocity at takeoff. Essentially, the faster you approach, the higher you will be able to jump. This finding is supported by the study conducted by Dapena (1988) on elite high jumpers. Dapena (1988) states that by having a faster approach a greater vertical force can be exerted on the ground. As the athlete carries a certain amount of forward momentum into the plant, the front leg tries to resist flexion, but is unable to. This forced flexion puts the leg extensor muscles on a stretch which is believed to produce stimulation of the muscles causing a forceful extension at takeoff into the jump.

The second correlation found for vertical velocity at takeoff was ankle velocity at takeoff. A strong positive relationship was found between these two variables (0.71) indicating that as ankle velocity increases at takeoff vertical velocity of the center of mass will increase at takeoff as well. This high velocity of ankle is the last movement to occur at takeoff. According to Vergroesen et al. (1982), during the jump, there is a summation of forces from larger muscle joint movements to smaller ones to increase velocity of the limb. Therefore, there would be an adding of forces generated from the hip extension to the knee extension and then to the ankle plantar flexion. It would appear that ankle plantarflexion is an important movement in the two foot high kick.

One Foot High Kick –Female

Due to the small number of subjects for the one foot high kick, testing for significance on some variables was not possible. However, the two variables that could not be tested for significance were shown to have very high correlations to vertical velocity at takeoff.

The first variable, horizontal approach velocity was found to have a perfect correlation, 1.00, to vertical velocity. This perfect correlation is most likely not accurate due to the small sample size. However, based on the fact that horizontal velocity for male one foot and female two foot was significantly correlated, the current researcher believes that it would be correlated and probably significant for the female one foot high kick if more subjects were tested.

The second variable found to be highly correlated but not testable for significance was distance between the feet in the forward/backward direction at takeoff. There was a strong negative correlation (-0.81) between this variable and vertical velocity at takeoff. As the distance increases between feet in the forward/backward direction, the lower vertical velocity will be. With the feet closer together in the forward/backward direction, the forces in both legs will be acting in the same direction, straight downward. As the feet begin to separate, the direction of the forces of the legs become unequal. This inequality in the line of force could possibly cause one or both legs to have a larger horizontal component. If the amount of force produced by the body segments is the same and there is an increased distance between feet, vertical velocity will decrease as the resultant velocity will have a greater horizontal component.

Two Foot High Kick – Male

Again, two variables were found to be significantly correlated with vertical velocity at takeoff. For the male athletes in the two foot high kick, trunk angular velocity and knee angular velocity at takeoff were the two correlated variables.

Trunk angular velocity had a positive correlation of 0.65 indicating that as trunk angular velocity at takeoff increases, vertical velocity at takeoff will increase as well. Considering the trunk takes up 50 % of the body's mass, it is no surprise that there is a high correlation. As more force is used by the back extensors to accelerate the trunk upward, more force is applied to the ground to accelerate the body upward. Although the upward angular accelerations of the trunk are not presented in this study, it can be assumed that higher velocities will yield higher accelerations if the time is the same between subjects because acceleration is the change of velocity divided by time.

A high correlation (0.64) between knee angular velocity at takeoff and vertical velocity of the body at takeoff was also found to be statistically significant. Therefore it can be assumed that as knee angular velocity at takeoff increases, vertical velocity will increase as well. As the knees extend forcefully, they apply a large force to the ground which causes the body's center of mass to accelerate upward, F=ma. As well, as the horizontal approach velocity increases, the amount of stretch on the quadriceps increases. This forceful eccentric contraction will cause a stretch reflex in the muscle causing a faster, more forceful contraction of the knee extensors (Chu, 1998). The faster, more forceful contraction of the knee joint will ultimately aid in producing a larger vertical velocity at takeoff.

Two Foot High Kick – Female

Correlation analysis for the female two foot high kick showed two variables to be statistically significant when correlated to vertical velocity at takeoff. The most highly correlated variable was again horizontal approach velocity (0.87). Of the four high kick groups, this is the third group to have horizontal velocity correlate significantly with vertical velocity at takeoff. As the horizontal velocity of the female two foot high kick increases, the vertical velocity will therefore increase as well.

The second variable to be highly correlated to vertical velocity is hip angular velocity at takeoff (0.86). Thus, vertical velocity at takeoff will increase if the hip angular velocity of the athlete is increased. The reason for this is similar to that of trunk angular velocity and knee velocity. As the hips extensors contract forcefully they apply a force to the ground causing the upward acceleration of the body.

Stepwise Regression Analysis

The final statistical analysis performed on the data for these skills was a forward stepwise multiple regression. It was conducted in order to determine the most important variables related to the vertical velocity of the athlete at takeoff. The analysis itself not only determines the relationships between the independent variables and the dependent variable, it takes into account interrelationships between independent variables and eliminates them accordingly.

Although this forward stepwise regression analysis seems to be the most appropriate, it does have some limitations, which should be discussed. The analysis will select one variable and eliminate another variable if it is too closely related to the one selected, this is called collinearity. Collinearity is defined as the condition of relatively high correlation between variables. Both variables are deemed equally important, and therefore, the analysis sees them as holding the same information as the other, and eliminates one. This can have a dramatic effect on the model as choosing one variable over the other will drastically change the model overall. Essentially, there could be many models that accurately predict vertical velocity at takeoff. One way the current researcher was aided in gaining the best model possible was to force a variable into the equation. This is a process that includes forcing a variable that is highly correlated and statistically significant into the equation on the first step of the analysis. It is noted that the variables presented here in these models should not be considered as the only contributors to jump height and that there may be other models that predict jump height as accurate.

Male One Foot High Kick Regression Analysis

The regression analysis performed on the male one foot high kick gave two key predictors of the vertical velocity at takeoff. Of the nineteen possible variables, horizontal velocity of the approach and the step length were the two variables deemed most important in this model. The regression equation accounts for 83% of total variance and is as follows:

$$\mathbf{y = 2.115+0.729HV-0.79SL \quad (r^2 = 0.827)}$$

Where: **y** = Vertical velocity at takeoff (m/s)

HV = Horizontal velocity of the approach (m/s)

SL = Step length of the last step (m)

The regression analysis suggested that horizontal velocity was the most important variable related to the one foot high kick and was positively correlated. Horizontal velocity as the main predictor of vertical velocity suggests that as the athlete increases the horizontal velocity of the approach, the greater the vertical velocity at takeoff will be due to the high positive correlation. Again, by increasing the horizontal velocity during approach, the athlete enters the plant with an extended leg that tries to resist flexion but cannot because of the forward momentum, causing a forced flexion of the knee (Dapena, 1988). This forced flexion causes a stretch in the quadriceps that leads to a forceful concentric contraction of the knee extensors, which increases the force applied to the ground and in turn a greater vertical velocity is achieved.

The second predictor of vertical velocity for the male one foot high kick was step length. Contrary to what the current researcher hypothesized, the step length here actually had a negative correlation. That is, as step length increases, vertical velocity will decrease. This is contrary to what the current researcher believed, as a longer step length would cause a “braking” force to slow the horizontal velocity. With a longer last step, the foot contacts the ground further in front of the line of gravity of the athlete which produces a large horizontal “braking” force back on the athlete. It is this “braking” force that causes the deep flexion of the knee putting the extensors on a stretch. And according to Chu (1991), the more forceful the eccentric contraction is the more powerful the stretch reflex and ultimately a faster concentric contraction.

Female One Foot High Kick Regression Analysis

As the subjects for the female one foot high kick were limited, the regression model may be somewhat inadequate. As well, the regression equation produce, accounted is said to account for 100% of the total variance. This seems very unlikely and the current researcher believes that the vertical velocity of the female one foot high kick cannot be solely dependent one variable. The regression analysis is as follows:

$$\mathbf{y = 1.939+0.457HV \quad (r^2 = 1.00)}$$

Where **y** = Vertical velocity of the center of mass at takeoff

Hv = horizontal approach velocity

The regression showed that horizontal approach velocity was the most important variable in predicting vertical velocity at takeoff. As previously discussed, it has been suggested that horizontal velocity is crucial in producing a greater vertical velocity at takeoff (Dapena, 1988). However, it should be noted that the model may be inadequate as there were very few subjects for this skill. The stepwise testing procedure will not take more steps than there are subjects and therefore the basis of the model can only be made on one or two steps and only one variable was statistically strong enough to enter the equation.

Male Two Foot High Kick Regression Analysis

The regression analysis for the male two foot high kick identified four key variables to best predict the vertical velocity of the center of mass at takeoff. It should be noted here that one variable was forced into the equation as it had the highest correlation and smallest p value from the correlation analysis. The first model that was given did not include this variable, and the researcher believes that; as it was the highest correlated variable that it should logically be included in the regression model. The regression model accounted for 94% of the variance and given here:

$$\mathbf{y = 3.573+0.007TV-0.10MSE+0.012MKF-0.003HVT \quad (r^2 = 0.943)}$$

Where: **y** = Vertical velocity of the center of mass at takeoff

TV = Trunk angular velocity at takeoff

MSE = Maximum shoulder extension

MKF = Maximum knee flexion

HVT = Hip angular velocity at takeoff

The most important variable, trunk angular velocity at takeoff, was the variable that was forced into the equation. This forcing of trunk angular velocity into the model is justified as it was the highest correlated variable for the male two foot high kick. Trunk angular velocity is important to the vertical velocity as it has such a large mass. The force of the extensors to accelerate the trunk upward causes a downward force that is applied to the ground. This large force acting on the ground produces the upward acceleration of the body's center of mass.

The second most important variable for predicting vertical velocity in this model is maximum shoulder extension. However, there is a negative correlation of the shoulder angle to vertical velocity. Thus, it is implied that more shoulder extension during the backswing will actually decrease the vertical velocity at takeoff. This result seems out of place to the current researcher. As the arms swing upward they cause a downward force on the ground that increases the ground reaction force, which in turn accelerates the center of mass upward. A greater backswing may be less important or in fact, according to this model, detrimental to vertical velocity, as the force from the arm swing is contributed during the upswing. Starting the arm swing from a more backward position does not provide a faster upswing.

Maximum knee flexion appeared in the equation as the third most important variable for predicting vertical velocity. The positive correlation suggests that an increase in knee flexion will increase vertical velocity. As the knee flexion increases it causes the quadriceps to eccentrically contract and lengthen. This stretch will cause a faster and more forceful contraction which will produce a greater force on the ground and in turn a greater vertical velocity.

The final and most surprising portion of the multiple regression equation is that hip velocity at takeoff was negatively related to vertical velocity. It would be expected that a faster hip flexion would yield higher accelerations and greater force on the ground. However, according to this model as the hip angular velocity increases, vertical velocity decreases. This may be related to the timing of the joint movements during jumping. The hip, knee and ankle joints should move in a sequence from larger to smaller joints. Early motion at the hip may disrupt the timing of the remainder of the jump.

Female Two Foot High Kick Regression Analysis

The regression model for the female two foot high kick has explained 100% of the variance. This seemingly accurate ability to predict vertical velocity is again most likely due to the low subject numbers. Four variables were selected to best predict vertical velocity with the following equation:

$$\mathbf{y = 1.657+0.479HV+0.026MTF-0.007MKF-1.128E\text{-}4AV \quad (r^2 = 1.00)}$$

Where **y** = Vertical velocity of the center of mass at takeoff

HV = Horizontal approach velocity

MTF = Maximum trunk flexion

MKF = Maximum knee flexion

AV = Ankle velocity at takeoff

The first and most important variable produced by the equation is the horizontal approach velocity. The importance of this variable has been seen previously and explained many times throughout the analyses of the various types of high kick, therefore it is not surprising to see it as the most important variable for the female two foot high kick.

Trunk flexion was the second most important variable for predicting the vertical velocity at takeoff. By increasing the trunk flexion, you are effectively increasing the range of motion through which the trunk can move when extending. As the range of motion increases, greater accelerations of the trunk can be reached as there is more space to move through. And as was discussed previously, more force produced by the back extensors creates higher accelerations, which causes more force down, that will accelerate the center of mass upward according to Newton's second law of motion.

Maximum knee flexion had a negative relationship with vertical velocity in this model, indicating that more knee flexion will cause less vertical velocity. This relationship may often be seen in females, as they tend to have less quadriceps strength. This implies that as the female athlete enters a position of deep knee flexion, they may not be able to effectively recover from this position and the force provided from knee extension will be decreased.

The final portion of the equation is explained by the negative relationship of the ankle angular velocity at takeoff. This implies that as the ankle angular velocity increases vertical velocity decreases. This finding is questionable as a high ankle angular velocity would indicate a greater force applied to the ground and in turn an accelerated center of mass upward. Much like male two foot athlete's negative relationship of hip angular velocity and vertical velocity, the timing of the joint movements during the jump may be incorrect for the female two foot athletes.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

The purpose of this study was to provide a biomechanical analysis of the one foot and two foot high kicks from the analysis of elite athletes in these sports. This purpose was addressed by measuring and identifying the key variables that are responsible for improving vertical velocity at takeoff. As well, identification of the airborne movements of elite athletes provided insight into optimal technique. An additional purpose of this study was to compare the male and female athletes in these events to determine possible kinematic differences in technique and strategies used in these events. It was hypothesized that an optimal technique for the one foot and two foot high kicks would be obtained from the results of the study. Additionally, it was hypothesized that males would have higher values for the measured angles and angular velocities as well as the linear velocities throughout the skill.

Data was collected from a total of 31 subjects from two separate competitions, the Arctic Winter Games in Fort McMurray, Alberta, Canada and the World Eskimo Indian Olympics in Fairbanks, Alaska, USA. The one foot high kick group consisted of nine males and 4 females and the two foot group consisted of 12 males and 6 females. All athletes were considered to be elite, as they were competing at the highest level for their sport.

There were a total of 57 variables measured for the one foot high kick and 47 variables measured for the two foot high kick. The variables were measured using video analysis with the Dartfish analysis system. These variables included: trunk, hip, knee and ankle angles and angular velocities, as well as vertical velocity at takeoff. The measurement of these variables provided several results for the optimal technique. As well, when comparing the means between genders, several significant differences were identified.

One Foot High Kick

The vertical velocity at takeoff was shown to be significantly different between male and female athletes. The difference between the two velocities was almost 1m/s. This finding is consistent with the hypothesis that the linear velocity would be greater in males.

The approach phase yielded two variables with significant differences. Horizontal velocity of male athletes was over 1m/s larger than the horizontal velocity of female athletes. Step length was the second variable to show a significant difference, with males again having the larger value. Five male athletes approached the target using a curved path, and three used a straight approach. All three female athletes approached with a straight approach.

Maximum hip flexion angle was the first variable to be significantly different in the backswing phase. Males had a larger hip flexion angle by almost 16 degrees. The other variable significantly different in the backswing was maximum ankle dorsiflexion angle as males measured a mean value of 32.69 deg compared to 23.55 deg for female athletes.

The takeoff phase of the skill did not produce any significant differences in the variables other than vertical velocity at takeoff. All angles and angular velocities were statistically similar. This may suggest that because the angular velocities were similar between genders and vertical velocity was different, the angular accelerations, rather than the angular velocities, of male athletes were higher.

The majority of differences came in the touch portion of the skill. A total of five variables differed between genders. Both right shoulder angle and right shoulder angular velocity was larger for males. Males however used an asymmetrical arm swing causing the right shoulder to flex more. The right knee flexion angle was significantly larger in males than females. However, right knee extension angular velocity was higher in females. Finally, left hip angular velocity was significantly greater in females compared to males.

As the follow through is more of a reaction type movement than a planned movement, many variables were found to be significantly different. Females had a significantly larger right hip flexion angle, right knee flexion angle and trunk angle. This suggests that females had a crouched position upon landing. Females also had a significantly larger right knee extension angular velocity. The lone variable that was significantly larger for males was left hip flexion angle.

Two Foot High Kick

As seen in the one foot high kick, the vertical velocity at takeoff was shown to be significantly different between male and female athletes. The difference between the two velocities was over 1m/s.

The approach phase showed the same results as the one foot, with horizontal approach velocity and step length being significantly larger in males when compared to females. Ten of the 12 males approached the target using a curved path and all six females used a straight approach.

Mean maximum hip flexion was significantly larger (99.68 deg vs. 86.13 deg) for males compared to females. The maximum amount of trunk flexion was significantly larger in males as well.

At the takeoff phase, two variables, other than the vertical velocity, were found to be significantly different. First of all, male hip hyperextension angle was significantly greater than the female's measured angle. Secondly, trunk angular velocity was significantly larger in males (139.45 deg/s) compared to females (62.24 deg/sec).

During the touch portion of the kick, five variables were found to be significantly different. Males were found to have a significantly higher knee flexion angle, knee flexion angular velocity as well as knee extension angular velocity. Females during this portion of the skill had a significantly larger shoulder flexion angle as well as trunk flexion angle.

The final portion of the skill, follow through, was found to have seven variables that were significantly different. Female athletes had two significantly larger variables than males, in hip flexion angle and knee extension angle. Males were found to have significantly larger differences with regards to knee variables. Knee flexion angle, knee flexion angular velocity and knee extension angular velocity were all significantly larger than females. Trunk hyperextension was also significantly larger in males. At the point of contact with the ground neck angle differed significantly with females having a flexion angle and males having a hyperextension angle.

Kinematic Predictors of Vertical Velocity at Takeoff

Correlation data was calculated on all variables leading up to takeoff and the vertical velocity. These correlations were calculated to show which variables had a significant relationship with the vertical velocity at takeoff.

Male One Foot High Kick

The results from the male one foot high kick showed that there were two variables that had a significant relationship with the vertical velocity at takeoff. Both horizontal approach velocity and ankle angular velocity at takeoff showed a positive correlation to the vertical velocity. Horizontal approach velocity had the strongest relationship for the male one foot high kick

Female One Foot High Kick

The female correlation data did not produce any significant relationships between any variables and vertical velocity. However, two variables showed very high correlations, but because of the small sample size, a test for significance could not be completed. Horizontal approach velocity, according to this analysis had a perfect correlation of 1.00. Foot position in the forward/backward direction was second to horizontal velocity with a strong negative correlation of -0.81.

Male Two Foot High Kick

Trunk angular velocity at takeoff had the strongest relationship (0.65) with vertical velocity for this group of athletes. The next closest relationship was knee angular velocity with a correlation of 0.64. It is noted that this group was the only group to not have horizontal approach velocity significantly related to vertical velocity.

Female Two Foot High Kick

Once again horizontal approach velocity had the most significant relationship to vertical velocity at takeoff. A strong positive relationship (0.87) between these variables suggests that as the horizontal velocity increases, the vertical velocity will increase also. The second variable that was found to be significantly related to vertical velocity at takeoff was hip angular velocity. A strong positive relationship of 0.86 was found for this variable.

Stepwise Multiple Regression Analysis

A forward stepwise regression was used to determine the most important variables responsible for predicting changes in vertical velocity. The analysis was conducted individually on the four groups.

Male One Foot High Kick

Using this analysis, two variables were identified to predict vertical velocity. The two variables in order of importance are horizontal approach velocity and step length. These variables accounted for 83% of the variance in height jumped.

Female One Foot High Kick

Prediction of vertical velocity for this skill can be perfectly related to horizontal approach velocity. This model is inadequate as the amount of subjects was not large enough to accurately predict vertical velocity at takeoff. However, the current researcher still believes that horizontal approach velocity is the most important, but not the only, predictor of vertical velocity.

Male Two Foot High Kick

According to this analysis four variables were found to be of greatest importance to vertical velocity. These four variables are listed in order of importance are, trunk angular velocity at takeoff, maximum shoulder extension, maximum knee flexion, and hip angular velocity at takeoff. These variables accounted for 94% of the variance.

Female Two Foot High Kick

The regression analysis for this group showed that there were four important variables in predicting vertical velocity at takeoff. In order of importance, they are horizontal approach velocity, maximum trunk flexion, maximum knee flexion, and ankle angular velocity at takeoff. These variables accounted for 100% of that variance in height jumped.

CONCLUSIONS

Based on the findings of the study, the following conclusions appear to be justified:

1. Males have higher heights of the target reached than females.
2. Male athletes have higher vertical velocities than female athletes in the one and two foot high kick, which produce higher jump heights.
3. Male athletes have a larger horizontal approach velocity compared to female athletes in the one and two foot high kick.
4. The majority of male athletes use a curved approach to the target for the one and two foot high kick, which help to produce higher jump heights, whereas females use a straight approach.

5. Males have longer step lengths than females for both the one and two foot high kick.
6. Maximum hip flexion during the approach was larger in males for the one and two foot high kicks, which implies possible leg strength differences.
7. During the takeoff phase of the one foot high kick, all angles and angular velocities did not significantly differ between males and females.
8. Knee movements and angular velocities throughout the airborne phase of the two foot high were all significantly larger in male athletes.
9. The majority of angular velocities for the airborne phase of the one foot high kick were statistically the same between males and females
10. Horizontal approach velocity was the main predictor of vertical velocity at takeoff in all groups but male two foot high kick

RECOMMENDATIONS

The following recommendations are suggested for future studies on the one and two foot high kick:

1. Further studies should utilize the kick height as the measure of performance along with the vertical velocity to investigate how these two variables relate to each other.
2. Tight fitting attire with contrasting colors should be worn by the athletes on their trunk and limbs when filming is performed.

3. There is a need for more detailed studies to be performed on the accelerations of body segments of the one and two foot high kick, and how these contribute to height jumped.
4. As filming athletes in competition is quite difficult, there is a need for studies to be performed in a controlled setting, in which camera views and angles are not blocked.
5. The use of two camera data would be beneficial in measuring movements in other planes not observed in this study, such as a front view or an overhead view.
6. Further studies of Arctic Sports need to include more subjects to ensure significant results and better generalization to a wider range of subjects.
7. Further studies are required to examine Arctic Sports like the Alaskan high kick, kneel jump or knuckle hop.

COACHING RECOMMENDATIONS

Arctic sports are valued tradition in the Northern culture. As these sports grow and get passed on to younger generations, the need for development of coaches and technical instruction increases. In order to help continue these traditions and ability to train these unique athletes, some recommendations for the one and two foot high kick have been made:

1. A faster approach should be taught in order to increase the amount of forward momentum of the athlete, and put the knee extensors on a stretch. This approach velocity is relative to strength of the athlete, however, as athletes

with weaker quadriceps will not be able to control the deep knee flexion that the athlete's forward momentum produces.

2. A left foot forward approach during the last step should be used in the one foot high kick in order keep the weight on the left side of the body so that the right leg is less weighted and is able to flex faster at takeoff.
3. There should not be a stagger between the feet in the front/back direction during the foot plant in order to maximize vertical forces.
4. A curved approach should be used in order to move the center of mass through a larger vertical range of motion, create a more vertical takeoff position, and to keep the weight on the left side of the body.
5. As the trunk accounts for 50% of the body's mass, larger trunk range of motion and angular velocity should be encouraged to create more downward forces on the ground.
6. At takeoff, a hyperextended trunk should be evident. This allows the same range of motion of the trunk and hips, but creates a more vertical leg position and ultimately a higher reach with the legs.
7. Encouraging a more flexed knee position in the preliminary airborne portion of both one and two foot kicks will allow for faster hip flexion.
8. The knees of the athlete during the force production phase of the kick should not extend until the hips have brought the thighs up past parallel.
9. Dynamic flexibility should be of great concern for these athletes as they are putting body segments into extreme positions at a high velocity. This is of special concern for the hamstring muscles, as they cross both the hip and knee

joints. Improving this flexibility will result in higher kicks as it allows the athlete to obtain these strenuous positions.

10. During follow through, the athlete should again flex the knee as soon as possible in order to allow the hip to extend faster.
11. At contact with the ground, the athlete should have a slightly bent knee in order to absorb the downward forces of the body. Quadriceps strength will be of great importance during this portion of the skill as the muscle must eccentrically contract in order to keep the athlete from collapsing to the ground.
12. A bouncing motion after contact with the ground will help the athlete maintain control of the body and allow for a longer time dissipate the downward force of the body.

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