A BIOMECHANICAL COMPARISON OF STARTING TECHNIQUE IN SPEED SKATING AND HOCKEY

By:

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A Thesis submitted to the Faculty of Graduate Studies of

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FACULTY OF GRADUATE STUDIES

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DEDICATION

I would like to dedicate this study to the memory of my cousin Cody who never got the opportunity to pursue his hopes and dreams. Always remember to keep your head up and your stick on the ice.

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ABSTRACT

The purpose of the study was to determine the most effective joint movements, velocities and body positions to perform the fastest start in ice hockey and the fastest start in short track speed skating in female athletes. Secondary purposes included determining which kinematic variables were different between speed skaters and hockey players as well as determining which variables were significant predictors of velocity at six meters. Thirteen hockey players and 11 speed skaters were filmed for the study, performing a start from a stationary position and skating through a 12 meter testing zone. Forty four variables were measured, with 25 of the variables being measured at skate touchdown and push off for the first three strides of the start. Variables were measured using Dartfish Team Pro 4.5.2 with Microsoft Excel and StatView being used for statistical analysis. Speed skaters were shown to skate with a faster velocity at six meters, however, this result was not statistically significant with a p-value of 0.07. Correlation analysis and forward stepwise multiple regression analysis was performed on both the speed skating group and the hockey group in order to determine which variables were significant predictors of velocity at six meters. Foot placement relative to the hip at third foot touchdown was determined to have the strongest predictive effect on velocity ($r = -0.711$) for the hockey players, however, time in double support at second foot touchdown was suggested ($r = -0.781$) for the speed skating group. Several significant differences in skating technique were noted during the initial ready position and the first step, however, with each successive step more similarities in technique were present between the two groups. Hockey players could benefit from assuming body positions more similar to speed skaters during the start to increase skating velocity.

CHAPTER I

Introduction

Skating has been enjoyed as far back as one thousand years in such countries as Scandinavia and the Netherlands where individuals skated across frozen canals and waterways (About Speed Skating, n.d.). However, skating has evolved over the years due to technological advancements as well as specialization of various sports in which skating is an essential component. Skating was primarily used as an alternative method of transportation by Dutch travelers in the early 1600's, however, with the introduction of iron skate blades in 1592 speed skating began to take off in popularity (About Speed Skating, n.d.). Following the introduction of iron skates, the first skating club opened up in Edinburgh, Scotland in 1642 and the first organized speed skating race was contested in 1763 which consisted of a 24 kilometer race on the Fens in England (About Speed Skating, n.d.).

Speed Skating

Speed skating continued to grow and develop in Europe, however, in 1850 the North Americans made their first advancement in the sport of speed skating with the introduction of the steel blade (About Speed Skating, n.d.). Speed skating was enhanced by the creation of the steel blade which produced a lighter and sharper blade increasing the velocity of the skaters. Several years later, in 1889, the first World Championships were organized by the Netherlands where four races were contested at 500 meters, 1500 meters, 5000 meters, and 10,000 meters (About Speed Skating, n.d.). The end of the nineteenth century brought the creation of the International Skating Union (ISU) in 1892 by the Dutch which became the governing body for speed skating and continues to be one of the oldest international winter sports federations (International Skating Union History, n.d.).

Speed skating first made its appearance in Canada in 1854, when a race was contested among three British army officers on the St. Lawrence River (Hurdis and Gambles, 1980). Speed skating continued to grow in Canada and in 1887 the Amateur Skating Association of Canada (known today as Speed Skating Canada) was formed and the first official championship was contested (Hurdis and Gambles, 1980).

Hockey Skating

Skating has also made significant contributions elsewhere in the sporting world as it plays a significant role in the sport of hockey. The sport of hockey has many theories as to where it began, however, "all accounts [suggest] the game evolved out of the Irish field game called Hurley" (History of Hockey, n.d.). Hurley, a game played with a ball and stick, made its way to Nova Scotia, Canada in the early 1800's, however, due to the snowy conditions of the winter, the game was moved onto ice. As a result, "Hurley on Ice" was created at King's College in Windsor, Nova Scotia (History of Hockey, n.d.).

The game of "Hurley on Ice", continued to develop and undergo several name changes including Rickets and Shinny, but in the late 1800's the name was officially changed to Hockey. Hockey was typically contested on an outdoor ice surface, but in the mid 1870's the first official hockey game was contested inside a rink and organized by James Creighton. Creighton further went on to develop a set of rules which were known as "Halifax Rules" which had nine players on each team (History of Hockey, n.d.). The number of players that were allowed to play continued to evolve as the twentieth century rolled around, when nine players were decreased to seven (3 forwards, 2 defensemen, 1 rover and a goalie) and from seven to six (when the rover was dropped) and the National Hockey League (NHL) was formed in 1917 (History of Hockey, n.d.).

Both Hockey and Speed Skating are considered to be sports which require a high degree of power and skill, however, technique plays a significant role in the success or failure of the athlete. In hockey, the acceleration of the athlete plays a substantial role in determining who will win the race to the puck and gain possession or control of the puck. In speed skating, the athlete's ability to accelerate will provide them with a slight advantage at the beginning of the race which can prove to be important when races can be won or lost by a fraction of a second. Therefore, both sports require a clear understanding of the proper technique which can be utilized to maximize an athlete's acceleration over their first five to ten strides. A greater understanding of the similarities and differences which exist between the two sports may prove to be beneficial in determining which variables need to be emphasized for the start in both hockey and speed skating. Understanding the proper mechanics and timing of movements will be beneficial to both coaches and athletes of hockey and speed skating. Therefore, it is important to increase the understanding of the start in both hockey and speed skating in order to identify mistakes in technique and improve the overall performance of the athletes in their respective sports.

Purpose of the Study

The purpose of the study is to determine the kinematic differences between the start executed in speed skating and the start executed in hockey by investigating the key variables which are associated with maximizing the athlete's velocity over the first six meters of the skating sequence. A secondary purpose is to determine the most effective body movements and body positions to perform the fastest start in ice hockey and the fastest start in short track speed skating in female athletes. A final purpose of the study is to develop a checklist which can be used to identify and organize the key characteristics associated with the start in each of speed skating and hockey.

Null Hypothesis

1. The movement patterns and kinematic variables of the start in hockey will not differ from the start in speed skating.
2. The variables which will be identified as key kinematic components of the skill will be very similar between the two skating styles.

Rationale for the Study

Short track speed skating and hockey are two very different sports; however, they both employ the skating stride as the method of propulsion on the ice surface. It would be beneficial to increase the knowledge base of skating starts by making a comparison between the two techniques to determine where similarities and differences may occur. By gaining a greater understanding of what determines an effective start, coaches and athletes will be better able to improve technique at a younger age and shape their technique in a way which is beneficial for their particular sport. Hockey in particular is a game which is won and lost by winning races for the puck. Therefore, athletes who are able to accelerate faster have a greater chance of gaining control of the puck and winning the battles within the game itself. The acceleration of a player is an essential aspect in the sport of hockey as stated by promising junior hockey player Ryan Reaves in 2006, "The biggest thing for me to work on is my first two steps. I'm a fast skater in full flight but I need to get there quicker" (Lawless, 2006). As a result, acceleration in hockey must be taught properly and understood at a young age to enable young hockey players to advance to the next level and participate in professional hockey. Speed skating on the other hand, only requires the athlete to start once within each individual race, however, the athlete must demonstrate superior starting technique in order to gain the edge over their opponent from the initial firing of the starting pistol.

Female subjects were chosen for the study due to the rapid growth of female hockey over the past several decades. Statistics from Hockey Canada provided in Figure 1.1 shows that in 1990-91 less than 10,000 females were registered in hockey and in 2006-07 there were 73791 registered female hockey players.

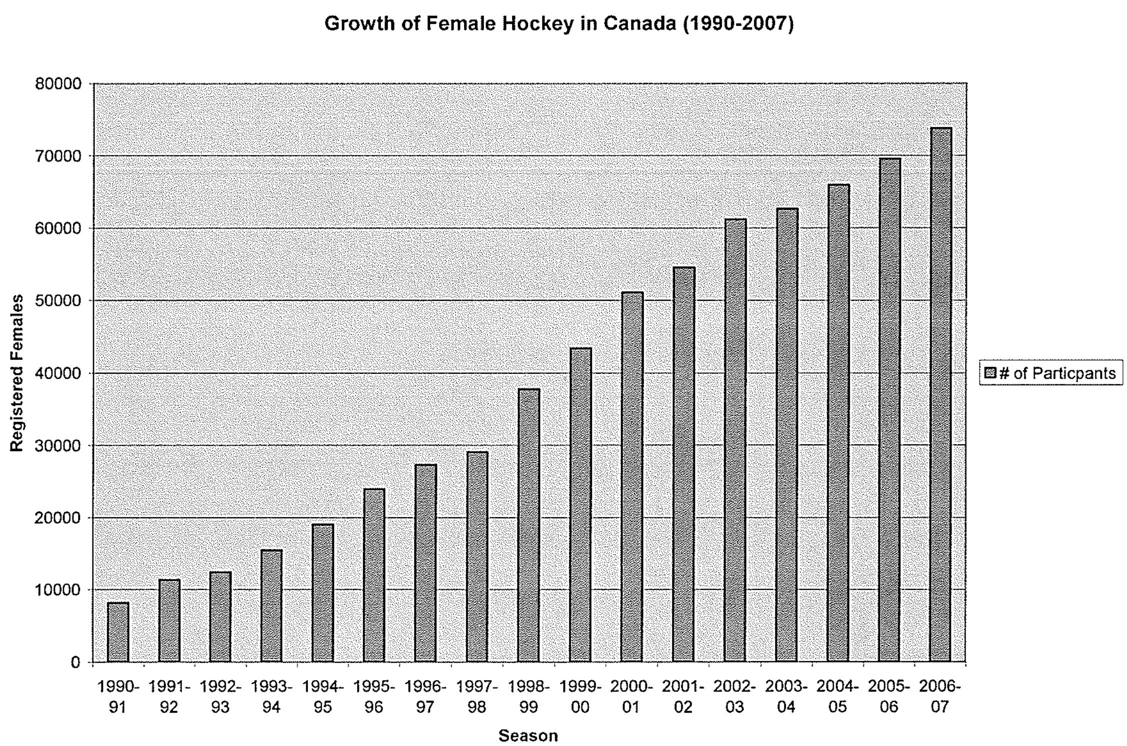


Figure 1.1: Growth of female hockey over the past 17 seasons.

In 1992, Manon Rheaume became the first female hockey player to play in a professional hockey game (Russell, 1992). Rheaume was the goaltender for the Tampa Bay Lightning in a National Hockey League preseason game against the St. Louis Blues.

More recently, Haley Wickenheiser, "the longtime member of Canada's National and Olympic women's hockey teams" (Down, 2007) and probably the most skilled power forward in women's hockey played two seasons in Finland with H.C. Solamat from 2002-2004. Since the women's hockey game has continued to develop, more studies focusing on female athletes and a greater knowledge of how female athletes' technique compares to their male counterparts will be beneficial. Furthermore, female subjects were chosen due to the limited number of studies (in both speed skating and hockey) focusing primarily on female athletes.

Short track speed skating was chosen (as opposed to long track speed skating) due to similarities in the starting technique utilized by hockey players. Short track speed skaters utilize the sprint start in which the upper body is oriented towards the direction of travel. This start is similar to the front start utilized in hockey based on the athlete's starting position as well as their initial movements. An additional reason for choosing short track speed skaters instead of long track speed skaters is due to the difference in skating blades. Long track speed skaters use a clap skate which "is equipped with a hinge between [the] shoe and blade under the ball of the foot" (Houdijk, de Koning, de Groot, Bobbert and van Ignen Schenau, 2000). The hinge has shown to be beneficial as it allows the athlete to go through a larger range of plantarflexion at the end of the push off, while allowing the full blade to remain in contact with the ice (Van Ignen Schenau, de Groot, Scheurs, Meester and de Koning, 1996). Short track speed skaters do not use the clap skate. Therefore, due to the invention of the clap skate in long track speed skating, the similarities between the hockey skate and the conventional short track speed skate allow for a more accurate comparison, without having to take into account the additional plantarflexion from the clap skate.

Figure 1.2: 1. Clap skate with a hinge located on the front toe 2. Standard hockey skate 3. Standard short track speed skate with boot firmly fixed on the blade.

The primary concern when comparing a short track speed skate to a hockey skate is the increased blade length which has been linked to speed skaters achieving higher velocities during full velocity skating. The effect of the longer blade on the short track start is not currently known. Short track speed skates also have a slight offset with the blade located on the inside edge of the skate in order to allow for better stability during corners.

The outcome of the study will be beneficial for both coaches and athletes as it will provide insight as to what components of the start should be emphasized within their respective sports. By gaining a greater understanding of the important joint movements, timing of movements and velocity of movements, the coaches will be better able to identify mistakes in technique and improve these technical errors before the athletes have created an incorrect motor pattern that displays improper technique

Limitations

1. The subjects for the study were wearing the skates which they would normally wear during competition. As a result, a slight difference in skating strides may be attributed to the different skates used by short track speed skaters and hockey players.

2. The selection of the groups from two different sports may have resulted in the groups being of slightly different skill levels, however, all athletes were considered skilled as they are part of an elite training program.
3. The hockey players were filmed wearing tight fitting clothing (as opposed to the equipment normally seen in hockey) which may reduce the ability to generalize the results. However, this increased the accuracy of locating joint centers for analysis.

Delimitations

1. The selection of only skilled female subjects decreases the ability to generalize the results of the study to their male counterparts.

Description of the Skill

The following section provides a brief description of the start as performed by elite hockey players and elite speed skaters. The information has been gathered from skill analysis which was performed on elite athletes who are considered highly skilled in their respective sports.

Elite Hockey Starting Technique

Ready Position

Elite hockey players have made use of several different starting techniques during game situations, however, for the purpose of this study the standard start will be described. The standard start occurs in hockey when the athlete is facing the desired direction of travel. The ready position of the standard start, as seen in elite hockey players, positions the athlete with their feet slightly wider than shoulder width apart and one foot slightly ahead of the other. The athlete has a moderate degree of trunk forward flexion at 45 degrees from the horizontal which will allow for an optimal angle to apply force downwards against the ice during the start. The athlete also has a moderate degree of knee flexion in both legs with approximately 60 degrees of flexion in the rear leg and 70 degrees of flexion in the front leg (see Figure 1.3). The front leg will have slightly more knee flexion due to the athlete's line of gravity being located closer to the front of the athlete's base of support. Increased knee flexion will allow the athlete to lower their center of gravity as well as increase the range of motion for force production during the push off.

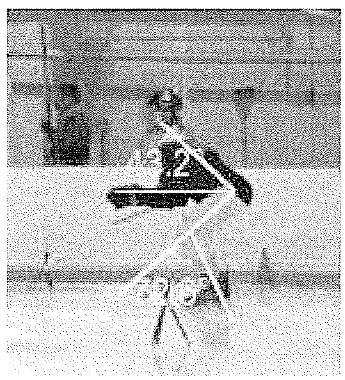


Figure 1.3: Ready position of elite hockey player performing the standard start

Stride

During the start, elite hockey players will focus on maximizing their horizontal velocity over the shortest period of time in order to increase their acceleration. The athlete will increase their stride rate significantly from that seen during the normal skating stride. The stride rate in elite hockey players has been measured to 4.56 steps/second which is substantially higher than the stride frequency measured in elite speed skaters at 3.4 steps/second. An increased stride rate is often achieved by decreasing the stride length or going through a smaller range of motion during the force producing phase. Hockey players who are able to increase their stride rate while not having a negative impact on their stride length are able to accelerate rapidly. Therefore, elite hockey players are able to go into a high degree of extension at the hip (20 degrees short of full extension) and the knee (20 degrees short of full extension) during the first push off in order to increase the force production (see Figure 1.4). Elite hockey players are seen to plant their support skate with a moderate degree of knee flexion at 55 degrees, which is significantly less than that seen in elite speed skaters who planted their skate with 100 degrees of knee flexion. Furthermore, elite hockey players are seen to go into a moderate degree of knee extension during the push off with 20 degrees of flexion remaining in the knee, similar to that seen in elite speed skaters.

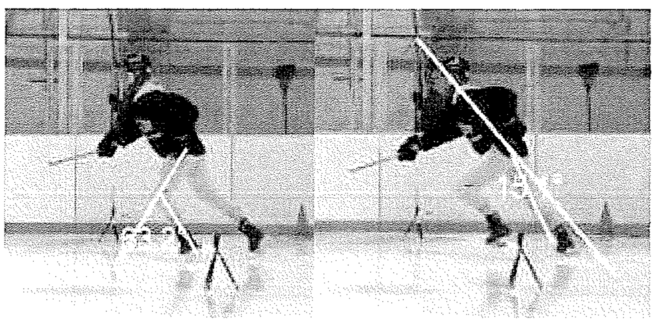


Figure 1.4: Knee extension and knee flexion of elite hockey players

As a result, elite hockey players go through a smaller range of motion during each stride of the start than that seen in elite speed skaters. The range of motion of hockey players at the knee is 40 degrees, while the range of motion for knee extension in speed skaters is 80 degrees.

Elite hockey players are seen to plant their support leg facing perpendicular to the direction of travel over the first two strides. From this point, the skater will angle the skate blade slightly less with each successive stride until they have reached maximum velocity and the skate is angled at 45 degrees from the direction of travel. The skater should plant the skate blade perpendicular to the direction of travel because it allows the athlete to maximize the forces applied in the posterior direction during which the skate blade is fixed on the ice surface. As the skater accelerates, the blade will no longer be fixed on the ice surface and therefore, the forces will be applied in a more lateral direction to maximize ground reaction forces. During maximum velocity skating, the skate blade will be gliding across the ice surface and therefore, the skate blade will not have a fixed position from which to push off. This results in an increased contribution to the lateral push off at maximum velocity skating seen while the skate blade is angled closer to 45 degrees from the direction of travel.

Elite Short Track Speed Skating Starts

Ready Position

Elite short track speed skaters use the sprint start technique in order to maximize their acceleration during the start. The ready position in speed skating begins with the athlete positioning their rear skate parallel to the starting line (or 90 degrees to the direction of travel) at a position between 60 to 80 centimeters behind the starting line (see Figure 1.5). The front skate is placed facing towards the direction of travel with the toe of the skate blade digging slightly into the ice surface. The front leg should be flexed to approximately 100 degrees at the knee and 130 degrees at the hip. This position will allow the athlete to increase their trunk forward lean to approximately 15 degrees from the horizontal which positions the athlete's center of gravity in the middle of their base of support. In elite athletes, the ready position will also feature a moderate degree of knee flexion in the rear leg of approximately 70 degrees which allows for an increased range of motion for force application during the push off.

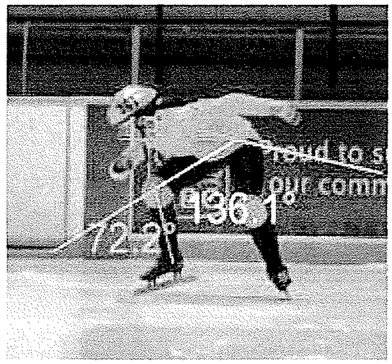


Figure 1.5: Ready position as seen in elite speed skaters

Stride

Elite speed skaters must balance the contribution of stride rate and stride length to the overall velocity produced during the start in order to maximize their acceleration. During the first push off, elite speed skaters will forcefully extend their rear leg and leap onto their front foot while entering a small airborne phase. The first push off should result in the athlete going into near full extension at the knee (approximately 20 degrees short of full extension) and near full extension at the hip (see Figure 1.6). In conjunction with hip and knee extension, the athlete will also decrease their angle of trunk forward lean to approximately 40 degrees from the horizontal to allow for the force to be directed at an increased angle against the ice surface. As the athlete completes the end of the push off there should be minimal hip abduction present as the push off should be directed backwards against the ice surface.

After completion of the first push off, the athlete will plant their new support leg with approximately 80 degrees of knee flexion and their hip in lateral rotation allowing for the skate blade to be planted at a 70 degree angle to the intended direction of travel (see Figure 1.6). The new support leg will begin extending immediately following skate touchdown in order to increase stride rate during the first five to six strides.

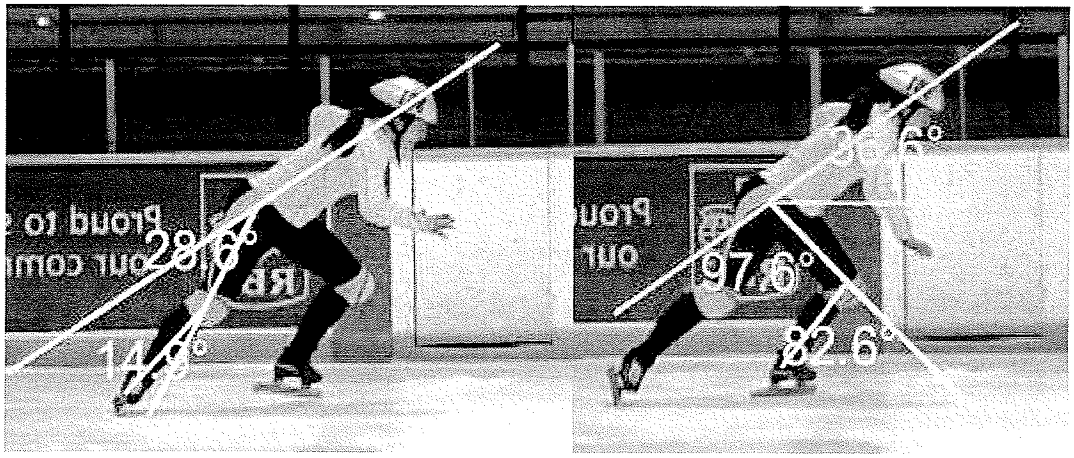


Figure 1.6: Extension of the push off leg and flexion of the landing leg during elite speed skating

The athlete will extend to 20 degrees short of full extension at the knee and back to a neutral position at the hip during the end of the second push off and plant their new support leg with a high degree of knee flexion of approximately 90 degrees in order to increase the range of motion for force production during the next push off.

Elite speed skaters also show a high degree of knee flexion of 120 degrees in their recovery skate which allows for a decreased moment of inertia of the lower limb during the recovery (see Figure 1.7). By decreasing the moment of inertia of the lower limb, the athlete is able to swing the leg through with less resistance to angular motion, allowing the skater to clear the toe of the skate blade as well as conserve muscle torque and energy.

Figure 1.7: Note the high recovery leg of the elite speed skater

Elite speed skaters will follow a pattern of forceful knee and hip extension followed by foot plant of the opposite leg during the first five to six strides. After the initial five or six strides, the short track speed skater will enter the first corner and alter their technique from that seen during the start. During the initial five or six strides, short track speed skaters will have a high stride rate of approximately 3.4 steps/second measured from elite speed skating video. They continue to go through a large range of motion of knee extension through 80 degrees and hip extension through 120 degrees during the force producing or push off phase of the stride. Elite speed skaters demonstrate a slight airborne phase during the first three or four pushoffs in order to allow for a more efficient skate touchdown which allows them to increase their stride frequency during the start.

Arm Movement

During the sprint start in speed skating, elite athletes demonstrate a vigorous arm action in order to compliment the powerful pushoff against the ice by the lower limb. The arm action is beneficial during the start as it allows the athlete to increase the ground reaction forces which can be applied against the ice surface. Elite speed skaters will flex and adduct their right shoulder in front of and across their chest in conjunction with the forceful hip and knee extension of the right leg at the end of the push off. Meanwhile, the athlete's left shoulder will be extended and abducted behind the athlete's body. As the athlete continues to take strides, more of the arm action will be orientated in the frontal plane (shoulder abduction and adduction) in order to compliment the increased degree of hip abduction present during the push off.

Elite speed skaters will compliment the shoulder action with a moderate degree of elbow flexion and extension. Elite speed skaters are shown to extend at the elbow in conjunction with shoulder extension and abduction (this motion will place the athlete's arm in an excellent position to flex it forward and adduct it across their body for the next push off).

Definition of Terms

Acceleration (a): rate of change in velocity with respect to time (Enoka, 2002)

$a = (v_f - v_i)/t$: where a = average acceleration; v_f = final velocity; v_i = initial velocity; and t = time.

Anatomical Reference Position: an erect standing position with the feet slightly separated and the arms hanging relaxed at the sides, including the palms of the hands facing forward; considered the starting position for body segments (Hall, 2007)

Angular Acceleration (α): rate of change in angular velocity (Hall, 2007)

$\alpha = (\omega_f - \omega_i)/t$: where α = angular acceleration; ω_f = final angular velocity; ω_i = initial angular velocity; and t = time

Angular Velocity (ω): rate of change of an angular position or change in angle with respect to time, measured in degrees/sec or rad/sec (Hall, 2007)

$\omega = \theta/t$: where ω = angular velocity; θ = angular displacement; and t = time

Average Velocity (v): rate of change in position which occurs over a designated time interval, measured in meters/sec (Enoka, 2002)

Axis of Rotation: imaginary line perpendicular to the plane of rotation and passing through the center of rotation, about which a body or segment rotates (Hall, 2007)

Center of gravity: the point around which the mass of the system is evenly distributed (Enoka, 2002)

Double Support Time: the time during which both skates are in contact with the ice during the stride (Marino, 1983)

Force (F): push or pull; the product of mass and acceleration (N) (Hall, 2007)

$F = ma$: where F = force; m = mass; and a = acceleration

Horizontal Velocity (V_h): the horizontal (or x component) of the velocity of an object or person, measured in meters/sec (Hall, 2007)

Instantaneous Velocity: the rate of change in position which occurs over a very small time interval, measured in meters/sec (Hall, 2007)

Impulse: the product of a force and the time interval over which the force is applied; impulse produces a change in linear momentum (Hall, 2007) or the area under the force time graph, measured in Newton seconds (Enoka, 2002)

$I = Ft$: where I = impulse; F= force; and t = time

Inertia: the resistance an object offers to any changes in its motion (Enoka, 2002)

Line of Gravity: a vertical line extending through an objects center of mass, which is the line around which the body's weight is equally balanced, directed towards the earth's core (Hall, 2007)

Linear Displacement: change in location; or the directed distance from initial to final location (Hall, 2007)

Linear Momentum (M): the quantity of motion possessed by an object or the product of mass x velocity, measured in kgm/s (Enoka, 2002)

$M = mv$: where M = momentum; m = mass; and v = velocity

Moment Arm: the shortest distance (perpendicular) from the line of action of a force vector to an axis of rotation (Enoka, 2002)

Moment of Inertia: the resistance that an object offers to any change in its angular motion or the product of moment of inertia x angular velocity, measured in kgm^2 (Enoka, 2002)

$I = mk^2$: where I = moment of inertia; m = mass; and k = radius of gyration

Range of Motion (ROM): angle through which a joint moves from anatomical position to the extreme limit of segment motion in a particular direction (Hall, 2007)

Rocker: the curve applied to the bottom of the skate blade during sharpening. Hockey players have an increased rocker (rounder blades) which results in a smaller gliding surface, whereas, speed skaters have a smaller rocker (flatter blades) with a larger gliding surface (No Icing Sports, n.d.)

Single Support Time: the time during which only one skate is in contact with the ice during the stride (Marino, 1983)

Stretch Shortening Cycle: an eccentric muscle contraction followed immediately by a concentric muscle contraction, whereby the eccentric muscle contraction fires the stretch reflex, producing a reflex contraction of the muscle (Hall, 2007)

Stride Length: the distance between the pushoff location of the right toe and the subsequent pushoff location of the right toe, measured in meters (Marino, 1983)

Stride Rate: the number of strides taken per second (Marino, 1983)

CHAPTER II

Review of Literature

Chapter two will provide a review of literature on starting technique in both hockey and speed skating. The chapter begins with a discussion of the key characteristics previously studied by hockey researchers, followed by a discussion of the key characteristics studied by speed skating researchers. Lastly, the chapter will highlight key information regarding video analysis techniques with emphasis placed on Dartfish video analysis.

Starts in Hockey

The technique for "initiating forward movement" (Naud and Holt, 1979) or starting in the sport of hockey has been sparsely examined over the past 30 years with the majority of the work conducted at the University of Windsor by G. Wayne Marino and at Dalhousie University by Ronald L. Naud and Laurence E. Holt in the late 1970's and early 1980's. As a result, there is a need for updated research in this area due to the technological advancements in the game, the equipment and the players, resulting in a faster paced style of play and a greater demand placed on the skating ability of upcoming players. Researchers in biomechanics have primarily focused on analyzing the temporal components of the start with a limited number of studies looking at ideal kinematic patterns relating to the optimal technique. Research has been conducted on the effectiveness of the different starting techniques which are utilized in forward skating, including the crossover technique, the thrust and glide technique, with the majority of studies looking at the standard technique.

Standard (Front) Start

The standard technique of starting in hockey is described by Naud and Holt (1979) as having "the subject in a standing position, knees slightly flexed, feet parallel and approximately 12 [inches] apart, with the skate blades at a 90 degree angle to the starting line" (p. 8). The starting position represents the standard ready position seen in the sport of hockey and has practical implications for the sport (see Figure 2.1).

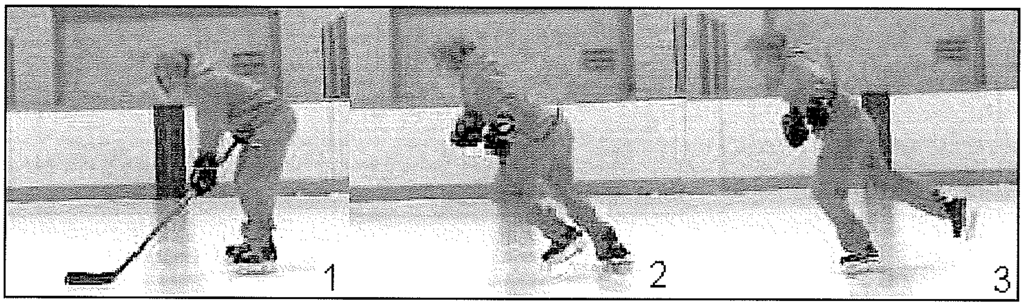


Figure 2.1: Sequence picture of the standard starting technique utilized by hockey players as described by Naud and Holt, 1979 (viewed from left to right)

However, the starting position could be improved by having a greater degree of knee flexion in order to preload the knee extensors (quadriceps) and enable them to store greater strain energy resulting in a greater force output. By having only a slight degree of knee flexion, the athlete is forced into a position in which they would need to lower their center of gravity (increase their knee flexion) prior to their first stride or push off from a nearly fully extended knee which would result in a significantly smaller range of motion for force application. Another potential limitation to the standard starting position was discussed by Naud and Holt (1979) when they conducted a study on 24 hockey players (with equal sized groups from Bantam, College, Junior B, and Professional). The subjects performed several trials of starts using the standard technique, the crossover technique and the thrust and glide technique. From the study, it was determined that the angle of push off of the driving skate during the standard start was 45 degrees from the direction of travel as opposed to the ideal angle of 90 degrees (Naud and Holt, 1979). It is believed that a 90 degree angle to the direction of travel is beneficial because it allows for the majority of the muscular force to be applied directly backwards against the ice surface.

Crossover Start

The crossover start is described by Naud and Holt (1979) as having "the skate blades parallel to the starting line" and "involved crossing the rear foot in front of the lead foot (cross over) then skating forward as quickly as possible" (p. 8) (see Figure 2.2).

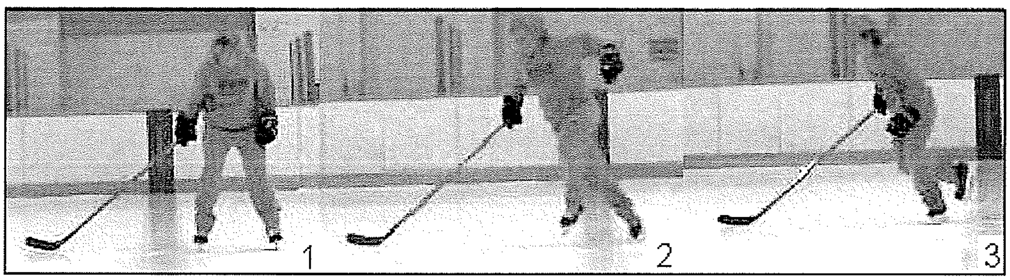


Figure 2.2: Sequence picture of the crossover starting technique utilized by hockey players as described by Naud and Holt, 1979 (viewed from left to right)

Once again, there are practical applications of this starting technique as the player begins in the ready position in preparation to initiate the forward movement. However, due in part to the crossover and in part to the elevation of the center of gravity, this position could potentially place the athlete off balance and in a very unstable position. Naud and Holt (1979) stated that the crossover start was the slowest "because the cross over step caused an elevation in the center of gravity and suspension of the body in the air for a short period of time" (p. 10). As a result, the athlete has used energy to elevate the center of gravity which could have been utilized to increase the athlete's forward velocity and thus decrease the efficiency of the start. Another potential reason why the crossover start was slower is mentioned by Naud and Holt (1979) when they discuss the skate positioning after the crossover as being less than 90 degrees. As a result, the athlete is not able to produce maximal force in the backwards direction upon the initiation of forward movement which would result in less impulse applied in the backwards direction and therefore a slower acceleration.

Thrust and Glide Start

The thrust and glide technique was described by Naud and Holt (1979) as having the athlete "in a standing position, knees slightly bent, feet parallel, 12 inches apart, and skate blades parallel to the starting line" (p. 8) (see Figure 2.3). The thrust and glide portion of the technique involves the athlete laterally rotating their front foot (closest to the starting line), pushing backwards, perpendicular to the direction of travel with their rear skate and entering a gliding position on the front skate (Naud, 1975).

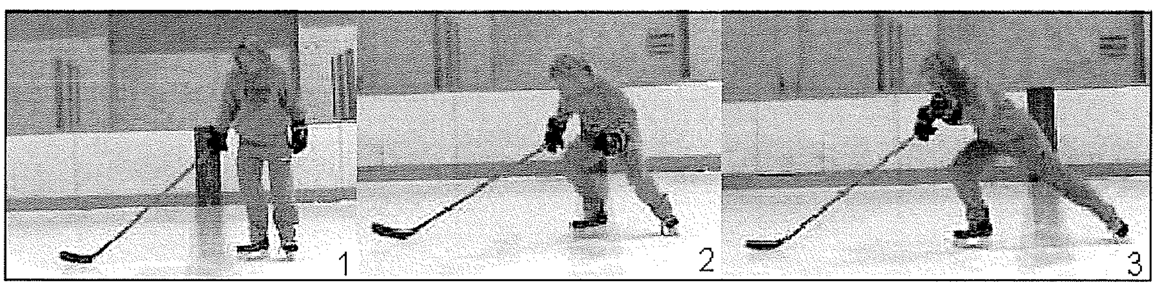


Figure 2.3: Sequence picture of the thrust and glide technique utilized by hockey players as described by Naud, 1975 (viewed from left to right)

The thrust and glide technique also called a t-start was determined to be the most effective method of initiating forward movement because it allowed the athlete to "accelerate immediately" (Naud, 1975). Naud and Holt (1979) later determined the thrust and glide to be "better because this technique made use of the 90 degree angle of the rear skate during the initial thrust enabling all the muscular energy to drive the body forward immediately" (p. 10). Therefore, the thrust and glide technique was superior to other methods at initiating the forward movement because it enabled the athlete to immediately begin applying force from a moderately flexed rear knee acting directly backwards against the ice surface. As a result, the athlete is able to gain significant benefit in their start due to a more efficient starting position. This enables the athlete to go through a moderate range of motion of knee extension and a greater impulse applied backwards against the ice surface.

Skill Analysis of the Hockey Start

Single and Double Support Phases

The start in hockey (and the skating stride itself) has been described as being "biphasic in nature" (Marino, 1979, p. 55). Marino (1979) describes the two phases of the skating stride as being "alternate periods of single and double support" (p. 55). The single support portion of the stride begins immediately after the pushoff and continues through the recovery of the pushoff leg until the leg touches down near the midline of the skater. The double support portion of the stride begins when the recovery skate touches down and continues through the force producing phase up until the end of the push off. The pattern is cyclical in nature with the right and left legs alternating in periods of single support and alternating in periods of force production. Due to the nature of the skating stride, it has been suggested by Marino (1979) that "during the double support period the skater would accelerate forward and during the single support or glide phase he or she would decelerate because the only forces acting horizontally are friction and air resistance, and both act in the direction opposite to the direction of movement" (p. 56).

As a result of the deceleration present in the glide phase of the skating stride, the skater should concentrate on shortening the length of the glide phase (having a fast recovery of the skating leg) and attempt to maximize the amount of time spent in the force producing (or double support phase). By increasing the time spent in the force production phase of the skating stride, the skater is better able to achieve the objective of the start which is "to develop a relatively high horizontal velocity over a relatively short period of time" (Marino, 1979, p. 56).

Several researchers have conducted temporal analyses of the skating stride for the standard start in hockey, with the stride broken down into the single support phase and the double support phase. Marino (1979) determined that "skaters are able to maintain positive acceleration throughout both the single and double support periods of at least the first three or four strides in a starting task" (p. 58). Therefore, it is important to note that positive acceleration can be maintained over the first three or four strides of the start, even though, research suggests that "the double support period of the first three strides comprised, on average, only 14.7 % of each stride" (Marino, 1979, p. 59). Another study conducted by Marino (1983) focused on collecting video from a wide variety of subjects performing a starting task. The subjects all had a background in skating and at least one year of hockey experience while several of the subjects were members of the University of Illinois hockey team. Marino (1979) selected a wide variety of performance or technique variables (knee flexion, hip abduction, single support time, double support time, stride length, etc) as well as height, weight, and leg length for each of the subjects and performed a multiple regression analysis in order to determine the variables which best predicted the subject's time to six meters. From the study, it was determined "that a long single support time is related to a relatively slow skating time, and concomitantly a low rate of acceleration" (Marino, 1979, pg. 58).

Therefore, research conducted by Marino (1979) suggests that skaters should increase the length of time in the double support phase during the start in order to maximize acceleration. Marino (1979) suggests that over the first three strides positive acceleration can be present during the single support phase due to the high stride rate and rapid turnover of the skates which occurs. The acceleration is maintained due to "the recovery leg [coming] down in a position of outward rotation with hip, knee, and ankle flexion, so that propulsion could begin during double support and last throughout the entire stride" (p.58). Therefore, the subjects in the study performed the skill by having very short, choppy strides which resulted in an increased stride rate at the expense of a shorter range of motion for force production.

Marcotte (1975) has suggested that "there is no gliding on the first stride" (p. 31) which would result in the low percentage of time spent in double support during the first three strides. A study by Greer and Dillman (1984) reported a stepwise multiple regression analysis with 13 variables and found the two greatest predictors of acceleration were lower single support time and higher double support time. Once again, the study showed the importance of minimizing the time spent in single support during the initiation of the start as well as lengthening the time spent in the double support phase in order to have continuous force production during the stride. Therefore, research has shown that single support time and double support time are both significant contributors to acceleration in the ice hockey start.

Recovery Leg Placement

Researchers have discussed several potential reasons why the timing of the skating stride is important and have discussed several variables which have resulted in the way the skating stride is performed during the start. One of the most important variables which determines the length of time spent in single and double support is the placement of the recovery leg at touchdown as the skater begins the double support phase. In a study conducted by Marino (1983) he determined “the importance of placing the foot down underneath rather than in front of the body in order to facilitate the onset of the subsequent propulsive phase” (p. 237) (see Figure 2.4). Therefore, if the skater positions their plant foot too far in front of their body it is believed that this will cause higher deceleration while the body catches up to the skate.

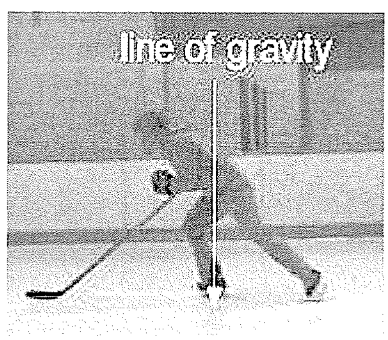


Figure 2.4: Note how the athlete has positioned her foot underneath her center of gravity. The above position enables her to prevent her body from decelerating due to her foot placement being located in front of her line of gravity.

As a result of the skate being positioned too far in front of the body, “the body has to move forward over it until it reaches a suitable position at which it can be rotated outward prior to propulsion” (Marino, 1983, p. 237). The position of the skate during the plant is also important relative to the midline of the athlete’s body. To maximize the range of motion of force production, it is believed that the skate should be planted directly underneath the athlete's midline before initiating the thrust (Holt, 1980). Therefore, by increasing the range of motion of the leg (by planting the recovery skate underneath the midline) the skater decreases the stride rate which can be obtained due to a subsequent increase in stride length. However, Marino (1983) has suggested that a high stride frequency is beneficial during the start and should not be traded off for an increase in stride length due to the fact that a high stride rate allows the skater to overcome the body's inertia by having longer and more frequent periods of force application to the ice.

The ability of an athlete to accelerate during the initiation of forward movement is dependent on the skater's ability to produce a large range of motion over a short period of time. As a result, the skater is able to increase the impulse they are able to apply to the ice surface and thus increase the momentum they are able to produce. The impulse momentum equation states that $I = \Delta M$ where I = Force x time and ΔM = change in momentum (Hall, 2007). Based on the impulse momentum equation, which is a deviation of Newton's second law of motion, a greater force applied over the same time will result in a greater change in Momentum (or an increase in the skater's velocity). During the skating stride, Holt (1980) has suggested that "fast skaters get a smaller angle of knee flexion than slow skaters" (or have an increased degree of knee flexion) and that "the angle at the knee prior to pushing should be 90 to 110 [degrees]" (p. 78). By entering a high degree of knee flexion of around 90 degrees, the skater has positioned their knee in an optimal position to begin the force producing phase, however, little research has investigated the angle of knee flexion used during the start in hockey. Many athletes decrease the angle of knee flexion (for a moderate degree of knee flexion) in order to increase the stride rate which can be obtained during the start.

Holt (1980) also discussed the importance of knee extension during the skating stride "as all good skaters extend their drive leg to almost 180 degrees" (p. 79). Once again, many athletes go into a smaller degree of knee extension in order to maintain a higher stride frequency and thus increase their acceleration during the start. Greer and Dillman (1984) have suggested that "the greater flexion [in the support knee] would place the extensor muscles in a stretched position thus increasing their physiological capabilities" (p.204) due to the use of strain energy stored in the knee extensors prior to the push off. Increased knee flexion is beneficial during the skating stride, however, during the start, it is probable that too much knee flexion would result in increasing the length of time for each stride. As a result, the stride frequency for the skater would be substantially reduced and the skater would have a slower acceleration during the start.

Trunk Angle

Several researchers have conducted stepwise multiple regression analysis on the first three or four strides of the standard start in hockey and have suggested variables which are considered good predictors of acceleration. In studies conducted by Marino (1983), Marino and Dillman (1976) and Greer and Dillman (1984), all three researchers found trunk angle at foot touchdown and leg angle at takeoff (the angle formed by the leg relative to the horizontal at the end of the push off) to be important variables to be emphasized during the skating start. Greer and Dillman (1984) suggested that a greater trunk angle at touchdown of 50 degrees from the horizontal would be beneficial to the skating start because it would "put the skater in position to exert greater horizontal force and therefore benefit from a greater ground reaction force in the direction of desired movement" (p. 204). In both studies conducted by Marino (1976 and 1983) it was suggested that increased trunk forward lean would place the skater in an optimal position to apply the greatest magnitude of force in the horizontal direction and subsequently greater ground reaction forces in the direction of intended travel. A high degree of trunk forward lean is important in forward skating as it allows for a better propulsive angle to be created between the player and the ice surface. An increased trunk forward lean also puts the athlete's gluteus maximus on a greater stretch and therefore helps produce a greater force output from the muscle itself. Furthermore, it allows the player to position the skate directly under their center of gravity (due to the center of gravity being moved horizontally) thus placing the skate in an optimal position to begin force production. Marino and Dillman (1976) also suggested that "at the end of double support the angle of takeoff should be as low as possible" (p.199). One of the primary ways of lowering the angle of takeoff can be achieved by increasing the forward trunk lean during the skating stride as well as skating with a greater amount of knee flexion in the support leg.

Skate Blade Position

Another important aspect which has been briefly studied during the initiation of forward movement is the position of the skate blade relative to the intended direction of travel. Marcotte (1975) has suggested that one of the most effective ways to determine the skill level of a player is to evaluate the tracings left behind on the ice surface. During the initiation of the start, Marcotte (1975) has suggested that "one will have to get the first skate in as close to 90 degrees to the intended direction of movement as possible" (p. 31) in order to ensure that the first stride takes the player directly towards their target direction, as seen in Figure 2.5. It is important to note that upon the completion of the first stride, the angle of force application will decrease progressively until it reaches approximately 30 degrees from the direction of travel during the normal skating stride.

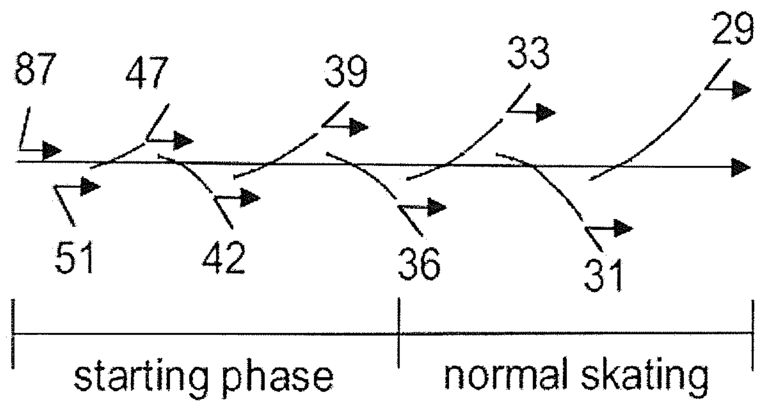


Figure 2.5: Angle of skate blade during the acceleration of the skating stride in degrees (modified from Marcotte, 1975)

The angle of the skate blade is closely related to the impulse which is applied to the ice surface during the skating stride. In a study conducted by Roy (1977), it was determined that "the resultant angle of application of the vertical and lateral forces is around 80 degrees at the take-off phases of all three starting styles but approaches 70 degrees during the skating strides" (p. 139). As a result, the research confirms the importance of having the force primarily focused backwards during the initiation of the start, indicated by the horizontal velocity in Figure 2.6, while the lateral push is increased as the skating stride begins to reach peak velocity, as indicated by the vertical velocity in Figure 2.6.

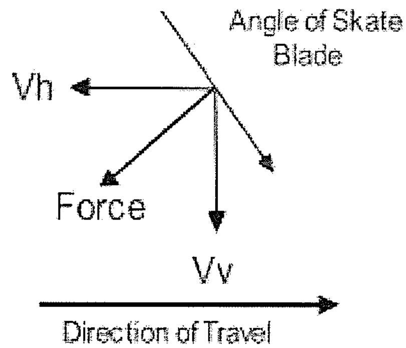


Figure 2.6: The force vector above can be broken down into horizontal and vertical components with the Force representing the application of the skate blade pushing against the ice. During the start it is important for the athlete to emphasize a more backwards directed force (Vh) in order to maximize their acceleration forwards. (modified from Hall, 2007)

Starts in Speed Skating

Speed skating technique has been studied frequently over the past 20 years with the majority of work focusing on skating technique on the straight-aways and skating technique during the corners. Very little research has been conducted studying the technique utilized during the start, however, research in this area is becoming a focus for several researchers in Europe (de Koning, de Groot, and van Ingen Schenau, 1989; de Koning, Thomas, Berger, de Groot, and van Ingen Schenau, 1995; and de Boer, Schermerhorn, Gademan, de Groot, and van Ingen Schenau, 1986). The starting technique during speed skating sprints requires increased research due to the importance of acceleration during the shorter races. The majority of the research has taken place in Europe and Asia, as well as a few studies which have been conducted in North America. The most common technique utilized by elite level speed skaters is referred to as the sprint start technique.

Sprint Start Technique

The sprint start in speed skating "is one of the most important parts of the race" (p. 151) especially the 500 m events during which the skater's ability to accelerate rapidly over the beginning portion of the race is extremely important (de Koning et al., 1989). In a study conducted at the 1988 Olympic Games in Calgary, Alberta, de Koning et al. (1989) collected data from the 500 m race and "calculated correlation coefficients of 0.88 for the first 100- compared to the 500-meter times for both male and female speed skaters" (p. 151). As a result of de Koning et al.'s (1989) study, it was determined that "almost 80% of the variation in final times is associated with the extent to which the skater is able to accelerate during the first 100 meters" (p. 151). In a recent speed skating event in Heerenveen Netherlands, Jenny Wolf of Germany finished first with a time of 38.16 seconds (ahead of Svetlana Kajkan of Russia with a time of 38.62) and a split time during the first 100 meters of 10.31 seconds (International Skating Union, n.d.). Therefore, the athlete's ability to accelerate at the beginning of the race plays a significant role in their ability to reach maximum velocity and thus enable the athlete to skate the race in the shortest time possible.

The sprint start in speed skating has been compared to the start in track and field as well as the technique utilized by speed skaters during the straightaway. The speed skater begins the race by assuming a ready position which enables them to place themselves in an excellent position to initiate muscle contractions at the sound of the pistol. Research by Ji, Ji, Ai, Liu, and Liu (2000) has suggested that the body should lean forward with the angle between the trunk and the horizontal plane measured at 13 degrees for one speed skater. As soon as the skater initiates movement, Teasdale, Gazquez, Tremblay, Bouchard, Fleury, and Bard (1996) suggested that "the first event recorded was a short duration in-flight phase (on average 40 ms)" (p. 444). The significance of the airborne phase allows the skater to position their skate directly under their center of gravity and have continuous forward acceleration. In a study conducted by de Koning et al. (1995), it was suggested that "the push off leg has to be decelerated and accelerated prior to the next push off" (p.1703). As a result, the skater needs to concentrate on minimizing the time spent decelerating the skating leg during the recovery by ensuring the leg is planted under the center of gravity as opposed to in front of the center of gravity. If the skate is positioned in front of the center of gravity, there is an instant in the skating stride in which the skater is decelerating and this will hinder the skater's ability to maintain maximum acceleration.

Starting technique in speed skating is often linked to the athlete's ability to increase their stride frequency during the first two to four steps of the start. In a study conducted by Kwon and Jun (1997) on "The effects of a short-term power training of the ankle joint on the starting technique of Korean female national short track speed skaters" it was determined that a 2 week power training program using a Cybex 600 had a positive effect on the starting time for elite speed skaters. Kwon and Jun (1997) determined that "[t]he start interval (14m) time was decreased from 3.20 s (SD 0.09) to 3.11 s (SD 0.04) by 0.09 s on average" (p. 280) which is the result of a faster acceleration during the initial phase of the start, as well as a decreased time for the entire race. The decreased starting time and increase in "initial acceleration ability was specifically enhanced due to the increase in step rate and step length in the early phase of the start" (Kwon and Jun, 1997, p. 280). The step rate was calculated in the study as going from 2.32 steps/second to 2.45 steps/second after the 2 week ankle training program (Kwon and Jun, 1997). As a result, the researchers emphasized the importance of ankle strength and step rate on the skater's ability to accelerate during the initiation of forward movement.

Skill Analysis of Starts in Speed Skating

Leg Movements in the Start

The start in speed skating has been broken down into two separate velocity vectors by de Koning et al. (1995) in regards to the action during the force producing phase of the push off as he describes the start as going "from running to gliding". The first component is the extension velocity component which is "associated with the shortening and lengthening of the leg segment by hip, knee and ankle flexors and extensors" (de Koning et al., 1995, p. 1704). The second component is described by de Koning et al. (1995) as the rotational velocity component which is "the result of the backward rotation of the leg segment in the sagittal plane" (p. 1704) (see Figure 2.7). The rotational component occurs when the skater laterally rotates their hip in order to position their skate more perpendicular to the direction of travel. Both of the components are seen during the sprint start in running and speed skating because in both skills, "the point of application of the push-off vector is fixed on the ground" (de Koning et al., 1995, p. 1704). As a result, the speed skater begins the race by replicating the action produced by an elite sprinter in regards to their hip, knee, and ankle extension as well as their rotation seen in the leg segment. In the study by de Koning et al. (1995), it was discovered that "[i]n the first running like push-offs the contribution of the rotational velocity v_r to forward velocity is larger than the contribution of extension velocity (v_e)" (p. 1707) and as the skater begins to increase their velocity to "a mean velocity of 6.7 m/s

(±0.3 m/s), after about 6 push offs" (p. 1707) the contribution from extension velocity begins to increase.

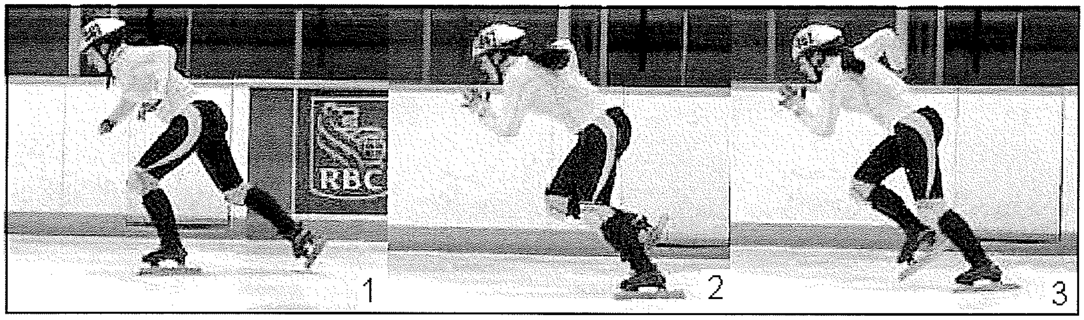


Figure 2.7: Extension and Rotation components of the left skate during the force production phase of the skating stride from touchdown to end of push off.

Subsequently, as the skater begins to increase their velocity, the stride no longer resembles that of a sprinter because the vector is no longer fixed on the ground due to the gliding seen in the plant or support skate. The athlete's ability to forcefully extend at the hip, knee, and ankle becomes of greater significance. The technique of changing from running to gliding was also discussed by de Koning et al. (1989) when it was determined that "the knee and hip angles during the gliding phases become smaller for successive strokes and that the duration of the gliding phase becomes longer" (p. 158). As a result, de Koning et al. (1989) suggested that the difference between pre-extension knee angles during the start as compared to during steady state velocity is similar to a running technique utilized during the start.

Pre-extension knee angles were measured (by taking the inside angle formed by the hamstring and the gastrocnemius) by de Koning et al.(1989) at "~ 130° for females and ~120° for males" (p. 165) during the first few steps. Therefore, the results are indicative of a running approach during the initiation of movement, followed by a gliding approach during steady state velocity. Furthermore, the greater degree of knee flexion measured during steady state velocity would suggest a greater contribution of the extension velocity component to the overall forward velocity as mentioned in the study conducted by de Koning et al. (1995). Lastly, de Koning et al. (1989) measured the athlete's knee extension velocities for females to be 639 ± 66 degrees/second and for males to be 683 ± 54 degrees/second.

Starting technique in speed skating has focused on the skater's ability to accelerate rapidly over the first seconds. In a study conducted by de Koning et al. (1989) and reported by van Ingen Schenau, de Koning, and de Groot, (1994) it was reported that the mean acceleration in the first second is about 5 m/sec^2. Ingen Schenau et al. (1994) also reported that "from about 5 seconds after the start the advantages of the gliding technique begin to allow speed skaters to reach their (considerably) higher velocities than sprint runners" (p. 272). As a result, speed skaters should focus on using the running technique (increasing stride rate) during the initial five seconds of the race, where elite athletes have been calculated to take approximately 17 strides, and then make use of the gliding technique from five seconds until the end of the race.

Starting Technique and Center of Gravity

The starting technique performed by elite sprinters is similar to both hockey and speed skating. One of the most important variables which occurs in starts during sprinting, speed skating and hockey is the athlete's ability to position their center of gravity at the front edge of their base of support. In a study conducted by Adrian and Cooper (1995) on sprinting technique, it was determined that entering a crouched starting position was more effective than a standing start because it positions the athlete's center of gravity at the front edge of their base of support. This crouched start resulted in the athlete having to accelerate rapidly in order to maintain their balance and thus reach their maximum velocity over the shortest distance possible. The starting position seen in elite sprinters is similar to that seen in elite speed skaters as there is an emphasis on positioning their line of gravity at the front edge of their base of support.

Dartfish Advanced Video Analysis Software

Dartfish video analysis software (2004) is a recently developed software package which enables researchers, coaches, and athletes to review video and make in depth analyses, both qualitative and quantitative, on the performance of a skill. The use of Dartfish as a training tool for athletes has been growing and as of June 2005 after the release of Dartfish 4.0 software, "Dartfish now counts more than 10,000 users worldwide" (Dartfish Video Analysis Software, 2004)

In 1997, "at the Swiss Federal Institute of Technology in Lausanne, Switzerland" (Dartfish Video Analysis Software, 2004) a software package known as Simulcam™ technology was created which allowed for two videos to be superimposed overtop of each other with minimal interference from the background of the videos. The following year, in 1998, InMotion technology (now known as Dartfish) was founded "to commercially develop SimulcamTM and other digital imaging applications" (Dartfish Video Analysis Software, 2004). With the high degree of success of the Simulcam™ software, in 2001, StroMotion™ software was developed to be marketed alongside Simulcam™ and marketed through the InMotion technologies company.

Dartfish software had a major impact on the recent 2006 Olympic Games in Torino Italy, as numerous Olympic Committees (ie. Canadian Olympic Committee and United States Olympic Commitee) and athletes became committed to using Dartfish software. It was reported that "nearly 60% of all Olympic contenders used Dartfish in 2006" with a reported 138 medal winners using Dartfish either during the competition or during preparation for the games (Dartfish Video Analysis Software, 2004). The significance of Dartfish for athlete analysis is presented in a testimonial by Kevin Conrad (US Speed Skating Sport Scientist) when he stated "[t]he Dartfish software has been a tremendous help to our athletes and coaches in preparation for the Games. The Dartfish program has provided the means to break down skating technique in order to make those subtle, yet important adjustments" (Dartfish Video Analysis Software, 2004).

The use of Dartfish analysis software has recently been utilized at the University of Manitoba by recent MSc graduates Dana Way (Traditional Arctic Sports: A Biomechanical Analysis of the One Foot and Two Foot High Kick, 2005) and Carolyn Taylor (A Biomechanical Comparison of the Rotational Shot Put Technique used by Males and Females, 2007).

CHAPTER III

Methods

Subjects Recruited

Twenty four subjects were recruited for the study ranging in age from 13 to 18 years of age. Thirteen female hockey players were recruited during two separate filming sessions. The first session was held on July 5th 2007 at Max Bell Arena in Winnipeg, Manitoba during Hockey Manitoba's Program of Excellence Summer Evaluation Camp, where six subjects participated in the study. The second hockey filming session occurred on September 18th, 2007 at the Winnipeg Winter Club Arena in Winnipeg, Manitoba. The filming occurred during a practice session with the Balmoral Hall Blazers, a top tier women's high school hockey team. The remaining seven subjects were recruited from this group.

Eleven speed skating subjects were also recruited for the study during four separate filming sessions. The first session was held on March 15th, 2007 at Pioneer Arena in Winnipeg, Manitoba during a filming session arranged with the head coach of the Manitoba Short Track Speed Skating team, where three subjects were recruited. The second filming session occurred on September 17th, 2007 at River Heights Arena in Winnipeg, Manitoba during a Manitoba Provincial Short Track Speed Skating team practice where five subjects were recruited. Two subjects were recruited from the Edmonton Speed Skating Association during a filming session at Clareview Arena in Edmonton Alberta on November 13th, 2007. The final subject was added from the pilot data which was filmed on January 11th, 2007 at Pioneer Arena. This subject was a member of the Manitoba Provincial Speed Skating team and was added because she was not available for filming during the other filming sessions with the Manitoba Short Track Speed Skating subjects. The subjects recruited for this study were considered to be skilled for their age as they are members of elite sports programs in Manitoba. The speed skaters recruited from the Edmonton Speed Skating Association were on the developmental Provincial Speed Skating team and were considered to be prospects for the Alberta Provincial Speed Skating team. The study was approved by the Education/Nursing Research Ethics board at the University of Manitoba (see Appendix A). Prior to the filming session, the participants were required to provide written informed consent acknowledging their participation in the study (see Appendix B). For subjects under 18 years of age, informed consent was provided by a parent or guardian.

The researcher was unable to recruit as many subjects as originally planned due to a scarcity of available female speed skaters in the province of Manitoba. As a result, two additional skaters were recruited from the Edmonton Speed Skating Association. The researcher also encountered difficulties booking filming sessions, due to the limited amount of available ice time, as well as difficulties associated with the athletes not willing to give up potential practice time to participate in the study.

Filming Technique

Filming of the subjects for the study took place in Winnipeg, Manitoba at four separate arenas (Max Bell Arena at the University of Manitoba, River Heights Arena, Pioneer Arena, and the Winnipeg Winter Club Arena) and at the Clareview Arena in Edmonton, Alberta. Camera set up was replicated at all of the filming sessions in order to ensure accurate comparisons between the subjects filmed at the various sessions. A four camera set up was utilized during the filming procedure in order to produce a three dimensional view of the skill being analyzed (see Figure 3.1). All four cameras were Canon digital camcorders with built-in image stabilizers and manual camera set up options to increase the quality of the video. One Canon GL2 camera was located 5 meters behind the starting line which captured the body movements occurring in the frontal plane (hip abduction, shoulder abduction, position of foot plant relative to line of gravity, and lateral displacement of the push off leg). A second Canon GL2 camera was located at a 90 degree angle from the first camera, which captured the first six meters of the skating stride and provided important measurements from the first four strides in the sagittal plane (knee flexion, trunk forward lean from horizontal axis, hip flexion, ankle flexion, joint velocities and accelerations). A third camera, the Canon ZR700 was positioned along the far boards at the six meter distance and captured the sagittal view of the skating stride (focusing on the first 12 meters). The Canon ZR700 captured the first 8-10 strides taken by the participant and was used to determine velocity and acceleration of the subjects.

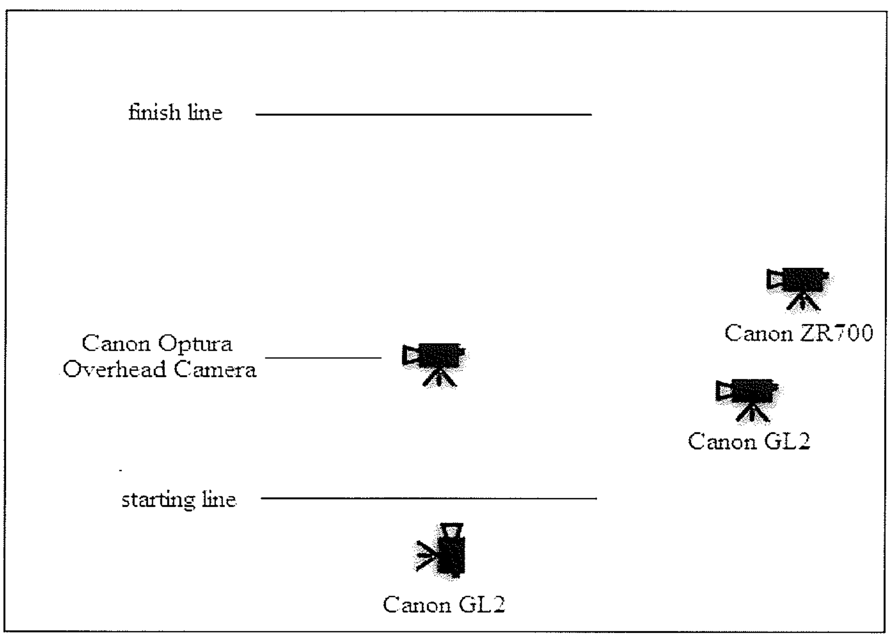


Figure 3.1: Camera Placement for Filming the Start in Skating

Overhead Camera Filming

A fourth camera, the Canon Optura, was suspended from a modified overhead camera frame (see Figure 3.2) which captured the first four strides and the movements occurring in the transverse plane (angle of skate at push off). The overhead camera was not included during the filming sessions at the Clareview Arena in Edmonton due to difficulties associated with transporting the camera on the airplane. The camera was also not available for the pilot study as the overhead camera was added in order to ensure accuracy of measuring the angle of the skate blade relative to the direction of travel.

The overhead camera frame consisted of a steel pipe which had the handle of the Canon Optura camera securely fastened to the end of the pipe. The pipe was then anchored over the edge of the glass on the boards at the beginning of the starting line (this positioning was determined based on the height of the boards at the arena, in which a higher area of the boards allowed the camera to be anchored higher above the athlete). The overhead camera was connected to a Toshiba Satellite A100 laptop by a 4 pin to 4 pin fire wire. The fire wire allowed the laptop to collect live video footage of the first four steps through the use of the In the Action mode of Dartfish Team Pro 4.1.5., which ensured that the desired video footage was being captured.

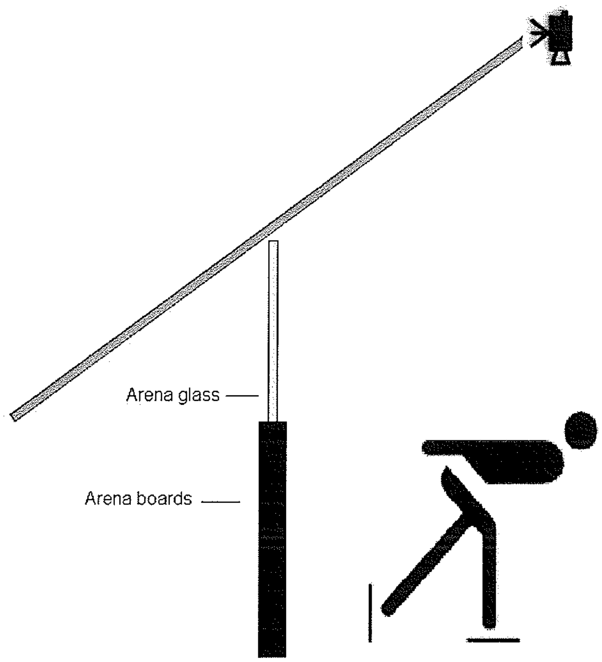


Figure 3.2: Overhead Camera Apparatus

Timing Gate Data

In conjunction with the video capture, Brower timing gates were set up along the starting path (see Figure 3.3). These timers began calculating the time when the subject broke the plane of the starting line through the use of a sensor and recorded the time until the subject passed the next gate. Three sets of timers were utilized to increase the accuracy of measuring the athlete's time from 0-6 and 6-12 meters.

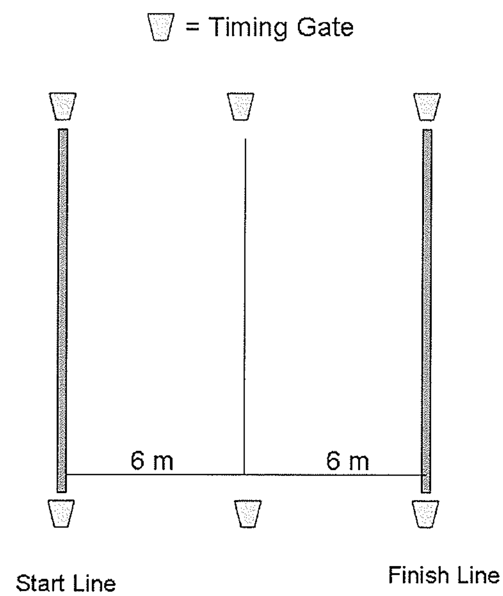


Figure 3.3: Timing gate set up

The timing gates were borrowed from the Canadian Sport Center Manitoba located in the Frank Kennedy Center at the University of Manitoba and were used with varying degrees of success. During the initial filming session of the speed skaters on March 18th, 2007 the timing gates provided data regarding the total time, the time from 0-6 meters as well as the time from 6-12 meters. The second speed skating filming session on September 17th, 2007 provided less consistent results with data being provided for two of the five subjects over the 6-12 meter interval, however, no timing gate data were gathered for the remaining three subjects. The study required the use of three sets of timing gates (a total of six timing gates) however, several of the timing gates were not in working order. The researcher was unable to identify the exact reason for the timing gate failure, however, it was noted that the gates were in place but the athlete was not triggering the gate as they skated through the zone. As a result, during the filming sessions the researcher was only able to collect data over one of the two intervals, and was not able to collect all of the desired data. The timing gates were not available for the filming session at the Clareview Arena in Edmonton because the researcher was unable to borrow the timing gates from the Canadian Sport Center Manitoba and did not have access to timing gates while in Edmonton. Similar to the overhead camera, the timing gates were also not used during the pilot study and therefore, timing gate data were not available for the subject added from the pilot study.

Timing gate data during the hockey filming sessions were also very inconsistent. During the initial filming session on July 5, 2007 no timing gate data was gathered due to complications with the timing gates. The timing gates were positioned as described by the protocol of the study, however, the sensors from the timing gate were not being triggered as the athlete broke the plane. The researcher was unable to determine the exact cause for the failed timing gate data, however, it should be noted that the gates are very sensitive to being properly set up, as well as sensitive to matching up pairs of gates which work together. During the second filming session on September 18th, 2007 timing gate data was gathered for all seven subjects over the 0-6 meter interval, however, neither the second split time from 6-12 meters nor the total time was gathered. However, the remaining timing gate data were supplemented through the use of the Dartfish time code feature which is accurate to 1/60th of a frame. By counting film frames elapsed between successive timing gates, an estimate of time between gates could be determined.

Filming Procedures

The three camera set up (posterior, sagittal and transverse views) provided a three-dimensional view of the skating stride. From the camera set up, accurate and reliable measurements for all joint angles of interest and angular velocities were obtained by the investigator using the Analyzer mode in Dartfish Team Pro 4.1.5. The investigator has considerable experience collecting kinematic data from video film.

The cameras were manually set to a shutter speed of 1/500th of a second in order to reduce the risk of blurring, due to the high velocity actions seen in the skating stride. In one of the arenas, the walls were dark and the lighting was limited, and as a result, a high shutter speed resulted in slightly darker video. The two Canon GL2 cameras and the ZR700 camera, capturing the posterior and sagittal views, were securely attached to tripods in order to decrease the amount of camera movement and subsequently increase the quality of the video footage.

Filming Protocol

The participants in the study were instructed to perform the start as they normally would in competition or during a game. Furthermore, each subject was instructed to attempt to reach maximum velocity over the shortest period of time (or accelerate at the fastest rate possible). The subjects in the study were equipped with three joint markers on the left side of their body (the markers were located at the hip joint, knee joint, and ankle joint). Subjects one to three, six and eight from the speed skating group were filmed performing five trials, with the fastest acceleration or shortest time from 0 – 12 meters being analyzed in the study. Subjects four, five, seven, and nine to eleven in the speed skating group were filmed performing only two trials, due to other commitments from the subjects, with the faster trial being included in the study. In the hockey group, subjects one to seven were filmed performing five trials, with the fastest trial being included in the study and subjects eight to 13 being filmed performing two trials due to the time constraints of the facility booking.

Three pylons of known height and width were located on the ice surface to act as a known distance measure as well as to identify the position of the skater at 3 m and 9 m to determine the acceleration between the two stages (see Figure 3.1). A known distance measure was required to calculate the skater's velocity, stride length, width of base of support, and distance from line of gravity to position of the skate. A second known distance measure was included in the video to ensure that accurate results were obtained. The speed skaters all had 0.42 m blades, which provided a more accurate distance measurement due to it being located in the same plane as the subject. The hockey subjects were provided with a 0.5 meter dowling in order to prevent the subjects from breaking the plane with their stick prior to their body, which also provided a known distance measure in the same plane of movement as the skill was performed.

The skaters were instructed to start before the timing gate located at the zero meter mark and on the researcher's command skate in an all out effort alongside the timing gates until they passed the gate at 12 meters. A successful trial was considered a trial in which the subject did not start prior to the researcher's command and skated through the gate at 12 meters.

Digital Video Analysis

Video analysis was used to collect quantitative data from the video, therefore allowing the researcher to compare the techniques employed during the start in speed skating and hockey. The primary variables of interest in the study were the velocity of the skater at six meters and 12 meters as well as the acceleration experienced between the two distance intervals (0-6 meters and 6-12 meters). However, numerous other variables were collected in order to create a biomechanical template to compare the starting techniques employed by speed skaters and hockey players.

Variables Measured

The measurement of joint angles using Dartfish was conducted using the 180-degree system which refers all measurements back to anatomical position. Anatomical position is considered a position of zero degrees and any joint movements occurring in the posterior direction are referred to as hyperextension. Variables measured in the study which were determined to be different than the angle which was intended to be measured were entered as a negative value. For example, if the angle of hip adduction was being measured, and the athlete was in a position of hip abduction, the data point would be entered as negative 10 degrees of adduction. The two primary positions of interest for joint measurements in the study were at foot touchdown and at the end of the push off (or force production phase). At foot touchdown, the angles of trunk flexion (see Figure 3.4), hip flexion, knee flexion, hip adduction and ankle dorsiflexion were measured, while at the end of the push off phase, the angles of trunk flexion, hip flexion, hip abduction, knee flexion (see Figure 3.5), ankle plantarflexion and the angle of the skate relative to the direction of travel (see Figure 3.6) were calculated, as well as the range of motion for the hip and knee joints during the force producing action.

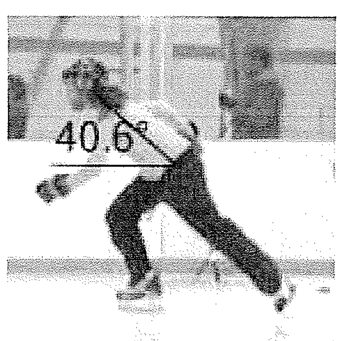


Figure 3.4: Trunk forward lean of a hockey player measured relative to the horizontal

For the purpose of the study, the investigator focused on the first three strides for the measurement of variables, to follow a similar protocol to Marino and Dillman (1976). When measuring the position at the ankle, the 180-degree system considers a neutral ankle (foot perpendicular to the tibia) as a position of zero degrees and therefore, any movement up or down will be recorded as degrees of dorsiflexion or plantarflexion respectively.

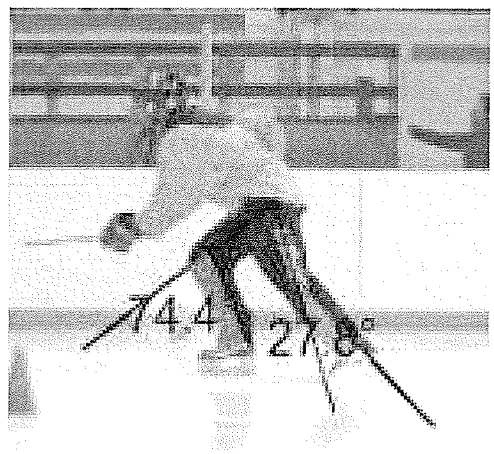


Figure 3.5: Knee flexion and knee extension angles measured using the 180 degree measuring system with anatomical position representing zero degrees

The variables listed in the table 3.1 were chosen as they are similar to the variables studied in previous skating research conducted by Marino and Dillman (1976) and Marino (1983) as well as several of the variables studied by de Koning et al. (1989, 1995).

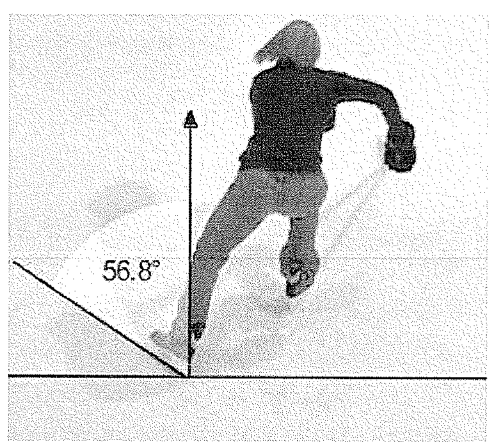


Figure 3.6: Skate blade measured relative to the direction of travel as observed from an overhead camera.

The two studies conducted by Marino (1976, 1983) used the following variables as they were believed to be indicators of maximum acceleration in hockey: stride length, stride rate, single and double support times, maximum vertical displacement of the recovery foot, horizontal distance between the toe and hip of the recovery leg at touchdown (see Figure 3.7), angles of the hip and knee at takeoff, angle of takeoff, angles of forward lean at both takeoff and touchdown, propulsive angle of the skate blade and time from first movement to takeoff during the first stride. The current study has included several of the variables measured by Marino, including stride rate, single and double support times, distance between the toe and hip of the recovery leg at touchdown, angles of the trunk, hip, knee and ankle at both touchdown and takeoff as well as the propulsive angle of the skate blade.

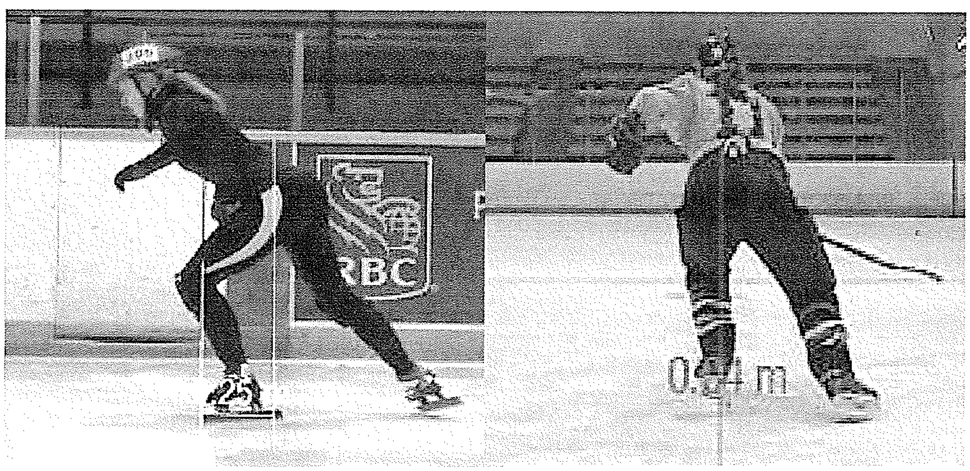


Figure 3.7: Position of skate touchdown measured relative to the hip from the posterior view of a hockey player and the sagittal view of a speed skater.

Research conducted by de Koning (1989) et al. and Ignen Schenau et al. (1995) on speed skating measured similar variables including trunk lean, knee flexion at touchdown, knee extension at push off and knee extension velocity. However, measurements of single and double support times have not been reported in the speed skating literature. As a result, the investigator has focused on the temporal characteristics associated with the start including single and double support times, as well as times for hip and knee extension in order to calculate angular velocities during the force producing phase. Research has suggested that elite speed skaters show significantly higher knee extension velocities when compared to a lesser skilled group, which shows the importance of knee extension velocity on force production and therefore a skater's ability to accelerate during the start (de Boer et al., 1986). In conjunction with the temporal analysis, the investigator has also examined the research variables pertaining to upper body movements (primarily at the shoulder) as they may have significant impact on the skater's ability to apply force to the ice during the push off. The variables chosen for the study were also determined based on the results of the pilot study (see Appendix C).

Table 3-1: Variables measured from skating video

Phase of the Skill	**Variable(s) Measured**
Start Position	➢ Trunk lean relative to horizontal (degrees) ➢ Width of base of support (forwards/backwards) (m) ➢ Rear knee flexion angle (degrees) ➢ Front knee flexion angle (degrees) ➢ Rear hip flexion angle (degrees) ➢ Front hip flexion angle (degrees) ➢ Rear ankle flexion angle (degrees) ➢ Front ankle flexion angle (degrees) ➢ Skate blade relative to direction of travel (m) ➢ Left shoulder flexion angle (degrees) ➢ Left shoulder abduction (degrees) ➢ Right shoulder flexion (degrees) ➢ Left shoulder abduction (degrees)

Table 3-1 (continued): Variables measured from skating video

End of 1st Push Off	➢ Rear hip flexion angle (degrees) ➢ Rear knee flexion angle (degrees) ➢ Rear ankle plantarflexion angle (degrees) ➢ Time for extension velocity (sec) ➢ Skate blade relative to direction of travel (m) ➢ Time in double support (sec) ➢ Left shoulder extension angle (degrees) ➢ Left shoulder abduction angle (degrees) ➢ Right shoulder flexion angle (degrees) ➢ Right shoulder adduction angle (degrees) ➢ Rear hip abduction angle (degrees) ➢ Hip extension velocity (degrees/sec) ➢ Knee extension velocity (degrees/sec)
1st Step Touchdown (TD)	➢ Skate position relative to hip (frontal) (m) ➢ Knee flexion angle at TD (degrees) ➢ Hip flexion angle at TD (degrees) ➢ Ankle dorsiflexion angle at TD (degrees) ➢ Trunk lean from horizontal (degrees) ➢ Time in single support (sec) ➢ Distance of foot placement in front of TD leg hip (m) ➢ Left shoulder extension angle (degrees) ➢ Left shoulder abduction angle (degrees) ➢ Right shoulder flexion angle (degrees) ➢ Right shoulder adduction angle (degrees) ➢ Hip adduction angle at TD (degrees)
End of 1st Push Off	➢ Rear hip flexion angle (degrees) ➢ Rear knee flexion angle (degrees) ➢ Rear ankle plantarflexion angle (degrees) ➢ Time for extension velocity (sec) ➢ Skate blade relative to direction of travel (m) ➢ Time in double support (sec) ➢ Left shoulder extension angle (degrees) ➢ Left shoulder abduction angle (degrees) ➢ Right shoulder flexion angle (degrees) ➢ Right shoulder adduction angle (degrees) ➢ Rear hip abduction angle (degrees) ➢ Hip extension velocity (degrees/sec) ➢ Knee extension velocity (degrees/sec)

Table 3-1 (continued): Variables measured from skating video

End of 2nd Push Off	➢ Rear hip flexion angle (degrees) ➢ Rear knee flexion angle (degrees) ➢ Rear ankle plantarflexion angle (degrees) ➢ Time for extension velocity (sec) ➢ Skate blade relative to direction of travel (degrees) ➢ Time in double support (sec) ➢ Left shoulder flexion angle (degrees) ➢ Left shoulder adduction angle (degrees) ➢ Right shoulder extension angle (degrees) ➢ Right shoulder abduction angle (degrees) ➢ Rear hip abduction angle (degrees) ➢ Hip extension velocity (degrees/sec) ➢ Knee extension velocity (degrees/sec)
2nd Step TD	➢ Skate position relative to hip (frontal) (m) ➢ Knee flexion angle at TD (degrees) ➢ Hip flexion angle at TD (degrees) ➢ Ankle dorsiflexion angle at TD (degrees) ➢ Trunk lean from horizontal (degrees) ➢ Time in single support (sec) ➢ Distance of foot placement in front of TD hip (m) ➢ Left shoulder flexion angle (degrees) ➢ Left shoulder adduction angle (degrees) ➢ Right shoulder extension angle (degrees) ➢ Right shoulder abduction angle (degrees) ➢ Hip adduction angle at TD (degrees)
End of 3rd Push Off	➢ Rear hip flexion angle (degrees) ➢ Rear knee flexion angle (degrees) ➢ Rear ankle plantarflexion angle (degrees) ➢ Time for extension velocity (sec) ➢ Skate blade relative to direction of travel (degrees) ➢ Time in double support (sec) ➢ Left shoulder extension angle (degrees) ➢ Left shoulder abduction angle (degrees) ➢ Right shoulder flexion angle (degrees) ➢ Right shoulder adduction angle (degrees) ➢ Rear hip abduction angle (degrees) ➢ Hip extension velocity (degrees/sec) ➢ Knee extension velocity (degrees/sec)

Table 3-1 (continued): Variables measured from skating video

3rd Step TD	➢ Skate position relative to hip (frontal) (m) ➢ Knee flexion angle at TD (degrees) ➢ Hip flexion angle at TD (degrees) ➢ Ankle dorsiflexion angle at TD (degrees) ➢ Trunk lean from horizontal (degrees) ➢ Time in single support (sec) ➢ Distance of foot placement in front of TD hip (m) ➢ Left shoulder extension angle (degrees) ➢ Left shoulder abduction angle (degrees) ➢ Right shoulder flexion angle (degrees) ➢ Right shoulder adduction angle (degrees) ➢ Hip adduction angle at TD (degrees)

Video Analysis Techniques

All the collected video from the study was imported into a Toshiba Satellite A100 laptop using the Dartfish "In the Action" setting which allows the video to be played through a digital camcorder into the computer through the use of a 4 pin to 4 pin firewire. Following the video importing, the video was opened in the Dartfish "Analyzer Mode" which allowed the three camera views for each athlete to be viewed at the same time through a split screen mode. For the analysis of the starting technique employed in both speed skating and hockey, the time code tool measured the variables of time in single support and double support as well as calculated the timing of joint movements (ie. extension of the knee joint) to determine angular velocities and to supplement the missing timing gate data. The computerized time code is accurate to within 0.017 seconds as Dartfish counts the frames of the film to every 1/60th of a second.

Another tool utilized during the analysis was the angle drawing tool which measured the relative and absolute angles by land marking key joints and measuring the angle which was formed. A third tool utilized during the analysis of the skating stride was the distance measuring tool which allows for a known distance measure to be calculated (ie. length of a limb segment) and then allows this value to be set as a reference value for any other distances which are measured. The measuring tool makes use of a conversion factor which is calculated by dividing the length of the image in real life by the length of the image on the screen. As a result, all additional values are able to be calculated based on the conversion factor. Dartfish data tables were utilized to produce tables that can report average velocity and instantaneous velocity as the researcher tracks the athlete across the screen at specified time intervals. The subject's instantaneous velocity at six meters was calculated through the use of a Dartfish data table which reported the linear velocity of the subject's hip marker over a 0.017 second interval. The athlete's hip was tracked for one frame as they moved across the screen using the stationary camera. This then allowed Dartfish to calculate the distance which the athlete's hip traveled during the one frame, providing an instantaneous velocity at the six meter distance. The subjects in the study skated at a maximum effort over the 12 meter interval in order to determine the rate of acceleration from 0-6 meters as seen in previous studies (Marino and Dillman, 1976; Marino, 1983; and Naud and Holt, 1979) but as well to measure the acceleration from 6-12 meters in order to determine if maximum acceleration had been attained at six meters.

In addition to the tools that were utilized for quantitative analysis, Dartfish was used to play the video frame by frame and allow for qualitative analysis of the skills. Dartfish has the capability to import up to four separate videos onto the screen and synchronize the videos to a specific point (ie. skate touchdown) by making use of a timeline feature. Furthermore, Dartfish has the ability to zoom in and magnify the video in order to increase the accuracy of the measurements while landmarking for the measurement of angles and the measuring of selected distances. Lastly, all drawings and measurements created on the video were saved as a Dartclip alongside the video file. The drawings and measurements were saved by making use of the snapshot tool which allows a picture of the screen to be taken and saved as a JPEG or bitmap file. The pictures were saved to a clipboard and through the use of Adobe Photoshop were enhanced to improve sharpness and quality of the images. Stromotion was utilized in the study to highlight key components of the skating stride and create a sequence picture of the athlete performing the start. The final method which was used to analyze the participants was Simulcam which allows two videos to be superimposed over top of each other (on the same background) and adjusted to a key feature in the skill (ie. maximum knee flexion). Using Simulcam, small differences in timing and technique were noted through the use of both qualitative and quantitative analysis. The Dartfish tools utilized in the study are summarized in Table 3-2.

Table 3-2: Summary of the Dartfish analysis tools used in the study.

Angle Tool	Allows the researcher to measure angles
Data Table	Allows the researcher to calculate time-dependent data (measurement of velocities and acceleration)
Drawing Tool	Allows the researcher to draw lines and shapes to highlight important points
Distance Tool	Allows the researcher to measure distances based on a calculated reference value from an object of known length
Frame in Frame Tool	Allows the researcher to enlarge (zoom in on) a specific portion of the video, while the rest of the video remains the same
Simulcam Tool	Superimposes one video over top of another video while limiting the background interference
StroMotion Tool	Allows still pictures to be taken in sequence of the athlete during several frames of the video

Statistical Analysis

Reliability Test

A reliability test was conducted in order to ensure that the researcher was able to accurately measure the variables of interest in the study. During the reliability test, the researcher measured ten variables at the end of the second push off for one of the subjects in the study. The ten variables (trunk lean from the horizontal, hip flexion, trunk flexion, left shoulder flexion, right shoulder extension, ankle plantarflexion, distance of foot to hip, right shoulder abduction, left shoulder abduction and hip abduction) were measured on five separate occasions over a three week interval. The mean and standard deviations for the measured variables were calculated as well as the range, maximum value, minimum value and the coefficient of variance. The coefficient of variance is a ratio of the standard deviation compared to the mean and determines the accuracy of the measurements, whereby a small coefficient of variance indicates a high degree of accuracy. Accuracy is defined as the ability to reproduce a data point indicating that the researcher is reliable in accurately measuring the data points.

Statistical Tests

Means and standard deviations for each of the variables measured were calculated for the subjects in both the speed skating and hockey groups. The statistical data were analyzed by use of the statistics program Statview and the statistics functions in Excel. The variables for the two groups were compared using standard t-tests with $p \leq 0.05$ to determine if any differences in starting variables existed between the two groups. Next, a Pearson's correlation analysis was conducted to determine if collinearity existed between any of the dependent variables and the independent variable of instantaneous velocity of the athlete's hip at six meters. Collinearity occurs when two of the dependent variables are highly correlated and therefore have the same overall effect on the independent variable.

A forward stepwise multiple regression analysis was conducted in order to eliminate any variables which were not found to be significant predictors of the velocity at six meters. The forward stepwise multiple regression analysis provided a list of variables which were considered to be significant contributors to the dependent variable, instantaneous velocity at six meters. During the first step of the regression analysis, one variable was selected from the entire list of independent variables to determine which variable was most significant in predicting velocity at six meters. Upon completion of the first step, all of the remaining independent variables were again tested against the dependent variable to determine which variable made the next greatest contribution to velocity at six meters. The stepwise regression analysis process continued until the list of independent variables no longer provided a significant contribution to the prediction of the dependent variable, at which time an equation was produced showing all of the independent variables which were found to be significant. A forward stepwise multiple regression analysis was conducted on the hockey and speed skating groups separately in order to determine which variables were considered significant contributors to the start in hockey and which were significant contributors to the start in speed skating. A comparison was made of the predictive variables produced for each type of skating start, to determine which variables were similar and which variables were different between the hockey and speed skating starts.

CHAPTER IV

Results

Chapter four will describe the results of the statistical analysis and outline several key differences which were determined between the starting techniques utilized by female speed skaters as compared to the starting technique used by female hockey players. The height, age and weight of the participants in the study are outlined in Table 4-1 (see Appendix D)

Table 4-1: Descriptive characteristics of subjects.

	Speed Skaters N = 11		**Hockey Players N = 13**	
	Mean ± SD	Range	Mean ± SD	Range
Age (years)	15.3 ± 1.5	13 – 18	15.3 ± 1.0	13 - 17
Height (meters)	1.64 ± 0.04	1.6 – 1.72	1.65 ± 0.05	1.57 – 1.77
Weight (kilograms)	60.2 ± 5.9	50.0 – 72.6	60.9 ± 7.2	52.2 – 65.8

Reliability Test

All of the 10 variables measured in the reliability analysis had a coefficient of variance between 0 and 0.12, indicating that there was no significant variation in the measurement of any variables between the five trials. The results of the reliability test are shown in Table 4-2 (see Appendix E).

Table: 4-2: Results of the reliability test.

Variable (end of 2^{nd} push off)	Mean	S.D.	Minimum	Maximum	Range	Coefficient of Variance
Knee flexion	20.6	0.89	19.3	21.3	2.0	0.044
Hip flexion	33.2	1.18	31.5	34.5	3.0	0.035
Trunk lean	33.6	0.81	32.2	34.3	2.1	0.024
Left shoulder flexion	72.0	1.76	70	74.7	4.7	0.024
Right shoulder extension	21.5	1.51	19.1	22.7	2.6	0.070
Ankle plantarflexion	4.8	0.58	4.2	5.5	1.3	0.120
Foot to hip distance	0.07	0	0.07	0.07	0	0
Right shoulder abduction	89.7	1.89	87.6	92.7	4.8	0.021
Left shoulder abduction	15.2	1.30	14	17.1	3.1	0.085
Hip abduction	19.78	1.49	17.8	21.6	3.8	0.075

Comparison of Means and Standard Deviations for Speed Skaters and Hockey Players

The following section describes the means and standard deviations for the two groups in the study as well as the results of the independent t-tests which were performed. The section is broken down into the key phases of the skill which were highlighted in the methods section, beginning with the ready position and highlighting each successive push off and touchdown.

Phase 1: Ready Position

In the ready position of the start, 13 variables were measured. The variables as well as the means and standard deviations for both the hockey (see Appendix F) and speed skating (see Appendix G) groups are presented in Table 4-3. Using a t-test comparison and based on an alpha value of 0.05, nine of the 13 measured variables were shown to be significantly different, indicating that the two groups vary in their starting positions. The variables which were significantly different between the speed skaters and the hockey players include: angle of trunk lean from the horizontal, width of the base of support in the forwards/backwards direction, angles of front hip and knee flexion, angle of rear hip flexion, angle of front ankle flexion, angles of right and left shoulder flexion and the angle of the skate blade relative to the direction of travel. The calculated mean angle for the athlete's rear hip flexion for the speed skaters and hockey players was 109.9 degrees and 80.6 degrees respectively (see Figure 4.1). Similarly, the calculated means for front hip flexion for the speed skaters and hockey players were 133.2 and 81.5 degrees respectively (see Figure 4.1). The two groups were also significantly different in the angle of their skate blade relative to the direction of travel. The mean angle of the skate blade relative to the direction of travel in the ready position for the hockey group was 44.0 degrees, while the mean angle of the skate blade for the speed skating group was 75.0 degrees (see Figure 4.2).

Table 4-3: T-test comparisons of means and standard deviations of the measured variables in the ready position of the start ($p \leq 0.05$).

Variable	Hockey Players N = 13		Speed Skaters N = 11		t-value	p-value
	Mean	SD	Mean	SD		
Trunk Lean from Horizontal (degrees)	41.85	6.63	17.76	7.87	8.01	0.0000001*
Width of Base of Support (forward/backward) (m)	0.46	0.18	0.68	0.14	-3.56	0.002*
Rear Knee Flexion (degrees)	54.8	19.993	64.98	13.55	-1.45	0.15
Front Knee Flexion (degrees)	52.25	18.90	84.08	10.25	-5.23	0.0005*
Rear Hip Flexion (degrees)	80.61	16.16	109.91	10.30	-5.37	0.00003*
Front Hip Flexion (degrees)	81.50	15.96	133.16	13.89	-8.48	0.0000002*
Front Ankle Flexion (degrees)	12.05	10.87	0.03	10.68	2.72	0.013*
Rear Ankle Flexion (degrees)	14.76	9.71	17.11	4.37	-0.78	0.44
L. Shoulder Abduction (degrees)	19.38	16.74	27.05	36.36	-0.64	0.53
R. Shoulder Abduction (degrees)	23.28	9.03	44.89	35.27	-1.97	0.07
L. Shoulder Flexion (degrees)	23.27	24.00	82.22	39.18	-4.35	0.0005*
R. Shoulder Flexion (degrees)	19.08	20.04	-28.60	22.14	5.49	0.00002*
Skate Blade relative to Travel (degrees)	44.03	20.49	74.98	8.74	-4.78	0.0002*

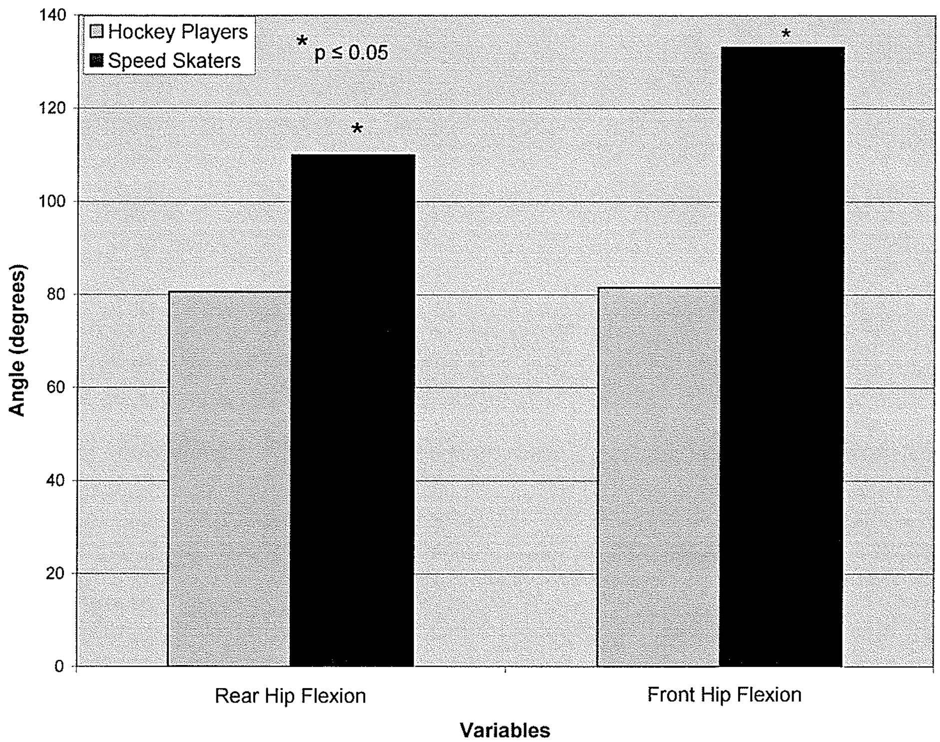


Figure 4.1: Comparison of the mean angles of front and rear hip flexion for speed skating and hockey (* $p \leq 0.05$)

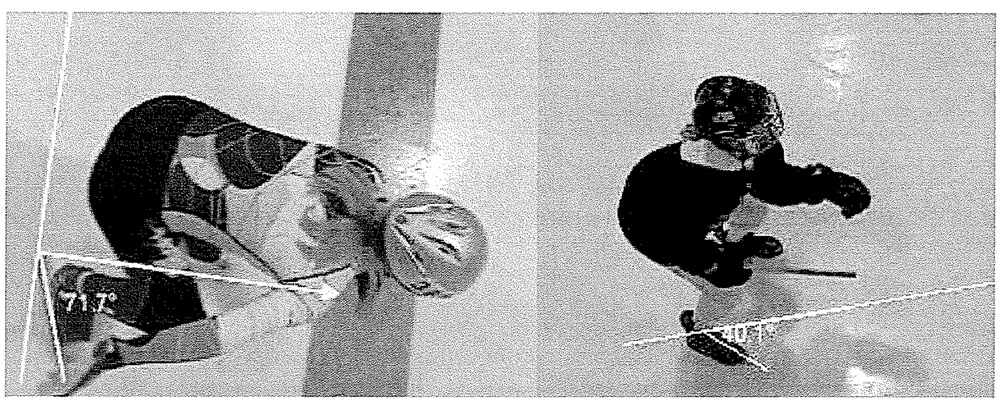


Figure 4.2: Comparison of angle of skate blade relative to the direction of travel for speed skating and hockey. Speed skaters demonstrate a significantly greater angle relative to the direction of travel in the ready position ($p \leq 0.05$).

Phase 2: End of First Push Off

At the end of the first push off, 13 variables were measured. Comparisons of the means for the measured variables at the end of the first push off are presented in Table 4-4. The eight variables which were calculated to be significantly different between the two groups were: The angle of rear hip flexion (see figure 4.3), the angle of the skate blade relative to the direction of travel, angle of left shoulder extension, angle of right shoulder flexion, angle of left shoulder abduction, hip and knee extension velocity, and time spent in double support. The mean angle of right shoulder flexion for the speed skating group was 64.3 degrees, while the hockey group showed a significantly lower angle of shoulder flexion of 46.1 degrees at a p-value of 0.006. Similarly, the speed skating group also showed a significantly higher mean angle of left shoulder extension at 57.4 degrees compared to 36.6 degrees of shoulder extension demonstrated by the hockey group. This comparison was shown to be significant with a p-value of 0.01. The hockey players were calculated to spend a mean time of 0.16 seconds in double support, while the speed skaters were calculated to spend 0.05 seconds in double support. The difference between the two means was calculated at a p-value of 0.002. Another significant difference identified at this point in the skill was the inability of the speed skating group to apply force in the posterior direction. The angle of the skate blade relative to the direction of travel for the hockey group was measured to be 91.4 degrees, while the speed skating group was measured at 81.2 degrees (see Figure 4.4). This difference between the two means was calculated at a p-value of 0.008 being significant to $p \leq 0.01$.

Table 4-4: T-test comparisons of means and standard deviations of the measured variables at the end of the first push off (* $p \leq 0.05$).

Variable	Hockey Players n = 13		Speed Skaters n = 11		t-value	p-value
	Mean	SD	Mean	SD		
Rear Hip Flexion (degrees)	26.97	8.74	36.87	7.07	-3.07	0.006*
Rear Knee Flexion (degrees)	25.79	13.56	20.01	9.39	1.23	0.23
Rear Hip Abduction (degrees)	12.65	7.28	13.02	4.48	-0.15	0.88
Rear Ankle Plantarflexion (degrees)	0.52	8.86	3.19	9.12	-0.73	0.48
Skate Blade relative to Travel (degrees)	91.41	9.47	81.19	6.38	2.95	0.008*
Time for Extension Velocity (sec)	0.43	0.08	0.44	0.07	-0.25	0.81
L. Shoulder Abduction (degrees)	71.55	14.30	96.79	22.75	-3.19	0.006*
R. Shoulder Adduction (degrees)	-19.89	11.72	-11.72	36.87	-0.71	0.49
L. Shoulder Extension (degrees)	36.58	19.01	57.36	17.66	-2.77	0.01*
R. Shoulder Flexion (degrees)	46.05	14.78	64.33	14.57	-3.04	0.006*
Hip Extension Velocity (degrees/sec)	126.88	41.11	180.77	36.69	-3.39	0.002*
Knee Extension Velocity (degrees/sec)	65.31	29.87	105.43	35.04	-2.99	0.007*
Time in Double Support (sec)	0.16	0.10	0.05	0.03	3.76	0.002*

The two groups were also shown to be significantly different in their mean angular velocities for both hip and knee extension. The speed skating group was calculated to extend their hip at a mean angular velocity of 180.8 degrees/sec, while the hockey group demonstrated significantly less hip angular velocity at 126.9 degrees/sec. Similarly, the speed skating group also demonstrated a significantly higher angular velocity of knee extension at 105.4 degrees/sec as compared to 65.3 degrees/sec measured in the hockey group (significant to $p \leq 0.01$).

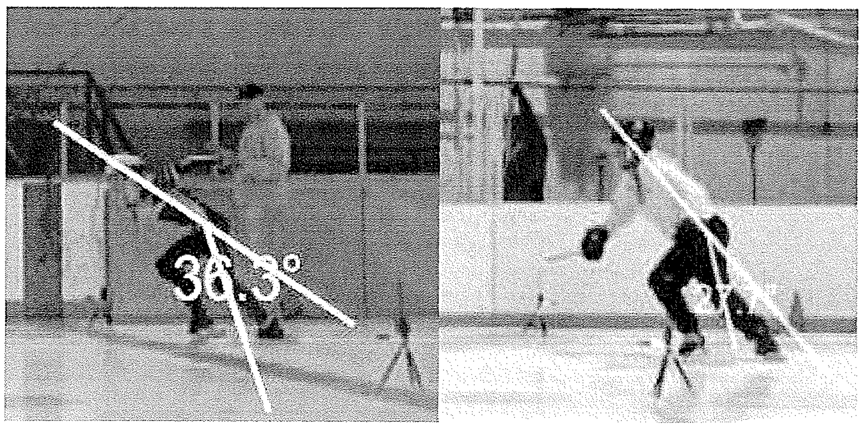


Figure 4.3: Speed skaters demonstrated significantly less hip extension at the end of the first push off compared to the hockey players.

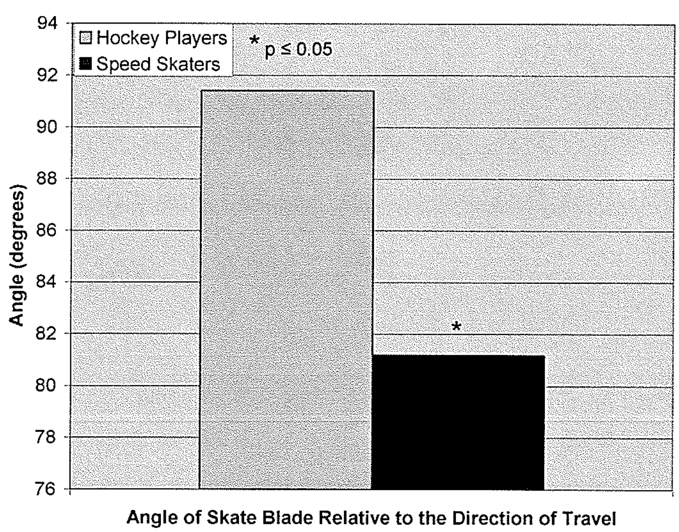


Figure 4.4: Angle of skate blade relative to the direction of travel at the end of the first push off (* $p \leq 0.05$)

Phase 3: First Foot Touchdown

A summary of the means and standard deviations as well as the p-values for the comparison of all the variables measured at first foot touchdown are shown in Table 4-5. During first foot touchdown, six of the 12 variables measured in the study were shown to be significantly different between the two groups including: time in single support, angle of hip flexion, trunk lean relative to the horizontal, angle of left shoulder abduction and extension, as well as the angle of right shoulder flexion. Both right shoulder flexion and left shoulder extension continued to be significantly different at foot touchdown, in addition to left shoulder abduction which was measured to be 64.4 degrees in the hockey players and 99.3 degrees in the speed skating group (see Figure 4.5). Another significant difference which also appeared in the ready position, was the angle of trunk lean relative to the horizontal. The hockey players demonstrated 45.2 degrees of trunk lean from the horizontal, while the speed skaters demonstrated significantly more trunk lean at 35.8 from the horizontal ($p \leq 0.001$) (see Figure 4.6). The final significant difference between the two groups at first foot touchdown was the time spent in single support. The speed skaters were calculated to be in single support for a mean time of 0.28 seconds, while the hockey players were calculated to be in single support for a slightly shorter time of 0.24 seconds ($p \leq 0.001$) (see Figure 4.7).

Figure 4.5: Speed skaters are shown to demonstrate significantly more shoulder abduction at first foot touchdown.

Table 4-5: T-test comparisons of means and standard deviations of the measured variables at first foot touchdown (* $p \leq 0.05$).

Variable	Hockey Players N = 13 Mean	Hockey Players N = 13 SD	Speed Skaters n = 11 Mean	Speed Skaters n = 11 SD	t-value	p-value
Skate position relative to Hip (rear) (m)	0.0023	0.05	0.03	0.05	-1.11	0.28
Knee Flexion at TD (degrees)	74.45	10.89	76.39	9.06	-0.48	0.64
Hip Flexion at TD (degrees)	90.39	15.09	102.68	11.06	-2.29	0.031*
Hip Abduction at TD (degrees)	5.08	9.62	8.89	18.20	-0.62	0.54
Ankle Dorsiflexion at TD (degrees)	9.85	11.41	11.71	7.94	-0.47	0.64
Trunk Lean from Horizontal (degrees)	45.19	5.09	35.84	6.39	3.91	0.0009*
Time in Single Support (sec)	0.24	0.02	0.28	0.02	-4.19	0.0005*
Distance of Foot Placement in front of hip (m)	0.08	0.07	0.12	0.07	-1.31	0.20
L. Shoulder Abduction (degrees)	64.44	18.15	99.32	14.05	-5.30	0.00002*
R. Shoulder Adduction (degrees)	-22.06	13.29	-17.25	25.66	-0.56	0.58
L. Shoulder Extension (degrees)	32.07	15.03	56.21	28.55	-2.52	0.023*
R. Shoulder Flexion (degrees)	35.02	12.75	57.80	17.04	-3.65	0.002*

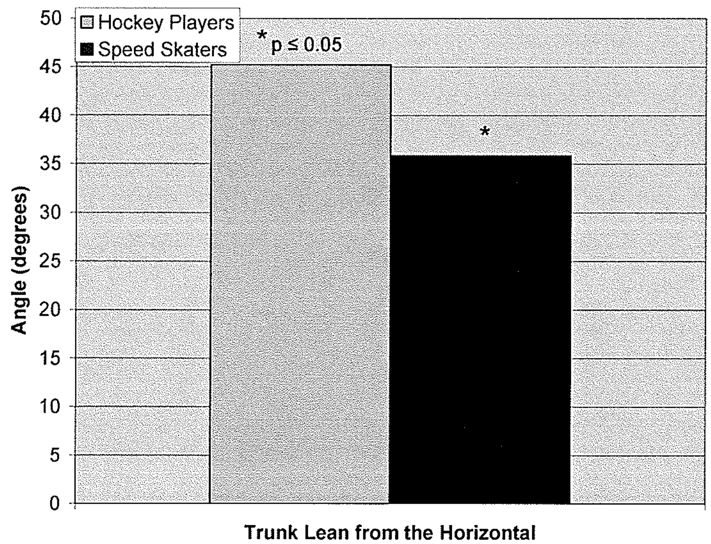


Figure 4.6: Angle of trunk lean relative to the horizontal at first foot touchdown (* $p \leq 0.05$).

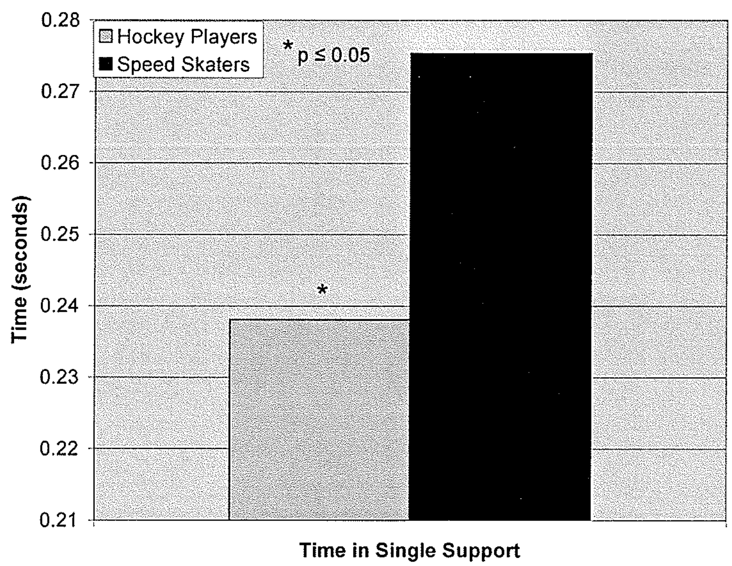


Figure 4.7: Comparison of means for time in single support at first foot touchdown (* $p \leq 0.05$)

Phase 4: End of Second Push Off

Table 4-6 is a summary of the means, standard deviations and comparisons for the variables measured at the end of the second push off. During this phase of the skill, seven of the 13 measured variables were shown to be significantly different.

Table 4-6: T-test comparisons of means and standard deviations of the measured variables at the end of the second push off (* $p \leq 0.05$).

Variable	Hockey Players n = 13 Mean	Hockey Players n = 13 SD	Speed Skaters n = 11 Mean	Speed Skaters n = 11 SD	t-value	p-value
Rear Hip Flexion (degrees)	34.51	10.47	46.79	9.53	-3.00	0.007*
Rear Knee Flexion (degrees)	26.63	9.35	31.61	10.27	-1.23	0.23
Rear Hip Abduction (degrees)	20.18	5.02	16.03	4.30	2.18	0.04*
Rear Ankle Plantarflexion (degrees)	14.03	10.13	1.30	7.99	3.44	0.002*
Time for Extension Velocity (sec)	0.26	0.05	0.29	0.05	-1.07	0.296
Skate Blade relative to Direction (degrees)	64.02	7.85	45.89	8.57	4.86	0.0003*
Hip Extension Velocity (deg/sec)	205.85	35.93	201.93	50.64	0.22	0.83
Knee Extension Velocity (deg/sec)	181.30	31.45	164.28	57.79	0.87	0.396
Time in Double Support (sec)	0.05	0.02	0.03	0.02	1.96	0.06
L. Shoulder Adduction (degrees)	11.36	16.22	19.14	14.28	-1.25	0.23
R. Shoulder Abduction (degrees)	53.47	37.68	94.74	32.65	-2.87	0.009*
L. Shoulder Flexion (degrees)	58.05	16.08	75.42	17.48	-2.52	0.02*
R. Shoulder Extension (degrees)	38.09	21.03	53.74	15.81	-2.08	0.049*

Those variables which were calculated to be significantly different include: angle of rear hip flexion and abduction, angle of rear ankle plantarflexion, angle of skate blade relative to direction of travel, angle of right shoulder abduction, angle of left shoulder flexion and the angle of right shoulder extension. Several of the variables that indicated significant differences at the end of the first push off were also shown to be significantly different at the end of the second push off. Angle of rear hip flexion, angle of skate blade relative to the direction of travel (see Figure 4.8), and angle of shoulder flexion (even though at the end of the second push off the lead arm is not the left arm) were all shown to be different at the end of the first two push offs. At the end of the second push off, the hockey group also demonstrated a significantly greater degree of ankle plantarflexion with a mean angle of 14.0 degrees compared to the speed skating group which had a mean angle of 1.3 degrees of plantarflexion in the ankle. This resulted in a significant difference between the mean of the two groups at $p \leq 0.005$. The end of the second push off also indicated that the angle of rear hip abduction was significantly greater in the hockey group with 20.2 degrees of abduction, compared to 16.0 degrees measured in the speed skating group (significant to $p \leq 0.05$). Lastly, the athlete's right shoulder abduction was shown to be significantly different between the two groups. The angle of shoulder abduction was measured to be 94.7 degrees in the speed skating group and significantly lower at 53.5 degrees in the hockey group (see Figure 4.9), while the angle of right shoulder extension was measured to be 38.1 degrees in the hockey group and 53.7 degrees in the speed skating group (see Figure 4.9 and Figure 4.10).

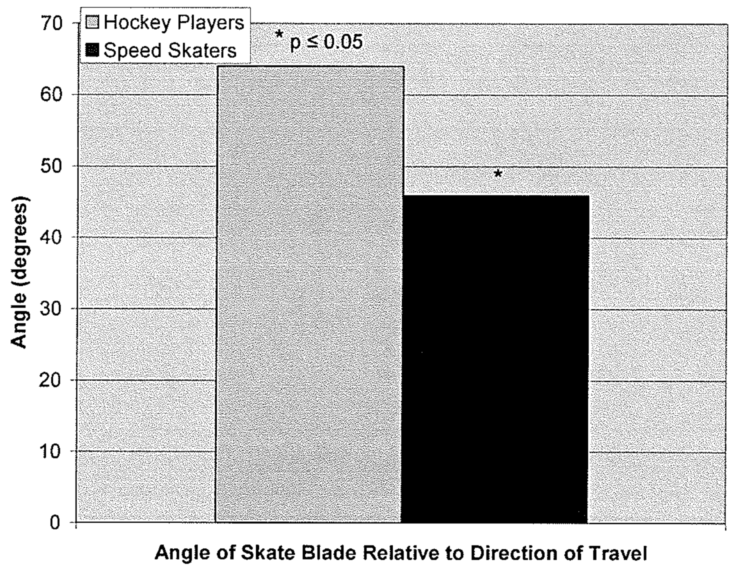


Figure 4.8: Angle of skate blade relative to direction of travel at the end of the second push off (* $p \leq 0.05$)

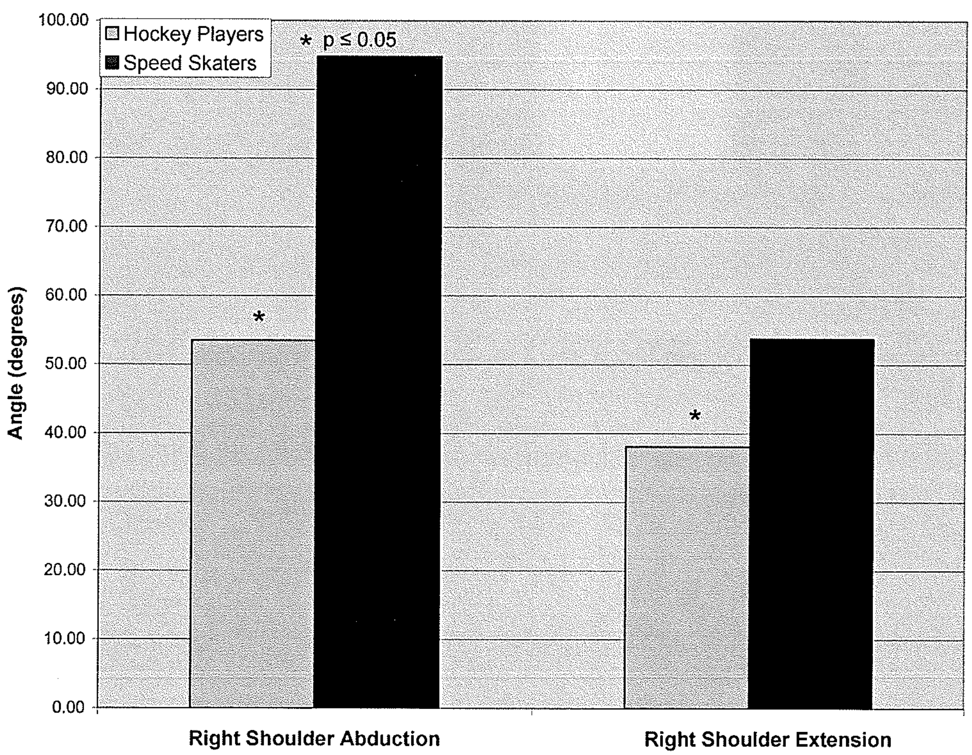


Figure 4.9: Angles of right shoulder abduction and shoulder extension at the end of the second push off (* $p \leq 0.05$).

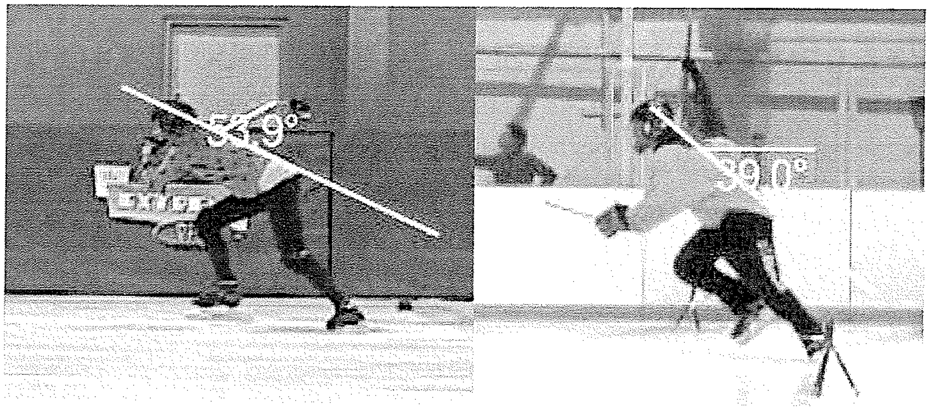


Figure 4.10: Speed skaters were found to exhibit a greater degree of shoulder extension at the end of the second push off.

Phase 5: Second Foot Touchdown

Table 4-7 summarizes the means and standard deviations as well as the comparisons for the variables measured at second foot touchdown. At this phase of the skill, five of the 12 measured variables were shown to be significantly different. These variables include: time in single support, trunk lean relative to the horizontal, right shoulder abduction, left shoulder flexion (see Figure 4.11) and right shoulder extension. The most significant difference at this point in the skill was the athlete's time spent in single support with a p-value calculated at 0.003. The subjects in the hockey group were calculated to spend significantly less time in single support with a mean time of 0.23 seconds as compared to the speed skating group which spent a mean time of 0.26 seconds. It can be noted from the results that one of the primary differences between the two groups is the range of motion of the arm actions throughout the skating start, these shoulder variables are presented in Figure 4.12. The speed skaters produced significantly greater shoulder range of motion than the hockey players in this phase.

Table 4-7: T-test comparisons of means and standard deviations of the measured variables at second foot touchdown (* $p \leq 0.05$).

Variable	Hockey Players n = 13		Speed Skaters n = 11		t-value	p-value
	Mean	**SD**	**Mean**	**SD**		
Skate position relative to Hip (rear) (m)	-0.02	0.05	0.02	0.06	-1.78	0.09
Knee Flexion at TD (degrees)	72.95	8.94	72.80	10.84	-0.35	0.97
Hip Abduction at TD (degrees)	12.06	5.66	11.11	12.08	0.24	0.81
Hip Flexion at TD (degrees)	95.37	15.33	105.50	10.61	-1.90	0.07
Ankle Dorsiflexion at TD (degrees)	17.58	4.60	13.03	9.03	1.52	0.15
Trunk Lean from Horizontal (degrees)	40.28	8.97	32.55	6.58	2.43	0.02*
Time in Single Support (sec)	0.23	0.01	0.26	0.03	-3.50	0.003*
Distance of Foot Placement in front of hip (m)	0.11	0.05	0.15	0.07	-1.60	0.13
L. Shoulder Adduction (degrees)	7.68	17.72	16.78	16.94	-1.28	0.21
R. Shoulder Abduction (degrees)	55.36	29.43	92.90	31.27	-3.01	0.007*
L. Shoulder Flexion (degrees)	40.82	13.64	61.58	21.41	-2.78	0.01*
R. Shoulder Extension (degrees)	28.80	21.58	48.26	16.31	-2.51	0.02*

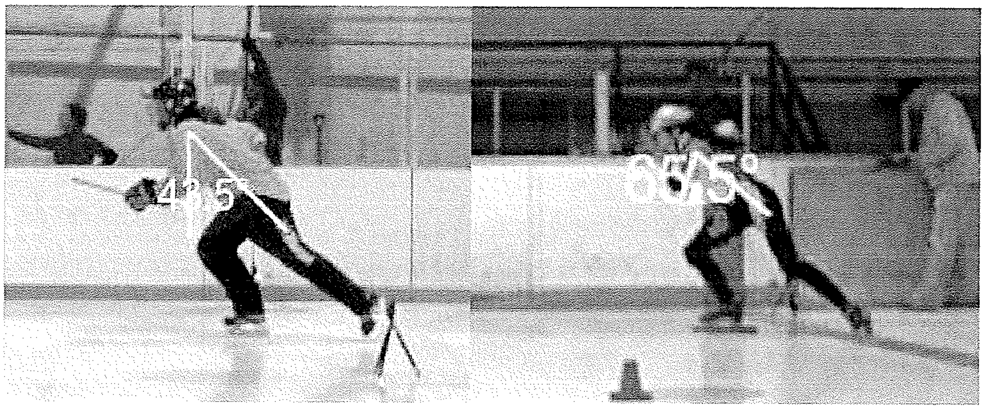


Figure 4.11: Speed skaters were found to exhibit a greater degree of shoulder flexion at second foot touchdown.

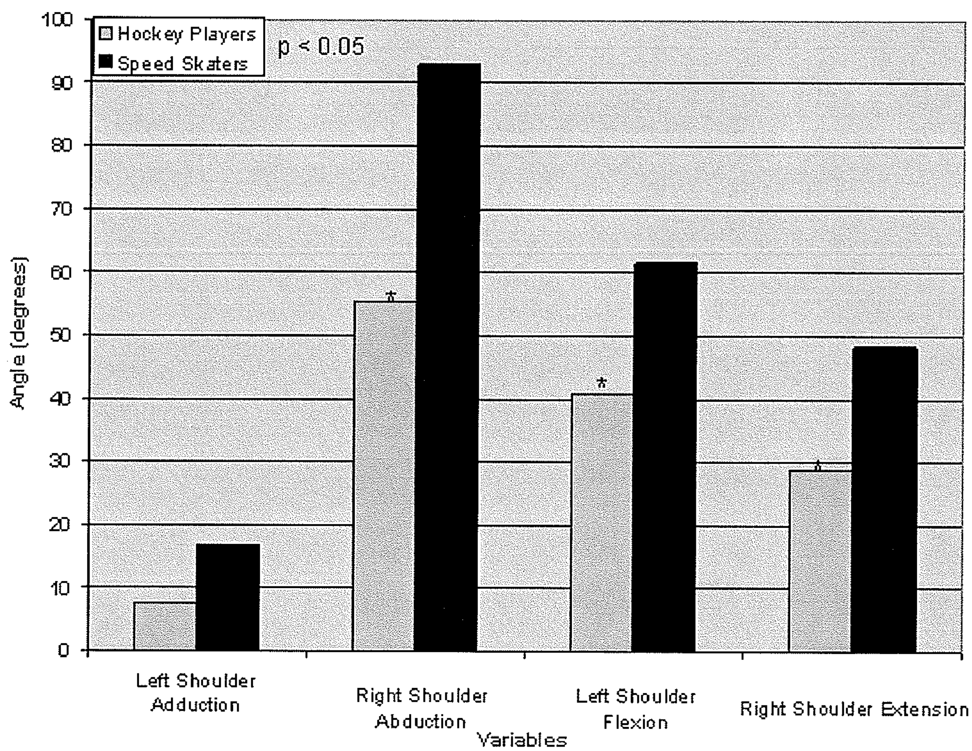


Figure 4.12: Mean angles for shoulder variables measured at second foot touchdown (* $p \leq 0.05$)

Phase 6: End of Third Push Off

At the end of the third push off, four of the 13 measured means for variables were found to be significantly different (see Table 4-8).

Table 4-8: T-test comparisons of means and standard deviations of the measured variables at the end of the third push off (* $p \leq 0.05$).

Variable	Hockey Players n = 13 Mean	Hockey Players n = 13 SD	Speed Skaters n = 11 Mean	Speed Skaters n = 11 SD	t-value	p-value
Rear Hip Flexion (degrees)	34.44	10.31	43.39	8.03	-2.39	0.025*
Rear Knee Flexion (degrees)	25.87	7.21	27.07	9.17	-0.35	0.73
Rear Hip Abduction (degrees)	19.20	6.98	12.50	4.93	2.74	0.012*
Rear Ankle Plantarflexion (degrees)	12.59	5.52	5.07	23.65	1.03	0.32
Time for Extension Velocity (sec)	0.24	0.04	0.26	0.05	-0.90	0.38
Skate Blade relative to Direction (degrees)	53.13	9.39	41.34	8.26	3.02	0.008*
Hip Extension Velocity (deg/sec)	252.54	51.43	239.55	49.87	0.63	0.54
Knee Extension Velocity (deg/sec)	196.35	53.56	182.08	44.89	0.71	0.49
L. Shoulder Abduction (degrees)	58.55	39.18	108.71	11.44	-4.40	0.0006*
R. Shoulder Adduction (degrees)	-10.85	8.31	6.66	25.67	-2.17	0.051
L. Shoulder Extension (degrees)	45.11	18.00	58.29	18.65	-1.75	0.09
R. Shoulder Flexion (degrees)	54.42	17.89	59.39	28.98	-0.49	0.63
Time in Double Support (sec)	0.05	0.02	0.03	0.03	1.29	0.21

The variables which showed significant differences at this point in the skill were the angles of rear hip abduction and hip flexion, the angle of the skate blade relative to the direction of travel, and the angle of left shoulder abduction. The angle of rear hip abduction for the hockey group was measured to be 19.2 degrees, which was significantly larger than the mean angle of hip abduction for the speed skating group at 12.5 degrees (significant at $p \leq 0.05$) (see Figure 4.13 and Figure 4.14). The angle of rear hip flexion for the speed skating group was significantly higher (indicating that they had not gone into as much extension) than that measured in the hockey group with a mean angle of 43.4 degrees of hip flexion in the speed skating group compared to 34.4 degrees in the hockey group (significant at $p \leq 0.05$) (see Figure 4.14). The third variable, angle of the skate blade relative to the direction of travel, was shown to be significantly different at the end of each of push off one, two and three. The mean angle of the skate blade for the speed skaters was 41.3 degrees as compared to the mean angle for the hockey group at 53.1 degrees (significant at $p \leq 0.01$) (see Figure 4.15). The final significant variable during this phase was highly significant at $p \leq 0.005$. The angle of left shoulder abduction was measured to be 108.7 degrees in the speed skating group and 58.6 degrees in the hockey group.

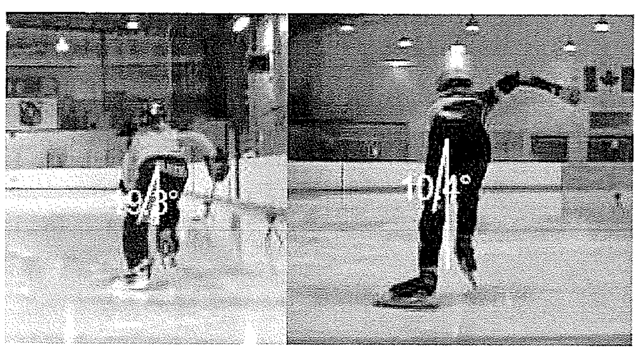


Figure 4.13: The hockey players were found to utilize a greater degree of hip abduction at the end of the third push off compared to the speed skating group.

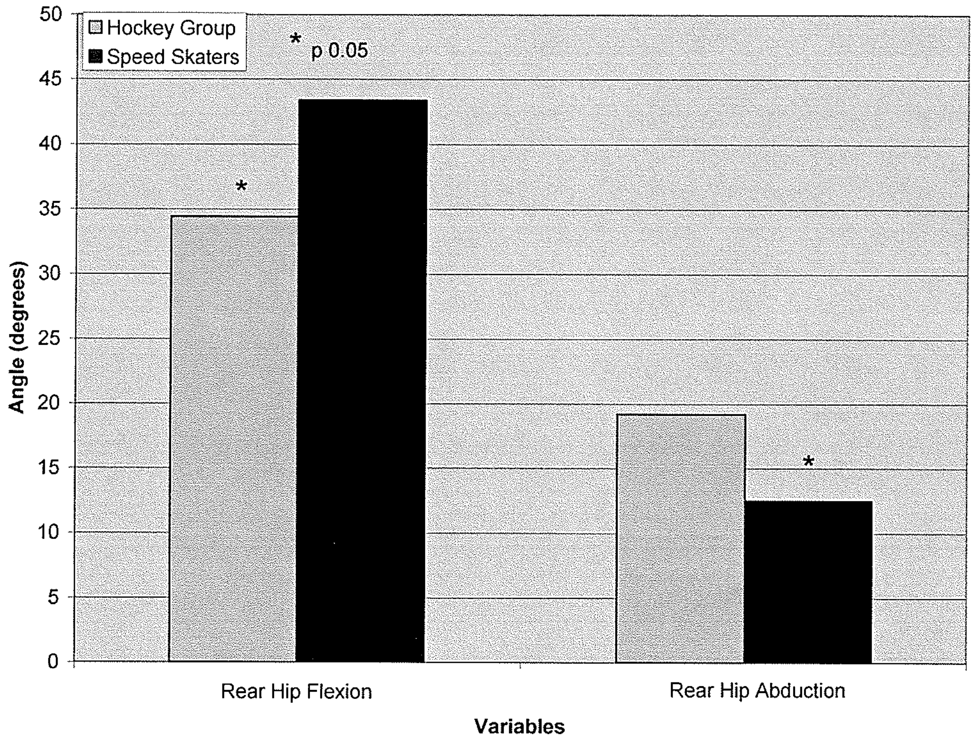


Figure 4.14: Comparison of mean angles of rear hip flexion and hip abduction at the end of the third push off phase for both speed skaters and hockey players (* $p \leq 0.05$)

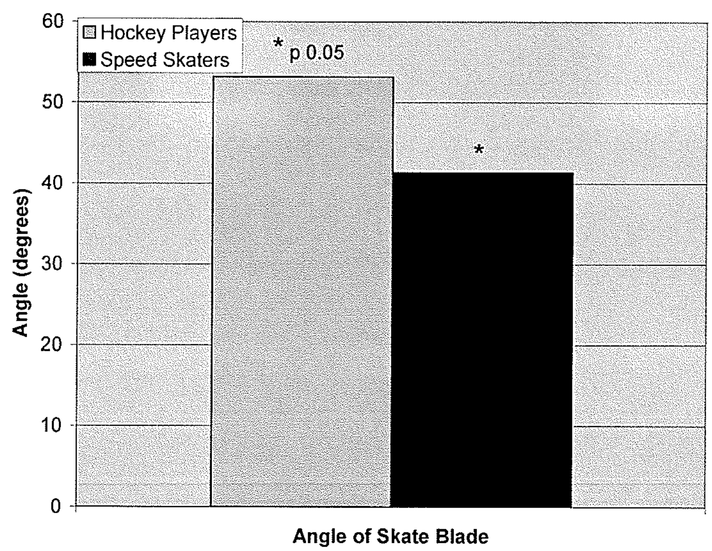


Figure 4.15: Comparison of mean angle of skate blade relative to the direction of travel at the end of the third push off (* $p \leq 0.05$).

Phase 7: Third Foot Touchdown

Table 4-9 provides a summary of the means and standard deviations as well as comparisons for the variables measured at third foot touchdown. During this phase of the skill, four of the 12 measured variables were found to be significant. These variables include: angle of knee flexion at touchdown, the distance of foot placement in front of the athlete's hip at touchdown (from a sagittal view), time in single support, and the angle of left shoulder abduction. The mean angle of knee flexion at touchdown was calculated to be 79.9 degrees for the hockey group, however, the speed skating group demonstrated a significantly smaller ($p \leq 0.05$) angle of knee flexion at 73.1 degrees (see Figure 4.16). The two groups also demonstrated a significant difference in the position of their skate relative to their hip. The speed skaters were shown to position their skate a mean distance of 0.19 m in front of their hip. The hockey group was shown to position their skate slightly closer to their hip at a mean distance of 0.12 m in front of their hip. The time in single support for the two groups was significantly different at this point in the skill, as the speed skaters were calculated to spend a mean time of 0.27 seconds in single support compared to 0.24 seconds in the hockey group (significant at $p \leq 0.05$). The last variable (significant at $p \leq 0.005$) was the angle of left shoulder abduction. This was similar to the difference identified at third foot touchdown due to the fact that both of these events occur very close to each other in timing.

Table 4-9: T-test comparisons of means and standard deviations of the measured variables at third foot touchdown (* $p \leq 0.05$).

Variable	Hockey Players n = 13 Mean	Hockey Players n = 13 SD	Speed Skaters n = 11 Mean	Speed Skaters n = 11 SD	t-value	p-value
Skate position relative to Hip (rear) (m)	-0.03	0.04	0.00	0.04	-1.51	0.15
Knee Flexion at TD (degrees)	79.88	6.42	73.07	7.25	2.41	0.025*
Hip Flexion at TD (degrees)	101.99	8.70	106.21	9.07	-1.05	0.31
Hip Abduction at TD (degrees)	0.83	6.58	5.88	7.14	-1.79	0.09
Ankle Dorsiflexion at TD (degrees)	15.08	4.34	11.75	5.69	1.59	0.13
Trunk Lean from Horizontal (degrees)	39.39	6.33	35.55	7.39	1.36	0.19
Time in Single Support (sec)	0.24	0.02	0.27	0.03	-2.82	0.012*
Distance of Foot Placement in front of hip (m)	0.12	0.04	0.19	0.06	-2.98	0.008*
L. Shoulder Abduction (degrees)	57.17	38.43	107.57	14.56	-4.37	0.00048*
R. Shoulder Adduction (degrees)	-6.73	9.47	6.50	26.78	-1.56	0.14
L. Shoulder Extension (degrees)	41.15	19.53	45.08	36.86	-0.32	0.75
R. Shoulder Flexion (degrees)	46.79	19.20	59.63	10.64	-2.06	0.052

Figure 4.16: The hockey players were found to exhibit a significantly greater degree of knee flexion at third skate touchdown.

Four other differences were also determined when interpreting the data for total time, time from zero to six meters and the athlete's velocity at 12 meters. The results of the analysis of these variables can be identified in Table 4-10.

Table 4-10: Means, standard deviations and comparisons of variables measured through out the skating start (* $p \leq 0.05$).

Variable	**Hockey Players n = 13**		**Speed Skaters n = 11**		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Time to 6 m (sec)	1.36	0.06	1.58	0.12	-5.60	0.000006*
Time from 6 to 12 m (sec)	1.00	0.03	1.00	0.05	0.17	0.87
Total Time (sec)	2.36	0.08	2.57	0.16	-4.08	0.001*
Step Rate (steps/sec)	3.27	0.27	2.94	0.39	1.73	0.03*
Time for 1st Three Steps (sec)	0.93	0.08	1.03	0.13	1.75	0.03*
Instantaneous Velocity at 6 m (m/sec)	5.45	0.38	5.89	0.66	-1.95	0.07
Instantaneous Velocity at 12 m (m/sec)	6.04	0.23	6.41	0.62	-1.87	0.09

One of the primary variables of interest was the athlete's time to six meters. It should be noted that the speed skating group demonstrated a slower time to six meters, but a faster linear velocity by the time they reached the six meter distance (see Figure 4.17).

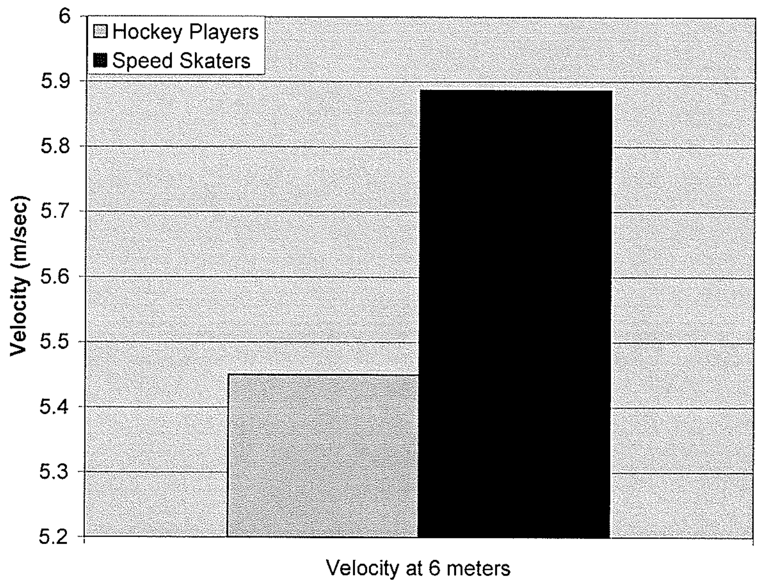


Figure 4.17: Comparison of mean velocities at 6 meters for speed skating and hockey groups (not significant).

Kinematic Relationships of Skating Variables with Velocity at Six Meters

A sub purpose of the study was to determine which variables were strongly correlated to the athlete's velocity at 6 meters. A Pearson's product moment correlation analysis was performed for both the speed skating and hockey groups separately in order to determine which variables in each skill were significantly related to the athlete's velocity at six meters. A correlation matrix was also produced in order to identify which variables were strongly correlated with each other. Upon completion of the correlation analysis, all of the variables were entered into a forward stepwise multiple regression equation, for each of the speed skating and hockey groups separately, in order to determine which variables had the strongest predictive effect on the athlete's velocity at six meters.

Correlation Analysis of Hockey Players

Table 4-11 has reported the nine variables which have the strongest correlation with the hockey group's velocity at six meters, with six of the variables being significant at $p \leq 0.05$. The six variables which were identified as having a significant relationship to velocity at six meters were right shoulder flexion at the end of the first push off, hip extension velocity at the end of the first push off, right shoulder flexion at first foot touchdown, time in double support at the end of the third push off, the distance of foot placement in front of the hip at third foot touchdown and the time to six meters.

Table 4-11: Variables demonstrating the strongest correlation with velocity at six meters for the hockey subjects. Relationships are indicated as positive (+) or negative (-).

Variable	Correlation (Hockey Players) n = 13 r-value	p-value
Right Shoulder Flexion at Ready Position (degrees)	+ 0.522	0.0673
Right Shoulder Flexion at End of 1st Push Off (degrees)	- 0.583	0.0350*
Hip Extension Velocity at End of 1st Push Off (degrees)	+ 0.579	0.0365*
Right Shoulder Flexion at 1st Foot TD (degrees)	- 0.667	0.0092**
Time in Double Support at End of 3rd Push Off (sec)	- 0.564	0.0435*
Skate Position Relative to Hip (rear) at 3rd Foot TD (meters)	+ 0.487	0.0923
Foot Placement Relative to Hip (Side) at 3rd Foot TD (meters)	- 0.711	0.0049***
Right Shoulder Flexion at 3rd Foot TD (degrees)	- 0.491	0.0892
Time to 6 meters (sec)	- 0.559	0.0458*

* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.005$

Note: TD = touchdown

The variable which showed the highest correlation with velocity at six meters in hockey was the position of the athlete's foot placement relative to their hip at third foot touchdown measured from the side view. This variable was found to have a negative correlation (-0.711) with the athlete's velocity at six meters, meaning that the further the athlete positioned their skate in front of their hip, the slower their velocity at six meters. Figure 4.18 represents this relationship graphically.

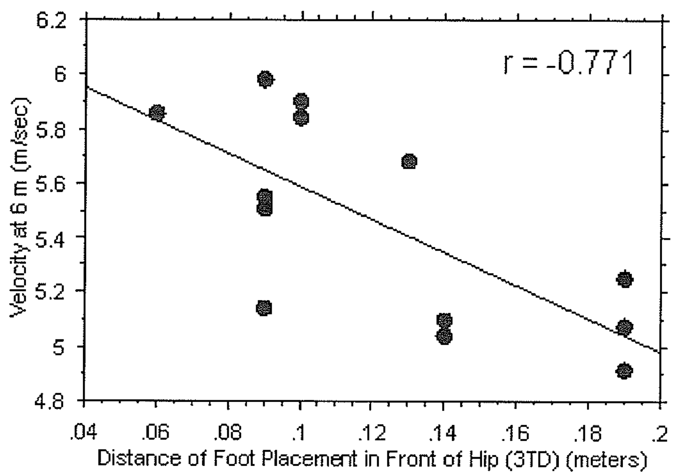


Figure 4.18: Relationship between velocity at 6 meters of hockey players and distance of foot placement relative to hip. $r = -0.771$; $p \leq 0.005$

The angle of right shoulder flexion at first foot touchdown was also shown to have a negative correlation with velocity at six meters, indicating that less shoulder flexion at this point in the skill was associated with greater velocity at six meters. This relationship was significant at $p \leq 0.01$ and is displayed graphically in Figure 4.19.

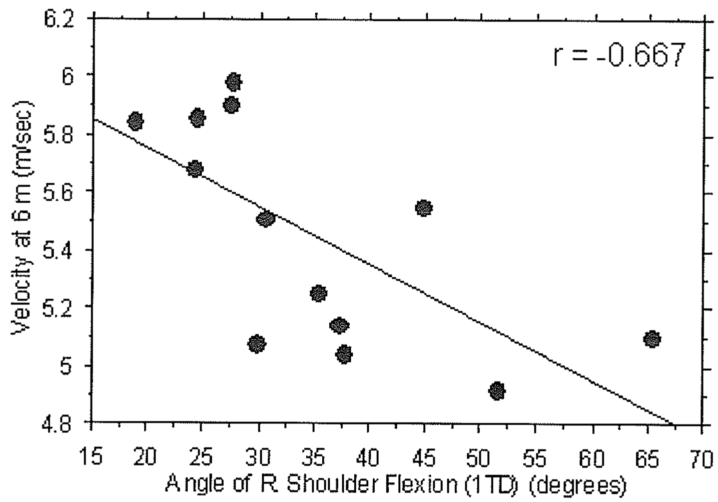


Figure 4.19: Relationship between right shoulder flexion at first foot touchdown and velocity at six meters for the hockey group. $r = -0.667$; $p \leq 0.01$

Right shoulder flexion was also shown to have the same negative relationship at the end of the first push off as previously identified at first foot touchdown. The proximity of these two events (first foot touchdown and end of 1st push off) likely resulted in the angle of shoulder flexion being significant at both positions. This relationship was significant at $p \leq 0.05$ with a correlation of $r = -0.583$.

Hip extension velocity at the end of the first push off produced a significant positive correlation with the athlete's velocity at six meters, indicating that athletes that were able to produce a high angular velocity of hip extension were shown to have a greater velocity at six meters. This relationship is shown in Figure 4.20.

The final two variables which were shown to have a significant relationship with the athlete's velocity at six meters were both related to temporal analysis. The time spent in double support at the end of the third push off was negatively correlated (-0.564) with their velocity at six meters, indicating that those athletes who spent longer time in double support had slower velocity at six meters. This relationship is illustrated in Figure 4.21.

Lastly, the athlete's time to six meters was shown to have a negative correlation (-0.559) with their velocity at six meters, showing that those athletes who were able to reach six meters the fastest had a greater velocity at six meters (see Figure 4.22).

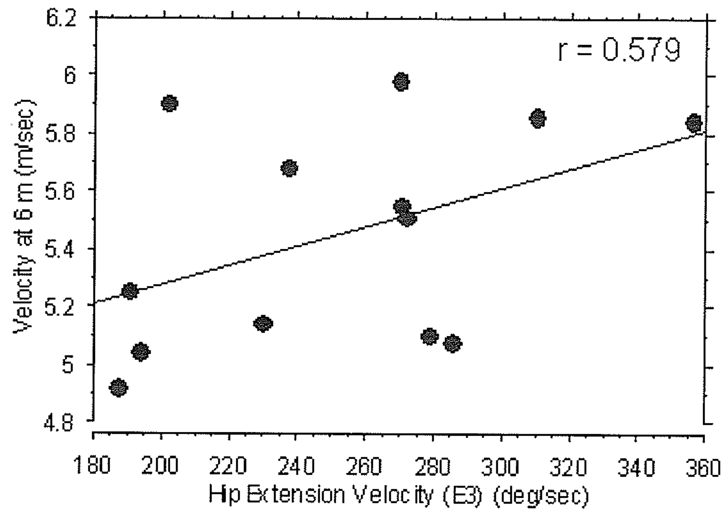


Figure 4.20: Relationship between hip extension velocity and skating velocity at 6 meters. $r = +0.579$; $p \leq 0.05$.

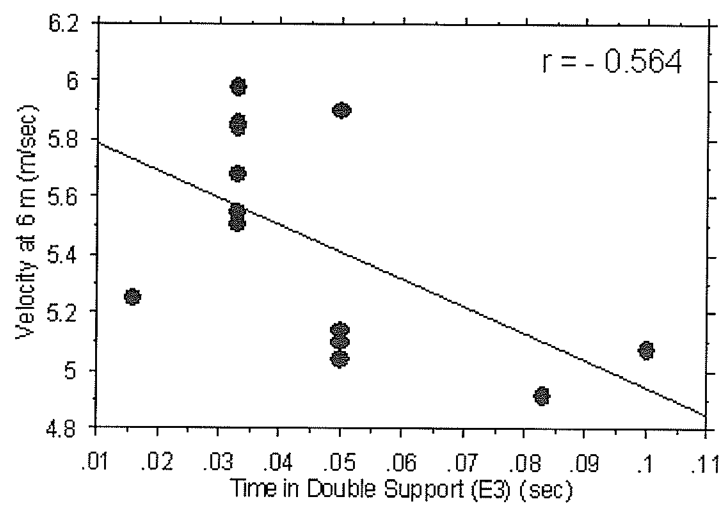


Figure 4.21: Relationship between time in double support at the end of the third push off and velocity at 6 m. $r = -0.564$; $p \leq 0.05$.

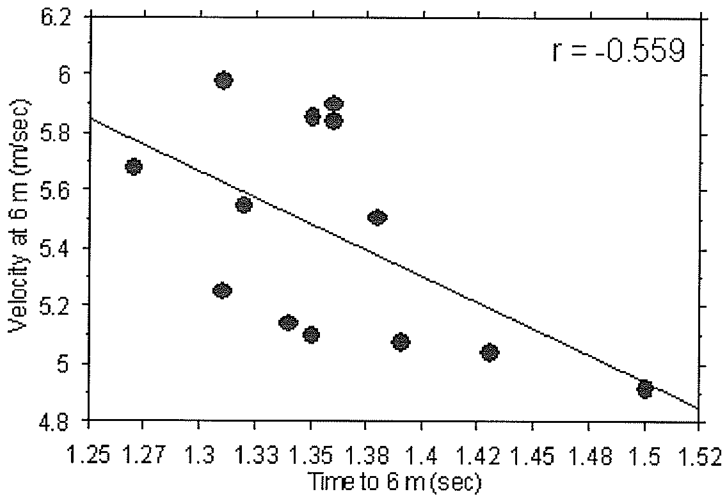


Figure 4.22: Relationship between velocity at six meters and time to six meters. r = 0.-559; $p \leq 0.05$.

Several other variables had strong correlations with the athlete's velocity at six meters, however, they were not determined to be significantly correlated. The angle of right shoulder flexion in the ready position was shown to have a strong relationship to the athlete's velocity at six meters. The angle of shoulder extension was represented as a negative value (indicating that the shoulder was in flexion) because it was expected that the athlete would position this arm in extension at the initiation of the start. These signs allowed the researcher to differentiate between an angle measured as shoulder flexion (negative number) and one measured as shoulder extension (positive number). This relationship was shown to be positive (+ 0.522), whereby a greater angle of shoulder extension was associated with a greater velocity at six meters. The athlete's skate position relative to their hip at third foot touchdown (from the rear view) was shown to have a positive correlation (+ 0.487) to velocity at six meters indicating that athletes who had their foot positioned outside of their hip had a greater velocity at six meters. Lastly, the athlete's right shoulder flexion at 3rd foot touchdown was shown to have a negative relationship (-0.491) with the athlete's velocity at six meters, indicating that a greater angle of shoulder flexion is associated with a slower velocity at six meters.

Correlation Analysis of Speed Skaters

Following the correlation analysis of the hockey subjects, a correlation analysis was performed on the variables from the speed skating group in order to determine which variables were strongly correlated with the athlete's velocity at six meters (Table 4-12). Ten variables were shown to be significantly correlated with the athlete's velocity at six meters. The variable with the most significant relationship to velocity at six meters, was the subject's time spent in double support during the second push off. This variable had a negative correlation (- 0.781) and was significant at $p \leq 0.005$, indicating that athletes who spent less time in double support during the second push off also had the greatest velocity at six meters (see Figure 4.23). Time in double support was also shown to be significantly negatively related to the athlete's velocity at six meters during both the first and third push off, indicating the importance of this variable in determining the speed skater's velocity at six meters (see Figure 4.24). In all cases, those athletes who spent less time in double support had an increased velocity at six meters.

Table 4-12: Variables demonstrating the strongest correlation with velocity at six meters for the speed skaters. Relationships are indicated as positive (+) or negative (-).

Variable	Correlation (Speed Skaters) n = 11 r-value	p-value
Right Shoulder Flexion in Ready Position (degrees)	+0.673	0.0211*
Time in Double Support at End of 1st Push Off (sec)	-0.751	0.0058**
Distance of foot placement in front of Hip at 1st Foot Touchdown (meters)	-0.680	0.0190*
Rear Hip Flexion at End of 2nd Push Off (degrees)	-0.659	0.0254*
Time in Double Support at End of 2nd Push Off (sec)	-0.781	0.0031***
Right Shoulder Abduction at End of 2nd Push Off (degrees)	+0.640	0.0320*
Rear Knee Flexion at end of the 3rd Push Off (degrees)	+0.606	0.0471*
Rear Ankle Plantarflexion at end of 3rd Push Off (degrees)	-0.613	0.0434*
Time for Extension Velocity during 3rd Push Off (sec)	-0.679	0.0192*
Time in Double Support at end of 3rd Push Off (sec)	-0.624	0.0386*

* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.005$

Note: TD = touchdown

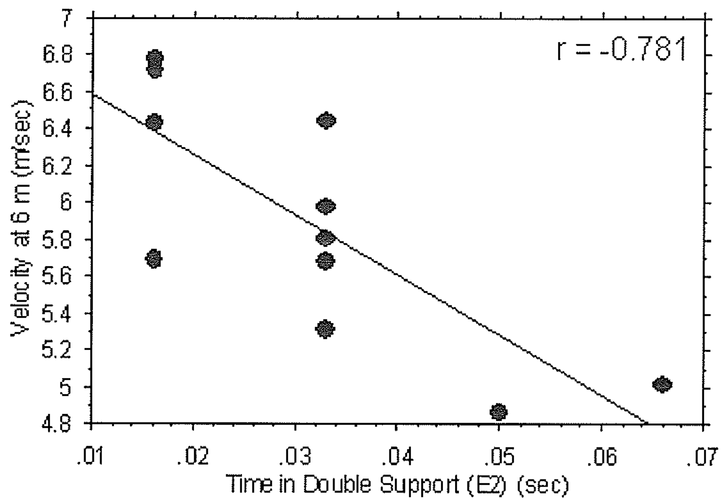


Figure 4.23: Relationship between the athlete's velocity at 6 meters and time spent in double support at the end of the 2nd push off. r = -0.781; $p \leq 0.005$.

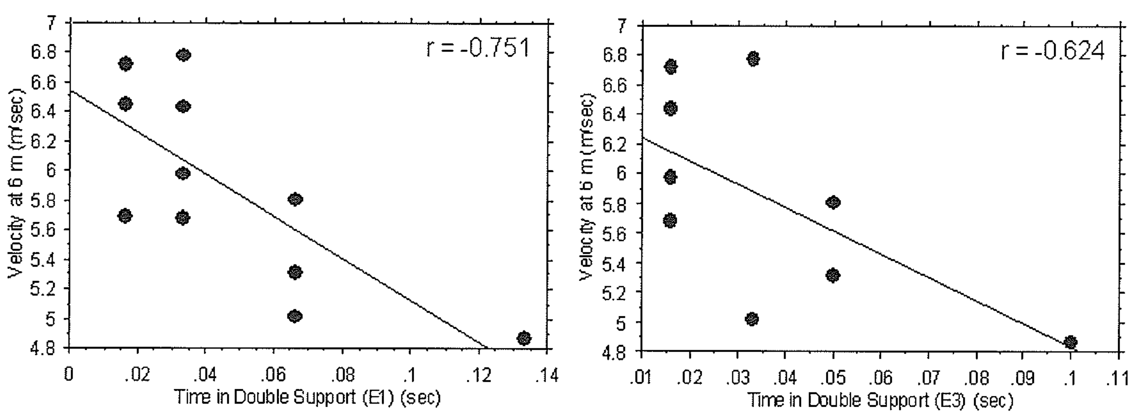


Figure 4.24: The relationship between the time spent in double support at the end of the first push off (left) and the end of the third push off (right) compared to the athlete's velocity at 6 meters

The majority of the variables which were shown to have a significant correlation with the athlete's velocity at six meters occurred during the end of the push off, primarily occurring at the end of the second and third push offs. Only one variable was determined to be significantly correlated with velocity at six meters in the ready position. The angle of right shoulder flexion was significantly correlated (+0.673) with velocity at six meters indicating that those athletes who had less shoulder extension would have a greater velocity at six meters (see Figure 4.25).

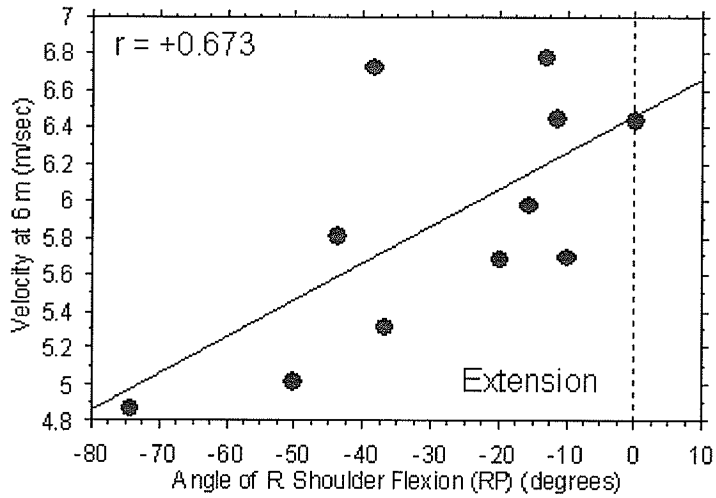


Figure 4.25: The relationship between the angle of right shoulder flexion (note how all subjects were in an extended position with their right arm) and velocity at 6 meters. $r = +0.673$; $p \leq 0.05$.

First foot touchdown variables produced one variable which was significantly correlated with velocity at six meters. The distance of the athlete's foot placement in front of their hip at touchdown was negatively correlated ($r = -0.680$) with their velocity at six meters (see Figure 4.26). Therefore, athletes who planted their support skate closer to their hip (or underneath their hip) were determined to have a greater velocity at six meters.

Right shoulder abduction at the end of the second push off was strongly correlated with the athlete's velocity at six meters, with an r-value of + 0.640. This relationship suggests that a greater angle of shoulder abduction was associated with a greater velocity at six meters.

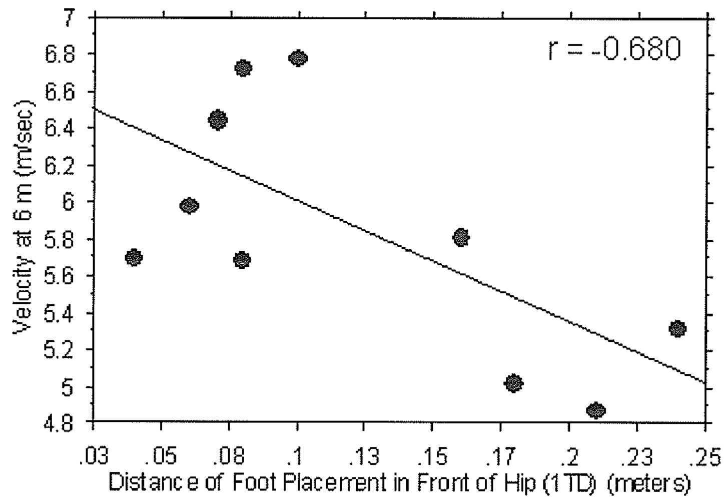


Figure 4.26: The relationship between the distance of foot placement in front of the hip relative to athlete's velocity at 6 meters. r = -0.680; $p \leq 0.05$.

The angle of rear hip flexion at the end of the second push off was calculated to have a strong negative relationship (r = -0.659) with velocity at six meters (see Figure 4.27). This relationship suggests that athletes exhibiting a more extended hip position (less hip flexion) had a greater velocity at six meters.

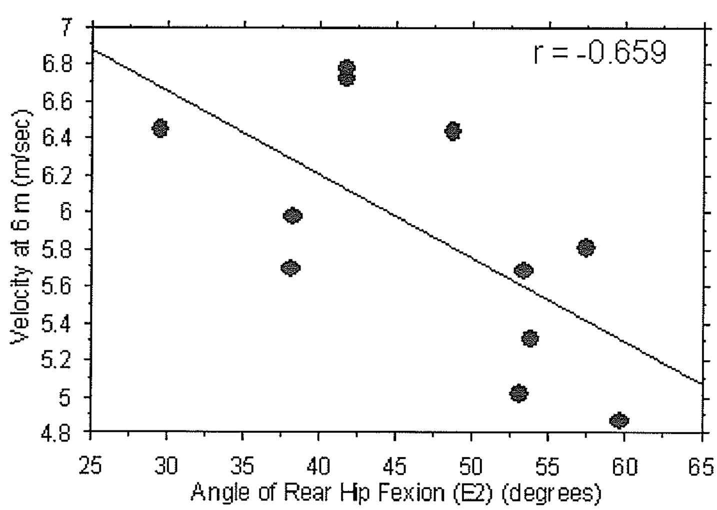


Figure 4.27: The relationship between the angle of rear hip flexion and the athlete's velocity at 6 meters at the end of the second push off. r = -0.659; $p \leq 0.05$.

Time for extension velocity during the third push off (or time which the athlete extended their hip and knee) was determined to have a strong negative relationship ($r = -0.679$) with velocity at six meters. Athletes who were able to extend their knee and hip over a shorter time were also shown to have a greater velocity at six meters.

The athlete's rear ankle plantarflexion at the end of the push off was also shown to have a strong negative relationship ($r = -0.613$) with velocity at six meters. Similarly, those athletes who demonstrated a more neutral ankle (or did not go into excessive plantarflexion at the end of the push off) had a greater velocity at six meters.

The final variable which was shown to be significantly correlated with the athlete's velocity at six meters was the angle of rear knee flexion at the end of the 3rd push off as shown in Figure 4.28. As a result, an increased angle of knee flexion remaining at the end of the 3rd push off is associated with a greater velocity at six meters.

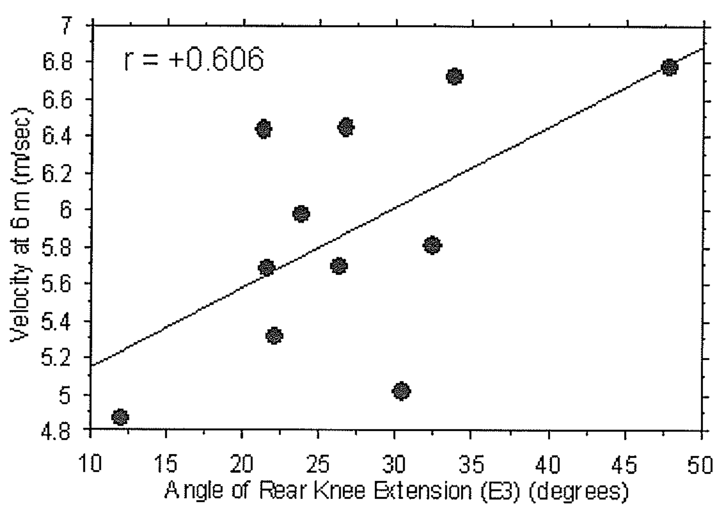


Figure 4.28: Relationship between angle of rear knee flexion at the end of the 3rd push off and the velocity at 6 meters. $r = 0.606$; $p \leq 0.05$.

Stepwise Multiple Regression Analysis

The final step in the statistical analysis of the study was performing two separate stepwise multiple regression analyses on the speed skaters and hockey players in order to determine the effect of each variable on the velocity at six meters. All of the variables which were gathered in the study were entered into an equation with the exception of the timing variables. These variables were removed for calculation of the stepwise regression equation because it was assumed that a skater who reached the timing gate at six meters in a shorter time would have a greater velocity, eliminating the collinearity present between these variables. The speed skating regression equation also eliminated the four variables measuring the angle of skate blade relative to the direction of travel due to missing values for three of the subjects when the overhead camera was not available for filming. These variables were removed in order to allow for the regression equation to include all 11 subjects. It was decided to take a safe approach whereby only variables that all subjects had measured would be included in the calculation of the regression equation. (T. Hassard, personal communication, 2007).

Hockey Players Regression Equation

Upon completion of the stepwise multiple regression analysis on the hockey players data, seven variables were identified as being able to explain the majority of the variance within the velocity at six meters. These variables are shown in Table 4-13.

Table 4-13: Summary of the variables which were selected by the stepwise multiple regression analysis for the hockey subjects.

Variables	Coefficient	Std. Error	Std. Coefficient	F
Angle of front hip flexion (ready position)	0.008	0.001	0.332	103.353
Angle of left shoulder abduction (end of 1st push off)	- 0.006	0.001	-0.215	29.035
Angle of right shoulder adduction (end of 1st push off)	0.003	0.001	0.094	8.038
Time in single support (1st foot touchdown)	-7.096	0.669	-0.349	112.427
Angle of right shoulder flexion (1st foot touchdown)	-0.018	0.001	-0.596	194.477
Angle of left shoulder abduction (end of 3rd push off)	0.002	0.000038	0.176	19.239
Distance of foot placement in front of hip (3rd foot touchdown)	-2.925	0.371	-0.342	62.139
F to enter = 4.00				
F to remove = 3.996				

The seven variables identified in Table 4-12 can explain 99 % of the variance in the athletes' velocity at six meters. The regression equation for the prediction of the dependent variable is expressed in Figure 4.29.

Regression equation:

$$y = 7.846 + 0.008x_1 - 0.006x_2 + 0.003x_3 - 7.096x_4 - 0.018x_5 + 0.002x_6 - 2.925x_7$$

Where:

Intercept = 7.846

y = velocity at 6 meters

x_1 = angle of hip flexion (ready position)

x_2 = angle of left shoulder abduction (end of 1st push off)

x_3 = angle of right shoulder adduction (end of 1st push off)

x_4 = time in single support (1st foot touchdown)

x_5 = angle of right shoulder flexion (1st foot touchdown)

x_6 = angle of left shoulder abduction (end of 3rd push off)

x_7 = distance of foot placement in front of hip (3rd foot touchdown)

Figure 4.29: Regression equation to predict hockey player velocity at 6 meters.

Speed Skating Regression Equation

Regression analysis of the speed skating subjects identified nine variables, however, only four of these variables were included in the regression equation as they could account for 99% of the variation in velocity at six meters. The four variables which were included in the regression analysis are shown in Table 4-14 and the regression equation is displayed in Figure 4.30.

Table 4-14: Summary of the variables which were selected by the stepwise multiple regression analysis for the speed skating subjects.

Variables	Coefficient	Std. Error	Std. Coefficient	F
Angle of right shoulder adduction (1st foot touchdown)	0.013	0.001	0.508	94.617
Time in double support (end of 2nd push off)	-60.623	2.406	-1.455	635.035
Angle of rear hip flexion (end of 3rd push off)	0.066	0.004	0.808	285.987
Angle of right shoulder adduction (end of 3rd push off)	-0.010	0.002	-0.387	40.911
F to enter = 4.000				
F to remove = 3.996				

Regression equation:

$$y = 5.199 + 0.013x_1 - 60.623x_2 + 0.066x_3 - 0.010x_4$$

Where:

Intercept = 5.199

y = velocity at 6 meters

x_1 = angle of right shoulder adduction (1st foot touchdown)

x_2 = time in double support (end of 2nd push off)

x_3 = angle of rear hip flexion (end of 3rd push off)

x_4 = angle of right shoulder adduction (end of 3rd push off)

Figure 4.30: Regression equation to predict speed skater velocity at 6 meters.

CHAPTER V

Discussion

Introduction

The starts in both speed skating and hockey are skills which both require explosive power and excellent technique, however, due to the nature of the skills it is probable that differences in technique may occur. The purpose of this study was to determine the most effective body movements and body positions to perform the fastest start in ice hockey and the fastest start in short track speed skating for female athletes. Emphasis was placed on determining the key kinematic variables which are associated with maximizing speed skaters' and hockey players' velocity at six meters. It is important to identify which variables play an important role in determining velocity at six meters in order to determine which variables should be emphasized when teaching these skills to developing athletes or in coaching these skills in more advanced athletes.

This study analyzed the starting position as well as the first three steps performed by the subject, emphasizing the athlete's position at the end of the push off and at skate touchdown for each successive step. The same variables were measured at each of the two positions identified (end of the push off and touchdown) for the first three steps through the use of Dartfish 4.5.2 video analysis software. Following the measurement of variables, statistical analyses were performed in order to determine which variables differed between the two groups. Differences were determined by performing student t-tests on the variables measured for both the speed skating and hockey groups for all of the variables of interest in the study in order to determine the kinematic differences between the two starts as identified in the purpose of the study. Next, correlation analysis was performed in order to determine which variables showed the strongest correlation to velocity at six meters for the two groups separately. Lastly, forward stepwise multiple regression analysis was performed in order determine which variables were the best predictors of velocity at six meters for the two groups separately as identified in the sub purpose of the study. The discussion will be presented following the seven phases identified in the results section. Each phase will contain a discussion of the results of the t-tests, followed by the relevant correlations and multiple regressions.

Ready Position

The ready position (or starting position) in both speed skating and hockey occur with the athlete's body facing the direction of intended travel, however, due to the nature of the two sports the ready positions are shown to be significantly different. During the front start in hockey, research by Naud and Holt (1979) has suggested that the athlete begins "in a standing position, knees slightly flexed, feet parallel and approximately 12 [inches] apart, with the skate blades at a 90 degree angle to the starting line" (p. 8) (see Figure 5.1A). The subjects in this study were not shown to replicate this exact position as only one of the subjects had their skates orientated parallel to the direction of travel (with an angle of 5.4 degrees relative to the direction of travel). Instead, the hockey subjects positioned their rear skate blade at a mean angle of 44 degrees to the direction of travel (see Figure 5.1B).

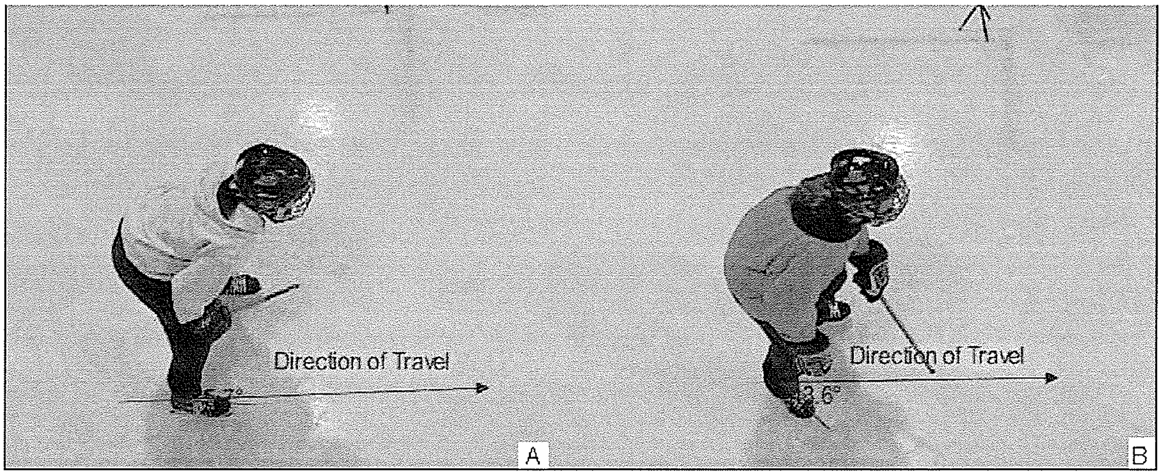


Figure 5.1: A. Ready position in hockey start as indicated by Naud and Holt (1979) with the skates facing the intended direction of travel. **B.** Ready position in hockey start commonly seen in the current study with the push off skate angled at approximately 45 degrees to the direction of travel.

This position of having the skate blade angled at approximately 45 degrees to the direction of travel will be beneficial for the athletes as it has been suggested by Marcotte (1975) that "one will have to get the first skate in as close to 90 degrees to the intended direction of movement as possible" (p. 31) in order to ensure that the first stride takes the player directly towards their target direction. When comparing the angle of the skate blade between the two groups, the speed skaters were able to position their rear skate in a substantially better position with a mean angle of 75 degrees to the intended direction of travel. This will benefit the speed skating group as the skate is angled closer to 90 degrees from the direction of travel and therefore the speed skater will be able to forcefully extend at the hip and knee in order to take the first step. It is important that the athlete emphasize a push in the posterior direction in order to maximize the force which can be applied to the ice and therefore maximize the ground reaction forces which will be applied back on the skater. The hockey players in the current study could benefit by positioning their skate closer to 90 degrees to their intended direction of travel during the ready position.

Trunk Lean Relative to the Horizontal

The ready position of the skill also demonstrated several other significant differences which were likely dictated by the nature of the skill. The speed skaters were shown to have a significantly lower angle of trunk lean relative to the horizontal with a mean angle of 17.8 degrees compared to a mean angle of 41.9 degrees in the hockey group (see Figure 5.2). This difference was calculated to be statistically significant. The speed skater with the highest angle of trunk lean relative to the horizontal was measured at 29.3 degrees. This angle is lower than the lowest angle of trunk lean measured in the hockey group at 33.1 degrees. A more horizontal trunk position as demonstrated by the speed skating group will be beneficial for the athlete due to the positive effect that trunk extension may have on increasing the angle of rear knee flexion prior to the push off. As the athlete extends at the trunk (stands more upright during the first push off) it was noted that a slight increase in the athlete's rear knee flexion occurred. This slight increase in knee flexion will be beneficial as it will allow the athlete to increase the stretch on the quadriceps muscles and utilize the stretch-shortening cycle, whereby a muscle which is stretched prior to contraction has been shown to produce more force. A second benefit of a more horizontal trunk position is an increased stretch on the gluteal muscles. By increasing the stretch on the gluteals, the athlete will be able to generate more force during hip extension and therefore increase the force which can be applied against the ice.

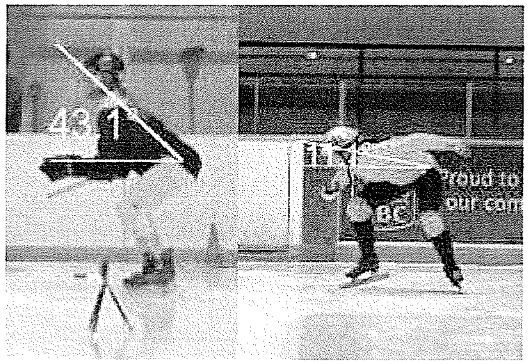


Figure 5.2: Comparison of trunk flexion angles in the ready position between a speed skater and a hockey player.

Hip and Knee Flexion

The ready position comparisons produced the greatest number of significant differences between the two groups with eight of the 13 variables producing a significant difference. The speed skating group was shown to produce a more flexed ready position with an increased angle of front knee flexion and an increased angle of front and rear hip flexion compared to the hockey group. All of these variables were shown to be statistically significant at $p \leq 0.0001$. This flexed ready position seen in the speed skating group should produce a better position to initiate the start due to a greater range of motion which can be achieved during the first push off. Hockey players could benefit from entering a more flexed ready position in order to be in a more effective position to initiate the start. It is important to note here that with young developing athletes there may be limited strength in some of the key muscle groups. For example, in order to gain the benefits of a high degree of knee flexion, the athlete must possess enough quadriceps strength to extend out of this low position. An athlete who does not display adequate quadriceps strength is likely to produce lower force output during knee extension and therefore will not be able to explode from the starting line.

Shoulder Flexion

Another area of significant difference between the two groups was their shoulder flexion angles in the ready position. The speed skating group was measured to have a mean angle of left shoulder flexion of 82.2 degrees, compared to 23.3 degrees seen in the hockey group (see Figure 5.3).

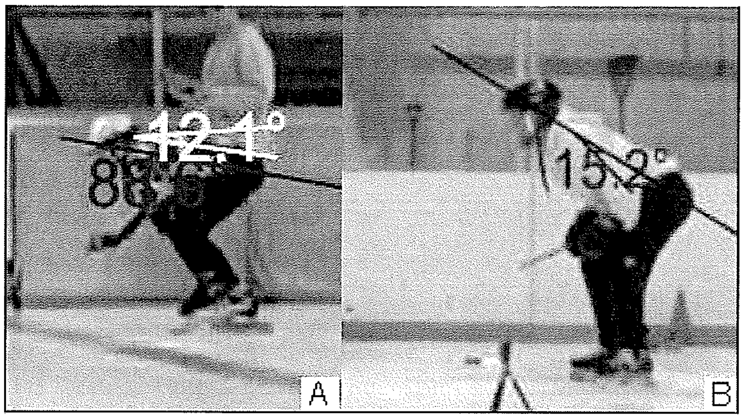


Figure 5.3: **A.** Angle of left shoulder flexion seen in the speed skating group (88.6 degrees indicated by blue angle) and right shoulder extension (12.1 degrees indicated by yellow angle) in the ready position. **B.** Angle of shoulder flexion seen in the hockey group. Note how both shoulders are in a flexed position in the ready position.

Similarly, the speed skating group was significantly different from the hockey group in the position of their right shoulder in the ready position. The speed skating group was shown to position their right shoulder in a mean angle of 28.6 degrees of shoulder extension, whereas the hockey group positioned their right shoulder in a mean angle of 19.1 degrees of flexion (see Figure 5.3). From this position, the speed skating group is able to make use of a large range of motion for their arm movements which can be utilized to increase the ground reaction forces applied to the ice during the start.

Correlation Analysis

When the correlation analysis was performed on both groups separately, the angle of right shoulder flexion was shown to be positively correlated with the athlete's velocity at six meters for both the speed skating and hockey groups. The correlation was much stronger with an r-value of + 0.673 in the speed skating group as compared to an r-value of + 0.522 in the hockey group. This finding is interesting due to the significant difference noted previously that the athlete's right shoulder was in a position of extension in the speed skating group and flexion in the hockey group. As a result, the correlation suggests that less shoulder extension (or more flexion) is generally associated with a greater velocity at six meters. This finding is different than the researcher expected because more shoulder extension would allow for a larger range of motion for the athlete to flex their arm through, resulting in an increased amount of force which can be applied against the ice. The current researcher believes that both groups should position their right shoulder in a position of slight shoulder extension in order to place the arm in a more effective position to initiate the first arm swing.

Regression Analysis

After the completion of the stepwise multiple regression analysis, only one variable was shown to be a predictor of velocity at six meters from the ready position. This variable was the angle of front hip flexion in the ready position for the hockey group. The coefficient for this variable was quite small, however, for every 1 degree increase in the angle of hip flexion, there was a 0.008 m/sec increase in the athlete's velocity at six meters. A greater angle of hip flexion produced in the hockey group will be beneficial as the athlete will be able to lower their center of gravity. Due to a lowered center of gravity, the athlete will be able to benefit from a push which minimizes the vertical deviation of the center of gravity and therefore allow greater force to be applied in the horizontal direction.

End of First Push Off

The end of the first push off during the start also produced several key differences between the two groups. This position of the skill is important as it is the first force producing movement.

Hip Flexion

The speed skating group was shown to have a greater degree of hip flexion remaining at the end of the first push off with a mean angle of 36.8 degrees compared to the hockey group who had a mean angle of 27.0 degrees of hip flexion remaining. It is generally believed that a larger range of motion is beneficial as it will produce a larger distance over which to apply force to the ice, however, in the start utilized in skating skills a rapid turnover or an increased stride rate has been shown to be related to a faster acceleration (Marino, 1978). It is important to note from these results that the speed skating group was actually shown to produce a larger range of motion for hip extension at 70.9 degrees compared to the hockey group which was calculated to go through 53.6 degrees. It is also important to note that since the speed skating group demonstrated a smaller angle of trunk forward lean from the horizontal than the hockey group, they were able to apply force to the ice over a greater distance during the push off.

Hip and Knee Extension

Another important component of the start was how fast the athlete was able to perform their hip and knee extension. In the study, the two groups were calculated to have very similar times for hip and knee extension, with a mean time of 0.44 seconds for the speed skating group and a mean time of 0.43 seconds for the hockey group. As a result, the speed skating group was shown to have a greater angular velocity for both hip and knee extension due to the larger range of motion achieved at both the hip and knee joints during the force producing action. A greater angular impulse applied to the ice produces a greater torque on the ice and therefore a greater angular velocity for hip and knee extension seen in the speed skating group. Therefore, it is important for the athletes to emphasize a high angular acceleration in order to maximize their torque. This relationship is explained by the equation $T = I\acute{\alpha}$ where I is the athlete's moment of inertia and $\acute{\alpha}$ is their angular acceleration, whereby athletes with a greater change in angular velocity will be able to produce a greater torque. However, neither hip extension velocity nor knee extension velocity were shown to be significantly correlated to the speed skaters' velocity at six meters with a correlation of + 0.356 and + 0.075 respectively. Non significant correlations between angular velocity and velocity at six meters likely occurred due to a limited sample size, resulting in a large variation for hip and knee extension. Interestingly enough, hip extension velocity was shown to have a significant positive correlation (+0.579) to the hockey players' velocity at six meters. As a result, an increased angular velocity of hip extension at the end of the first push off will be beneficial for both speed skaters and hockey players as it will allow them to maximize their velocity at six meters. The results from this study showed that the speed skaters produced substantially less angular velocity for knee extension during the push off as compared to the subjects in de Koning et al. (1989) where female athletes' knee extension velocities were calculated to be 639 ± 66 degrees/second compared to 105.43

degrees/second for the present study. There could be several possible reasons for the difference in angular velocities reported during the first push off. The first reason could be the difference in skill level and strength between the two groups with the subjects in de Koning's (1989) study being more skilled and significantly stronger than the subjects in the current study. A second reason could be due to the difference in knee extension velocities between short track speed skaters and long track speed skaters as de Koning's (1989) study was conducted on long track speed skaters using a standard skate. The final reason may be due to a difference in methods utilized to measure the angular velocity. In the current study, the angular velocity was measured from the ready position to the end of the push off, however, if the athlete were to increase their knee flexion prior to their push off then this would have a negative effect on their angular velocity. The researcher chose to measure the knee extension velocity beginning at the ready position because this would result in a more consistent methodology for each of the three push off phases.

Time in Double Support

Time in double support has been demonstrated by several researchers as being an important variable in maximizing acceleration during the start. Marino (1979) has suggested that during a hockey start, athletes who are able to spend a greater time in double support are able to accelerate forward, while during single support or the glide phase the athlete would decelerate. As a result, Marino (1983) has recommended that athletes emphasize a fast recovery of the skating leg in order to reposition the skate on the ice and increase the amount of time spent in double support (or increasing the time spent applying force to the ice). Marino (1983) has also suggested that a long single support time is related to a relatively slow skating time and therefore a low rate of acceleration.

Marino (1983) has simply identified that the relationship between single support time and double support time is inverse in nature, with a greater time in double support resulting in greater acceleration or a greater time in single support resulting in less acceleration (see Figure 5.4)

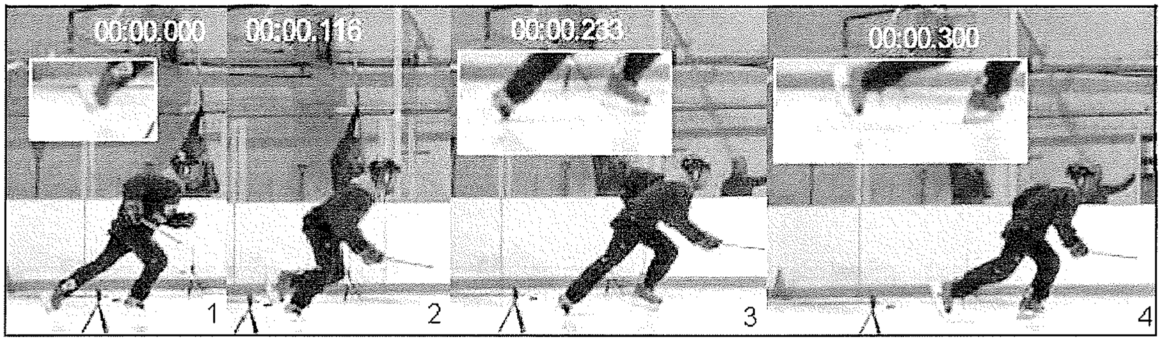


Figure 5.4: Sequence picture identifying periods of single and double support. 1. Single support begins as only the right (front) skate is in contact with the ice. 2. Single support continues during the mid recovery phase. 3. Double support begins as both skates are in contact with the ice. 4. Start of next single support phase begins as rear skate is removed from the ice.

Research involving the athlete's time in single and double support during the start in speed skating has suggested a slightly different approach. Research conducted by Teasdale et al. (1996) has suggested that "the first event recorded was a short duration in-flight phase" (p. 444). It has been recommended that speed skaters spend no time in double support during the first push off phase of the start. As a result, when the speed skaters in the group were shown to spend a mean of 0.05 seconds in double support at the end of the first push off they were attempting to have the suggested airborne phase. None of the subjects in the study were shown to enter this airborne phase, however, seven of 11 subjects were found to spend between 0.016 and 0.033 seconds in double support. Upon review of speed skating starts performed during the Olympic games in Torino, Italy, it was noted that the top skaters were shown to have an airborne phase during the first step. Several of the elite athletes continued to display an airborne phase during the following three or four steps.

When a t-test was conducted to determine the differences between times in double support at the end of the first push off, it was suggested that the speed skaters and hockey players used significantly different approaches during the start. The hockey players were shown to spend significantly more time in double support at 0.16 seconds. Similar to the speed skaters, the hockey players were also shown to perform the start as suggested by hockey researcher Marino (1979, 1983) by spending a greater time in double support allowing them to maximize their time spent in force production. When examining the athletes' time in double support and its relationship to their velocity at six meters, it can be noted that for the speed skating group, there was a significant negative correlation at $r = -0.751$. However, when looking at the correlation between the hockey players' velocity at six meters and their time in double support at the end of the first push off, no correlation was present. As a result, from this study, there was no evidence to suggest that those hockey players who spent increased time in double support were able to reach a greater velocity at six meters. Therefore, hockey players in the current study could benefit from spending less time in double support in order to maximize the athlete's velocity at six meters.

Arm Movements

The end of the first push off also showed a significant difference in regards to the range of motion for the arm action in the sagittal plane. Speed skaters were shown to have significantly greater shoulder flexion with a mean angle of 64.3 degrees, than the hockey group with a mean angle of 46.1 degrees. Similarly, the mean angle of left shoulder extension was also shown to be significantly different between the two groups, with a mean angle of 57.4 degrees for the speed skating group and 36.6 degrees for the hockey group. In regard to the arm motion, the speed skaters were shown to produce a significantly larger range of motion, which will allow the athlete to make better use of a vigorous arm action to aid in the production of ground reaction forces. The arm movements in both speed skating and hockey are less understood than many of the lower body movements as the majority of research focuses on variables pertaining to the trunk, hip, knee and ankle for both sports. However, sports such as high jumping and volleyball teach their athletes to use a large arm swing beginning in shoulder hyperextension and flexing forward in conjunction with knee and hip extension. This movement is believed to increase the ground reaction forces that the athlete can apply against the ground and therefore increase the force which the ground will apply back on the athlete due to Newton's 3rd Law of Motion, the Law of Reaction. As a result, when the athletes in this study are able to use a vigorous arm swing as they are extending at the knee and hip, it will allow them to increase the force which they can apply against the ice, therefore increasing the force applied by the ice on the athlete.

After the completion of the correlation analysis, a significant correlation was reported between the hockey players' right shoulder flexion at the end of the first push off and their velocity at six meters. This relationship had a correlation of $r = -0.583$, indicating that those subjects who had less shoulder flexion at this point in the skill had a greater velocity at six meters. No significant correlation was evident at the same point in the skill for the speed skating group, as right shoulder flexion at the end of the first push off had a correlation of $r = +0.100$ with the athletes' velocity at six meters. This relationship could occur due to the high step rate taught in hockey starts, where a large range of motion at the shoulder joint may hinder the athletes' velocity because the time for the push off does not allow for an increased range of motion about the shoulder joint (or the athletes who have a greater degree of shoulder flexion are continuing to flex their shoulder after the end of the push off resulting in no substantial increase in ground reaction forces being applied to the ice).

Angle of Skate Blade

The last finding from the end of the first push off was the significant difference found between the two groups in regards to the angle of the skate blade relative to the direction of travel. Previous research conducted by Marcotte (1975) on the hockey start has suggested that the first push off should be applied as close to 90 degrees from the direction of travel as possible with each successive push off being angled slightly less until it reaches 30 degrees from the direction of travel during the normal skating stride. (see Figure 2.5).

When comparing the angle of skate blade relative to the direction of travel for this study, the two groups are significantly different with the speed skaters having their skate blade angled at a mean angle of 81.2 degrees to the direction of travel as compared to the hockey group with a mean angle of 91.4 degrees to the direction of travel. The direction of the push off plays an important role in the start as it determines the direction in which the athlete will be traveling. Therefore, the hockey group was able to apply the force from their push off directly backwards at the end of the push. However, from a qualitative analysis, it was shown that the hockey players rotated on their skate as they were initiating the first push off action as opposed to starting with the skate in that position and forcefully driving off the skate (see Figure 5.5 and Figure 5.6).

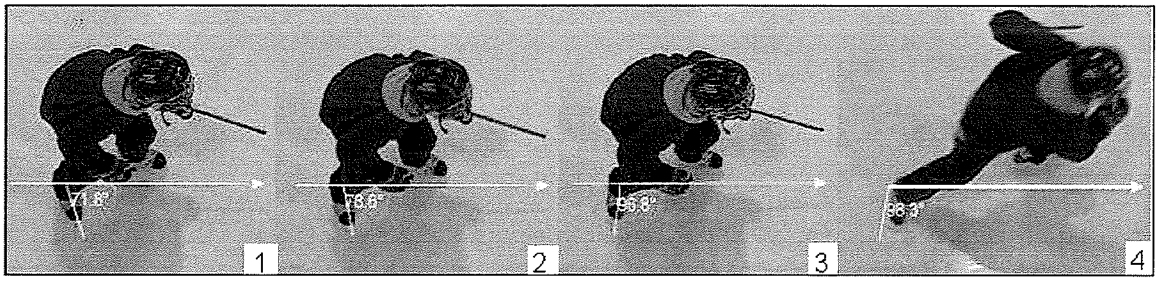


Figure 5.5: Note how the hockey player has changed the angle of the skate blade by rotating at the hip from the ready position (1) through until the end of the first push off (4) with the yellow arrow indicating the direction of travel.

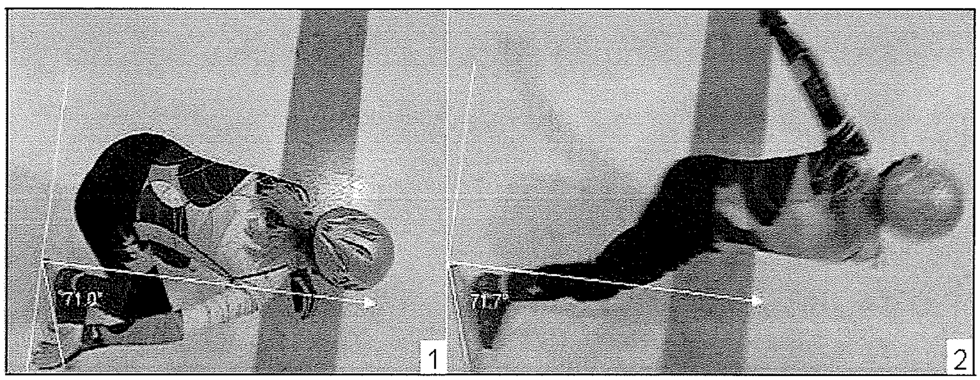


Figure 5.6: Note how the angle of the skate blade has stayed constant throughout the push off in the speed skating start with the yellow arrow indicating the direction of travel.

The starting technique utilized by the speed skating group allows them to be in a better position to apply force in the backwards direction against the ice. However, since minimal rotation occurs throughout the push off it is essential that the athlete begins with the skate blade at 90 degrees to the direction of travel during the ready position.

First Foot Touchdown

First foot touchdown during the hockey start and speed skating start can occur at one of two points in the skill. The skate can touchdown immediately following the end of the first push off or it can touchdown well before the end of the first push off. Among the subjects in this study, it was much more common that the athletes planted their new support skate prior to the end of the first push off, with only one of the hockey subjects demonstrating a slight airborne phase resulting in the skate being planted at the end of the first push off (see Figure 5.7). The remaining 22 subjects demonstrated some overlap between the end of the first push off and the plant of the skate at first foot touchdown, resulting in a greater time spent in double support.

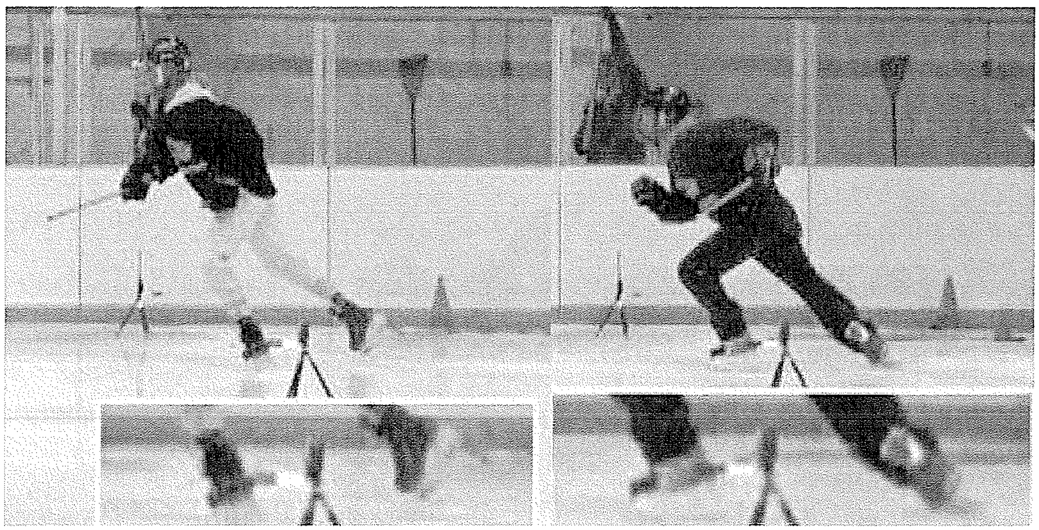


Figure 5.7: The athlete on the left exhibits first foot touchdown after the end of the first push off, while the athlete on the right exhibits first foot touchdown prior to the end of the first push off.

The speed skating group demonstrated the starting technique displayed by the athlete on the left in Figure 5.7, in which the athlete is shown to plant the left skate near the end of the push off phase resulting in a small overlap between the end of the first push off and first foot touchdown. The hockey group tended to plant the support skate earlier during the push off, resulting in both skates being in contact with the ice for a greater period of time or a greater overlap between the end of the first push off and first foot touchdown. Both groups need to emphasize minimizing the length of time spent in double support (or attempt to reach a slight airborne phase) during the first push off. It is important for hockey players to have a very small overlap between first foot touchdown and the end of the second push off.

Time in Single Support

When comparing the speed skating group to the hockey group in the time spent in single support at first foot touchdown, it was noted that the hockey players spent a significantly shorter time in single support. The hockey group was shown to spend 0.04 seconds less time in single support, and this was significantly different from the speed skating group. This finding is not surprising due to the increased length of time the speed skaters took to reach the six meter mark that probably occurred due to the increased difficulty associated with clearing the recovery leg. As a result of a slower recovery leg, the speed skating group was required to spend a greater time in single support. Another possible explanation for an increased time spent in single support by the speed skaters may be the result of a slightly more "clumsy" skate placement. It was noted by the researcher that during the filming sessions, the speed skaters' skates made a much louder sound at skate touchdown, resulting in a heavy skate at touchdown. The loud sound was probably a direct result of the increased mass and blade length of the speed skates compared to the hockey skates. This increased the difficulty of recovering the skate and resulted in an increased force of the skate at touchdown as the skate is accelerating downwards towards the ice. This is explained by the relationship $F = ma$, where a greater mass being accelerated by gravity at 9.81 m/s^2 will also result in an increased force at skate touchdown. Since the skate is being planted with a greater force at touchdown this will result in greater ground reaction forces being applied to the ice by the skate. The increased force at touchdown of the speed skate will come at the expense of a slower recovery skate. The speed skaters in the current study demonstrated a slower recovery skate than the hockey players due to the difficulty associated with clearing the recovery skate as well as an increased force required to lift the heavier skate at the end of the push off.

Trunk Angle

Another significant difference between the speed skating group and hockey group was the angle of the trunk relative to the horizontal at first foot touchdown. The difference in trunk angle was likely a result of the different ready positions utilized by the two groups. Qualitative analysis of the two groups showed the speed skating group was increasing the angle of trunk lean from the horizontal (the angle was becoming larger) while the hockey players were maintaining a similar angle of trunk lean from the horizontal throughout the skill (see Figure 5.8). At this point in the skill, the angle of trunk lean relative to the horizontal for the speed skating group was measured to be 35.8 degrees and for the hockey group it was measured to be 45.2 degrees. The 9.4 degree difference in the angle of trunk lean was statistically significant, however, the difference between the two groups was less than that measured in the ready position at 24.0 degrees. As a result, the skills became more similar as the start progressed. Similarly, the angles of the support skate leg (hip flexion, knee flexion, and ankle dorsiflexion) between the two groups were all not statistically significant, however, in the initial ready position all of these joint angles showed statistically significant differences.

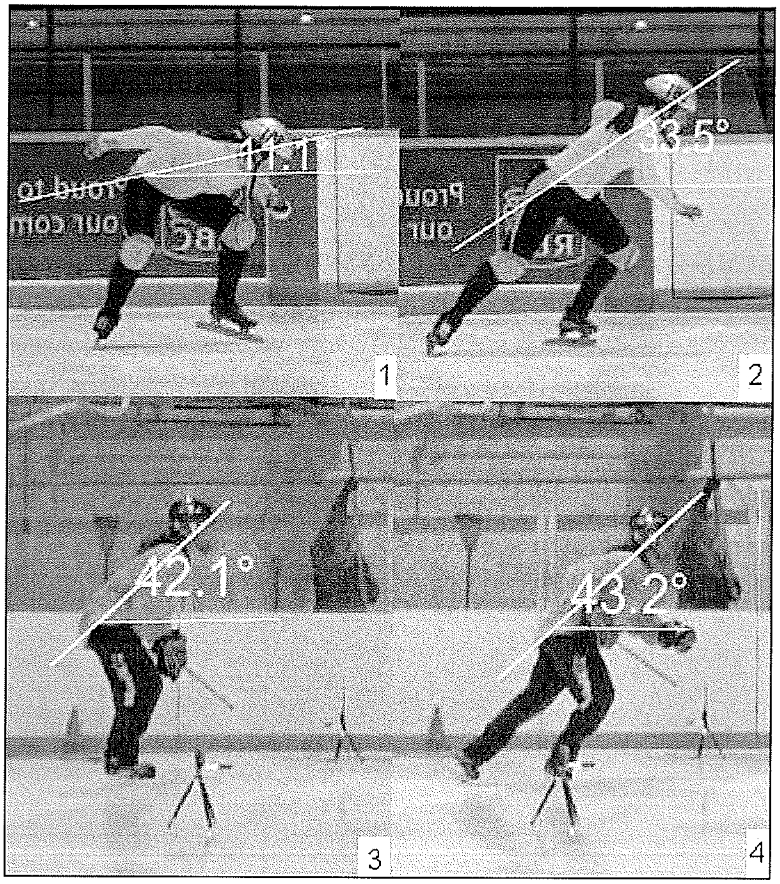


Figure 5.8: Note how the trunk angle has increased relative to the horizontal in the speed skating group (pictures 1 and 2), however, in the hockey group the angle of trunk lean remains almost constant (pictures 3 and 4).

In a study conducted by Greer and Dillman (1984) it was suggested that a greater trunk angle at touchdown of 50 degrees from the horizontal (smaller angle) would be beneficial to the skating start because it would "put the skater in a position to exert greater horizontal force and therefore benefit from a greater ground reaction force in the direction of desired movement" (p. 204). The speed skating group which demonstrated a more horizontal trunk position will be able to increase the force which can be applied in the horizontal direction, increasing the horizontal ground reaction forces being applied to the ice. The hockey players in the current study could benefit from a greater degree of trunk forward lean in order to maximize the force applied horizontally to the ice.

Arm Movements

Similar to the end of the first push off, the athletes' upper body movements were shown to be significantly different, with the speed skaters showing a larger range of motion in both shoulder abduction/adduction and shoulder flexion/extension. The speed skating group positioned their rear or left shoulder in a significantly greater degree of shoulder extension at 56.2 degrees and shoulder abduction at 99.3 degrees. When compared to the hockey group, the speed skaters exhibited 24.1 degrees more shoulder extension and 34.9 degrees more shoulder abduction. These differences may be attributed to the fact that the speed skating group spends a greater time in single support (or a greater time in force application with their push off leg) and therefore, there is an increased time over which the athlete can move the shoulder joints in conjunction with the push off.

A substantially larger range of motion shown in the speed skating group will be beneficial as it will allow the athlete to make better use of Newtons 3rd Law, the Law of Reaction. The action-reaction law states that "for every action there is an equal and opposite reaction" (Hall, 2007, p. 389). In regards to the application of forces, Hall (2007) has suggested that the law read as follows "When one body exerts a force on a second, the second body exerts a reaction force that is equal in magnitude and opposite in direction on the first body" (p. 389). When the athlete forcefully swings their contralateral arm backwards and away from their body in conjunction with the push off, as well as swinging the ipsilateral arm forwards and across the body they will be able to increase the force which can be applied against the ice surface. This occurs as the arm swing applies a force away from the ice surface, increasing the force which the lower leg can apply towards the ice surface. As a result, when the speed skater exhibits a greater range of motion for their shoulder movements, it is probable that they will be able to increase the force that they can apply against the ice and therefore increase the force that the ice will apply back on them. The hockey players in the current study could benefit from utilizing a larger range of motion at the shoulder joint.

The speed skaters' right shoulder flexion angle was also determined to be significantly greater than the hockey players, with 22.8 degrees more shoulder flexion at this point in the skill. As previously mentioned, this arm swing is beneficial in increasing the amount of force which can be applied in the posterior direction during the push off. One point of interest during the push off is whether or not the athlete should perform the arm action with a greater contribution coming from shoulder abduction/adduction or from shoulder flexion/extension. In regards to force application against the ice, it is probable that during the first push off, the arm action should be directed primarily in the sagittal plane with shoulder flexion and extension movements. This is beneficial as the athlete wants to apply as much of the force during the push off at a 90 degree angle to the direction of travel or directly backwards. However, the arm action during the start should be modified as the athlete begins to apply force at less than 90 degrees to the direction of travel. As the athlete begins to increase the lateral deviation of the push off, their arm action during the push off should also change in order to be performed in the same plane as the skate blade push off. As a result, with each successive push off, an increase in the amount of shoulder abduction/adduction should also be incorporated into the skating stride.

The position of the athletes' right shoulder at first foot touchdown was shown to have a strong negative correlation with the hockey players' velocity at six meters and was selected as a variable in the regression equation. On the other hand, the correlation between velocity at six meters and right shoulder flexion for the speed skaters was calculated to be - 0.150 and was not shown to be significant. As a result, the study has suggested that hockey players who demonstrated less shoulder flexion at first foot touchdown will have a greater velocity at six meters. This finding is somewhat surprising due to the fact that a greater angle of shoulder flexion would result in a greater range of motion for the shoulder joint, however, it is possible that those athletes demonstrating a greater degree of shoulder flexion had reached this position prior to the end of the push off and therefore were not gaining additional benefits from the arm action to increase the force being applied to the ice.

Knee Flexion

The angle of knee flexion at first foot touchdown was not shown to be significantly different between the two groups, as both groups were shown to have approximately 75 degrees of knee flexion at skate touchdown. The subjects in this study demonstrated more knee flexion than those skaters in the study conducted by de Koning (1989) which suggested that pre-extension knee angles for females averaged 50 degrees during the first few steps. As a result, the subjects in this study are shown to plant their skate with more knee flexion (probably resulting in the subjects going through a greater range of motion), therefore resulting in a lower stride frequency.

Foot Placement

Only one variable was shown to have a significant correlation with velocity at first foot touchdown for the speed skating group. The distance of foot placement in front of the hip at first foot touchdown was determined to have a significant negative correlation with the athletes' velocity at six meters. As a result, those speed skaters who planted their support skate a greater distance in front of their hip were also shown to have a slower velocity at six meters. In a study conducted by Marino (1983) on starting technique in hockey, he determined "the importance of placing the foot down underneath rather than in front of the body in order to facilitate the onset of the subsequent propulsive phase" (p. 237). This indicates the importance of not allowing the support skate to be planted in front of the body as this will result in delaying the onset of the upcoming force producing phase. As a result, the athletes must emphasize planting the skate directly underneath their hip (or underneath their center of gravity) in order to eliminate any potential deceleration phase prior to the initiation of the subsequent force producing phase. Hockey players were determined to be more efficient at planting their support skate directly underneath their hip allowing them to minimize any potential deceleration prior to the upcoming force production phase.

Multiple Regression

Upon completion of the stepwise multiple regression analysis, there was only one variable from this phase which was determined to be a significant contributor to the athletes' velocity at six meters. However, it is important to note that this variable was only selected for the hockey players. The hockey players' time spent in single support at first foot touchdown was shown to have a negative relationship to the velocity at six meters, whereby athletes who spent an increased length of time in single support would be predicted to have a slower velocity at six meters. This relationship alone provided a moderate correlation (-0.417) between the time in single support and the athletes' velocity at six meters. With the fact that the athletes' time spent in single support was selected as a significant predictor of velocity at six meters, it is probable that athletes who are able to demonstrate fast feet or a high turnover of steps would be able to skate with an increased velocity at six meters. Marino (1979) suggested that "during the double support period the skater would accelerate forward and during the single support or glide phase he or she would decelerate because the only forces acting horizontally are friction and air resistance, and both act in the direction opposite to the direction of movement" (p. 56). As a result, the hockey players in this study demonstrated this relationship, whereby less time in single support would allow for a greater time in the force producing phase and ultimately a greater linear velocity at six meters.

End of Second Push Off

The end of the second push off helped identify several differences between the speed skating group and the hockey group. It was important to note that several of the variables which were shown to be significantly different at the end of the first push off continued to be significantly different at the end of the second push off. The variables which were significant at the end of both the first and second push offs were the angle of rear hip flexion, angle of the skate blade relative to the direction of travel, and the angle of shoulder flexion (left shoulder flexion at the end of the second push off as opposed to right shoulder flexion at the end of first push off).

Angle of Rear Hip Flexion

The relationship between the angle of rear hip flexion remaining at the end of the second push off, was similar to that at the end of the first push off, as the hockey players were shown to have a more complete hip extension at 34.5 degrees. This was compared to the speed skating group with a mean angle of 46.8 degrees of hip flexion remaining at the end of the push off. This resulted in both groups performing a similar range of motion for hip extension during this force producing action due to the speed skaters initiating the push off with 12.3 degrees more hip flexion at foot touchdown. As a result, the speed skaters are shown to begin with a greater degree of hip flexion but not achieve complete hip extension. On the other hand, the hockey group began with a lower degree of hip flexion, however, they were shown to achieve more complete hip extension. Therefore, both speed skaters and hockey players were shown to go through a similar range of motion during the force producing action.

Angle of Skate Blade

The relationship between the angle of the skate blade relative to the direction of travel also continued to be similar between groups from the end of the first push off and the end of the second push off. The hockey group was measured to push off at a mean angle of 64.02 degrees to the direction of travel, as compared to the speed skating group at 45.98 degrees to the direction of travel. Referring back to the study conducted by Marcotte (1975) (see Figure 5.5) it was suggested that the skate should be angled to approximately 51 degrees to the direction of travel. Therefore, the hockey group in this study may be demonstrating too small an angle for their skate blade relative to their direction of travel, directing the push off too much in the posterior direction. This angle of the skate blade may negatively affect the hockey players depending on how much of a glide is present at the end of the push off. For example, if there is no glide present at the end of the push off then it would be advantageous to be pushing primarily in the backwards direction. However, if a small gliding phase is present, pushing in a backwards direction will limit the range of motion for hip and knee extension due to the point of contact with the ice no longer being fixed as suggested by de Koning (1995). The angle of the skate blade relative to the direction of travel for the speed skating group shows a greater resemblance to the angle suggested by Marcotte (1975) of 51 degrees to the direction of travel. Therefore, this angle of push off will be more efficient allowing the athlete to complete the push off in the case that a small amount of gliding is occurring during the forceful hip and knee extension.

Shoulder Flexion

The angle of front shoulder flexion was found to be statistically different between the two groups with a greater degree of shoulder flexion present in the speed skating group. Similar to the end of the first push off, this will allow the speed skaters to go through an increased range of motion at the shoulder joint allowing them to maximize the contribution of the arm swing to increasing the ground reaction forces which can be applied during the push off. Hockey players in the current study could benefit from an increased range of motion at the shoulder joint in order to aid in the production of ground reaction forces.

The end of the second push off also produced five variables which were significantly different between the speed skating group and hockey group, which were not significant at the end of the first push off. These variables were the angle of rear ankle plantarflexion, as well as the angles of left shoulder adduction, right shoulder abduction, right shoulder extension, and rear hip abduction.

Ankle Plantarflexion

The angle of rear ankle plantarflexion is an important component of the skating stride as reinforced by the invention of the clap skate which allows the athlete's blade to stay in contact with the ice for an increased length of time at the end of the push off in long track speed skating. However, in both short track speed skating and hockey, the athletes do not wear clap skates and therefore, as the ankle goes into a greater degree of plantarflexion, it is probable the athlete will begin digging the toe of the skate into the ice at the end of the push off (see Figure 5.9). It is important for the athlete to maximize the length of time that they are able to apply force to the ice with the entire blade in order to ensure a full transfer of force between the two surfaces which are in contact with each other (in this case the skate blade and the ice). By going into ankle plantarflexion, there is a tendency for the toe of the athlete's skate to dig into the ice and minimize the transfer of force between these two surfaces. Both groups were shown to display a large amount

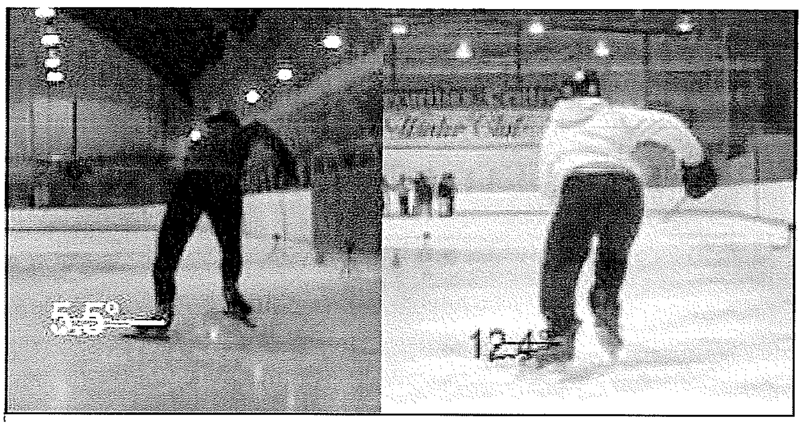


Figure 5.9: Note the angle of rear ankle plantarflexion between the speed skater on the left and the hockey player on the right. By increasing the ankle plantarflexion at the end of the push off, the athlete may decrease the amount of blade in contact with the ice during force production.

of variability in their ankle position at the end of the push off, however, it is important to note that the hockey players had a greater tendency to plantarflex their ankle and dig the toe of their skate blade into the ice at the end of the push off. This motion could be associated with the slight difference in skate blades (due to the rounded hockey blades) which allows for slightly more plantarflexion during the push off.

Arm Movements

Another significant difference between the two groups at the end of the second push off was the direction of the arm movements during the start. The arm motion during the start plays a significant role in speed skating and hockey as it can contribute to the force which the athlete can apply against the ice during the push off. At the end of the second push off, it was noted that the speed skaters were using an arm motion which occurred in both the sagittal plane (flexion and extension) and frontal plane (abduction and adduction). This arm action is beneficial as it occurs in the same direction as the push off with the skating leg. The hockey players emphasize a more sagittal arm action with the majority of the action occurring through flexion and extension at the shoulder joint. The speed skating group produced a mean angle of 19.1 degrees of shoulder adduction and 94.7 degrees of shoulder abduction as compared to the hockey group which had a mean angle of 11.4 degrees of shoulder adduction and 53.5 degrees of shoulder abduction. It was also noted that four of the 13 hockey players maintained a position of shoulder abduction with the lead arm (when the arm should be in a position of adduction), compared to only one of the speed skaters assuming a position of shoulder abduction. Therefore, the speed skating group was significantly better at directing their arm action in a more direct line with their push off skate (see Figure 5.10). It is beneficial for the athlete to direct the arm action in the opposite direction of the push off (as seen by the speed skater) in order to maximize the contribution of the arm actions to the push off. By applying the force in the same plane of movement, the speed skater is able to maximize he force applied in the posterior direction, whereas the hockey player will be losing the benefits which could be gained from the arm action due to applying the force at a slight angle to the direction of the push off. The hockey players must emphasize directing their arm swing in the opposite direction of the push off.

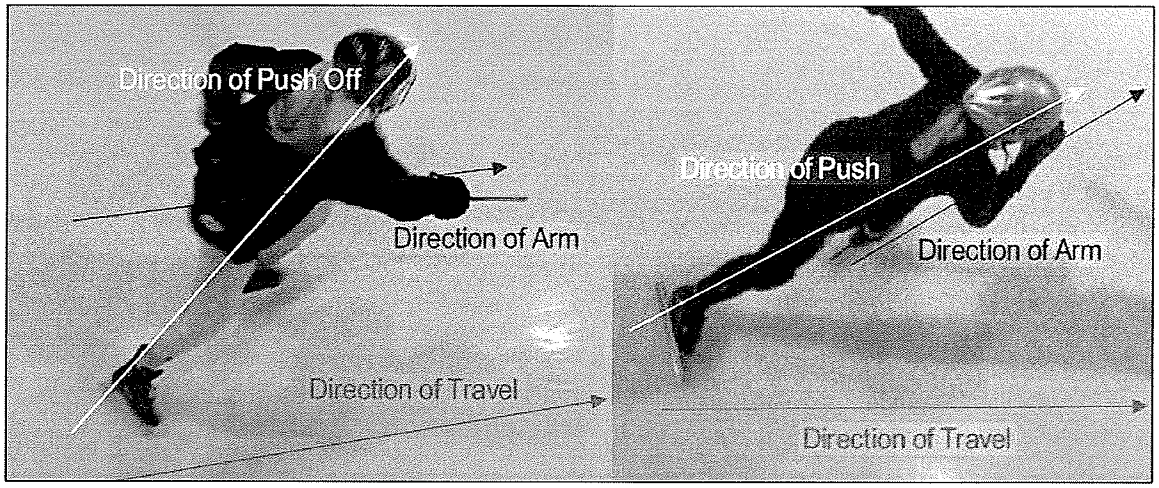


Figure 5.10: Note how the speed skater on the right has moved her right arm in the direction of her push off as compared to the hockey player who is moving her right arm primarily in the sagittal plane (or in the direction of travel).

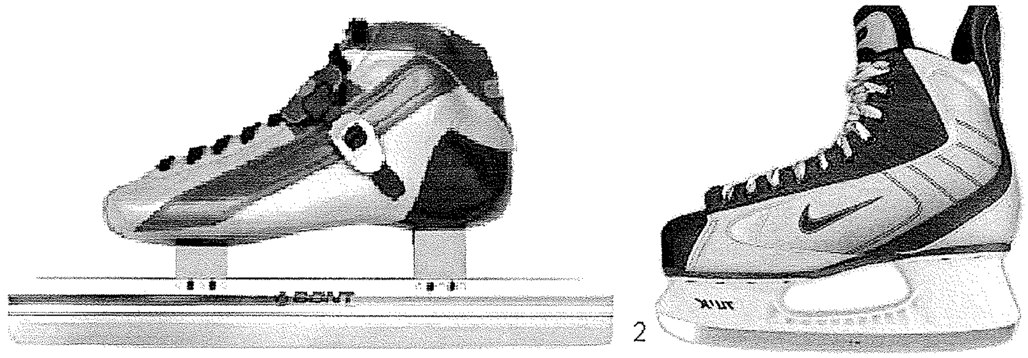
Correlation and Regression Analysis

The end of the second push off produced three significant correlations for the speed skaters, however, none of the variables measured at the end of the second push off were significantly correlated to velocity at six meters in the hockey group. The angle of rear hip flexion for the speed skaters was negatively correlated to the velocity at six meters, indicating that athletes who had more hip flexion remaining would have a slower velocity at six meters. This relationship indicates that athletes who are able to go into more complete hip extension will be able to go through a greater range of motion and therefore increase their velocity at six meters.

The angle of right shoulder abduction in the speed skaters was determined to be positively correlated to the athletes' velocity at six meters. As a result, those subjects who were able to position their shoulder in a greater degree of abduction are in a better position to initiate the arm swing for the upcoming push off. The importance of the arm swing occurring in both the sagittal and frontal planes has been previously discussed, however, it is important for the athlete to position the arm in an abducted and extended position in order to be able to drive the arm forwards and across the body in conjunction with the push off from the ipsilateral leg.

The final variable which was significantly correlated to velocity at six meters was the time spent in double support. This relationship was negative indicating that a larger time in double support would result in a slower velocity at six meters. Time in double support was also the first variable selected by the multiple stepwise regression equation indicating its importance in predicting the speed skaters' velocity at six meters. The current literature on the speed skating start suggests that the athlete should enter a slight airborne phase (Teasdale, 1996) during the first push off, but no literature was found suggesting the relationship between single and double support times for the subsequent push offs.

Research conducted by Marino (1989) on starting technique in hockey has suggested that spending greater time in double support will result in a faster acceleration. This relationship does not hold true during the sprint start in short track speed skating, whereby, a running action in which the athlete spends very little time in double support has been shown to be beneficial for increasing velocity in the current study. It is probable that the rounded blades (with an increased rocker) used by hockey players allow them to plant their skates with a toe to heel motion as seen in the current study, however, due to the long, flat blade (with a decreased rocker) on the speed skate, the skate must be planted down and underneath the athlete which may force them to leap from skate to skate and minimize the double support time (see Figure 5.11)



1 2

Figure 5.11: 1: Speed skate with a long, flat blade which may hinder the ability to plant the skate on the ice. 2: Hockey skate with a short, rounder blade which may be beneficial in allowing for a smooth skate plant at touchdown enabling for a greater time spent in double support.

The speed skaters need to concentrate on spending less time in double support (represented by the sprinting action as explained by de Koning's (1989) theory of running to gliding) in order to emphasize planting the support leg underneath the athletes' center of gravity and minimizing the time spent with both skates on the ice.

Second Foot Touchdown

Second foot touchdown was shown to be very similar to first foot touchdown when comparing the two groups. All five variables which were shown to be significantly different at second foot touchdown were also significantly different at first foot touchdown. Those variables were angle of trunk forward lean, time in single support, rear shoulder abduction angle, rear shoulder extension angle, and front shoulder flexion angle. All of the variables which were shown to be significantly different at the first foot touchdown were shown to follow the same relationship at second foot touchdown. As a result, the speed skaters were shown to have significantly higher values for the following variables: time in single support (due to spending less time in double support), angle of trunk forward lean, angle of shoulder abduction in their rear arm, angle of shoulder extension in their rear arm, as well as the angle of shoulder flexion in their lead arm.

Skate Touchdown

The position of the skate at touchdown has been shown to be important in the start performed in hockey by Marino (1983) when he suggested "the importance of placing the foot down underneath rather than in front of the body in order to facilitate the onset of the subsequent propulsive phase" (p. 237). The subjects in this study were shown to plant their skate in front of their hip at touchdown by 0.11 meters in the hockey group and 0.15 meters in the speed skating group. This may result in both groups experiencing a slight deceleration phase as their upper body is required to catch up to the skate before they can initiate the upcoming push off. Similarly, the two groups also planted their skate close to their hip in the sagittal plane. The speed skating group was shown to plant their skate slightly lateral to their support hip, while the hockey group was found to plant their support skate slightly medial to their support hip. As a result, the hockey players in this study demonstrated a better skate position at touchdown as they were able to plant their skate more directly underneath their hip and allow for a quicker initiation of the subsequent push off. The speed skaters could benefit from a more efficient skate plant with the skate being positioned directly underneath the hip at skate touchdown.

Knee Flexion

The angle of knee flexion at touchdown was shown to have the largest p-value at 0.97, indicating that the two groups were considered to have almost identical angles of knee flexion at touchdown. A p-value of 0.97 suggests that there is very small chance that the two groups are significantly different in their angle of knee flexion at skate touchdown. The speed skaters produced a mean angle of 72.8 degrees, while the hockey players produced a mean angle of 72.95 degrees. The angle of knee flexion at touchdown in the speed skating group was positively correlated to their velocity at six meters, however, there was no correlation present between these variables in the hockey group. Research conducted on skating in hockey has suggested that "fast skaters get a smaller angle of knee flexion than slow skaters" (or have an increased degree of knee flexion) and that "the angle at the knee prior to pushing should be 90 to 110 [degrees]" (Holt, 1980) or between 70 to 90 degrees when measured using the anatomical reference system. The study conducted by Holt (1980) only focused on skating at maximum velocity, however, the current study indicates that a high amount of knee flexion is also beneficial during the start.

Correlation and Regression

It was interesting to note that at second foot touchdown no variables from either the hockey group or the speed skating group demonstrated any significant correlation with the athletes' velocity at six meters. This also resulted in no variables from second foot touchdown being included in the regression equation for both speed skaters and hockey players.

End of Third Push Off

The end of the third push off was shown to be the point in the skating start where the two groups began to perform the skating stride with greater similarities in technique. The two groups were shown to have several differences during the ready position and the first and second force producing steps, however, at the end of the third push off only four variables were shown to be significantly different between the two groups. The variables which were significantly different between the speed skating group and hockey group at the end of the third push off were the angle of rear hip abduction and extension, the angle of the skate blade relative to the direction of travel, and the angle of left (rear) shoulder abduction.

Angle of Skate Blade

The angle of the athletes' skate blade relative to their direction of travel was calculated to be significantly different between the two groups at the end of all three push offs. The speed skating group was found to push off with a significantly lower angle relative to their direction of travel, or with a more sideways directed push off, compared to the hockey players during all three push offs. The study by Marcotte (1975) has suggested that the skate should be angled 47 degrees to the direction of travel at the end of the third push off (see Figure 2.5). Therefore, in this study the speed skating group continues to direct their push off too far to the side with a mean angle of 41.3 degrees to the direction of travel, as opposed to the hockey group which continues to direct their push off too much in the posterior direction with a mean angle of 53.1 degrees to the direction of travel. A push off which is directed too much in the posterior direction may hinder the athletes ability to fully extend at the knee and the hip due to the skate no longer being fixed to the ice surface. On the other hand, a push off which is directed too much to the side may hinder the athlete's ability to skate directly forwards during the start.

Hip Movements

Hip flexion at the end of the third push off continued to display the same relationship as the previous two push offs in which the hockey group produced a more extended position. The speed skaters exhibited a mean angle of 43.4 degrees of hip flexion, while the hockey players produced a mean angle of 34.4 degrees of hip flexion. Once again, the mean difference in hip flexion does not indicate the range of motion over which the two groups were able to apply force against the ice. At second foot touchdown, the speed skaters displayed 10 degrees more hip flexion which resulted in both groups going through approximately 60 degrees of hip extension during the force producing action.

The two groups also displayed significantly different angles of hip abduction at the end of the third push off. The athletes' hip abduction angle at the end of the push off will have a strong association with direction of the athlete's push off. A greater angle of hip abduction will result in a more laterally directed push off. In this study, the hockey players were measured to have a significantly greater angle of hip abduction at the end of the push off compared to the speed skating group. This is a very interesting finding in the study. A more probable finding at the end of the third push off would have been one indicating a greater angle of hip abduction in the speed skating group due to the hockey players arm motion occurring primarily in the sagittal plane. One of the primary weaknesses of the subjects in the study is an inability to coordinate the direction of their push off with the direction of their arm motion (see Figure 5.10).

Shoulder Movements

The speed skating group also continued to exhibit a much greater range of motion for shoulder abduction with a mean angle of shoulder abduction of 108.7 degrees compared to 58.6 degrees measured in the hockey group. Similar to the previous discussion on the athletes' shoulder abduction, a greater angle of shoulder abduction is associated with a frontal plane arm action which needs to be incorporated into the start when the athlete begins to direct their push off to the side with a greater degree of hip abduction.

Another interesting finding at the end of the third push off is the similarities between the angles of shoulder flexion and shoulder extension between the two groups. At the end of the first two push offs, the speed skating group demonstrated a significantly greater degree of shoulder flexion in their lead arm and shoulder extension in their rear arm, however, with an increase in arm motion in the frontal plane, there was a decrease in arm motion in the sagittal plane. Therefore, the hockey players' arm motion can be described as occurring primarily in the sagittal plane as they were measured to have 54.4 degrees of shoulder flexion compared to 59.4 degrees seen in the speed skating group with this difference no longer being significant. The hockey group has produced more shoulder extension in their rear arm which will allow them to increase their range of motion for shoulder flexion/extension. It is quite evident at this point in the skill that the speed skating group is focusing their arm action in the frontal plane (shoulder abduction/adduction) and the hockey group is focusing their arm action in the sagittal plane (flexion/extension). This is a primary difference between the start performed by speed skaters and the start performed by hockey players.

Hockey Correlation and Regression

When a correlation analysis and stepwise multiple regression analysis was performed, several variables at the end of the third push off were shown to be significantly correlated to the athletes' velocity at six meters and several variables were selected as predictors of velocity at six meters.

The correlation analysis performed on the hockey group selected one variable which was significantly correlated to the athlete's velocity at six meters. The athletes' time in double support was shown to have a moderately strong negative correlation (-0.564) to the athlete's velocity at six meters, indicating that those athletes that spent less time in double support were shown to have a greater velocity at 6 meters. The findings from this study are contradictory to the results found by Marino (1983) who suggested that a long single support time is related to a relatively slow skating time or that a longer time in double support is related to a greater skating time. Marino also suggested that skilled athletes spend "only 14.7 % of each stride" (Marino, 1979, p. 59) in double support. The hockey players in this study were determined to spend 17.8% of each stride in double support, suggesting that the athletes in the current study are spending greater time in double support than suggested by Marino (1979). It is possible that the hockey players in this study that had a high velocity at six meters were utilizing the standard technique of the speed skating start where a brief airborne phase may be identified as well as a running start approach as suggested by de Koning (1989).

Only one variable at the end of the third push off was selected by the multiple regression analysis as being a significant predictor of the hockey players' velocity at six meters. The angle of the athletes' left shoulder abduction was determined to have a small, positive coefficient at +0.002, indicating that every one degree increase in shoulder abduction will result in an increase in velocity of 0.002 m/s at six meters. This is somewhat suggestive of the importance of directing the arm motion in the same plane as the push off. Therefore, those hockey players that had a more laterally directed push off (accompanied with an increase in shoulder abduction) may be able to skate with a faster velocity at six meters.

Speed Skating Correlation and Regression

At the end of the third push off, rear knee flexion, rear ankle flexion, time for extension velocity, and time in double support all demonstrated significant correlations to the athlete's velocity at six meters for the speed skating group. The athletes' rear knee flexion had a correlation of +0.606 with velocity at six meters, indicating that athletes who were able to have a greater angle of knee flexion remaining were able to skate with a greater velocity at six meters. This indicates that the speed skaters were shortening their knee extension at the end of the push off in order to begin the recovery phase sooner (allowing for the recovery leg to have a moderate degree of knee flexion remaining) and allow the skate to be swung through with less delay. The speed skating group may also benefit from not going into full extension as the muscles have been shown to produce more force during the mid range where optimal cross bridge overlap may occur. The cross bridge theory suggests that when muscle fibers are at moderate length (or maximum overlap of thin and thick filaments is occurring) the muscle will be able to apply maximum force (Enoka, 2002). Enoka (2002) further suggests that "a sarcomere length of about 2.5 to 2.8 micrometers" will result in "maximum overlap between the cross bridges and the binding sites on the thin filaments" (p.258). As a result, when an individual sarcomere shortens there will be less overlap between the myofilaments and less available binding sites on the thin filaments. Similarly, as the individual sarcomere lengthens there is minimal overlap of the thin and thick filaments resulting in minimal cross bridges and binding sites. Therefore, a muscle which is maximally shortened (muscle fibers are completely overlapped) or maximally extended (muscle fibers are not overlapped at all) can produce very little force. By producing force through the mid flexion range, the speed skaters in this study will be able to make use of the optimal relationship of muscle fiber overlap.

Rear ankle plantarflexion at the end of the third push off had a strong negative correlation with the athletes' velocity at six meters with an r-value of -0.613. This relationship indicates that athletes who are able to maintain a more neutral ankle position at the end of the push off are shown to have a greater velocity at six meters. Athletes that are able to maintain a neutral ankle position are able to maintain full blade contact with the ice throughout the force producing phase (see Figure 5.10). On the other hand, athletes which exhibited a plantarflexed position have a tendency to dig the toe of their blade into the ice, resulting in a less efficient transfer of force between the two surfaces.

A strong negative relationship also existed between the athletes' time for extension and their velocity at six meters. As a result, those athletes that are able to extend their hip and knee over shorter time interval were shown to have a higher velocity. This relationship holds true for both the speed skaters and the hockey players, however, it was only statistically significant for the speed skating group. Therefore, it is important for speed skaters to emphasize a quick time for extension in order to make use of a rapid turnover of the skates. Athletes that demonstrate a very slow extension time will be negatively affected as it will result in a longer time in single support, a lower step frequency, as well as lower hip and knee extension velocities as a high degree of collinearity existed between these variables at the end of the third push off.

Similar to the hockey group, the speed skating group also displayed a strong negative relationship (-0.624) between the athletes' time in double support and their velocity at six meters. As a result, the two groups show a similar relationship whereby less time in double support will result in a greater velocity at six meters. The speed skaters are displaying a similar result to that noted by Teasdale (1996) in that a brief airborne phase may initially occur and then during the first 3-4 steps (or while the athlete's skate has not yet began to glide) a very short time may be spent in double support. This decreased time in double support will be beneficial as it will allow the athlete to utilize the running technique and allow them to emphasize planting their skate directly underneath their center of gravity and immediately initiate the subsequent push off phase.

Upon completion of the multiple regression analysis for the hockey players, two variables were selected to enter the regression equation. The angle of rear hip flexion at the end of the push off and the angle of right shoulder adduction were both determined to be significant predictors of velocity at six meters. The angle of rear hip flexion had a small coefficient of 0.066. Therefore, for every 1 degree increase in rear hip flexion at the end of the push off, there is a 0.066 m/s increase in velocity at six meters. It is possible that this variable was selected due to the sliding filament theory whereby more force can be produced by a muscle during the mid range of flexion. A second reason why less hip flexion may be beneficial for increasing velocity is that it may have a positive effect on the athlete's recovery. By not going into complete extension, the athlete may be able to gain the additional benefits associated with having a shorter distance to recover the skate and therefore position the recovery skate on the ice with less of a delay. This fast recovery is important during the skating start in order to shorten the overlap created when both skates are on the ice in double support.

The angle of right shoulder adduction was also shown to have a small negative effect on the athletes' velocity at six meters, with a coefficient of -0.01. The shoulder movements in the start have not been studied in great detail in the past, however, from the current study, several shoulder joint angles were shown to have a significant relationship with velocity at six meters as well as be selected as important predictors of the athletes' velocity. Therefore, the current researcher believes that greater emphasis must be placed on directing shoulder movements in the same plane as the push off (see Figure 5.11). This arm motion will allow the athletes' to increase the ground reaction forces which they can apply against the ice and therefore increase the force produced during the push off.

Third Foot Touchdown

Third foot touchdown was the final position measured during the skating start and a similar trend occurred as seen at the end of the third push off, with the starting technique becoming more similar between the two groups at this point in the skill. Four variables were shown to be significantly different at this point in the skill, including the angle of knee flexion at touchdown, time in single support, the distance of foot placement in front of the support hip, and the angle of left shoulder abduction. The angle of left shoulder abduction will not be discussed here because of the similarities of this position with the end of the third push off and due to the proximity of these two events. A greater angle of shoulder abduction as demonstrated by the speed skating group will benefit the athlete as it places the shoulder in an optimal position to initiate the arm swing.

Skate Plant relative to Hip

The position of skate plant relative to the hip is important as it determines where the athlete will initiate the push off from relative to their support hip. The hockey group is shown to plant their support leg with a significantly smaller distance between their support hip and their support ankle (indicating the skate is planted more underneath their hip at this point in the skill) (see Figure 5.12). This has been shown by Marino (1983) to be beneficial as he determined "the importance of placing the foot down underneath rather than in front of the body in order to facilitate the onset of the subsequent propulsive phase" (p. 237). The speed skating group in the current study may enter a slight deceleration phase as their body is forced to catch up to their skate before they can initiate the subsequent push off phase. The speed skating group was also shown to plant their skate closer to their midline with the foot being positioned medially to the hip (due to a smaller angle of hip abduction). This is important as it will allow the athlete to maximize the range of motion for force production. It has been suggested that the skate should be planted directly underneath the athlete's midline before initiating the thrust (Holt, 1980) in order to increase the range of motion for hip abduction during the push off. The hockey players in the current study were significantly more skilled at planting their support skate during touchdown compared to the speed skaters.

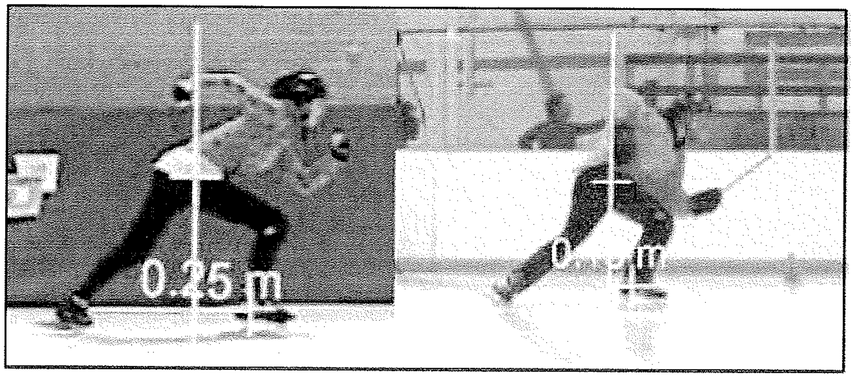


Figure 5.12: Note how the speed skater has planted their support skate significantly farther ahead of her support hip (0.25 m) which results in her upper body having to move over top of her support skate in order to initiate the push off as compared to the 0.13 m measured for the hockey player.

Knee Flexion

The hockey group in the current study was found to increase their knee flexion by almost 7 degrees from the previous foot touchdown, while the speed skating group planted their skate at a similar angle of 73 degrees. Therefore, the hockey players are showing a superior skill level at this point in the skill as Holt (1980) suggests that skilled athletes are able to skate with close to 90 degrees of flexion in their support knee prior to the push off. If the hockey players have adequate leg strength (primarily in the quadriceps muscles) they will be able to increase their range of motion for force production during the upcoming push off. The current study also noted that there was a strong relationship between the angle of knee flexion and the position of the skate relative to the hip, indicating that athletes who plant their skate well in front of their hip generally have less knee flexion as the knee is extended in order to maintain a horizontal blade position at skate touchdown. Note how the speed skater demonstrates less ankle dorsiflexion in Figure 5.13, which results in her plant skate being placed further in front of her hip at touchdown. This may be one benefit for the hockey players as they are able to increase their ankle dorsiflexion and knee flexion, allowing the skate to slide under their center of gravity as opposed to the speed skaters who must maintain a horizontal blade position as skate touchdown is initiated.

Single Support

Lastly, the two groups were also significantly different in regards to their time in single support. The hockey players in the study were shown to spend only 0.24 seconds in single support, while the speed skaters spent significantly more time in single support at 0.29 seconds. Once again, this relationship was due to the hockey players' ability to have a quick recovery skate and have it planted on the ice significantly faster than the speed skaters. As a result, the hockey players were shown to spend a greater percentage of time in double support compared to the speed skating group. Marino (1989) has suggested that a greater time in double support during the start will allow for a faster acceleration, indicating that the subjects in this study are skilled at performing the front start in hockey.

Correlation and Regression Analysis

The correlation analysis which was performed on the variables at third foot touchdown determined only one variable to be significantly correlated to the athletes' velocity at six meters. The position of the foot placement in front of the athletes' hip at touchdown was shown to be significantly correlated to the hockey players' velocity at six meters (see Figure 5.13). This relationship had a negative correlation of -0.711, suggesting that those athletes who planted their support skate in front of their hip would have a slower velocity at six meters. Due to this high correlation, the position of the skate at touchdown was also chosen by the stepwise multiple regression equation to be a significant predictor of the athlete's velocity at six meters. The coefficient for the regression equation was -2.925 suggesting that planting the foot in front of the hip would result in a slower velocity at six meters and planting the foot behind the hip would result in a greater velocity at six meters.

Velocity at Six Meters

The dependent variable, velocity at six meters, was not significantly different between the two groups, however, the hockey group was shown to reach the six meter distance over a shorter period of time. This is an interesting result since the speed skaters were shown to have a greater instantaneous velocity at six meters but took a longer time to reach this distance. As a result, the average acceleration of the speed skating group was 3.82 m/sec^2 as compared to an average acceleration of 4.00 m/sec^2 seen in the hockey group. The reason why the speed skaters were able to produce a greater velocity at six meters while taking a longer time to reach this position was due to the difficulty associated with having fast feet and a quick recovery leg. It is more challenging for the speed skaters to have a quick recovery skate due to the increased length and weight of the skate. As a result, the speed skaters will have to overcome a greater moment of inertia in order to clear the recovery skate in preparation for skate touchdown. A faster recovery leg will be beneficial for the speed skaters as it would allow them to have their recovery skate in a better position to initiate the next push off, allowing for more periods of force production. However, once the speed skaters began to accelerate, a combination of better technique and a longer skate blade allowed them to reach a greater velocity at six meters.

The speed skaters in this study were determined to be skilled as they were able to reach a mean velocity of 5.89 m/sec (±0.7 m/sec) at six meters (while performing an average of six steps) which is slightly less than the results found in a study conducted by de Koning (1995) where the skaters reached "a mean velocity of 6.7 m/s (±0.3 m/s), after about 6 push offs" (p. 1707). Six push offs resulted in an approximate distance of six meters for the speed skating subjects in the current study, therefore allowing for a reasonable comparison between the two studies.

Another significant difference between the two groups was their step rate during the first three steps of the start. The hockey players were found to have a significantly higher step rate at 3.27 steps/second compared to 2.94 steps/second measured in the speed skating group. This difference was not surprising to the researcher due to the results of the pilot study which also showed the hockey players utilized a higher step frequency. One of the primary reasons for the difference in step rate during the start for the two groups could be due to the effect of the rounded blade commonly associated with the hockey skate. A rounded blade (or one with an increased rocker) allows hockey players to slide the skate underneath their hip during the recovery. Speed skaters on the other hand are required to have a slightly higher recovery, in order to clear their recovery skate, which causes them to have a slightly lower step rate during the start. This difference in recovery technique is most likely influenced by the type of skate blade used in speed skating and hockey, however, more research looking specifically at the recovery skate may be beneficial.

The timing gate variables measured in the study resulted in two significant differences, with time from 0-6 meters and time from 0-12 meters being significantly less for the hockey players. The rationale for why the speed skaters were shown to have a greater velocity at 6 meters, but took a significantly longer time to reach this distance has already been discussed. However, it is important to note that this difference occurred because the velocity which was calculated at six meters was an instantaneous velocity which focused on the athletes' velocity over the instant their hip crossed the six meter barrier. Another reason for why the hockey players were able to reach the six meter mark in a significantly shorter time is likely due to the positive effect of an increased stride frequency. This increased stride frequency will allow the hockey players to have more periods of force production and therefore allow them to reach the six meter mark during a shorter time interval. As a result, it is important for speed skaters to emphasize this high stride frequency during the start in order to increase their periods of force production.

Regression Equations to Predict Velocity

In order to verify the multiple regression equations for both the speed skating and hockey groups, the researcher entered the values for six of the subjects into the regression equations. This allowed the researcher to determine the ability of the equation to predict the velocity as it compared to the calculated velocity for that subject in the study. Table 5-1 has identified the predicted velocities for several of the subjects in the hockey group.

Table 5-1: Predicted velocities for hockey players using the regression equation.

Variables	Coefficients	Subject 1	Subject 5	Subject 9
Front Hip Flexion (Ready Position)	+ 0.008	82.1	98.5	78.0
L. Shoulder Abduction (End of 1st Push Off)	- 0.006	81.3	80.4	47.5
R. Shoulder Adduction (End of 1st Push Off)	+ 0.003	-41.3	-14.6	0
Time in Single Support (1st Foot Touchdown)	- 7.096	0.266	0.25	0.25
R. Shoulder Flexion (1st Foot TD)	- 0.018	37.8	18.9	51.4
L. Shoulder Abduction (End of 3rd Push Off)	+ 0.002	69.6	84.3	0
Distance of Foot Placement in front of Hip (3rd Foot TD)	- 2.925	0.14	0.1	0.19
Intercept	7.846	7.846	7.846	7.846
Predicted Velocity (m/sec)	________	5.05	5.87	4.93
Actual Velocity (m/sec)	________	5.04	5.84	4.92

Table 5-2 has identified the predicted velocities for several of the subjects in the speed skating group. Both the regression equations for the speed skating group and the hockey group were shown to predict a velocity similar to that calculated in the study.

Table 5-2: Predicted velocities for speed skaters using the regression equation

Variables	Coefficients	Subject 1	Subject 5	Subject 9
R. Shoulder Adduction (1st Foot TD)	+ 0.013	-26.2	-22.7	-37.3
Time in Double Support (End of 2nd Push Off)	- 60.623	0.016	0.033	0.016
Rear Hip Flexion (End of 3rd Push Off)	+ 0.066	49.0	44.2	43.5
Right Shoulder Adduction (End of 3rd Push Off)	- 0.010	28.9	25.8	-4.7
Intercept	5.199	5.199	5.199	5.199
Predicted Velocity (m/sec)	________	6.83	5.68	6.66
Actual Velocity (m/sec)	________	6.78	5.56	6.73

Checklists

The third purpose of the study was to develop checklists for hockey (see Appendix H) and speed skating (see Appendix I) respectively. The roles of the checklists are to provide coaches and athletes with a list of key features which need to be emphasized when teaching and analyzing starting technique in speed skating and hockey respectively.

Hockey Starts Technique Checklist

It is important for players and coaches in hockey to encourage their athletes to utilize a starting technique which is more commonly encouraged by coaches in speed skating whereby the athletes are shown to spend minimal time in double support. As a result, hockey players should be encouraged to perform a running action during the initial three to four steps in order to allow for quick feet and a high stride frequency.

Another key feature of starting technique in hockey is to encourage athletes to initiate the start with a flexed ready position in order to allow the athlete to be in a more effective position to begin the first push off. Furthermore, during the ready position, it is important for the hockey players to emphasize applying force in the backwards direction during the first push off. When teaching or analyzing hockey players, it is important that the athlete's first push off is applied directly backwards at a 90 degree angle to the direction of travel with each successive push off being applied more in the sideways direction.

The end of the first push off in hockey plays a significant role in the success of the start. Several key features must be emphasized during the force producing action of the start. It is important for hockey players to emphasize a high angular velocity for hip and knee extension at the end of the push off in order to increase the force which the athlete can apply to the ice. Furthermore, two key features need to be emphasized during the start in hockey. Hockey players need to plant their support skate directly under their hip in order to position it directly underneath their center of gravity. This is important as it allows the athlete to initiate the upcoming push off immediately following skate touchdown. The second feature which needs to be emphasized is having the athlete extend the push off hip and knee to 20-30 degrees short of full extension. This movement allows the athlete to have an increased stride frequency as the athlete is able to initiate the recovery of the skate sooner at the expense of complete hip and knee extension.

The final important movements during the initial three to four strides of the start are the athletes' arm motion. Hockey players currently utilize a high degree of shoulder flexion and extension as they perform the initial strides of the start. An important aspect of the arm swing is determining the direction and range of motion for the athletes' arm swing. The current author believes that hockey players need to utilize more shoulder abduction and adduction during the start in order to direct their arm swing in the same plane as their push off and therefore, increase the ground reaction forces which can be applied to the ice.

Speed Skating Starts Technique Checklist

The start in speed skating is best described by de Koning (1989) when he suggests the athlete use a "running to gliding approach". Speed skating coaches must emphasize the athlete leaping from skate to skate during the initial three steps in order to reach a desired airborne phase. As a result, the athlete should develop a slight airborne phase and no time in double support. This approach is beneficial as it allows the athlete to plant the new support skate directly underneath their hip (as the upper body moves to a position ahead of the skate while airborne) and minimize any potential deceleration. In addition to planting the skate directly underneath their hip, the athlete must also focus on laterally rotating their hip in order to plant it in a position to begin the next push off immediately after skate touchdown.

The second part of de Konings (1989) theory on starts in speed skating revolves around the athlete utilizing a gliding phase during the start. This portion of the start will begin to occur as the athletes' support skate begins to glide along the ice. As a result, the speed skater must utilize this gliding action by emphasizing a more sideways directed push off. A more sideways directed push off will allow the speed skater to go through a larger range of motion during the push off which occurs with both hip abduction and extension.

Another key feature of the start in speed skating is determining the relationship between stride length and stride frequency during the start. During the start in speed skating, athletes must emphasize slightly less knee flexion at skate touchdown compared to full velocity skating as well as not go into complete hip and knee extension in order to allow for the initiation of the recovery phase sooner. By going through a smaller range of motion during the first three or four steps, the athlete will be able to increase their stride frequency.

The final area of concern when coaching athletes is determining the effectiveness of their arm swing during the start. An effective arm swing is one where the athlete is able to utilize the arm motion to aid in the production of ground reaction forces or increase the force which they can apply to the ice. In speed skating, the arm swing must be synchronized with the force producing action of the lower body. Therefore, when the athlete applies force to the ice with their right skate during the push off, their right arm should come forward and across their body (shoulder adduction and shoulder flexion) in conjunction with the left arm being driven backwards and away from their body (shoulder abduction and shoulder extension). It is important to note that the direction of the athlete's arm swing should be altered as the direction of their push off is altered. For example, during the first push off, the athlete should apply all of their force directly backwards against the ice and therefore the shoulder should move primarily in flexion and extension. However, with each successive step the athlete begins to push off in a sideways direction and therefore the athlete's arms should also be moved in a sideways direction with a greater contribution of shoulder motion occurring through abduction and adduction.

Chapter VI

Summary, Conclusions, and Recommendations

Summary

Starting technique in short track speed skating and hockey are two skills which have the same goal of trying to reach maximum velocity over as short a time as possible or maximizing acceleration. The purpose of the study was to determine the kinematic differences between the start executed in speed skating and the start executed in hockey by investigating the key variables which are associated with maximizing the athlete's velocity over the first six meters of the skating sequence. Video analysis was performed on both speed skaters and hockey players by measuring key kinematic variables and performing statistical analyses in order to determine any differences which may be present between the two groups. It was hypothesized that the movement patterns and kinematic variables of the start in hockey would not differ from the start in short track speed skating. A secondary purpose was to determine the most effective body movements and body positions to perform the fastest start in ice hockey and the fastest start in short track speed skating in female athletes' over the first six meters of the skating sequence.

Data were collected from a total of 24 subjects on five separate filming sessions: including the Manitoba Program of Excellence summer hockey camp in Winnipeg Manitoba, Balmoral Hall Blazers hockey practice in Winnipeg Manitoba, speed skating practice with the Edmonton Speed Skating Association and two separate Manitoba Speed Skating team practices. Thirteen hockey players and 11 speed skaters participated in the study, with all athletes considered skilled for their age being either prospective or current members of elite sports programs.

A three camera set up was utilized during the filming session, capturing video from the sagittal, frontal and transverse views. A fourth camera captured the sagittal movements from a greater distance allowing for the athletes' velocities at six and 12 meters to be calculated. The video was then imported into a Toshiba Laptop through Dartfish video analysis software and was stored there throughout the analysis.

Forty four variables were measured during the start, with 25 of those variables being measured at three separate points in the start during the first three steps (13 variables were measured as the athletes were in their ready position, 13 variables were measured at the end of each push off, and 12 variables were measured at each foot touchdown. The remaining variables were time to six and 12 meters and linear velocity at six and 12 meters. The angle of the skate blade relative to the direction of travel was not calculated for three speed skaters because an overhead camera was not available during the filming sessions. The variables were measured through the use of Dartfish Team Pro 4.5.1. These variables included: angles of the trunk, hip, knee, ankle and shoulders, as well as angular velocities for hip and knee extension, step rate, angle of the push off relative to the direction of travel and linear velocity of the skater. The data collected allowed the researcher to analyze several aspects of the starting technique and determine where similarities and differences occurred between the two groups. Statistical analyses were performed on the measured variables through the use of t-tests, Pearson's Product-Moment Correlations and Forward Stepwise Multiple Regression analyses. Due to missing data points, the angle of the skate blade relative to the direction of travel for the speed skating group was not included in the stepwise multiple regression analysis.

The results of the statistical analysis will be summarized below with many statistical differences occurring between the two groups.

T-Tests

Statistical analysis of the two groups revealed several differences in technique, with the majority of these differences occurring during the early phases of the skill. T-tests were performed in order to determine the kinematic differences between the start executed in speed skating and the start executed in hockey as identified as the purpose of the study.

Ready Position

Nine of the 13 variables measured during the ready position were shown to be significantly different between the two groups. This was a result of the speed skating group demonstrating a much more flexed ready position which was determined to be a key kinematic difference between the two groups during the start. The variables which were shown to be significantly different included: angle of trunk lean from the horizontal, width of the base of support in the forwards/backwards direction, angles of front hip, knee and ankle flexion, angle of rear hip flexion, angles of right and left shoulder flexion and the angle of the skate blade relative to the direction of travel. The speed skating group was shown to demonstrate a more horizontal trunk position, which resulted in greater angles of front and rear hip flexion due to these angles being measured using the 180 degree system. The speed skating group also demonstrated increased shoulder flexion in the front arm and increased shoulder extension in the rear arm allowing for a better position to initiate the arm swing from. The speed skating group was also shown to have a much wider base of support in the forwards/backwards direction as a result of their flexed ready position. The final variable that was determined to be significantly different was the angle of the skate blade relative to the direction of travel. The speed skating group initiated the start with the skate blade aligned in a more posterior direction, allowing them to be in a better position to initiate the first push off directly backwards or at 90 degrees to the direction of travel.

Variables Measured at the end of the Push Off

The variables at the end of the push off were shown to be very important as many of these variables were determined to be significantly correlated with the athlete's velocity and therefore selected during the stepwise multiple regression analysis. During the end of the first push off, the two groups were quite different with 8 of 13 variables being statistically different between the two groups, however, at each of the next two push offs fewer differences were noted between the two groups. At the end of the second push off only six of 13 variables were statistically different and during the third push off only 4 of 13 variables were statistically different.

Three variables were measured to be different at the end of all three push offs suggesting that these variables were important kinematic differences: including the angle of rear hip flexion, angle of the skate blade relative to the direction of travel, and the angle of rear shoulder abduction. These three variables followed the same relationship with each successive push off. The speed skaters demonstrated a significantly greater degree of hip flexion remaining at the end of the push off resulting in an incomplete hip extension. The speed skaters also had an increased angle of shoulder abduction which allowed them to initiate the upcoming arm swing from a more abducted position, resulting in a greater range of motion for shoulder adduction during the next push off.

Lastly, the speed skaters demonstrated a more sideways directed push off compared to the hockey group. This was important as the speed skaters directed the first two push offs too much in the lateral direction, not entering the ideal angle of 90 degrees to the direction of travel at the end of the first push off. As well the second push off was directed too much in the lateral direction as the skate was not yet gliding. However, at the end of the third push off, when the skate is no longer on a fixed point on the ice (or it is gliding) the sideways directed push off will be beneficial.

In the current study, speed skaters were shown to use a more vigorous arm action than the hockey players, which resulted in significant differences between the angles of shoulder flexion, extension and abduction during the first two push offs. This was evident in the study, as the speed skaters demonstrated horizontal adduction and abduction during the start, whereas the hockey players used primarily shoulder flexion and extension. As a result, it was suggested by the researcher that the speed skaters were better at directing their arm swing in the same plane as their push off, allowing for a better transfer of force to the ice. The range of motion at the shoulder joint was determined to be a key difference between the two groups.

Time in double support in the study was shown to be statistically different at the end of the first push off, however, no difference was identified at the end of the second or third push offs. This was an interesting finding due to the different methodologies of teaching starts to speed skaters and hockey players. Marino (1979) has suggested that hockey players who are able to spend greater time in double support will have a greater acceleration. However, Teasdale (1996) has suggested that speed skaters need to emphasize a slight airborne phase during the first push off producing a very low time in double support. Both groups in this study were able to reproduce the different methods of time in double support suggested by the literature in their field, indicating a high degree of skill level in the subjects in the study.

Variables Measured at Skate Touchdown

The variables measured at touchdown followed a similar pattern to those at the end of the push off, as the two groups began to use more similar techniques by third foot touchdown. First foot touchdown resulted in six of 12 measured variables being significantly different, second foot touchdown produced 5 of 12 measured variables to be significantly different, and third touchdown identified 4 of 12 measured variables to be significantly different. Only two variables were shown to be significantly different at the end of all three push offs, with the athlete's time in single support and their angle of rear shoulder abduction being significantly different. The angle of shoulder abduction followed a similar relationship to the end of the push off which resulted in the athlete being in a better position to initiate the subsequent push off. The speed skating group spent a significantly greater time in single support, with the difference becoming less significant with each successive push off. This difference likely occurred because of the greater difficulty associated with recovering the speed skate as compared to the hockey skate as well as the difficulty associated with planting the skate flat on the ice.

The arm movements, shoulder flexion, extension, and abduction were all significantly different at both first and second touchdown demonstrating the speed skaters were utilizing a larger range of motion with their arm movements. At third foot touchdown, shoulder flexion and extension were no longer significantly different because the speed skaters were using a frontal arm swing with primarily shoulder abduction/adduction, whereas the hockey players were utilizing an arm action with primarily shoulder flexion/extension.

First and second foot touchdown also revealed a significant difference in the athlete's trunk forward lean. The speed skating group demonstrated significantly more trunk forward lean than the hockey group. This difference occurred due to the speed skaters horizontal trunk position attained during the ready position, however, with each successive step the speed skaters began to resemble the decreased trunk lean measured in the hockey group.

The last two significant differences measured at skate touchdown occurred at third foot touchdown. The angle of knee flexion and the position of the skate plant relative to the hip were determined to be significantly different. Both of these variables are related to each other due to the fact that a greater degree of knee flexion (and ankle dorsiflexion) will allow the athlete to plant the skate more directly underneath their hip. The hockey group was significantly better at planting their support skate directly underneath their hip at third foot touchdown and also entered a significantly greater degree of knee flexion at touchdown.

Overall, the two groups were shown to be significantly different in regards to several of the kinematic variables which were measured during the initial three steps of the skating stride. The two groups were not shown to be significantly different in regards to their horizontal velocity at six meters, however, the speed skating group had a velocity of 5.89 m/sec compared to the hockey group with a velocity of 5.45 m/sec. One interesting finding from the study was that the speed skaters were able to reach a faster velocity at the six meter interval, however, the hockey players were determined to reach the six meter timing gate in a significantly faster time. The hockey players were found to reach the six meter mark with a mean time of 1.36 seconds as compared to the speed skating group which reached the six meter mark in a mean time of 1.58 seconds. This difference occurred due to the speed skaters being able to accelerate at a faster rate during second half of the starting zone. As a result, the speed skaters were able to cover the distance at the six meter mark over a shorter time, resulting in a greater velocity at six meters. Therefore, with a greater distance covered over the same time interval, the speed skaters were shown to have an increased velocity due to the relationship velocity = distance/time.

Kinematic Relationships with Velocity at Six meters

Correlation analysis was conducted on all the measured kinematic variables to determine which variables were significantly correlated to the athlete's velocity at six meters. This statistical test allowed the researcher to answer the secondary purpose of the study by determining which variables were key contributors to velocity at six meters for the two groups separately.

Hockey Correlation Analysis

The results of the hockey correlation analysis determined six of the variables to be significantly related to the athlete's velocity at six meters with a $p \leq 0.05$ or lower. Right shoulder flexion at the end of the first push off, right shoulder flexion at first foot touchdown, time in double support at the end of the third push off, foot placement in front of the hip at third foot touchdown, and time to six meters were all negatively correlated to the athlete's velocity at six meters. Hip extension velocity at the end of the first push off was the only variable shown to have a significant positive correlation with velocity at six meters.

Speed Skating Correlation Analysis

The results from the speed skating correlation analysis identified 10 variables which were significantly correlated to the athlete's velocity at six meters. Seven of the 10 statistically significant variables were shown to be negatively correlated. These variables include: time in double support at the end of the first push off, distance of foot placement in front of the hip at first foot touchdown, right hip flexion at the end of the second push off, time in double support at the end of the second push off, rear ankle plantarflexion at the end of the third push off, time for extension during the third push off, and time in double support at the end of the third push off. The remaining three variables were positively correlated to velocity at six meters: right shoulder flexion in the ready position, angle of right shoulder abduction at the end of the second push off, and rear knee flexion at the end of the third push off. The majority of these variables occurred at the end of the push off, indicating the significance of force producing action in the skill.

Stepwise Multiple Regression Analysis

A forward multiple stepwise regression analysis was conducted in order to determine which variables were important predictors of velocity at six meters. Forward multiple stepwise regression equations will allow the researcher to answer the secondary purpose which was to determine the most effective body movements and body positions to perform the fastest start in ice hockey and the fastest start in short track speed skating in female athletes' over the first six meters of the skating sequence. Separate regression equations were determined for both the speed skating group and the hockey group.

Hockey Regression Analysis

The regression equation to predict the athlete's velocity at six meters included seven variables that explained 99.8% of the velocity at six meters. These variables included angle of hip flexion in the ready position, angle of left shoulder abduction and right shoulder adduction at the end of the first push off, time in single support during first foot touchdown, angle of right shoulder flexion at first foot touchdown, angle of left shoulder abduction at the end of the third push off, and the distance of foot placement in front of the hip at third foot touchdown.

Speed Skating Regression Analysis

The forward stepwise multiple regression analysis performed on the speed skating group selected four variables which were able to predict 99% of the athlete's velocity at six meters. These variables included angle of right shoulder adduction at first foot touchdown, the time spent in double support during the second push off, the angle of rear hip flexion remaining at the end of the third push off and the angle of right shoulder adduction at the end of the third push off. Time spent in double support was determined to have the biggest contribution to predicting the athlete's velocity at six meters, with more time in double support resulting in a slower velocity at six meters for the speed skating group.

Conclusions

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

1. Hockey players in this study reached the six meter mark in a significantly shorter time (0.22 seconds) than the speed skater, however, this did not translate into a faster velocity at the six meter mark. Velocity at six meters was not statistically significant between the hockey players and the speed skaters.
2. Speed skaters utilized a significantly more flexed ready position (with a greater angle of trunk lean and a greater angle of rear and front hip flexion and front knee flexion).
3. Speed skaters used a significantly larger range of motion for shoulder flexion/extension and shoulder abduction/adduction, resulting in a more vigorous arm swing which occurred in a diagonal plane between the sagittal and frontal planes.
4. Speed skaters began with their skate blade angled in a more posterior direction in the ready position which resulted in a better position to initiate the first push off.
5. Hockey players were shown to laterally rotate their hip during the first push off resulting in a better position of the skate blade at the end of the push.
6. Speed skaters were shown to have significantly greater hip and knee extension velocities at the end of the first push off.
7. Hockey players were shown to spend a greater time in double support during the first push off, while the speed skaters attempt to have a slight airborne phase but were unable to do so.

8. Speed skaters tended to increase the angle of their trunk lean from the horizontal during the first two push offs up to second foot touchdown, while the hockey players maintained a constant angle throughout the start.
9. Speed skaters spent more time in single support at first, second and third foot touchdown due to the running action seen during the initial steps.
10. Speed skaters tended to have more hip flexion remaining at the end of the push off, however, they still produced a similar range of motion as the hockey players due to more hip flexion at touchdown.
11. Speed skaters had a tendency to have a more sideways directed push off during the start, with the skate blade angled less relative to the direction of travel during the first three push offs.
12. Hockey players tended to position their foot closer to their hip (in the forwards/backwards direction) allowing them to minimize any potential deceleration while their body was attempting to catch up to their skate.
13. Speed skaters were more skilled at directing their arm swing in the opposite direction of their push off which allows them to increase the ground reaction forces which can be applied to the ice.

Recommendations

The following recommendations are suggested for future studies conducted on starting technique in speed skating and hockey:

1. Future studies should calculate the athlete's velocity at 3 meters and six meters in order to determine the effect of the first three strides (which occur at or around the three meter mark) on the athlete's velocity.

2. Improved protocol on the athletes' positioning relative to the first timing gate could be incorporated into the study. In the current study, it was noted that several subjects' attempted to start slightly behind the first timing gate which potentially may have given them greater horizontal velocity when the first gate was reached allowing them to get through the starting zone during a shorter time interval.
3. A study conducted on athletes' who participate in both speed skating and hockey would allow for paired data and help to determine the effects of an increased blade length on starting technique.
4. A future study which examines the athlete's arm motion in relation to the direction of their push off (identifying their ability to maximize force against the ice using a modified force platform) would be beneficial in determining the ideal arm motion during the skating start.
5. More studies examining the potential differences between elite (Olympic and World Class athletes) and skilled subjects in order to determine if the two groups would still be significantly different in their starting techniques.
6. Future studies determining the advantages and/or disadvantages to spending more or less time in double support and the rationale for why the two groups utilize two different approaches.
7. Future studies need to include more subjects to ensure significant results and better generalization to a wider range of subjects.

Coaching Recommendations

Starting technique, in both speed skating and hockey, play an important role in the overall ability of an athlete to succeed at the elite level. In order for developing athletes to continue to improve, it is important that coaches and athletes understand the effects of technique flaws and how to improve these technique errors before they become ingrained in the athletes. As a result, some coaching recommendations have been made based on the significant findings of this study:

1. Speed skaters need to emphasize positioning their rear skate at a 90 degree angle to the direction of travel in order to apply maximum force in the posterior direction.
2. Speed skaters should work on having a slight airborne phase during the first push off and a very low time in double support during second and third push offs as an increased time in double support was shown to be negatively correlated to velocity at six meters in this study.
3. Hockey players are often taught to spend an increased amount of time in double support during the start, however, this study did not agree with this suggestion. It is possible that a decreased time in double support (as seen in the speed skating group) may produce a greater velocity at six meters assuming the athletes are able to practice with this technique.
4. It is important for both speed skaters and hockey players to concentrate on planting their support foot in an outwardly rotated position in order to have the skate angled at an appropriate direction to initiate the push off. It is also important for the athlete to emphasize positioning this skate along their midline (to allow a greater distance to apply force to the ice over) and directly under their center of gravity (to minimize any potential delay in force production for the athlete's center of gravity to catch up to the foot).

5. Hockey players could benefit from an increased range of motion in their shoulders (permitting they are not carrying a puck) in order to direct the arm swing in the same plane of movement as the push off. An arm swing which does not occur in the opposite direction of the push off will result in forces being applied at an angle to the ice surface and thus decrease the useful ground reaction forces occurring between the skate blade and the ice. For training purposes, athletes' who hold the stick in both hands may have a better arm swing as it encourages a greater degree of abduction and adduction at the shoulder joint.
6. Hockey players need to emphasize a better ready position (with slightly more trunk, hip and knee flexion) in order to be in a better position to initiate the start from. Hockey players tended to stand more upright and then start flexing their knees upon first movement. It would be beneficial for the athlete to begin with a greater degree of knee flexion at first push off.

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Appendix A

Ethics Approval

UNIVERSITY OF MANITOBA | OFFICE OF RESEARCH SERVICES
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APPROVAL FOR SERVICES

17 January 2007

TO: **Marion Alexander**
Faculty of Physical Education

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

Re: **Approval for Services to Elite Canadian and Manitoba Athletes**

Film Analysis of the Skills of Elite Canadian and Manitoba Athletes has been approved for 2007.

Bringing Research to Life

Appendix B

Informed Consent Forms

Informed Consent Form

Research Project Title: A Biomechanical Analysis of the Starting technique of Manitoba Speed Skating team and Manitoba Bison's Hockey Team.
Approach: How speed skating and hockey starting technique differ.
Researcher(s): Brian Shackel B.E.S.S. and Advisor: Marion J.L. Alexander, professor, Faculty of Physical Education and Recreation Studies

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

Outline of the Study:

The purpose of this study is to examine the starting techniques of members of the Manitoba Speed Skating team and Manitoba Women's hockey team, in order to determine the key movements of starting technique and assist coaches in improving the technique of starting. You are either currently a member of this team, or are considered to be a prospect for membership in this elite program.

Methodology:

You will be filmed, on one occasion, while practicing at the Max Bell Arena (Pioneer Arena, River Heights Arena, Winnipeg Winter Club Arena or Clareview Arena) using filming equipment from the Biomechanics Laboratory in the Faculty of Physical Education. All practices are administered by the coach and the investigator, who will instruct you regarding the skills to perform. Prior to filming you, the filming procedures will be explained. You will be asked to perform the skills as you normally would in a competitive situation, and your techniques will be filmed. You must provide informed consent for the study prior to filming. All filming procedures will be organized and administered by the graduate student, Brian Shackel, who will be assisted by the principal investigator, Dr. Marion Alexander and other qualified graduate students.

Video cameras will be used to film the athletes. The investigator will instruct you regarding which skills are to be performed while the cameras are filming. The cameras will continue to film you until all of the skills of interest have been performed

When filming is completed, the videos will be analyzed by the principal investigator and the graduate students working on the project. The types and ranges of motion in each of the skills, as well as selected linear and angular velocities in each of the skills will be described. An overall evaluation of the technique of each skill for each athlete will be provided to the coaches. Photos can be made from the collected video and do play a useful role in illustrating key features of starting technique for instructional materials and papers. The technique descriptions developed from this analysis and pictures developed from the video may eventually be published in a thesis titled "A biomechanical analysis of starting technique in speed skating and hockey".

Risk:

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

Confidentiality:

The film will be viewed only by the researchers involved in the study, the coaches, and by the athletes in the study. The amount of data available to the athletes will be determined by the coaches. The data derived from the film will be available to the coaches and athletes in order to help to improve performance. The video films and all of the research data will be kept in the Biomechanics laboratory. It is possible that the technique analysis data will be published in a technical journal, however the identity of all subjects in the study will be kept confidential. The photos made from the video film may be used to illustrate the thesis or technical papers prepared from the data.

Signature:

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

<u>Principal Researcher</u>: Marion J.L. Alexander, Professor, Faculty of Physical Education and Recreation Studies, Ph 474 8642

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122.

____________________	____________________	_______
Participant's name (print)	Signature	Date
____________________	____________________	_______
Parent/Guardian (if under 18 years of age)	Signature	Date
____________________	____________________	_______
Researcher and/or Delegate	Signature	Date

Appendix C

Pilot Study

Pilot Study

Introduction

The purpose of the pilot study was to collect video from subjects who would fit within the criteria for the population of interest of the thesis. The group included skilled female hockey players and skilled female speed skaters. The pilot study also provided the investigator with the opportunity to test the methods which will be utilized during the thesis including camera setup and the protocol to be followed during the filming sessions. A final purpose of the pilot study was to determine which similarities and differences may exist between the starts of skilled female speed skaters and skilled female hockey players.

The filming for the pilot study was conducted on two separate occasions. The speed skating starts were filmed on January 11, 2007 at Pioneer arena in Winnipeg, Manitoba and the hockey starts were filmed on January 31, 2007 at Max Bell Arena at the University of Manitoba, Winnipeg, Manitoba.

Methods

Subjects

The two speed skating subjects were recruited from the Manitoba Speed Skating team, while the two hockey players were recruited from the University of Manitoba women's hockey team. The subjects were provided an adequate amount of time to warm up, as instructed by the coaches, prior to the filming session.

Filming Technique

During the filming, a multiple camera set up was utilized which allowed video to be collected from two sagittal cameras (one focusing on the first four strides and the other capturing the 12 meter distance) as well as one rear camera view which captured movements in the frontal plane. The investigator also captured a front view of the athletes in order to see which view provided better measurements to be included in the final study.

Prior to the filming, the investigator was dealing with issues pertaining to setting up an overhead camera apparatus on the ice surface. As a result, several filming sessions were undertaken to attempt to capture an overhead view of the athlete during the first three to four strides in order to view the subjects skate blade relative to travel.

The sagittal and frontal cameras were positioned to allow for the cameras to be located at a ninety degree angle to each other. This allowed for a three dimensional view of the motions being performed by the subjects in the study. All cameras were set to a shutter speed of $1/500^{th}$ of a second to allow for an adequate amount of light to be exposed to the video, but prevent any blurring of the subjects during the skating tasks.

Experimental Procedure

The subjects were instructed to begin the skating stride as they would normally do during a competition. However, since the sport of hockey is an open skill, which means that the conditions changes within the game, the subjects performing the hockey start were instructed to perform a standard start (which required the subject's feet to be parallel to the direction of travel). The standard start was chosen because of it's resemblance to the start utilized in the sport of speed skating. The subjects were instructed to accelerate as fast as possible and continue skating through to the end of the second pylon which was indicating the 12 meter mark. Each subject performed five or six starts which were then imported into a Toshiba satellite A-100 laptop for further analysis.

Video Analysis

Video analysis was used to gather qualitative and quantitative information regarding the biomechanics of the start in both speed skating and hockey. The video analysis was performed using Dartfish Advanced Video Analysis Software version 4.0.9. (2005).

The video analysis will focus on the first three strides of the starting technique, similar to the methods reported by Marino and Dillman (1979). The primary variables of interest will be the subject's instantaneous velocity at six meters and their time to skate from zero to six meters. These two variables will be positive indicators of the subject's ability to accelerate rapidly over the first six meters of the skating task. Other variables of interest to be calculated from the pilot study are presented in Table 1.

Table 1: Variables to be measured in the Pilot Study.

Phase of the Skill	**Variable(s) Measured**
Start Position	➢ Trunk lean relative to vertical ➢ Width of base of support ➢ Left knee flexion ➢ Right knee flexion ➢ Left hip flexion ➢ Right hip flexion ➢ Left ankle flexion ➢ Right ankle flexion ➢ Skate blade relative to direction of travel
End of 1st Push Off	➢ Rear hip extension ➢ Rear knee extension ➢ Rear ankle plantarflexion ➢ Skate blade relative to direction of travel ➢ Time in double support ➢ Knee and Hip Angular Velocities

1st Step TD	➢ Skate position relative to center of gravity ➢ Knee flexion at TD ➢ Hip flexion at TD ➢ Ankle dorsiflexion at TD ➢ Trunk lean from vertical ➢ Time in single support
End of 2nd Push Off	➢ Rear hip extension ➢ Rear knee extension ➢ Rear ankle plantarflexion ➢ Skate blade relative to direction of travel ➢ Time in double support ➢ Knee and Hip Angular Velocities
2nd Step TD	➢ Skate position relative to center of gravity ➢ Knee flexion at TD ➢ Hip flexion at TD ➢ Ankle dorsiflexion at TD ➢ Trunk lean from vertical ➢ Time in single support
End of 3rd Push Off	➢ Rear hip extension ➢ Rear knee extension ➢ Rear ankle plantarflexion ➢ Skate blade relative to direction of travel ➢ Time in double support ➢ Knee and Hip Angular Velocities
3rd Step TD	➢ Skate position relative to center of gravity ➢ Knee flexion at TD ➢ Hip flexion at TD ➢ Ankle dorsiflexion at TD ➢ Trunk lean from vertical ➢ Time in single support

The investigator will determine all the above variables using the Dartfish Analysis software, as well as, angular velocities at the hip and knee of the push off leg.

Results

When video analysis was conducted between the starting technique utilized by speed skaters and hockey players, the results showed differences and similarities in regards to their mechanics. Table 2 shows the results for the variables which were measured during the pilot study.

Table 2: Kinematic variables measured in the Pilot Study.

Note: To accurately measure width of base of support and position from C of G need to have limb segment measurements to be exact.						
Note: For direction of blade relative to travel will need overhead camera (very inaccurate from current views)						
Position	**Speed Skater 1**	**Speed Skater 2**	**SS Average**	**Hockey 1**	**Hockey 2**	**Hockey Average**
Start						
Trunk Lean from Horizontal (deg)	13	30.5	21.75	74.4	70.6	72.5
Width of Base of Support (cm)	?	?		?	?	
Rear Knee Flexion (deg)	82.1	60	71.05	23.5	26.3	24.9
Front Knee Flexion (deg)	72.2	93.7	82.95	23.5	26.3	24.9
Rear Hip Flexion (deg)	128.5	107.3	117.9	18.3	19.2	18.75
Front Hip Flexion (deg)	136.1	131.2	133.65	18.3	19.2	18.75
Front Ankle Flexion (deg)	-5	9.5	2.25	-12.3	-6.5	-9.4
Rear Ankle Flexion (deg)	-29.1	-11.7	-20.4	-12.3	-6.5	-9.4
Skate Blade relative to Travel (cm)	?	?		?	?	
End of 1st Push Off						
Rear Hip Extension (deg)	33.2	30.4	31.8	25.6	19.9	22.75
Rear Knee Extension (deg)	17.3	27.1	22.2	23.3	36.3	29.8
Rear Ankle Plantarflexion (deg)	7.5	6.1	6.8	-8.9	3.6	-2.65
Skate Blade relative to Travel	?	?		?	?	
Hip Extension Velocity (deg/s)	336.7	384.5	360.6	-31.3	-1.7	-16.5
Knee Extension Velocity (deg/s)	228.9	164.5	196.7	0.85	-23.9	-11.525
Time in Double Support (sec)	0.016	0.033	0.0245	0.066	0.083	0.0745
1st Foot TD						
Skate position relative to Hip (cm)	?	?		?	?	
Knee Flexion at TD (deg)	75.8	75	75.4	35.1	72.2	53.65
Hip Flexion at TD (deg)	94.9	98.4	96.65	47.7	74.9	61.3
Ankle Dorsiflexion at TD (deg)	-36.2	-15	-25.6	-8.7	-21.2	-14.95
Trunk Lean from Horizontal (deg)	37.4	41	39.2	60.5	57.1	58.8
Time in Single Support (sec)	0.25	0.283	0.2665	0.266	0.266	0.266
End of 2nd Push Off						
Rear Hip Extension (deg)	41.7	45.1	43.4	24.6	20.7	22.65
Rear Knee Extension (deg)	28.3	31	29.65	39.2	36.1	37.65
Rear Ankle Plantarflexion (deg)	5.3	3.5	4.4	0	11.7	5.85
Skate Blade relative to Travel	?	?		?	?	
Hip Extension Velocity (deg/s)	228.3	213.2	220.75	99.1	191.5	145.3
Knee Extension Velocity (deg/s)	203.8	176	189.9	-17.6	127.6	55
Time in Double Support (sec)	0.016	0.033	0.0245	0.016	0.066	0.041

2nd Foot TD						
Skate position relative to Hip (cm)	?	?		?	?	
Knee Flexion at TD (deg)	71.8	75.2	73.5	70.5	90.2	80.35
Hip Flexion at TD (deg)	95.7	98.5	97.1	88	104.3	96.15
Ankle Dorsiflexion at TD (deg)	-9.1	-19.4	-14.25	-23.5	-20.7	-22.1
Trunk Lean from Horizontal (deg)	36.9	40.1	38.5	44	48.6	46.3
Time in Single Support (sec)	0.233	0.283	0.258	0.25	0.25	0.25
End of 3rd Push Off						
Rear Hip Extension (deg)	43.5	38.5	41	30.8	34	32.4
Rear Knee Extension (deg)	33.8	32.1	32.95	43.6	36.5	40.05
Rear Ankle Plantarflexion (deg)	10.2	12.8	11.5	0	10.9	5.45
Skate Blade relative to Travel (cm)	?	?		?	?	
Hip Extension Velocity (deg/s)	154.6	327.8	241.2	312.6	281.2	296.9
Knee Extension Velocity (deg/s)	338.3	235.5	286.9	146.9	214.8	180.85
Time in Double Support (sec)	0.016	0.033	0.0245	0.033	0.066	0.0495
3rd Foot TD						
Skate position relative to Hip (cm)	?	?		?	?	
Knee Flexion at TD (deg)	60.9	69.2	65.05	66.5	87.2	76.85
Hip Flexion at TD (deg)	90	93.2	91.6	88.4	101.3	94.85
Ankle Dorsiflexion at TD (deg)	-21.8	-6.7	-14.25	-19.5	-19.7	-19.6
Trunk Lean from Horizontal (deg)	43	50.2	46.6	45.8	48.7	47.25
Time in Single Support (sec)	0.266	0.266	0.266	0.25	0.25	0.25
Velocity at 6 m (m/s)	6.43	6.47	6.45	5.37	5.37	5.37
Velocity at 12 m (m/s)	6.8	6.77	6.785	5.77	6.27	6.02
Step Rate (steps/sec)	3.58	3.02	3.3	2.9	2.72	2.81

The table of results has several variables which were not measured due to the lack of the overhead camera during the filming sessions (i.e. skate blade relative to travel) as well as due to difficulties associated with accurate measurements for conversion factors. As a result, the investigator has added limb segment measurements to the methods section of the proposal. By having limb segment measurements, the investigator will always have a known distance measure in the video clip and will be allowed to measure variables including the position of skate touchdown relative to the center of gravity (which will be measured as the distance from the hip for the purpose of the thesis in order to increase the accuracy of the measurement) as well as the base of support measurements.

Instantaneous velocity was calculated for both the speed skaters and the hockey players at six meter and 12 meters. The results from the pilot study show that speed skater's velocity at six meters was calculated to be 6.47 m/s while hockey player's velocity at six meters was calculated at 5.37 m/s. As a result, the speed skaters had a 1.1 m/s faster velocity over the first six meters and therefore had a greater acceleration over the initial six meter interval. In regards to the velocity of the two groups at 12 meters, the speed skating group was able to increase their velocity to 6.77 m/s while the hockey group continued to increase their velocity to 6.02 m/s. Therefore, the hockey group was continuing to accelerate to a greater extent than the speed skaters over the second six meter interval.

A second area of difference between the two groups was in regards to the ready position utilized prior to the start. In the speed skating group, the athletes were able to produce a high degree of knee flexion at 71.05 degrees in the rear leg and 82.95 degrees in the lead leg. The group also produced a high degree of hip flexion in the rear leg at 117.9 degrees and in the lead skate at 133.65 degrees, as well as a high degree of trunk forward lean with an angle measured at 21.75 degrees from the horizontal. This position allowed the speed skaters to have a low center of gravity and position their line of gravity over top of their lead skate. By moving their line of gravity over top of their lead skate, the athlete is able to enter an unstable position and initiate forward movement by moving their center of gravity outside of the front edge of their base of support. This position is effective at initiating forward movement because it enables the athlete to begin forward movement with both a push off force against the ice, but also by allowing the position of their center of gravity to initiate forward momentum. The hockey group was significantly less effective at lowering their center of gravity during the ready position with less trunk forward lean measured at 72.5 degrees from the horizontal. The hockey group also entered a substantially less degree of hip flexion at 24.9 degrees in both legs and knee flexion at 18.75 degrees in both legs. This position resulted in the hockey group initiating the start in a less stable position due to their elevated center of gravity

The speed skating group was able to enter a significantly lower position of knee flexion and hip flexion during skate touchdown as compared to the hockey group. Both groups were similar in regards to their position of hip and knee extension at the end of the push off phase for each stride. As a result, the speed skaters were measured to go through a significantly larger range of motion at the knee and hip during the force production phase of the stride. The speed skating group was also measured to have increased knee extension velocity at 196.7 degrees/s and hip extension velocity at 360.6 degrees/s during the first push off. The hockey group on the other hand, due to their decreased angles of hip and knee flexion in the ready position was seen to increase their knee flexion of the plant foot after the first step. This resulted in the calculated knee and hip extension velocity to be negative numbers (meaning that the knee went into flexion) and therefore the knee flexion velocity for the knee and hip of the hockey group was 11.53 degrees/s and 16.5 degrees/s respectively. The speed skaters were able to maintain greater knee extension velocities throughout the first three strides of the start.

The speed skating and hockey groups are similar in regards to their calculated time spent in single support during foot touchdown at between 0.25 and 0.26 seconds.

However, when calculating the time spent in double support for the two groups, it was found that the speed skating group spent slightly less time in double support than the hockey group. At the end of the fist push off, the speed skating group was calculated to spend 0.0245 seconds in double support, while the hockey group was calculated to spend 0.0745 seconds in double support.

A final major difference between the two groups involved the position of their trunk forward lean during the first three strides. In the speed skating group, the trunk forward lean was shown to decrease with each successive step, while the hockey group's trunk forward lean was shown to increase with each successive step. In the hockey group, the athlete's trunk lean was measured at 72.5 degrees during the ready position, 58.8 degrees during the first foot touchdown, 48.6 degrees during the second foot touchdown and 48.7 degrees during the third foot touchdown. In the speed skating group, the athlete's trunk lean was measured at 21.75 degrees from the horizontal during the ready position, 39.2 degrees during the first foot touchdown, 38.5 degrees during the second foot touchdown, and 46.6 degrees during the third foot touchdown.

Discussion

The purpose of the pilot study was to collect video of skilled hockey players and speed skaters in order to compare the technique which is used to initiate forward movement from a stationary start. The results of the study showed that speed skaters were able to increase their horizontal velocity faster than hockey players, by accelerating at an increased rate from zero to six meters. Therefore, the pilot study has provided increased rationale for why further investigation of the biomechanical comparison between the starts used in speed skating and hockey. Several differences were measured between the two groups which may be indicative of an improved starting technique utilized by speed skaters over that used in hockey.

The speed skating group's ability to increase their knee flexion during foot touchdown has provided them an increased range of motion for force production during the push off. As a result, the speed skating group showed a significantly increased angular velocity for knee and hip extension during the push off. An increased range of motion and increased angular velocity during the push off will have a positive effect on the skaters ability to accelerate during the start. On the other hand, during the start in the hockey group, the skater's were shown to go through a smaller range of motion with a decreased angular velocity of hip and knee extension which has a negative effect on the skater ability to accelerate during the start. An increased range of motion for hip and knee extension will be beneficial to the speed skating group because it allows for greater range of motion for force production, however, in conjunction with the increased range of motion the skater must also perform the knee and hip extension over the shortest time possible in order to maximize the force which can be applied to the ice during the push off.

In regards to the temporal analysis of time spent in single and double support during the start, Marino has suggested that "skaters are able to maintain positive acceleration throughout both the single and double support periods of at least the first three or four strides in a starting task" (1978). As a result, when the speed skating group was measured to have substantially less time in the double support phase over the first three strides as compared to the speed skating group, this will not have a negative effect on their ability to accelerate during the start. The speed skating group was shown to have less time in double support because of an increased stride rate which allowed for a quicker recovery and therefore a decreased amount of time spent on the ice with both skates. Both groups were shown to have similar time spent in single support, which results in the speed skating group being able to increase their stride rate over that measured in the hockey player.

During the pilot study filming, both groups were instructed to skate as fast as they could over the designated 12 meter interval. However, when viewing the ready position in the group which contained the hockey players it was evident that neither athlete entered a basic ready position. As a result, it may be beneficial to instruct the subjects to enter a ready position (as seen in a game situation) and then begin skating with the intention of accelerating at the fastest rate possible. Another potential area of concern based on the pilot data is the lack of kinematic data which was collected on the upper body during the start. Increased attention should be focused on the upper body during the start due to the potential benefit of a powerful arm swing in increasing the ground reaction forces during the push off.

The pilot study provided the investigator with the opportunity to ensure that protocol and filming techniques would be adequate for data collection during the thesis. The investigator was able to measure the variables of interest using the two camera views which were collected, however, for the purpose of the thesis an overhead camera will need to be implemented in order to measure the angle of skate push off relative to the direction of travel. Overhead video has been collected from an alternative subject on order to make sure the angle of the skate relative to the direction of travel during the first three strides can be measured. The pilot study has provided useful feedback to the investigator in regards to the method and protocol for filming, as well as the rationale for the study of attempting to maximize the effectiveness of the start in both hockey and speed skating due to its significance in performance in both sporting events.

Appendix D

Subject Characteristics

Subject Characteristics

Subject	Variables		
Hockey Players	Age (years)	Height (m)	Weight (kg)
H1	15	1.67	56.69
H2	16	1.7	65.77
H3	15	1.7	52.16
H4	14	1.7	77.1
H5	13	1.57	51.25
H6	15	1.65	63.5
H7	16	1.62	70.3
H8	17	1.6	58.96
H9	16	1.65	61.23
H10	15	1.77	58.96
H11	16	1.65	54.43
H12	15	1.6	60.78
H13	16	1.65	61.23
Mean H	15.31	1.66	60.95
Speed Skaters			
SS1	15	1.7	63.5
SS2	13	1.6	58.96
SS3	14	1.72	72.57
SS4	17	1.65	63.5
SS5	16	1.65	61.23
SS6	16	1.62	61.23
SS7	15	1.6	58.96
SS8	18	1.62	58.96
SS9	16	1.65	61.23
SS10	14	1.62	52
SS11	14	1.6	50
Mean SS	15.27	1.64	60.19

Appendix E

Reliability Test Raw Data

Reliability Test

Trials Measured at End of 3^{rd} Push Off	Knee Flexion (degrees)	Hip Flexion (degrees)	Trunk Lean (degrees)	L. Shoulder Flexion (degrees)	R. Shoulder Extension (degrees)	Ankle Plantarflexion (degrees)	Foot to Hip Distance (rear) (m)	R. Shoulder Abduction (degrees)	L. Shoulder Abduction (degrees)	Hip Abduction (degrees)
Oct 23/2007	20.7	33.6	33.8	74.7	22.3	4.2	0.07	92.7	14.1	21.6
Oct 26/2007	21.3	34.1	33.8	72.3	21	5.3	0.07	90	15.1	20.5
Oct 31/2007	19.3	34.5	32.2	72.2	22.7	4.3	0.07	87.9	15.9	18.8
Nov 6/2007	19.4	31.5	33.9	70	19.1	5.5	0.07	89.8	17.1	17.8
Nov. 14/2007	19.6	32.9	34.3	71	22.5	4.8	0.07	88.3	14	20.2
Mean	**20.06**	**33.32**	**33.60**	**72.04**	**21.52**	**4.82**	**0.07**	**89.74**	**15.24**	**19.78**
S.D.	0.89	1.18	0.81	1.76	1.51	0.58	0.00	1.89	1.30	1.49
Minimum	19.30	31.50	32.20	70.00	19.10	4.20	0.07	87.90	14.00	17.80
Maximum	21.30	34.50	34.30	74.70	22.70	5.50	0.07	92.70	17.10	21.60
Range	2.00	3.00	2.10	4.70	2.60	1.30	0.00	4.80	3.10	3.80
Coefficient of Variance	**0.04**	**0.04**	**0.02**	**0.02**	**0.07**	**0.12**	**0.00**	**0.02**	**0.09**	**0.08**

Appendix F

`Hockey Players Raw Data

Hockey Players (Ready Position)

	Subjects														
Variables	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S 10**	**S 11**	**S 12**	**S 13**	**Mean**	**S.D.**
Trunk Lean from Horizontal (degrees)	38.5	43.2	51.6	44.8	36.5	49.8	33.1	48	43	35.5	34.9	50.1	35	**41.85**	**6.63**
Width of Base of Support (meters) (forwards/backwards)	0.44	0.31	0.37	0.28	0.54	0.29	0.41	0.86	0.56	0.68	0.35	0.29	0.57	**0.46**	**0.18**
Rear Knee Flexion (degrees)	22	72.6	66.2	38.5	48.6	44.2	61.4	74.9	65.6	55.8	92	26.7	43.9	**54.80**	**19.99**
Front Knee Flexion (degrees)	39.1	72.6	66.2	38.5	62	44.2	28	51.8	65.4	53.2	92	26.7	39.5	**52.25**	**18.90**
Rear Hip Flexion (degrees)	63.1	95.1	71.2	73.3	71.8	63.7	104.6	88.1	78.1	81.3	106.2	56.1	95.3	**80.61**	**16.16**
Front Hip Flexion (degrees)	82.1	95.1	71.2	73.3	98.5	63.7	80.3	70.6	78	107.6	106.2	56.1	76.8	**81.50**	**15.96**
Front Ankle Flexion (degrees)	0	20.4	27.8	0	10.5	15.8	0	20.6	0	8.8	32.2	8.4	12.1	**12.05**	**10.87**
Rear Ankle Flexion (degrees)	0	20.4	27.8	0	17.5	15.8	11.3	20	19.8	12.3	32.2	8.4	6.4	**14.76**	**9.71**
L. Shoulder Abduction (degrees)	28.6	0	12.5	7.2	15	13.6	27.5	0	31.3	25	63.5	17.7	10	**19.38**	**16.74**
R. Shoulder Abduction (degrees)	28.6	35.2	12.5	16.9	31.5	24	20.7	29.2	25.1	35	25.5	8.5	10	**23.28**	**9.03**
L. Shoulder Flexion (degrees)	12.1	53.8	21.4	35.9	25.4	21	0	30.3	47.3	48.9	-37.8	14.2	30	**23.27**	**24.00**
R. Shoulder Flexion (degrees)	0	0	21.4	35.9	25.4	0	0	0	47.3	51.2	39.3	0	27.5	**19.08**	**20.04**
Skate Blade relative to Travel (degrees)	53.5	40.1	39.1	43.6	70.5	20.3	5.4	74.2	32.9	40.2	32.8	44.5	75.3	**44.03**	**20.49**

Hockey Players (End of 1st Push Off)

	Subjects														
Variables	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	Mean	S.D.
Rear Hip Flexion (degrees)	31.7	16.1	36.7	30.1	5.2	29.1	30.1	27.1	27.4	23.5	38	22.9	32.7	**26.97**	**8.74**
Rear Knee Flexion (degrees)	12.3	36.4	30.3	6.2	9.9	21.6	19.7	50.4	26.1	43.5	36.8	13.5	28.6	**25.79**	**13.56**
Rear Hip Abduction (degrees)	3.4	25.9	11.9	6.3	5.5	17.7	10.8	16.1	23	17.4	7.3	3.9	15.3	**12.65**	**7.28**
Rear Ankle Plantarflexion (degrees)	0	9.2	-12.2	11.1	6	10	-4.3	-15.4	6.8	0	-11.3	2.9	3.9	**0.52**	**8.86**
Skate Blade relative to Travel (degrees)	108	90.8	96.8	85.3	95.2	97.8	89.9	95.6	69	87.5	100.4	87.3	84.7	**91.41**	**9.47**
Time for Extension Velocity (sec)	0.433	0.583	0.583	0.367	0.4	0.433	0.45	0.316	0.417	0.367	0.45	0.383	0.45	**0.43**	**0.08**
L. Shoulder Abduction (rear) (degrees)	81.3	75.1	84.2	73.7	80.4	88.8	51.9	84.2	47.5	60.1	82	50.6	70.4	**71.55**	**14.30**
R. Shoulder Adduction (front) (degrees)	-41.3	-17.9	-33.9	-18.1	-14.6	-14.2	-25.8	-24	0	-33.1	-4.2	-19.1	-12.4	**-19.89**	**11.72**
L. Shoulder Extension (rear) (degrees)	53.4	54.3	43.8	32.3	62.1	54.9	13.3	29.4	0	12.8	49.8	33.3	36.1	**36.58**	**19.01**
R. Shoulder Flexion (front) (degrees)	42.8	71.1	30.4	45.3	34	53.7	64.9	37.9	71.7	45	31.3	34.4	36.1	**46.05**	**14.78**
Hip Extension Velocity (degrees/sec)	72.5	135.5	62.3	117.7	166.5	79.9	165.6	193.0	121.6	157.5	151.6	86.7	139.1	**126.88**	**41.11**
Knee Extension Velocity (degrees/sec)	22.4	62.09	61.58	88.01	96.75	52.19	92.67	77.53	71.22	33.51	122.67	34.46	34	**65.31**	**29.87**
Time in Double Support (sec)	0.183	0	0.233	0.083	0.066	0.3	0.083	0.133	0.183	0.066	0.3	0.15	0.333	**0.16**	**0.10**

Hockey Players (1st Foot Touchdown)

	Subjects														
Variables	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	Mean	S.D.
Skate position relative to Hip (rear) (meters)	0	0.09	-0.08	0	0.09	0.05	-0.01	0	0.01	0	-0.04	-0.04	-0.04	**0.00**	**0.05**
Knee Flexion at TD (degrees)	76.9	45.7	83.3	63.4	71	74.7	71	80.9	89	80.4	71.3	78.9	81.3	**74.45**	**10.89**
Hip Flexion at TD (degrees)	94.1	55.5	97.3	77.7	83.9	79.7	86.6	93.8	116.7	89.8	94.3	96.1	109.6	**90.39**	**15.09**
Hip Abduction at TD (degrees)	6.6	21	-9.9	13.7	13.2	3	13.6	6.8	13.5	-5	-5.1	-5.3	0	**5.08**	**9.62**
Ankle Dorsiflexion at TD (degrees)	22.4	-9.4	-14.7	4.2	20.9	19	5.2	18.9	16.9	9.3	7.5	14.9	12.9	**9.85**	**11.41**
Trunk Lean from Horizontal (degrees)	45	54.7	43	46.8	45.8	50.7	47.9	45.7	38.5	44.3	35	48.6	41.5	**45.19**	**5.09**
Time in Single Support (sec)	0.266	0.25	0.233	0.216	0.25	0.266	0.216	0.216	0.25	0.233	0.233	0.25	0.216	**0.24**	**0.02**
Distance of Foot Placement in front of hip (m)	0.11	-0.02	0.12	-0.02	0.04	0.04	0.06	0.12	0.22	0.05	0.01	0.11	0.19	**0.08**	**0.07**
L. Shoulder Abduction (degrees)	70.8	58.8	83.9	59.2	78.3	88.7	54	72.6	45.7	50.3	93.5	37.8	44.1	**64.44**	**18.15**
R. Shoulder Adduction (degrees)	-29.7	-16.2	-33.9	-19.6	-13.5	-14.5	-22.7	-36.7	0	-44.3	0	-28.1	-27.6	**-22.06**	**13.29**
L. Shoulder Extension (degrees)	45.7	24.9	42.4	30	45.8	49.2	10.6	35	0	22.9	49.1	29	32.3	**32.07**	**15.03**
R. Shoulder Flexion (degrees)	37.8	35.5	29.9	44.8	18.9	37.3	65.4	24.1	51.4	27.6	27.4	30.7	24.4	**35.02**	**12.75**

Hockey Players (End of 2nd Push Off)

	Subjects														
Variables	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S 10**	**S 11**	**S 12**	**S 13**	**Mean**	**S.D.**
Rear Hip Flexion (degrees)	35.2	15.6	39.7	35.2	27.5	17.3	29.7	40.1	50.2	49.4	42.1	32.1	34.5	**34.51**	**10.47**
Rear Knee Flexion (degrees)	23.6	16.1	33.2	32.5	16.5	13.6	18.6	31.5	36.3	35.5	33	16.2	39.6	**26.63**	**9.35**
Rear Hip Abduction (degrees)	19.1	15.9	16.7	8.3	22.5	18	21.3	21	22.2	24.3	26.3	18.9	27.8	**20.18**	**5.02**
Rear Ankle Plantarflexion (degrees)	16.9	17.5	19.4	26.3	25.5	22.9	13.9	-10.7	12.5	14.4	13	10.8	0	**14.03**	**10.13**
Time for Extension Velocity (sec)	0.25	0.166	0.3	0.2	0.233	0.283	0.25	0.266	0.333	0.283	0.266	0.316	0.283	**0.26**	**0.05**
Skate Blade relative to Travel (degrees)	65.2	60.1	56.3	53.5	68.8	71.6	54	80.8	61.4	64.8	63	60.4	72.3	**64.02**	**7.85**
Hip Extension Velocity (degrees/sec)	235.6	137.4	192.0	212.5	242.1	220.5	227.6	201.9	199.7	142.8	196.2	202.5	265.4	**205.85**	**35.93**
Knee Extension Velocity (degrees/sec)	213.2	178.3	167.0	141.0	233.9	215.9	215.2	185.7	158.3	158.7	144.0	198.4	147.4	**181.30**	**31.45**
Time in Double Support (sec)	0.05	0	0.066	0.033	0.016	0.05	0.033	0.066	0.083	0.066	0.05	0.066	0.033	**0.05**	**0.02**
L. Shoulder Adduction (degrees)	35.9	21.6	13.9	28.6	21.8	-15.2	-8.6	23.8	-7.6	16.6	-7.9	15.6	9.2	**11.36**	**16.22**
R. Shoulder Abduction (degrees)	78.5	0	85.6	74.5	85.7	83.7	69.7	0	74.1	0	81.5	61.8	0	**53.47**	**37.68**
L. Shoulder Flexion (degrees)	72.4	67	67	54.4	46.1	72.6	74.6	52.5	45.6	72.7	19.6	45.1	65	**58.05**	**16.08**
R. Shoulder Extension (degrees)	31.5	45.5	46.7	39	51.4	37.6	0	81.4	38.8	49.5	32.1	0	41.7	**38.09**	**21.03**

Hockey Players (2nd Foot Touchdown)

	Subjects														
Variables	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S 10**	**S 11**	**S 12**	**S 13**	**Mean**	**S.D.**
Skate position relative to Hip (rear) (m)	0	0	-0.01	0.03	-0.02	-0.03	0	-0.03	-0.15	0.04	-0.04	-0.01	0.02	**-0.02**	**0.05**
Knee Flexion at TD (degrees)	66.3	46.5	80.3	76.8	76.2	76.9	73.3	70.7	79.1	71.6	77.2	80.5	73	**72.95**	**8.94**
Hip Abduction (degrees)	11.8	27.1	8.9	14.4	15.4	9.4	10.7	4.1	14.9	8.7	6.1	14.1	11.2	**12.06**	**5.66**
Hip Flexion at TD (degrees)	94.5	55.5	107.7	86.1	99.8	84.6	81.2	106.3	112.1	105.8	99.3	104.6	102.3	**95.37**	**15.33**
Ankle Dorsiflexion at TD (degrees)	10.6	13.5	16.4	26.4	16.2	24.3	13.6	17.3	19.4	18.8	22.3	13.4	16.4	**17.58**	**4.60**
Trunk Lean from Horizontal (degrees)	40.3	56.1	38	46.4	42.3	51.7	51.3	26.7	30.1	31.8	37.7	37.3	33.9	**40.28**	**8.97**
Time in Single Support (sec)	0.25	0.216	0.233	0.216	0.233	0.233	0.216	0.233	0.25	0.233	0.25	0.216	0.216	**0.23**	**0.01**
Distance of Foot Placement in front of hip (m)	0.14	0	0.18	0.02	0.12	0.1	0.08	0.12	0.18	0.12	0.13	0.1	0.13	**0.11**	**0.05**
L. Shoulder Adduction (degrees)	40.4	0	0	26.2	33.1	-12.4	-21.4	7.3	-7.6	10.1	0	13.3	10.8	**7.68**	**17.72**
R. Shoulder Abduction (degrees)	63.6	19	82	70.7	77.7	76.7	57.8	0	74.1	0	63.7	55.7	78.7	**55.36**	**29.43**
L. Shoulder Flexion (degrees)	60	30.6	47.4	43.5	31.7	48.4	39.7	51.6	35.6	46	4.6	50	41.5	**40.82**	**13.64**
R. Shoulder Extension (degrees)	38.4	0	43	34.3	38.6	36.3	0	70.9	37.5	47.2	16	0	12.2	**28.80**	**21.58**

Hockey Players (End of 3rd Push Off)

	Subjects														
Variables	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S 10**	**S 11**	**S 12**	**S 13**	**Mean**	**S.D.**
Rear Hip Flexion (degrees)	46.1	23.9	31.8	27.7	16.8	23.5	25.4	43.2	49.7	38.3	44.4	36.6	40.3	**34.44**	**10.31**
Rear Knee Flexion (degrees)	27	24.2	33	22	13.7	22.9	20.1	24	31.2	31.5	42	25.1	19.6	**25.87**	**7.21**
Rear Hip Abduction (degrees)	21.9	29.9	14.8	14.9	23.3	15.8	12	20.7	31	20	9.9	10.2	25.2	**19.20**	**6.98**
Rear Ankle Plantarflexion (degrees)	14.9	10.2	12.7	19.1	21	11.6	18.9	5.5	16.1	14.9	9.2	4.7	4.9	**12.59**	**5.52**
Time for Extension Velocity (sec)	0.25	0.166	0.266	0.216	0.233	0.266	0.2	0.266	0.333	0.25	0.266	0.25	0.2	**0.24**	**0.04**
Skate Blade relative to Travel (degrees)	48.8	58.4	60.2	41.4	54.1	58.3	64.8	39.3	55.2	39.9	45.9	56.2	68.2	**53.13**	**9.39**
Hip Extension Velocity (degrees/sec)	193.6	190.4	285.3	270.4	356.2	229.7	279.0	237.2	187.4	270.0	201.9	272.0	310.0	**252.54**	**51.43**
Knee Extension Velocity (degrees/sec)	157.2	134.3	177.8	253.7	268.2	204.1	266.0	175.6	133.8	160.8	132.3	221.6	267.0	**196.35**	**53.56**
L. Shoulder Abduction (degrees)	69.6	21.6	0	88.1	84.3	93.2	64.6	113	0	80.4	75	71.3	0	**58.55**	**39.18**
R. Shoulder Adduction (degrees)	-27.4	-11.9	-13.9	-12.1	-14.1	-9.4	-5.2	-13.2	5.6	-20.1	-12.4	-6.9	0	**-10.85**	**8.31**
L. Shoulder Extension (degrees)	26.5	66.2	71.7	59.6	55.6	58.4	17.1	55.6	39.3	43	31.2	17.4	44.8	**45.11**	**18.00**
R. Shoulder Flexion (degrees)	54.7	77	49.7	67.1	58.6	57.7	62.1	20.6	73.1	70.6	28.9	58.3	29.1	**54.42**	**17.89**
Time in Double Support (sec)	0.05	0.016	0.1	0.033	0.033	0.05	0.05	0.033	0.083	0.033	0.05	0.033	0.033	**0.05**	**0.02**

Hockey Players (3rd Foot Touchdown)

	Subjects														
Variables	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S 10**	**S 11**	**S 12**	**S 13**	**Mean**	**S.D.**
Skate position relative to Hip (rear) (degrees)	-0.08	0	-0.03	-0.01	-0.06	-0.03	-0.04	-0.04	-0.11	0.04	-0.07	0	0.04	**-0.03**	**0.04**
Knee Flexion at TD (degrees)	82.6	64.3	78.3	75.9	79	78.9	75.5	84.6	81	79.2	80.3	89.2	89.6	**79.88**	**6.42**
Hip Flexion at TD (degrees)	106.7	97.6	107.3	96.6	102.7	87.7	94.7	110.5	115.8	103.1	87.6	110.3	105.3	**101.99**	**8.70**
Hip Abduction (degrees)	-6.2	12.9	-5.2	-1.6	4.6	9.2	3.3	3.8	-8.3	-3.7	6.1	-6.2	2.1	**0.83**	**6.58**
Ankle Dorsiflexion at TD (degrees)	21.4	7.1	9.3	13.5	13.8	17.8	13	21.3	11.4	16	15.1	17.9	18.5	**15.08**	**4.34**
Trunk Lean from Horizontal (degrees)	36.9	48.4	37.6	42.5	38.7	49.2	45.9	31.7	30	35.7	45.6	33.9	36	**39.39**	**6.33**
Time in Single Support (sec)	0.266	0.233	0.25	0.233	0.233	0.25	0.216	0.25	0.25	0.266	0.216	0.233	0.216	**0.24**	**0.02**
Distance of Foot Placement in front of hip (m)	0.14	0.19	0.19	0.09	0.1	0.09	0.14	0.13	0.19	0.09	0.1	0.09	0.06	**0.12**	**0.04**
L. Shoulder Abduction (degrees)	61.2	21.6	0	86.1	83.1	96.2	74.5	99.8	0	90.6	54.1	76	0	**57.17**	**38.43**
R. Shoulder Adduction (degrees)	-16.1	11	-14.1	-5.1	-8.1	-9.1	0	-11.8	5.6	-14	-20.2	-10.6	5	**-6.73**	**9.47**
L. Shoulder Extension (degrees)	26	39.4	72.7	57.6	60.4	58.4	16.9	55.4	40.2	41.4	10	15.7	40.8	**41.15**	**19.53**
R. Shoulder Flexion (degrees)	48.5	56.5	49.2	66.2	41.2	43.9	54.1	10.4	77.1	62	15.1	54.8	29.3	**46.79**	**19.20**

Hockey Players (Additional Variables)

	Subjects														
Variables	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S 10**	**S 11**	**S 12**	**S 13**	**Mean**	**S.D.**
Time to 6 m (sec)	1.43	1.31	1.39	1.32	1.36	1.34	1.35	1.27	1.5	1.31	1.36	1.38	1.35	**1.36**	**0.06**
Time from 6 to 12 m (sec)	1.03	0.98	1.03	0.98	0.98	1.05	0.98	0.98	1.05	1	0.99	0.97	0.98	**1.00**	**0.03**
Total Time (sec)	2.46	2.29	2.42	2.3	2.34	2.39	2.33	2.25	2.55	2.31	2.35	2.35	2.33	**2.36**	**0.08**
Step Rate (steps/sec)	3.21	3.83	2.85	3.75	3.27	3.27	3.27	3.1	3.05	3.1	3.39	3.05	3.39	**3.27**	**0.27**
Time for 1st Three Steps (sec)	0.934	0.784	1.051	0.8	0.917	0.917	0.917	0.967	0.984	0.967	0.884	0.984	1.001	**0.93**	**0.08**
Velocity at 6 m (m/sec)	5.04	5.25	5.08	5.55	5.84	5.14	5.1	5.68	4.92	5.98	5.9	5.51	5.86	**5.45**	**0.38**
Velocity at 12 m m/sec)	5.82	6.14	5.87	6.21	6.01	5.91	6.18	6.57	5.6	5.98	6.05	6	6.15	**6.04**	**0.23**

Appendix G

Speed Skating Raw Data

Speed Skaters (Ready Position)

	Subjects												
Variables	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**Mean**	**SD**
Trunk Lean from Horizontal (degrees)	28.5	8.8	27.2	13.8	9.9	18.4	15.4	29.3	13	22.1	9	**17.76**	**7.87**
Width of Base of Support (meters) (forwards/backwards)	0.67	0.52	0.64	0.63	0.88	0.78	0.54	0.65	0.96	0.65	0.61	**0.68**	**0.14**
Rear Knee Flexion (degrees)	74.8	51.4	78.5	49.3	65.4	38.1	67.3	71.4	82.1	72.8	63.7	**64.98**	**13.55**
Front Knee Flexion (degrees)	100.4	84	70.6	82	78.8	77.8	83.9	103.5	72.2	87.6	84.1	**84.08**	**10.25**
Rear Hip Flexion (degrees)	98	126.2	111.6	109	106.9	97	106.2	100	128.5	112.1	113.5	**109.91**	**10.30**
Front Hip Flexion (degrees)	150.6	138.6	98.5	132	146.1	128.6	124.2	130.8	136.1	136.1	143.2	**133.16**	**13.89**
Front Ankle Flexion (degrees)	21.7	0	4.8	0	-7.6	-13	16.1	-1.7	-5	-10.7	-4.3	**0.03**	**10.68**
Rear Ankle Flexion (degrees)	19.3	18.5	16.6	16.6	19.8	5.9	15.5	20.8	14	20.2	21	**17.11**	**4.37**
L. Shoulder Abduction (degrees)	45.9	0	71.9	-14	31.8	-27.2	7.7	79.9	65.7	35.9	0	**27.05**	**36.36**
R. Shoulder Abduction (degrees)	78.3	53.5	78.9	42.9	73.8	26.5	29.5	-43.7	30	58.9	65.2	**44.89**	**35.27**
L. Shoulder Flexion (degrees)	20.5	84.2	0	78.2	106.2	109.4	83.6	79.9	121	123.2	98.2	**82.22**	**39.18**
R. Shoulder Flexion (degrees)	-13.2	-11.7	-74.5	0	-19.9	-10.1	-15.7	-43.7	-38.4	-37	-50.4	**-28.60**	**22.14**
Skate Blade relative to Travel (degrees)	94.9	71.7	67.6	67.5	72	73.6	75.1	77.4	n/a	n/a	n/a	**74.98**	**8.74**
Trunk Lean from Horizontal (degrees)	28.5	8.8	27.2	13.8	9.9	18.4	15.4	29.3	13	22.1	9	**17.76**	**7.87**

Speed Skaters (End of 1st Push Off)

	Subjects												
Variables	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**Mean**	**SD**
Rear Hip Flexion (degrees)	47.8	36.3	25.6	31.6	32.8	31.9	40.1	44.7	33.2	35	46.6	**36.87**	**7.07**
Rear Knee Flexion (degrees)	18.1	8.5	29.2	14.8	18.5	11.7	9.5	37	17.3	32	23.5	**20.01**	**9.39**
Rear Hip Abduction (degrees)	5.7	11.8	11.8	16.6	8.2	13.3	21.2	17.9	9.4	14.9	12.4	**13.02**	**4.48**
Rear Ankle Plantarflexion (degrees)	-7.5	12.3	2.7	13.7	4.3	8.2	13.2	-13.4	7.5	-6.7	0.8	**3.19**	**9.12**
Skate Blade relative to Travel (degrees)	90	76.9	90	78.3	73.2	76.5	79.6	85	n/a	n/a	n/a	**81.19**	**6.38**
Time for Extension Velocity (sec)	0.517	0.45	0.583	0.5	0.35	0.35	0.4	0.467	0.367	0.4	0.466	**0.44**	**0.07**
L. Shoulder Abduction (rear) (degrees)	78.7	117.2	38.5	102.6	95.6	109.6	117.3	89.1	101.9	99.5	114.7	**96.79**	**22.75**
R. Shoulder Adduction (front) (degrees)	-26.2	30.1	-76.3	18.6	27.1	-16.5	23.9	-49.4	-33.8	-43.5	17.1	**-11.72**	**36.87**
L. Shoulder Extension (rear) (degrees)	91.3	76.8	38.5	44.3	60.7	69.1	61	31.1	44.7	61.8	51.7	**57.36**	**17.66**
R. Shoulder Flexion (front) (degrees)	87.4	45	64.1	52.1	49.1	64	60.4	78.2	58.9	60	88.4	**64.33**	**14.57**
Hip Extension Velocity (degrees/sec)	198.8	199.8	147.5	150.6	211.7	186.0	165.3	134.9	257.6	192.8	143.6	**180.77**	**36.69**
Knee Extension Velocity (degrees/sec)	109.7	95.3	84.6	69.0	134.0	75.4	154.8	73.7	175.1	102.0	86.3	**105.43**	**35.04**
Time in Double Support (sec)	0.033	0.016	0.133	0.033	0.033	0.016	0.033	0.066	0.016	0.066	0.066	**0.05**	**0.03**

Speed Skaters (1st Foot Touchdown)

	Subjects												
Variables	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Mean	SD
Skate position relative to Hip (rear) (meters)	-0.02	0.11	-0.04	0.05	0.04	0.07	0.08	-0.04	0.07	-0.04	0.01	**0.03**	**0.05**
Knee Flexion at TD (degrees)	80.1	79	52.9	76	77.2	71.9	73.6	84.8	75.8	87.5	81.5	**76.39**	**9.06**
Hip Flexion at TD (degrees)	105.8	103.3	87.3	96.1	99.2	91.3	97.8	116.8	94.9	116.5	120.5	**102.68**	**11.06**
Hip Abduction at TD (degrees)	-3.1	24.1	-28.3	25	8.1	24.3	32.8	7.5	16.9	-9.5	0	**8.89**	**18.20**
Ankle Dorsiflexion at TD (degrees)	16.9	11.4	4.9	6	9	7.5	7	10.5	33.5	10.5	11.6	**11.71**	**7.94**
Trunk Lean from Horizontal (degrees)	34.2	36.7	33.4	42	34.3	47.9	40.1	30.7	37.4	34.5	23	**35.84**	**6.39**
Time in Single Support (sec)	0.3	0.3	0.266	0.283	0.233	0.266	0.283	0.266	0.25	0.316	0.266	**0.28**	**0.02**
Distance of Foot Placement in front of hip (m)	0.1	0.07	0.21	0.07	0.08	0.04	0.06	0.16	0.08	0.24	0.18	**0.12**	**0.07**
L. Shoulder Abduction (degrees)	78.7	117.2	81.5	101.8	97.9	101	117.2	85.2	94.3	99.5	118.2	**99.32**	**14.05**
R. Shoulder Adduction (degrees)	-26.2	30.1	-23.4	-6.3	-22.7	-19.5	26.7	-49.6	-37.3	-43.5	-18.1	**-17.25**	**25.66**
L. Shoulder Extension (degrees)	96.9	81.3	103.5	44.2	18.4	53.4	58.2	21.2	28.7	61.8	50.7	**56.21**	**28.55**
R. Shoulder Flexion (degrees)	78.3	65.9	51.3	44.1	62	31.1	55.5	51.6	43.5	60	92.5	**57.80**	**17.04**

Speed Skaters (End of 2nd Push Off)

	Subjects												
Variables	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**Mean**	**SD**
Rear Hip Flexion (degrees)	41.6	29.5	59.6	48.6	53.3	38.1	38.2	57.3	41.7	53.7	53.1	**46.79**	**9.53**
Rear Knee Flexion (degrees)	28.7	10.1	38.4	39.6	34.8	20.1	27.4	45.5	28.3	32.8	42	**31.61**	**10.27**
Rear Hip Abduction (degrees)	20.6	20.8	12	10.4	11.5	10.7	18.7	21.9	15.6	17.5	16.6	**16.03**	**4.30**
Rear Ankle Plantarflexion (degrees)	-14.8	14.1	-5.7	7.2	-2.2	6.2	2.7	-5.4	5.3	0	6.9	**1.30**	**7.99**
Time for Extension Velocity (sec)	0.3	0.283	0.4	0.266	0.233	0.216	0.266	0.283	0.233	0.35	0.316	**0.29**	**0.05**
Skate Blade relative to Travel (degrees)	51.1	45.9	31	47.1	60.1	48.9	44.2	38.8	n/a	n/a	n/a	**45.89**	**8.57**
Hip Extension Velocity (degrees/sec)	214.0	260.8	69.3	178.6	197.0	246.3	224.1	210.3	228.3	179.4	213.3	**201.93**	**50.64**
Knee Extension Velocity (degrees/sec)	171.3	243.5	36.3	136.6	182.0	239.8	173.7	138.9	203.9	156.3	125.0	**164.28**	**57.79**
Time in Double Support (sec)	0.016	0.033	0.05	0.016	0.033	0.016	0.033	0.033	0.016	0.033	0.066	**0.03**	**0.02**
L. Shoulder Adduction (degrees)	27	34.3	32	26.6	19.6	9.5	18.1	26.2	-17.8	20	15	**19.14**	**14.28**
R. Shoulder Abduction (degrees)	108.6	113	0	96.5	113.3	105.7	97.3	103.9	118.8	95	90	**94.74**	**32.65**
L. Shoulder Flexion (degrees)	82.9	77.3	62.5	77.9	86.1	46.9	75.3	86.5	45.2	102.6	86.4	**75.42**	**17.48**
R. Shoulder Extension (degrees)	77.8	73.1	57	59.3	58.1	45.1	23.3	32.8	59.9	53.6	51.1	**53.74**	**15.81**

Speed Skaters (2nd Foot Touchdown)

	Subjects												
Variables	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Mean	SD
Skate position relative to Hip (rear) (meters)	-0.03	-0.03	0.02	0	0.05	0.07	-0.02	0.09	0.12	0.04	-0.06	**0.02**	**0.06**
Knee Flexion at TD (degrees)	82.9	78.8	43.1	74.5	68.3	76.2	73.1	79	71.8	71.4	81.7	**72.80**	**10.84**
Hip Flexion at TD (degrees)	7.4	5.5	16.1	-5.4	16.5	16.2	-3.7	24.3	24.3	26.2	-5.2	**11.11**	**12.08**
Hip Abduction at TD (degrees)	106.7	113.4	90.6	110.6	107.7	97.5	95.5	99.6	95.8	122.5	120.6	**105.50**	**10.61**
Ankle Dorsiflexion at TD (degrees)	26.2	16.5	-6.3	9.2	8.7	15.5	14.6	20.2	15.7	2.8	20.2	**13.03**	**9.03**
Trunk Lean from Horizontal (degrees)	36.4	27.4	34.1	30.3	29.1	45.7	39.9	25.8	36.9	26.7	25.7	**32.55**	**6.58**
Time in Single Support (sec)	0.283	0.25	0.25	0.266	0.25	0.233	0.266	0.25	0.233	0.333	0.283	**0.26**	**0.03**
Distance of Foot Placement in front of hip (m)	0.16	0.12	0.16	0.15	0.14	0.18	0.06	0.05	0.13	0.3	0.19	**0.15**	**0.07**
L. Shoulder Abduction (degrees)	30	25.9	32	26.6	25.4	0	18.3	18.3	-26.9	20	15	**16.78**	**16.94**
R. Shoulder Adduction (degrees)	108	108.8	0	96.5	109.9	103	97.3	94.3	105.6	100	98.5	**92.90**	**31.27**
L. Shoulder Extension (degrees)	71.6	66.9	59.7	69.3	78.4	23.1	55.6	54.3	25.7	89.7	83.1	**61.58**	**21.41**
R. Shoulder Flexion (degrees)	75.9	61.6	58.3	33	64.7	32.7	23.3	38.9	39	56.9	46.6	**48.26**	**16.31**

Speed Skaters (End of 3rd Push Off)

	Subjects												
Variables	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Mean	SD
Rear Hip Flexion (degrees)	49	48.8	41.5	38.6	44.2	29.7	39	42.7	43.5	38.8	61.5	**43.39**	**8.03**
Rear Knee Flexion (degrees)	47.8	26.6	12	21.3	21.5	26.3	23.7	32.3	33.8	22.1	30.4	**27.07**	**9.17**
Rear Hip Abduction (degrees)	8.4	9.4	13.2	15.5	6.4	11.5	14.9	20.5	5.5	19.6	12.6	**12.50**	**4.93**
Rear Ankle Plantarflexion (degrees)	-50.7	13.3	21.4	19.6	15.3	12	14.1	22.5	-31.7	10.7	9.3	**5.07**	**23.65**
Time for Extension Velocity (sec)	0.266	0.233	0.333	0.266	0.25	0.2	0.233	0.25	0.183	0.333	0.316	**0.26**	**0.05**
Skate Blade relative to Travel (degrees)	36.8	48.9	52.1	32.4	35.7	43.6	49.7	31.5	n/a	n/a	n/a	**41.34**	**8.26**
Hip Extension Velocity (degrees/sec)	216.9	277.3	147.5	270.7	254.0	339.0	242.5	227.6	221.3	251.4	187.0	**239.55**	**49.87**
Knee Extension Velocity (degrees/sec)	132.0	224.0	93.4	200.0	187.2	249.5	212.0	186.8	207.7	148.1	162.3	**182.08**	**44.89**
L. Shoulder Abduction (degrees)	114.6	113	107.4	103.2	111.9	110.3	102.7	80.3	115.4	110.4	126.6	**108.71**	**11.44**
R. Shoulder Adduction (degrees)	28.9	37.9	-30.2	26.6	25.8	18.8	19.7	-41.1	-4.7	-8.4	0	**6.66**	**25.67**
L. Shoulder Extension (degrees)	67.8	54.5	78.3	61.6	56.4	53.8	72.5	10.8	72.4	68.3	44.8	**58.29**	**18.65**
R. Shoulder Flexion (degrees)	74	64.9	0	44.9	36.7	66.2	79.5	36.6	57.1	105.2	88.2	**59.39**	**28.98**
Time in Double Support (sec)	0.033	0.016	0.1	0.016	0.016	0.016	0.016	0.05	0.016	0.05	0.033	**0.03**	**0.03**

Speed Skaters (3rd Foot Touchdown)

	Subjects												
Variables	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**Mean**	**SD**
Skate position relative to Hip (rear) (meters)	-0.03	0.01	-0.02	-0.02	0.06	0.07	0	-0.03	0.04	-0.07	-0.04	**0.00**	**0.04**
Knee Flexion at TD (degrees)	79	71.5	65.4	78.6	62.5	74.9	75.6	83.6	60.9	76.9	74.9	**73.07**	**7.25**
Hip Flexion at TD (degrees)	109.1	103	101.6	108.3	97.3	97.8	101.1	113.1	90	121.9	125.1	**106.21**	**9.07**
Hip Abduction at TD (degrees)	-2.6	7.5	3.5	8	5.4	17.6	14	8.3	10.8	-4.5	-3.3	**5.88**	**7.14**
Ankle Dorsiflexion at TD (degrees)	19.8	9.3	7.3	10.3	11.8	11	4.8	17	21.8	4.4	11.7	**11.75**	**5.69**
Trunk Lean from Horizontal (degrees)	35.6	35.3	35.8	39.7	32.6	45.3	42.8	32	43	29.8	19.1	**35.55**	**7.39**
Time in Single Support (sec)	0.266	0.266	0.266	0.283	0.233	0.25	0.233	0.25	0.266	0.333	0.3	**0.27**	**0.03**
Distance of Foot Placement in front of hip (m)	0.18	0.11	0.21	0.2	0.13	0.17	0.19	0.17	0.17	0.34	0.19	**0.19**	**0.06**
L. Shoulder Abduction (degrees)	118.6	109.8	98.5	103	113.2	102.9	109.3	70.7	114.8	116.3	126.2	**107.57**	**14.56**
R. Shoulder Adduction (degrees)	43	30.1	-39.5	26.6	29.2	20.8	14.8	-28	-13.5	-12	0	**6.50**	**26.78**
L. Shoulder Extension (degrees)	87.5	60.4	0	53.4	25.8	57	63.2	-40.2	71.8	69.9	47.1	**45.08**	**36.86**
R. Shoulder Flexion (degrees)	66.3	42.8	62	53.2	51.9	53.4	56.7	70.6	50.1	73.9	75	**59.63**	**10.64**

Speed Skaters (Additional Variables)

	Subjects												
Variables	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**Mean**	**SD**
Time to 6 m (sec)	1.52	1.47	1.87	1.42	1.55	1.58	1.5	1.6	1.6	1.634	1.601	**1.58**	**0.12**
Time from 6 to 12 m (sec)	0.96	0.97	1.1	0.98	0.97	0.98	0.98	0.98	0.93	1.067	1.051	**1.00**	**0.05**
Total Time (sec)	2.48	2.44	2.97	2.4	2.52	2.56	2.48	2.58	2.53	2.702	2.652	**2.57**	**0.16**
Step Rate (steps/sec)	2.85	2.95	2.46	2.99	3.33	3.75	2.76	2.95	3.27	2.49	2.57	**2.94**	**0.39**
Time for 1st Three Steps (sec)	1.051	1.017	1.217	1.001	0.9	0.8	1.084	1.017	0.917	1.201	1.167	**1.03**	**0.13**
Velocity at 6 m (m/sec)	6.78	6.45	4.87	6.44	5.68	5.69	5.98	5.81	6.73	5.31	5.02	**5.89**	**0.66**
Velocity at 12 m (m/sec)	7.17	6.7	6.04	6.82	6.57	6.18	6.34	6.63	7.25	5.33	5.46	**6.41**	**0.62**

Appendix H

Hockey Starting Technique Checklist

Hockey Starting Technique Checklist

General Comments:

- Hockey players may benefit from emphasizing a "running action" during their initial 3 strides (similar to that taught in speed skating) in order to emphasize quick feet and allow for a high stride frequency.
- Hockey players need to emphasize a more flexed ready position to initiate the start. The athletes should have between 60-70 degrees of knee flexion and the 35 degrees of trunk lean from the horizontal as well as maintain these angles during the initial 3 strides (see Figure 1)

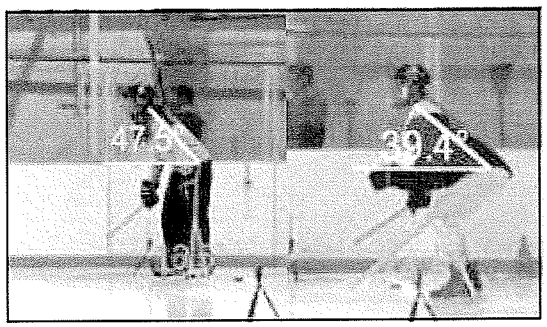

Figure 1: Note how the athlete on the right has entered a much more flexed ready position than the athlete on the right. This will allow the athlete to go through a larger range of motion during her first push off and generate more drive from the ice.

- Hockey players need to emphasize a high stride frequency (which can be increased by minimizing the time spent in single support) in order to have more periods of force production during the initial starting sequence.
- It is important for hockey players to emphasize a high angular velocity for both hip and knee extension, as this will allow them to increase the force they can apply to the ice. This can be achieved by going through a moderate range of motion over as short of time as possible, therefore allowing for a greater angular velocity at the joint.
- Hockey players need to emphasize positioning their push off skate at as close to 90 degrees from the direction of travel as possible and with each successive push off, the angle should be decreased to allow for a more horizontal push off (see Figure 2)
- It is important for hockey players to have an efficient arm swing, where the shoulders are flexed and extended during the first push off. Once the athlete begins utilizing a more lateral push off (during the second and third push offs) the athlete should begin to incorporate more lateral movement with the shoulders, therefore going into shoulder abduction and adduction during the skating stride.

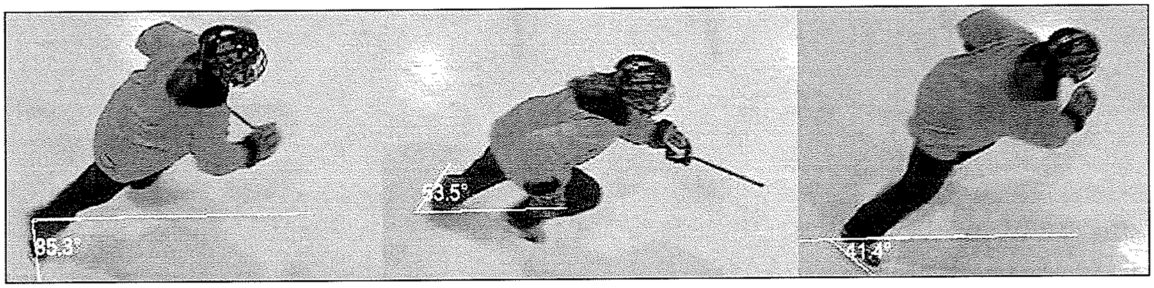

Figure 2: Note how the skater begins pushing directly backwards during the first push off (on left) and then with each successive push off the athlete utilizes more of a lateral push off.

- The timing of the shoulder movements must also be synchronized with the force producing action of the lower body. As the athlete extends and abducts at the right hip, the right shoulder should be moving into flexion and adduction allowing these two movements to occur in the opposite direction of each other, therefore increasing the ground reaction forces applied to the ice (see Figure 3)

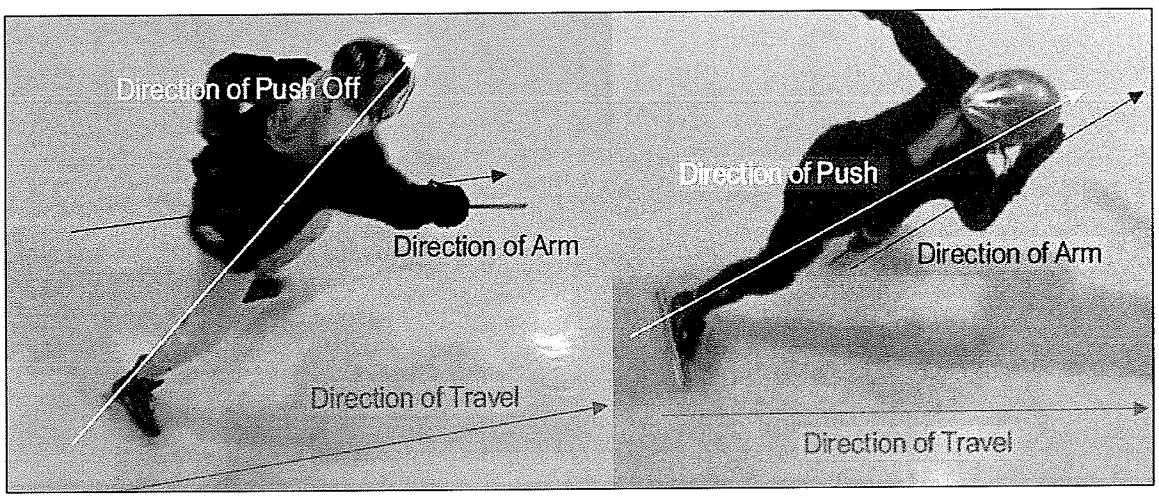

Figure 3: Note how the speed skater on the right has directed her arm swing in the opposite direction as the push off, however, the hockey player has moved her arm directly forwards.

- Hockey players should not go into full extension at the hip and knee during the push off, as this tends to have a negative affect on the athlete's stride frequency during the start. Ideally, the athlete should have between 20 and 30 degrees of knee flexion and hip flexion remaining at the end of the push off.
- It is important for hockey players to emphasize planting their support skate directly underneath their center of gravity in order to allow them to have a full weight shift onto the skate, but minimize any potential effects which could occur

if the skate is planted ahead of the center of gravity. When the skate lands ahead of the center of gravity, it has a tendency to cause the athlete to slow down or decelerate while their center of gravity moves ahead of their support skate (see Figure 4).

- During skate touchdown, the athlete must also plant the skate with their hip laterally rotated in order to plant the skate in an optimal position to initiate the upcoming push off by driving forwards off of the skate.

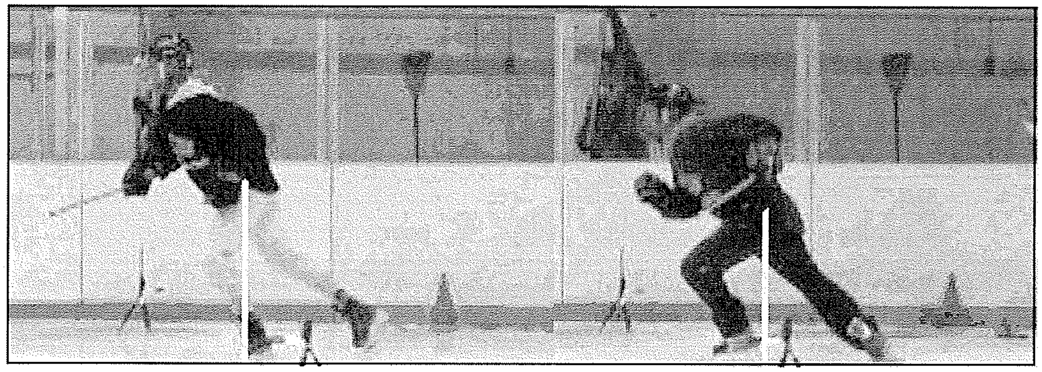

Figure 4: Note how the athlete on the left had laterally rotated her hip and planted her skate directly underneath her hip, however, the athlete on the right has planted her skate well in front of her hip which may result in a slight deceleration.

Appendix I

Speed Skating Start Checklist

Speed Skating Start Checklist

General Comments:

- Speed skaters need to emphasize a “running action” when performing the start in order to allow for a high stride frequency. As a result, the athlete must emphasize spending a very small amount of time in double support during the initial three strides (see Figure 1)

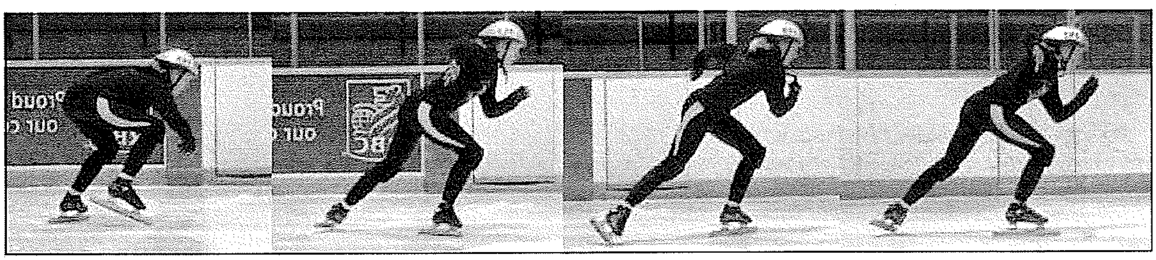

Figure 1: Note how there is a very small overlap between skate touchdown and the end of the push off. It is important for the athlete to emphasize a slight airborne phase in order to allow for the recovery skate to be planted under the center of gravity and initiate the upcoming push off.

- It has been recommended that a small airborne phase should be emphasized between the end of the first push off and the beginning of first foot touchdown. This is indicative of a powerful drive from the starting line.
- In the ready position, the speed skater should emphasize a low flexed position with a horizontal trunk and 70 to 80 degrees of knee flexion in the rear leg (note the low flexed position seen in figure 1 as the skater begins the start)
- Speed skaters need to emphasize skating with a moderate degree of knee flexion during the initial 2-3 strides of approximately 70 degrees, but then increase their angle of knee flexion to closer to 90 degrees when they reach steady state velocity.
- Speed skaters should not go into full extension at the hip and knee during the push off, as this tends to have a negative affect on the athlete’s stride frequency during the start. Ideally, the athlete should have between 20 and 30 degrees of knee flexion and hip flexion remaining at the end of the push off.
- Speed skaters need to emphasize positioning their push off skate at as close to 90 degrees from the direction of travel as possible in the ready position and with each successive push off, the angle should be decreased to allow for a more horizontal push off (see Figure 2).

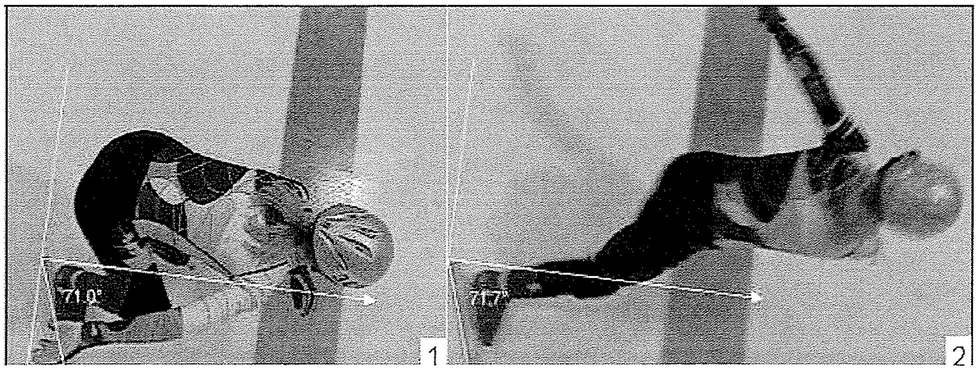

Figure 2: Note how the angle of the skate has maintained constant from the ready position (left) to the end of the 1st push off (right). This is why it is important for the athlete to begin with the skate angled to 90 degrees during the ready position.

- It is important for the speed skaters to emphasize planting their support skate with a laterally rotated hip at the appropriate angle for the upcoming push off in order to allow the skater to initiate the upcoming push off at the instant of skate touchdown.
- It is important for speed skaters to emphasize planting their support skate directly underneath their center of gravity in order to allow them to have a full weight shift onto the skate, but minimize any potential effects which could occur if the skate is planted ahead of the center of gravity. When the skate lands ahead of the center of gravity, it has a tendency to cause the athlete to slow down or decelerate while their center of gravity moves ahead of their support skate.
- It is important for speed skaters to have an efficient arm swing, where the shoulders are flexed and extended during the first push off and begin to utilize a greater degree of shoulder abduction and adduction when the skater begins to push more in the lateral direction (during the second and third push off) (see Figure 3)

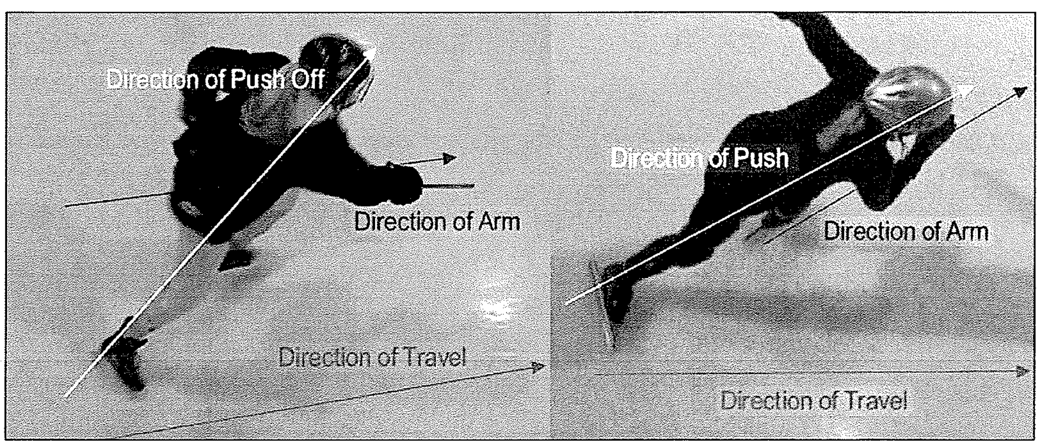

Figure 3: Note how the speed skater on the right has directed her arm swing in the opposite direction as the push off, however, the hockey player has moved her arm directly forwards. The movement seen in the speed skater will allow for a more efficient transfer of force to the ice.

- The timing of the shoulder movements must also be synchronized with the force producing action of the lower body. As the athlete extends and abducts at the right hip, the right shoulder should be moving into flexion and adduction allowing these two movements to occur in the opposite direction of each other, therefore increasing the ground reaction forces applied to the ice.
- Speed skaters need to emphasize a high angular velocity for both hip and knee extension in order to increase their ability to apply force to the ice.