Ground Reaction Forces Produced by Two Different Hockey Skating Arm Swing Techniques

by:

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Abstract

The main purpose of this study was to measure the differences in ground reaction forces (GRFs) produced from an anteroposterior versus a mediolateral style hockey skating arm swing. Twenty four elite level female hockey players performed each technique while standing on a ground mounted force platform, all trials were filmed using two video cameras. Force data was assessed for peak scaled GRFs in the frontal and sagittal planes, and resultant GRF magnitude and direction. Upper limb kinematics were assessed from the video using Dartfish video analysis software, confirming that the subjects successfully performed two significantly distinct arm swing techniques. The mediolateral arm swing used a mean of 18.38° of glenohumeral flexion/extension and 183.68° of glenohumeral abduction/adduction while the anteroposterior technique used 214.17° and 28.97° respectively. The mediolateral arm swing produced 37% greater frontal plane and 33% lesser sagittal plane GRFs than the anteroposterior arm swing. The magnitudes of the resultant GRFs were not significantly different between the two techniques however the mediolateral technique produced a resultant GRF with a significantly larger angle from the direction of travel (44.44°) as compared to the anteroposterior technique (31.60°). The results of this study suggest that the direction of GRFs produced by the mediolateral arm swing more consistent with the direction of lower limb propulsion, perhaps resulting in a greater contribution to high velocity skating. Based on the findings from the present study ice hockey skaters should perform the mediolateral arm swing to maximize the effective GRFs produced with each stride.

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CHAPTER I

Introduction

General Overview

The contribution of the arm swing to skating speed in forward hockey skating is less well understood than the contributions of the lower body as the majority of research is focused on lower body mechanics. The function of upper limb movement has been studied with regard to activities such as walking (Ortega, Fehlman, & Farley, 2008; Umberger, 2008), running (Arellano & Kram; Bhowmick & Bhattacharyya, 1988; Miller, Caldwell, Van Emmerik, Umberger, & Hamill, 2009), horizontal jumping (Ashby & Heegaard, 2002; Hara, Shibayama, Arakawa, & Fukashiro, 2008), and vertical jumping (Cheng, Wang, Chen, Wu, & Chiu, 2008; Feltner, Fraschetti, & Crisp, 1999; Hara, Shibayama, Takeshita, & Fukashiro, 2006; Harman, Rosenstein, Frykman, & Rosenstein, 1990; Lees, Vanrenterghem, & De Clercq, 2006; Shetty & Etnyre, 1989) but there has been very little research (Bracko, Fellingham, & Lyons, 1996) describing the function of the arms in skating activities.

Arm movements in travelling sport skills, such as running, jumping and skating where the primary force producing action occurs in the legs, can contribute to performance. The trunk and upper limbs facilitate ideal lower body mechanics by opposing and stabilizing the rotational movements of the lower body (Miller et al., 2009; Umberger, 2008). Forceful upward movement of the

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upper limbs can produce ground reaction forces that if used properly can help increase propulsive forces used for travelling sport skills (Dapena, 1988; Harman et al., 1990; Payne, Slater, & Telford, 1968; Shetty & Etnyre, 1989). Studies show that the faster and more powerful the arm swing the greater the resultant forces that can be used to propel the athlete in the direction of desired travel (Feltner, Bishop, & Perez, 2004; Hara et al., 2006; Lees et al., 2006). To date the only study that focuses specifically on the direction of the arm swing was done by Hara et al. in 2008 which examined the effect of arm swing direction of horizontal forward and backward jumping. The arm swing techniques studied included only sagittal plane arm swing techniques. The results of this study showed that the arm swing should occur in the same direction as the jump, that is the arms swing forward when the direction of travel is forward and the arms should swing backward if the jump is to travel backward.

Role of the Arm Swing in Forward Hockey Skating

Arm swing direction and the range of motion used may affect forward hockey skating performance. Certain features of ideal forward hockey skating mechanics should be considered in the analysis of arm swing techniques. Elite skaters use a large range of trunk rotation about the longitudinal axis of the body (Alexander, Hayward, & Taylor, 2010; Edwards, 2009). In order to maintain balance the upper limb movements should act to counter the angular motion of the lower body (Miller et al., 2009; Umberger, 2008) which will stabilize the body

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for travel in the forward direction. As the right leg pushes against the ice in a posterolateral direction the trunk and shoulders rotate to the left. The upper limbs should swing in a motion that is opposite to the actions of the lower limbs. This technique allows the athlete to maximize effective force production and transmission for high velocity forward skating.

The angle of push during propulsion is a result of the nature of skate blade to ice contact, which requires that propulsive forces be directed in a direction that is not parallel to the direction of travel (Hache, 2002; Humble & Gastwirth, 1988; Roy, 1977). If a skater were to push directly backward as in walking or running the skate would simply slide backward on the ice surface resulting in lost propulsive forces and very little forward motion of the athlete. The skater must apply a partially lateral force that is perpendicular to the long edge of the skate blade in order to increase friction between the blade and ice to produce forward motion (Hache, 2002). Use of an arm swing can create ground reaction forces (Cheng et al., 2008; Feltner et al., 2004; Miller et al., 2009; Umberger, 2008) that may help to propel the skater along the ice. The ground reaction forces produced by the arm swing should act in the same direction in which the skater is pushing against the ice with the leg in order to actively contribute to forward skating velocity. It has been shown that lateral ground reaction forces are desirable for high velocity forward hockey skating (Roy, 1977).

Forward Hockey Skating Arm Swing Techniques

Two styles of arm swing are commonly taught to hockey players though controversy exists as to which style is more likely to result in faster skating. The mediolateral arm swing uses glenohumeral flexion and adduction on the forward movement and extension and abduction on the backward movement, it occurs in both the frontal and sagittal planes, (see Figure 1).

Figure 1: A hockey player performs the mediolateral arm swing during the forward skating stride.

This style of arm swing is easily observed in speed skaters who swing the arms sideways, wide of the body corresponding to the sideways push of the skates on the ice (Alexander et al., 2010). The shoulders must abduct and adduct to counter the direction of push of the skates in the sideways directions, this will help "maintain balance, momentum, and increased velocity" (Edwards, 2009).

The anteroposterior arm swing is comprised of almost entirely sagittal plane glenohumeral flexion and extension (see Figure 2).

Figure 2: A hockey player performs the anteroposterior arm swing during the forward skating stride (Stamm, 2000).

This technique is taught by many hockey coaches (Bracko, 1999) and more closely mimics that seen in running (Glantz, 2010; Nauman, 2009; Rhoads, 2010; Stamm, 2000).

The ground reaction forces resulting from the contrasting arm swing techniques have not yet been examined. For a complete understanding of the function of the arm swing in maximum velocity forward hockey skating it is necessary consider both the resulting properties of ground reaction forces and the synchronicity of upper and lower body movements. The benefits of a forceful arm swing have long been understood by coaches in running and jumping sports, hockey coaches are beginning to use this concept in application to skating though controversy exists over the arm swing technique that is most beneficial to high velocity forward hockey skating. In order to examine the contribution of the arm swing to forward hockey skating velocity ground reaction forces resulting from the two arm swing techniques will be assessed.

Purpose of Study

The primary purpose of the study is to measure the differences in ground reaction forces produced from an anteroposterior versus a mediolateral style arm swing. To do this, subjects must successfully perform the two contrasting styles of arm swing while standing on a force plate. A secondary purpose is to relate the findings of this study to ideal forward hockey skating technique.

Hypotheses

1. Subjects will correctly perform the mediolateral and anteroposterior arm swings producing distinctly different movement patterns while standing on a force plate.

2. The mediolateral arm swing will produce lower peak sagittal plane ground reaction forces and higher peak frontal plane ground reaction forces than the anteroposterior arm swing.

3. The resultant ground reaction forces of the two arm swing techniques will be of similar magnitude but the mediolateral arm swing will produce a larger angle of the force vector from the sagittal plane than the anteroposterior arm swing.

Rationale for the Study

High performance athletes rely on the sport sciences to research and disseminate new information in the pursuit of athletic excellence. Coaches, trainers and athletes seek methods of improving competitive performance

through biomechanical analysis of movement patterns, including kinetic and kinematic variables. Forward skating in hockey is a fundamental skill necessary for the success of any hockey player. Athletes who can skate effectively will have an on ice advantage, being better able to get into position quickly whether on the offensive or defensive play. Skating is a basic skill in hockey that should be mastered at an early stage in an athlete's development.

The lower body kinematics and kinetics of the skating stride have been researched and described in the literature (Alexander, Taylor, & Shackel, 2007; Bracko et al., 1996; Edwards, 2009; Greer, 1990; Humble & Gastwirth, 1988; Marino, 1977; Marino & Weese, 1979; Page, 1977; Stidwill et al., 2010; Upjohn, Turcotte, Pearsall, & Loh, 2008) leading to a general consensus on ideal technique for fast and efficient skating. Only one author has studied the role of the arm swing in hockey skating (Bracko et al., 1996) and many questions remain. The role of the arms and trunk are not well understood and further research is needed to determine the most effective use of the upper body in forward hockey skating. This information would help coaches teach players more effective skating technique which would benefit their game performance.

To date there have been no studies located investigating ground reaction forces produced with the type of arm swing used in hockey skating. There is also limited research on the most biomechanically effective arm swing in forward hockey skating (Bracko et al., 1996). Because of a limited base of information on

the topic this study will attempt to lay the groundwork for future research by measuring the ground reaction forces produced with two contrasting styles of arm swing. In order to isolate the effects of only the arm swing athletes will be asked to perform the trials while standing stationary on two feet on top of a ground-mounted force platform. This will eliminate the effects of lower limb actions which could interfere with a direct analysis of the arm swing techniques. Athletes will be tested wearing their own running shoes to provide traction and stability while standing on the force platform. It was determined that athletes would not be tested wearing skates due to the difficulty of measurement of ground reaction forces, as well running shoes are safer and can be better accommodated in the laboratory setting.

The subjects for this study were high performance female hockey players. It was determined to be of importance to the present study to use skilled athletes for analysis who are practiced at performing a hockey skating style arm swing. Athletes who are skilled at using arm movements may produce a greater contribution to performance when using an arm swing than unskilled athletes (Shetty & Etnyre, 1989). Skilled athletes will have a more consistent arm swing technique resulting in less variation in the movement patterns. In order to collect the most valid data athletes must perform the two arm swing styles with smoothness and ease of movement to limit artifact in the ground reaction force data. At this level of performance the athletes have established natural and controlled movement patterns as well as have the ability to learn and master new

movement patterns in a timely manner. Female athletes were chosen for this

study due to the continued increase in popularity of female hockey in Canada.

Figure 3 illustrates that the number of registered female hockey players in

Canada has nearly doubled from 43421 in the 1999-2000 season to 85624 in

2009-2010 (Hockey Canada, 2011).
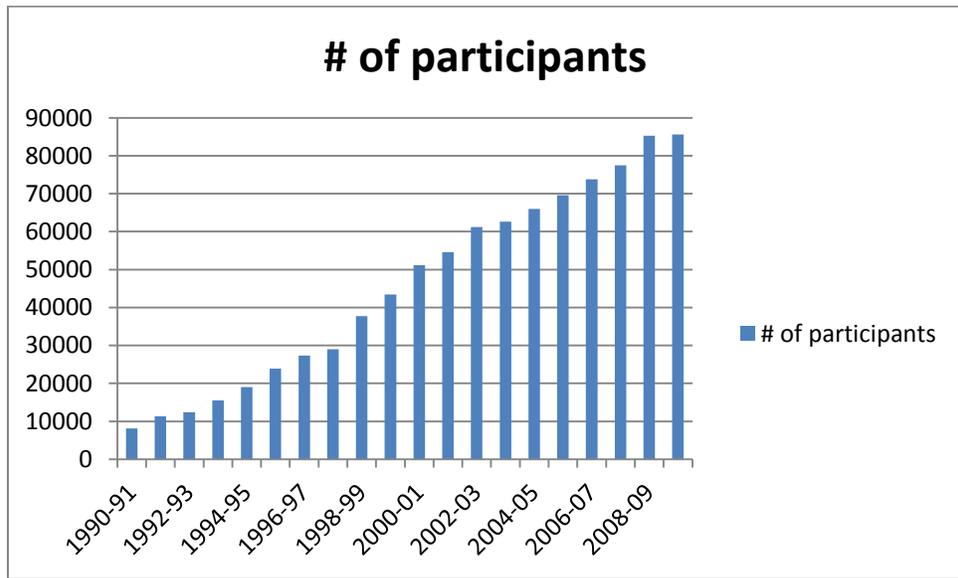
Figure 3: Registered female hockey players in Canada over the past two decades.

The steady increase in female participation in this country has led to

numerous successes at the international level of female hockey. Past research

on hockey biomechanics has focused on male athletes (Humble & Gastwirth,

1988; Marino, 1977; Marino & Weese, 1979; Page, 1977; Stidwill et al., 2010;

Upjohn et al., 2008) due to more accessible subjects with higher numbers and

possible greater interest in performance improvements. The present study aims

to broaden the scope of hockey biomechanical research matching the growing popularity of women's sport by including the use of female subjects.

The results of this study will benefit all hockey athletes and coaches as it will provide insight into the most effective arm swing biomechanics for forward hockey skating. By gaining a fundamental understanding of the basic movement pattern and kinetic properties of the arm swing in hockey we will be better able to advise coaches and athletes how to improve skating and game play.

Limitations

1. The subjects were young female athletes; the results of this study may not be generalizable to other populations.

2. The subjects were wearing running shoes and standing stationary on the force platform in a laboratory setting which does not perfectly mimic the action of on-ice forward hockey skating.

3. Subjects were performing arm swing techniques that may or may not be familiar to them. The learning of novel movement patterns could affect fluidity and ease of movement resulting in data artifact which might compromise reliability.

Definition of Terms

Acceleration: a rate of change in velocity (Adrian & Cooper, 1994)

Angular velocity: rate of change of an angular position or change in angle with respect to time, measured in degrees/second or rads/second (Hall, 2007)

Axis of rotation: an imaginary line about which all points in a rotating body describe circles (Adrian & Cooper, 1994)

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

Force platform: a device used for the measurement of applied forces using strain gauges to detect changes in pressure overtop the platform surface (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004)

Ground reaction force (GRF): the reaction force provided by the horizontal support surface (Enoka, 2002)

Moment of inertia: inertial property for rotating bodies representing resistance to angular acceleration; based on both mass and the distance the mass is distributed from the axis of rotation (Hall, 2007)

Momentum: the quantity of motion possessed by an object; a vector quantity equal to the mass of an object multiplied by its velocity (Enoka, 2002)

Power: the production of work, calculated as work divided by the time taken to complete the effort (Adrian & Cooper, 1994)

Propulsion: an external force that causes an increase in speed or change in

direction (Barthels & Kreighbaum, 1985)

Vector: a physical quantity that possesses both magnitude and direction (Hall,

2007)

Work: a transference of energy from one body to another resulting in motion or

displacement; expressed as a product of the force and the amount of

displacement (Adrian & Cooper, 1994)

CHAPTER II

Review of Literature

Ground Reaction Forces

Newton's third law of motion describes the interaction of two bodies (masses). The law of reaction states that "when one body applies a force to another body, the second body applies an equal and opposite reaction force on the first body" (Robertson et al., 2004).

When a skater contacts the surface of the ice, a force is applied to the Earth with a certain magnitude and direction. Concurrently the Earth applies a force that is equal in magnitude and opposite in direction to the skater, termed a ground reaction force (see Figure 4).

Figure 4: The interaction of a skater and the ice surface. The figure on the left depicts a skater exerting a force downward against the ice surface. The figure on the right shows the equal and opposite ground reaction force from the ice surface to the skater.

It is the propulsive effect of the ground reaction force that creates motion for all travelling skills such as walking, running, jumping and skating. Each of these

skills requires some force to be exerted in a downward and backward direction in relation to the direction of travel, which will produce a forward and upward resultant ground reaction force. Given that all ground reaction forces are vector quantities, forces should be analyzed for both direction and magnitude. The magnitude of the force vector is the quantity of force present, typically measured in Newtons. It is of equal importance to measure the direction in which the ground reaction force occurs as this will directly affect the direction in which the athlete is propelled.

The ground reaction force is a three dimensional vector quantity that can be broken into components for analysis (Robertson et al., 2004). It is comprised of the vertical component (F_z), the sagittal plane horizontal component (F_y) and the frontal plane horizontal component (F_x), see Figure 5. The resultant direction of the ground reaction force vector depends on the relative size of the three vector components.
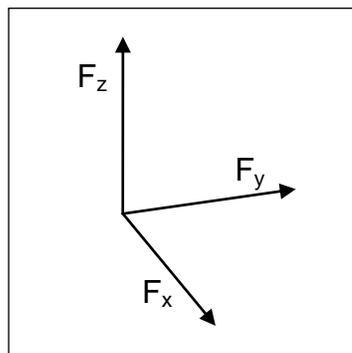
Figure 5: The ground reaction force can be broken into its three components; vertical force (Fz), sagittal plane force (Fy), frontal plane force (Fx).

Ground Reaction Forces in Sport

  The exertion of force against the ground to create upward momentum in a body is the very foundation of movement and is used in all sport activities. Jumping sports have long recognized the importance of using the movements of the upper body in producing additional ground reaction forces, emphasizing a large powerful arm swing beginning with shoulder hyperextension and then forcefully flexing the shoulder in coordination with knee and hip extension. The upward movement of the arms creates a downward force that is transmitted through the takeoff leg to the ground resulting in an increased upward force on the athlete by the ground, ultimately leading to a higher jump (Dapena, 1988).The use of a vigorous arm swing during vertical jumping has been associated with increases in vertical jump height (Feltner et al., 1999; Hara et al., 2006; Harman et al., 1990; Lees, Vanrenterghem, & Clercq, 2004; Shetty & Etnyre, 1989). Force platform investigations show an increase in ground reaction forces during the late propulsion phase of vertical jumping when an arm swing is used as compared with no arm action (Harman et al., 1990; Payne et al., 1968; Shetty & Etnyre, 1989).

  In 1968, Payne et al. produced one of the first studies which used force platform data for the investigation of athletic activities. Force data was obtained for the vertical jump, sprint start and second step, constant speed running, hurdles, shot put and weight lifting. During the analysis of force properties in vertical jumping the subject was asked to perform a vertical jump with the use of

a normal arm swing and then without the use of the arm swing, holding the arms beside the body. The results showed that the use of an upward arm swing created an extra peak in the measured vertical ground reaction force late in the propulsive phase (Payne et al., 1968). The generalizability of this study is limited due to the inclusion of only one subject. The results do however provide a rationale for further investigation of the use of an arm swing to increase propulsive force during athletic activities.

In 1989 Shetty & Etnyre studied the contributions of arm movement to maximum vertical jumps. Eighteen male subjects were instructed to perform maximal vertical jumps while standing on a force platform. Three trials were performed with restricted arm movement by having the subject cross the arms in front of the chest, and three trials were performed with the use of an arm swing as instructed one week prior during a training session. The use of the arm swing resulted in an increase in peak vertical ground reaction force by 6%. In addition the arm swing resulted in a 14% increase in work done, a 15% increase in power and a 6% increase in takeoff velocity.

In 1990 Harman et al. (1990) studied the effects of arm swing and countermovement on vertical jumping in eighteen males, including all combinations of arm swing or no arm swing and countermovement or no countermovement. The use of the arm swing had a greater effect than the use of a countermovement, increasing vertical ground reaction forces by 10% resulting

in increased takeoff velocity leading to an increase in jump height by 21% (Harman et al., 1990).

In 2009 Miller et al. expanded the use of force platform data in the analysis of arm actions to include running. Seven subjects including four males and three females were observed running under three conditions; normally with arms unrestricted, running with arms crossed in front of the chest and running with the arms held behind the back. There were no significant differences between the methods of arm restraint used. Peak vertical ground reaction forces were increased by as much as 12.8% with the use of an arm swing as compared to no arm swing during running (Miller et al., 2009). The use of arm movements during running also resulted in a reduction of peak frontal plane ground reaction forces by as much as 6.3% (Miller et al., 2009). These results show that the use of an arm swing results in the reduction of unwanted lateral force production during running. For efficient running all ground reaction forces should be directed in the sagittal plane acting to propel the athlete forward rather than laterally, the use of the arm swing helps to maintain balance resulting in greater mechanical efficiency of running technique.

There is very limited research that examines the directionality of arm swing used and its relation to performance factors such as skating velocity. In 2008, Hara et al. studied the effects of using arm swings in different directions while performing forward and backward squat jumps with the performance

measure as distance. Seven subjects were asked to perform maximal forward and backward squat jumps using three different arm swing techniques; no arm swing, a forward arm swing and a backward arm swing. Electromyographic and three dimensional kinematic data were collected for all trials. The total work done by the lower and upper limbs were highest during the forward jump using the forward arm swing and the backward jump using the backward arm swing, jump distance and takeoff velocity were significantly larger when the arm swing occurred in the same direction as the jump (Hara et al., 2008). The results of this study suggest that the direction of arm swing employed has a significant effect on performance factors, and should be a consideration for the successful performance of related movement skills.

Direction of Force Application

According to Newton's third law, for every action force there is a reaction force that is equal in magnitude and opposite in direction (Hall, 2007). In accordance with this principle all force should be applied to the ground in a direction that is exactly opposite to the desired direction of travel. When the desired outcome is to travel with maximal velocity in the forward direction all forces applied to the ground should be directly posterior and frontal plane motion should be eliminated as much as is possible. A lateral component to the applied force relative to the desired direction of travel will result in motion that is not directed anteriorly and is usually not desirable. An athlete's ability to produce

horizontal ground reaction forces depends on the nature of ground contact (Robertson et al., 2004).

The shape of skate blades and the nature of skate to ice contact make backward application of force nearly impossible. The mechanics of skating are drastically different from other travelling skills for two reasons: "(1) the base of support is much smaller (the width of the skate blade compared to that of the shoe or foot); and (2) the supporting surface offers little resistance to a horizontal push (ice compared to ground or floor)" (Adrian & Cooper, 1994).

Propulsive movements require some amount of friction between the propelling body (foot) and the ground surface in order to prevent the foot from simply sliding backwards. The coefficient of friction is a unitless number that is between zero and one "indicating the relative ease of sliding" (Hall, 2007) between the two surfaces. "The greater the mechanical and molecular interaction, the greater the value of [the coefficient of friction]" (Hall, 2007). The normal hockey skate blade is 3.2mm wide with the coefficient of friction equal to 0.0061 (Federolf, Mills, & Nigg, 2008), this requires a skater to create impulse for propulsion by applying force that is perpendicular to the length of the skate blade (De Boer, Ettema, Van Gorkum, De Groot, & Van Ingen Schenau, 1988). The skate blade must be rotated laterally in order for the edge to grip the ice to push off, by using the length of the blade and 'edging' it into the ice the skater can produce the friction required to develop propulsive forces. If a skater were to

apply a force from anatomical position directly backward in the sagittal plane, the skate would simply slide backward along the ice surface due to the near frictionless nature of the blade to ice contact.

In keeping with the principle of direction of force application (Alexander, 2010) it would be most desirable then for a skater to externally rotate the hips 90 degrees from anatomical position in order to turn the toes to face outward. This would allow them to apply a force perpendicular to the length of the skate blade directed exactly posteriorly in the sagittal plane, resulting in the most efficient method of producing forward motion. From a position of lateral rotation of the hip, the skater must compromise the principle of direction of force application by applying force at an angle to the direction of desired travel, creating an angle of push that is directed both backwards and sideways (Figure 6). A greater angle between the edge of the skate blade and the direction of travel produces greater forward acceleration (Hache, 2002). The backward component forces (F_y) act to propel the skater forward while the sideways forces (F_x) maximize friction between the skate blade and the ice (Alexander, 2010). The application of lateral forces is a characteristic of good skating technique (Roy, 1977).
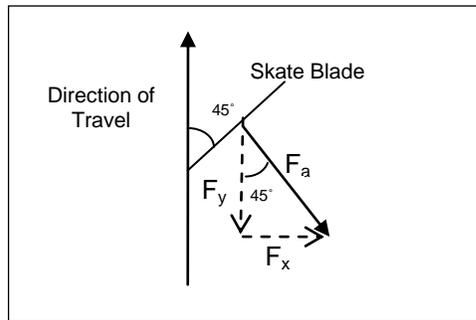
Figure 6: Direction of force application in forward hockey skating. The skater applies a force F_a at approximately 45 degrees to the direction of travel.

Forward Skating Technique

High velocity forward hockey skating is essential for success during game play. Fast skaters can get to the puck sooner increasing the potential for positive performance outcomes. The kinematics of forward hockey skating have been documented in the literature (Alexander, Taylor, & Shackel, 2007; Bracko et al., 1996; Edwards, 2009; Greer, 1990; Humble & Gastwirth, 1988; Marino, 1977; Marino & Weese, 1979; Page, 1977; Stidwill et al., 2010; Upjohn, Turcotte, Pearsall, & Loh, 2008) though studies are limited concerning actions of the upper limbs and trunk.

Current research has identified certain characteristics associated with successful high velocity forward skating. The skating stride is most simply broken down into two skill phases; the propulsive phase and the recovery phase. Propulsion consists of single and double support phases (Humble & Gastwirth, 1988; Marino & Weese, 1979).

Single and Double Support Propulsion

The single support phase begins after touchdown and lasts until the recovery foot contacts the ice near the midline of the skater, see Figure 7. Double support occurs when the recovery foot contacts the ice surface and continues until toe off of the propulsive leg, see Figure 8.

Figure 7: The single support phase of the left leg begins at touchdown (left) and ends with contact of the recovery leg (right).

Figure 8: The double support phase of the left leg begins with contact of the right leg (left) and ends at toe off of the left leg (right).

Initially during single support the athlete is gliding along the ice with very little force against the ice being produced, it is during the second half of single support that propulsion begins and lasts the remainder of the duration of the propulsive phase (Marino & Weese, 1979). During the propulsive phase the athlete pushes backwards and sideways with the support leg against the ice. The power for high velocity forward skating is generated by forceful and sequential extension and abduction of the hip, knee and plantarflexion of the ankle. The use of a large range of motion at these force producing joints has been found to be related to high caliber skaters (Upjohn et al., 2008). Upjohn (2008) concluded that faster skaters maintained deeper knee flexion during propulsion resulting in rapid extension of the push off leg. During propulsion the hip is laterally rotated and abducted to approximately 30 degrees to allow for the production of lateral forces against the ground (Alexander et al., 2007). The normal maximum amount of hip lateral rotation is approximately 60 degrees (Magee, 2002) placing the long edge of the skate blade at an angle of 30 degrees relative to the direction of travel. The full range of motion of lateral hip rotation is not normally observed during a skating stride, it is recommended that the hip be rotated at least 45 degrees laterally, so the long edge of the skate is directed at approximately 45 degrees relative to the direction of travel (Alexander et al., 2007), see Figure 6.

A study by Page (1977) measured selected biomechanical variables of youth, recreational, college and professional hockey players skating at top speed to determine the differences between fast and slow skaters. This research

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concluded that faster skaters had significantly greater stride widths than slower

skaters as a result of greater hip abduction angles by 13 degrees. Stride width

describes the lateral displacement of the foot during the propulsive phase and is

related to the amount of hip abduction that occurs. In 2008, Upjohn et al. also

concluded that greater stride width and angle of hip abduction was related to

high-caliber skaters. A common error in hockey skating is to plant the foot too far

laterally from the midline at the onset of the support phase (Alexander et al.,

2007) resulting in a reduced capacity for hip abduction during propulsion which

will result in a shorter stride width.

These findings emphasize the importance of lateral motion and the

production of lateral forces in forward hockey skating. "...fast skaters have wide

strides because they push to the side, abducting the hip during propulsion and

adducting and flexing the hip during recovery" (Edwards, 2009).

Recovery Phase

Following propulsion the recovery phase begins as soon as the foot

leaves the ice. The hip and knee are flexed, the ankle is dorsiflexed as the entire

leg is brought forward as quickly as possible ready for the next propulsive phase,

see Figure 9. The hip flexes and adducts placing the foot in line with the hip,

knee and shoulder for touchdown (Edwards, 2009).

Figure 9: The left leg is in mid recovery, preparing for touchdown close to the midline of the body.

It has been shown that stride rate increases with skating velocity but not stride

length (Marino, 1977). A fast recovery phase is key to achieving high velocity

skating (Marino, 1977; Page, 1977) which will allow the skater to reduce the time

taken to perform one stride, beginning the next propulsive phase sooner. The

time of the recovery phase can be reduced by flexing the knee so that the lower

leg is parallel to the ground. This will reduce the radius of gyration of the recovery

leg about the axis of rotation of the hip requiring less effort by the hip flexors and

adductors to return the leg to the propulsive phase start position.

The Trunk in Forward Hockey Skating

During the entire skating stride the trunk should be positioned with

approximately 50 to 60 degrees of forward lean (Alexander et al., 2007), see

Figure 10. This position allows for the muscles of the hip to make full contribution

to the propulsive phase via powerful extension and abduction (Greer, 1990).

Page (1977) found that faster skaters had approximately 10 degrees more forward trunk lean than slower skaters.

It is ideal to have a significant amount of trunk rotation, with rotation to the left occurring during right leg propulsion and rotation to the right occurring during left leg propulsion. When the propulsive leg pushes against the ice it tends to rotate the body about its longitudinal axis. This occurs because the line of force of the propulsive leg acts at a distance to the longitudinal axis of the body which creates a torque. When the right leg pushes against the ice the body will tend to rotate to the left. Similarly when the left leg pushes against the ice the body will tend to rotate to the right.
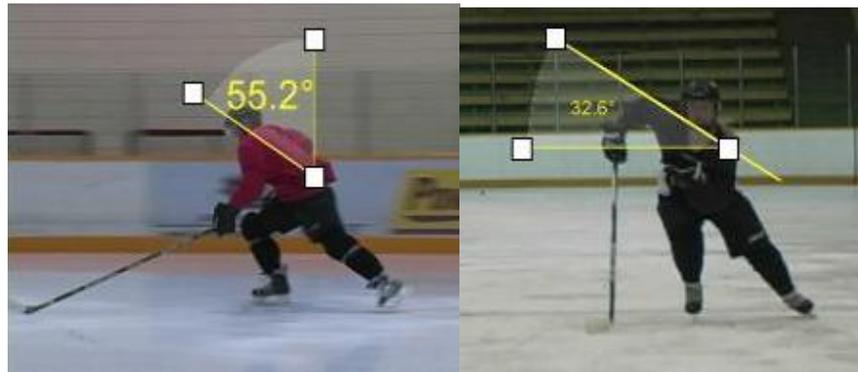
Figure 10: Forward trunk lean during forward skating should be approximately 50-60 degrees. Trunk rotation about the longitudinal axis of the body can be indirectly measured by the angle between the long axis of the shoulder girdle and the horizontal.

Figure 11: Fast forward hockey skating features a large amount of trunk rotation in opposition to the action of the legs (Alexander et al., 2007).

Trunk rotation in opposition to the leg movements in this manner helps to balance the angular motion about the longitudinal axis of the body. It also facilitates greater range of motion at the glenohumeral joint for a large free moving arm swing (Figure 11).

Forward Hockey Skating Arm Swing Techniques

The role of the arms is to maintain balance and to increase the lateral ground reaction forces (Alexander et al., 2007). The effectiveness of the arm swing in contributing to the forward velocity of the skater depends on the velocity, timing and direction of arm swing. The arm swing must be timed appropriately so that the peak height of the arm swing occurs simultaneously with toe off of the propulsive phase. The peak arm swing velocity should occur in mid range of the motion and during the mid range of the propulsive phase of the support leg (Alexander et al., 2007).

A controversy exists (Alexander et al., 20010; Bracko,1999; Glantz, 2010; McMurray, 2010; Nauman, 2009; Rhoads, 2010; Stamm, 2000) with respect to the most effective direction of the arm swing in forward hockey skating, currently two contrasting styles are taught to skaters in an effort to increase overall forward momentum of the athlete. The mediolateral arm swing uses primarily glenohumeral adduction on the forward movement and abduction on the backward movement, it occurs mostly in the frontal plane. The anteroposterior arm swing is comprised of almost entirely glenohumeral flexion and extension occurring mostly in the sagittal plane.

Advocates for the anteroposterior technique of arm swing claim that it helps the athlete to produce "momentum in the same way that swinging your arms does while running" (Nauman, 2009). It is believed that this forward momentum may contribute to forward translation in hockey skating just as it does during running and sprinting. It is sometimes argued that the sideways movement of the arms as used in the mediolateral technique is a waste of energy and power, perhaps even contributing to a loss of balance (Rhoads, 2010).

There has been very limited study of the biomechanics of the arm swing in hockey. One study (Bracko et al., 1996) examined acceleration of ice hockey players using 3 different arm swing techniques. These techniques included i) flexion and extension of the glenohumeral joint, ii) abduction and adduction of the glenohumeral joint, and iii) 45 degree angle movements of the glenohumeral

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joint. The study included two groups based on playing experience, divided into less than five years playing experience and more than five years playing experience. Although the results did not show statistical significance, the mean velocity in all groups was faster when using the abduction/adduction arm swing (Bracko et al., 1996). During the course of this study 13 of 31 subjects were eliminated due to improper technique leaving just 18 subjects for inclusion in the study. It is possible that the unexpected reduction in sample size had an effect on statistical testing due to the large reduction in sample size.

CHAPTER III

Methods

Description of Study

Elite level female hockey players were asked to perform two contrasting styles of hockey skating arm swing while standing on a force platform. Evaluation methods include anthropometric data, force platform measurements and video analysis to investigate biomechanical differences between the contrasting arm swing styles. This study received human ethics approval from the University of Manitoba Education/Nursing Research Ethics Board (Appendix A). All subjects submitted completed consent forms prior to testing, those not yet 18 years of age or older required parental/guardian consent in order to volunteer for this study (Appendix B).

Subjects

A power analysis based on pilot data with significance level (alpha) of 0.05 and a desired power of 0.80 yielded a required sample size of 32 subjects total (16 per group), see Appendix D. The paired study design allowed for each subject to participate in both groups, ultimately requiring a minimum of 16 subjects for the present study. 24 female subjects ages 16-25 were recruited from elite level hockey teams including high school, university and national team programs. Additional subjects were recruited on top of the required 16 in order to ensure maximum power behind the study. The high school team used for

recruitment competes in a North American wide junior women's hockey league committed to the highest level of competition. All other subjects recruited for this study played at the Canadian Interuniversity Sport (CIS) or the National Collegiate Athletic Association (NCAA) Division I level.

A letter including a summary of the study and requirements for participation was sent to the coaching staff of two elite female hockey teams including one high school and one university team. Information about the study as well as contact information was provided by the coaches to athletes fitting the description of prospective subjects. Subjects then contacted the researcher if willing to volunteer for this study and were informed further on testing procedures and times. All subjects were volunteers for this study, no compensation was offered. A copy of the results of the study was offered to all participating athletes and coaches.

Data Collection & Analysis

Subjects' leg dominance (right or left), preferred shooting hand (right or left), age, height, mass, reported number of years hockey experience and level of hockey experience was recorded prior to the onset of testing. Leg dominance was determined by asking subjects which side they preferred to use in a one legged hopping task, a brief trial was performed by each subject to confirm their preference. Of the 24 subjects 14 were high school players and 10 were CIS/NCAA level players. The mean age, height and mass of the subjects were

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18.17 years, 1.68m and 69.1kg respectively. The mean number of years of hockey experience was 12.17 years. Support leg dominance opposite to the preferred shooting side was reported by 58.33% of subjects. See Appendix C for a complete table of individual subject characteristics.

A ten minute training session was conducted to demonstrate and allow the subjects to practice the anteroposterior and mediolateral arm swing techniques. During the training session subjects were shown video clips of the arm swing techniques being performed both on ice and in the laboratory setting. Subjects were then given verbal instruction on how to correctly perform each arm swing including a review of the inclusionary criteria used to determine the successful performance of the arm swings during testing. A demonstration of the arm swing techniques was also provided to assist the subjects in learning the desired movement patterns.

In terms of inclusionary criteria, it was determined that the successful performance of the mediolateral arm swing technique would include shoulder abduction to at least 90º, shoulder adduction with the elbow reaching at least to the midline of the body and the hand passing underneath the shoulder at midswing. The successful anteroposterior arm swing included shoulder hyperextension so that the upper arm reached the horizontal, shoulder flexion with the upper arm reaching 45º to the vertical with the hands not crossing the midline of the body at any time.

A metronome was also used at this time to allow subjects to practice the arm swings at a uniform speed of 1 Hz, approximating typical moderately high velocity ice skating strides (Upjohn et al., 2008). The metronome was also used during data collection to keep consistent pace throughout all trials.

During data collection two video cameras recorded all trials from an anterior view and a sagittal view for later analysis of upper body kinematics using Dartfish motion analysis software. Subjects stood with their dominant foot on top of the ground mounted force platform wearing athletic shoes. Standing with feet slightly wider than shoulder width and the knees and hips flexed close to 90 degrees, the subjects were randomly assigned to perform 10 repetitions of either the anteroposterior or medioloateral arm swing to the pace of the metronome. Force platform data was collected for the duration of the 10 repetitions. Following a brief rest the subject repeated this procedure for a total of 3 trials. Following a resting period the subject was asked to complete the same test procedure while performing the remaining arm swing technique. Each subject completed three anteroposterior trials and three mediolateral trials to be included in the analysis.

Force Platform

Force data for this study was collected using an OR-6 model Biomechanics Force Platform manufactured by Advanced Mechanical Technology Inc. (AMTI) located at the Pan Am Clinic Foundation David and Ruth Asper Biomechanics Research Centre. The force platform data collection was performed by the technician from the Biomechanics Research Centre who has

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expertise and experience in data collection. The ground mounted platform is

designed for the measurement of ground reaction forces to be used in

biomechanics, engineering, medical research, orthopedics and rehabilitation

(Advanced Mechanical Technology Inc.). Force platform data was amplified with

an MSA-6 Mini Amp strain gauge amplifier with a gain of 4000, the recorded

sampling rate was 1000Hz. Data was recorded using the Vicon Workstation

software for later analysis. The recorded data includes ground reaction forces in

each of the three planes measured in Newtons as well as moments about the

three axes measured in Newton-meters.
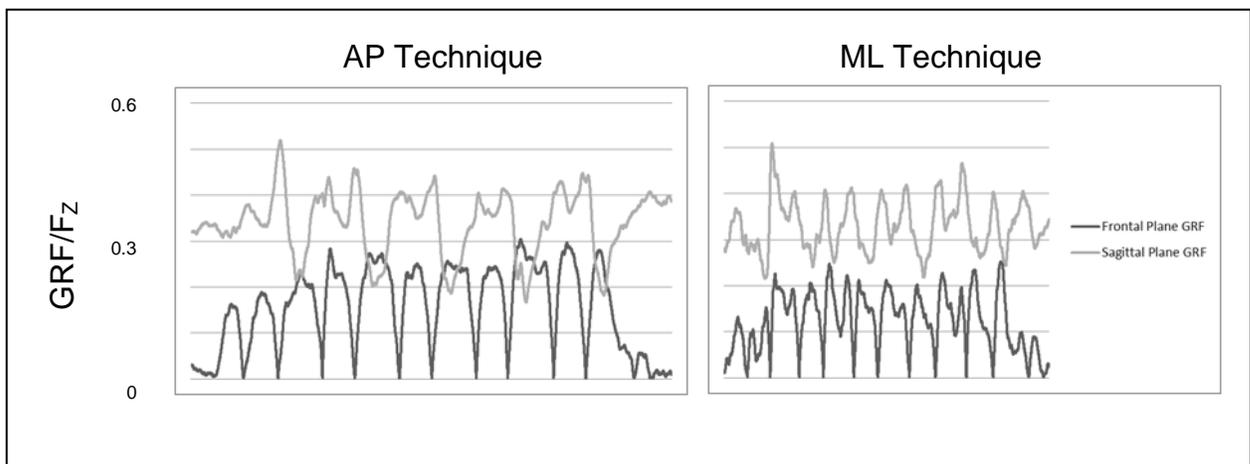
Figure 12: Sample Force platform tracings of the anteroposterior (AP) and mediolateral (ML) arm swing techniques. Force is measured in Newtons and standardized using vertical force (F_Z).

The frontal (F_X) and sagittal (F_Y) plane GRFs were scaled by dividing them by the corresponding vertical (F_Z) force at each time point. For each arm swing trial the peak scaled frontal and sagittal plane GRFs were identified. The mean peak scaled sagittal and frontal plane GRFs for each arm swing technique were determined for inclusion in the statistical analysis. See Figure 12 for sample tracings of the sagittal and frontal plane ground reaction forces produced by the anteroposterior and mediolateral arm swing techniques.
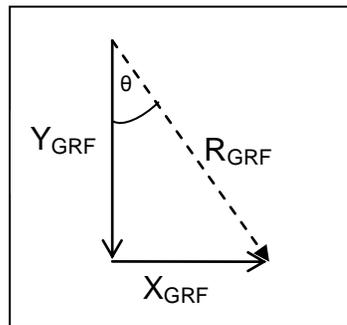
Figure 13: The frontal plane (X) and sagittal plane (Y) ground reaction force vector components determine resultant (R) ground reaction force. The angle (θ) represents the number of degrees the force is directed from the sagittal plane.

The magnitude and direction of the resultant force (R) of the mean peak scaled sagittal and frontal plane GRFs were calculated using simple trigonometric calculations. According to Pythagorean Theorem the magnitude of the resultant force of the frontal (F_X) and sagittal (F_Y) plane forces equals the square root of the sum of the squares of each component vector; $R=\sqrt{F_x^2+F_y^2}$. The direction of the resultant force expressed in degrees from the parasagittal plane (θ) is equal to the inverse tangent of the quotient of the frontal plane and sagittal plane vector components; $\theta=\tan^{-1}(F_x/F_y)$, see Figure 13. These

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calculations were performed and compared between the anteroposterior and the mediolateral arm swing techniques.

Kinematic Film Analysis

Two Canon GL2 standard definition digital video camcorders were used to film the subjects performing all trials during data collection. The cameras were mounted on tripods at a safe distance from the force platform to ensure no chance of the subjects contacting the cameras and/or tripods at any time during data collection. The cameras remained fixed and stationary during all trials for all subjects to ensure consistency of measurements. Kinematic analysis from the video footage was performed using Dartfish TeamPro software version 6.0 (2011).

The purpose of the video analysis in this study was to determine whether or not the subjects effectively performed the two arm swing styles as instructed. The key variables of interest to this study relate to the range of motion of the shoulder. Video data was calibrated with force data by synchronizing the instant the subject stepped on the force platform with the onset of vertical forces on the platform. The trials corresponding with the peak scaled forces produced in the frontal and sagittal planes were analyzed at key positions for joint angles. This data provides a kinematic description of the movement patterns performed during the testing session. This assessment was also used to determine whether or not the subjects correctly performed the two arm swing techniques according to the inclusion criteria previously described.

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Kinematic analysis from video footage

All angular variables for this study were measured using the 180 degree system. When in anatomical position using the 180 degree system all joints are at 0 degrees, deviation from this position is measured as the joint angle (Hall, 2007).

For the purposes of this study only the arm that is ipsilateral to the dominant leg was measured and analyzed. Shoulder and elbow measurements were taken at peak upswing and peak downswing for the mediolateral and anteroposterior arm swing trials of each subject. One arm swing was considered as the motion from peak upswing to peak downswing, the time taken to complete this motion was measured for assurance of adherence to the metronome timing of 1 Hz. All arm swings that produced a peak scaled ground reaction force were measured for kinematic variables.

Peak Upswing

Peak upswing occurs at the point in time when the shoulder reaches its maximum angle of flexion (anteroposterior arm swing) or abduction (mediolateral arm swing), see Figure 14.

Figure 14: Peak upswing for the right arm during the anteroposterior and mediolateral arm swing techniques.

Peak Down Swing

Peak down swing occurs at the point in time when the shoulder reaches

its maximum angle of extension (anteroposterior arm swing) or adduction

(mediolateral arm swing), see Figure 15.

Figure 15: Peak down swing for the right arm during the anteroposterior and mediolateral arm swing techniques.

Measurement of glenohumeral sagittal plane kinematics

Shoulder flexion and extension were measured as the angle between the long axis of the humerus and the long axis of the trunk in the sagittal plane, see Figure 16.
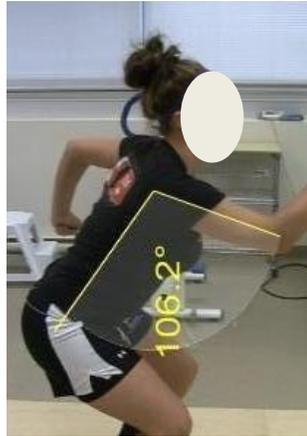
Figure 16: Measurement of shoulder flexion angle.

The long axis of the humerus was marked by a line connecting the centre of the glenohumeral joint and the lateral epicondyle of the humerus. The long axis of the trunk was located by a line connecting the centre of the glenohumeral joint and the greater trochanter of the femur. Total range of motion of the glenohumeral joint through flexion/extension was calculated from peak upswing to peak downswing for inclusion in the statistical analysis.

Measurement of glenohumeral frontal plane kinematics

Shoulder abduction and adduction were measured as the angle between the long axis of the humerus and the long axis of the trunk in the frontal plane, see Figure 17.

Figure 17: Measurement of shoulder abduction angle.

The long axis of the humerus was marked by a line connecting the centre of the glenohumeral joint and the lateral epicondyle of the humerus. The long axis of the trunk in the frontal plane passes through the centre of the glenohumeral joint and is parallel to the line passing through the umbilicus and centre of the sternum. Total range of motion of the glenohumeral joint through abduction/adduction was calculated from peak upswing to peak downswing for inclusion in the statistical analysis.

Measurement of elbow kinematics

Elbow range of motion was measured using the angle between the long axis of the humerus and the long axis of the forearm, see Figure 18.

Figure 18: Measurement of elbow flexion angle.

The long axis of the humerus was marked by a line connecting the centre of the glenohumeral joint and the lateral epicondyle of the humerus. The long axis of the forearm passes through the centre of the elbow joint and the centre of the wrist joint. Total range of motion of the elbow joint through flexion/extension was calculated from peak upswing to peak downswing for inclusion in the statistical analysis. Elbow range of motion was measured using the sagittal view camera for the anteroposterior arm swing and using the frontal view camera for the mediolateral style arm swing trials.

Joint Angular Velocities

The angular velocity of glenohumeral flexion/extension, glenohumeral abduction/adduction and elbow flexion/extension were calculated using the measured joint range of motion and the time from peak upswing to peak downswing. Values were recorded in degrees per second.

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Statistical Analysis

Alpha (α) was set at 0.05 for all statistical tests. Mean peak scaled ground reaction forces in the frontal and sagittal planes and resultant ground reaction force angle were assessed using one tailed paired t-tests. Resultant ground reaction force magnitude was analyzed using a two-tailed paired t-test. Kinematic measurement variables for statistical analysis include the time of the arm swing and joint ranges of motion of the glenohumeral and elbow joints at peak upswing and peak downswing. Paired t-tests were used to determine significant differences between the two arm swing techniques performed during the study (see Table 1 for a detailed listing of all measurement variables).

Table 1. Measurement variables for each of the experimental trials included in statistical analysis.

Kinematic Measurement Variables	Kinetic Measurement Variables
Glenohumeral flexion/extension range of motion (degrees)	Peak scaled sagittal plane ground reaction force (N/F_z)
Glenohumeral flexion/extension angular velocity (degrees/second)	Peak scaled frontal plane ground reaction force (N/F_z)
Glenohumeral abduction/adduction range of motion (degrees)	Peak scaled resultant ground reaction force magnitude (N/F_z)
Glenohumeral abduction/adduction angular velocity (degrees/second)	Peak scaled resultant ground reaction force angle (degrees)
Elbow flexion/extension range of motion (degrees)	
Elbow flexion/extension angular velocity (degrees/second)	
Time from peak upswing to peak downswing (seconds)	

CHAPTER IV

Results

Ground Reaction Forces

The resulting peak scaled frontal and sagittal plane ground reaction forces for the two arm swing techniques are summarized in Table 2 below, the results of the one-tailed paired t-test are recorded in Table 3.

Table 2. Descriptors of the scaled force platform data from the anteroposterior (AP) and mediolateral (ML) arm swing techniques.

		N	Mean (Newtons)	Std. Deviation
Frontal Plane GRF	ML	24	.445	.215
	AP	24	.281	.199
Sagittal Plane GRF	ML	24	.396	.183
	AP	24	.526	.233

Table 3. The results of the one-tailed paired t test of the scaled frontal and sagittal plane ground reaction forces during the mediolateral (ML) and anteroposterior (AP) arm swing, p<0.05.

	Paired Differences					t	df	p-value (1-tailed)
	Mean difference (Newtons)	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 ML – AP Frontal	.164	.279	.057	.046	.282	2.87	23	.004*
Pair 2 ML – AP Sagittal	-.130	.285	.058	-.251	-.010	-2.24	23	.018*

Frontal Plane

The one-tailed paired t-test revealed a statistically significant difference between the mean ($\bar{x}$) peak scaled frontal plane GRFs produced by mediolateral

($\bar{x} = 0.45, s = 0.22$) and the anteroposterior ($\bar{x} = 0.28, s = 0.20$) arm swing techniques (t(23)=2.87, p=0.004, α=0.05). This indicates that the mediolateral arm swing produced significantly higher GRFs in the frontal plane than the anteroposterior arm swing (Figure 19).

Sagittal Plane

The one-tailed paired t-test revealed a statistically significant difference between the mean peak scaled sagittal plane GRFs produced by mediolateral ($\bar{x} = 0.40, s = 0.18$) and the anteroposterior ($\bar{x} = 0.53, s = 0.23$) arm swing techniques (t(23)=2.24, p=0.018, α=0.05. This indicates that the mediolateral arm swing produced significantly lower GRFs in the sagittal plane than the anteroposterior arm swing (Figure 19).
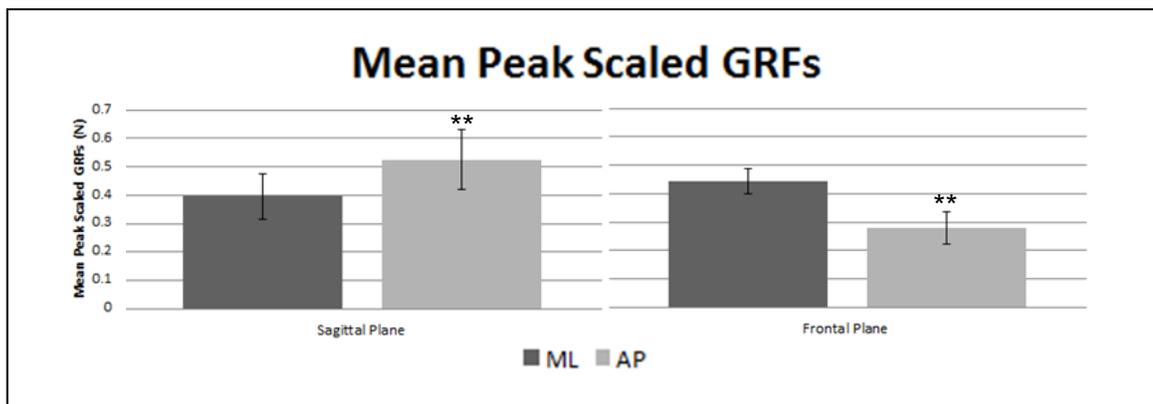
Figure 19: Mean peak scaled ground reaction forces in the frontal and sagittal planes produced by the mediolateral (ML) and anteroposterior (AP) arm swing techniques.$p\leq0.05$

It was hypothesized at the onset of the study that the mediolateral arm swing technique would produce greater frontal plane and lesser sagittal plane ground reaction forces than the anteroposterior arm swing. Statistical analysis of

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the data collected for this study confirmed this result with the mediolateral arm

swing producing 37% greater frontal plane and 33% lesser sagittal plane ground

reaction forces than the anteroposterior arm swing.

Resultant Magnitude & Direction of Ground Reaction Forces

The resultant (R) peak scaled ground reaction forces for the two arm

swing techniques are summarized in Table 4 below, the results of the two-tailed

paired t-test of the resultant GRF magnitudes are recorded in Table 5.

Table 4. Descriptors of the scaled resultant (R) ground reaction forces the anteroposterior (AP) and mediolateral (ML) arm swing techniques.

	Mean	N	Std. Deviation
ML-R (Newtons)	.600	24	.228
AP-R (Newtons)	.607	24	.249
ML-R angle (degrees)	44.4	24	17.8
AP-R angle (degrees)	31.6	24	19.1

Table 5. The results of the two-tailed paired t test of the scaled resultant (R) ground reaction force magnitudes during the mediolateral (ML) and anteroposterior (AP) arm swing, p<0.05.

	Paired Differences					t	df	p-value (2-tailed)
	Mean difference (Newtons)	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
ML – AP R	-.008	.306	.062	-.137	.122	-.122	23	.904

The two-tailed paired t-test failed to reveal a statistically significant

difference between the magnitudes of the resultant GRFs produced by

mediolateral ($\bar{x} = 0.60, s = 0.23$) and the anteroposterior ($\bar{x} = 0.61, s = 0.25$) arm

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swing techniques(t(23)=-0.122, p=0.904, α=0.05). This indicates that the

mediolateral and anteroposterior arm swings produced resultant GRFs of similar

magnitude (Figure 20).
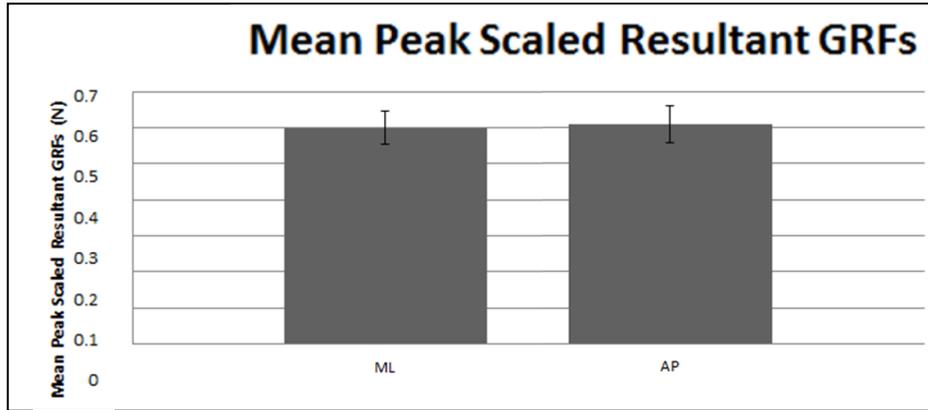
Figure 20: Mean peak scaled resultant ground reaction force magnitudes of the mediolateral (ML) and anteroposterior (AP) arm swing techniques.

The results of the one-tailed paired t-test of the angle of the resultant

GRFs are reported in Table 6.

Table 6. The results of the one-tailed paired t test of the resultant ground reaction force angles during the mediolateral (ML) and anteroposterior (AP) arm swing, p<0.05.

	Paired Differences					t	df	p-value (1-tailed)
	Mean difference (degrees)	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
ML - AP angle	12.8	25.4	5.18	2.12	23.5	2.48	23	.011*

The one-tailed paired t-test revealed a statistically significant difference between

the resultant GRF angles produced by mediolateral ($\bar{x} = 44.44, s = 17.84$) and

the anteroposterior ($\bar{x} = 31.6, s = 19.14$) arm swing techniques (t(23)=2.48,

p=0.01, α=0.05). This indicates that the mediolateral arm swing produced

significantly larger resultant GRF angles from the sagittal plane than the

anteroposterior arm swing, see Figure 21.

Kinematic Film Analysis

The time for one arm swing was defined as the time between peak

upswing and peak downswing. The two-tailed paired t-test failed to reveal a

statistically significant difference between the mediolateral ($\bar{x} = 1.00, \ s = 0.0110$)

and the anteroposterior ($\bar{x} = 0.999, s = 0.0125$) arm swing techniques
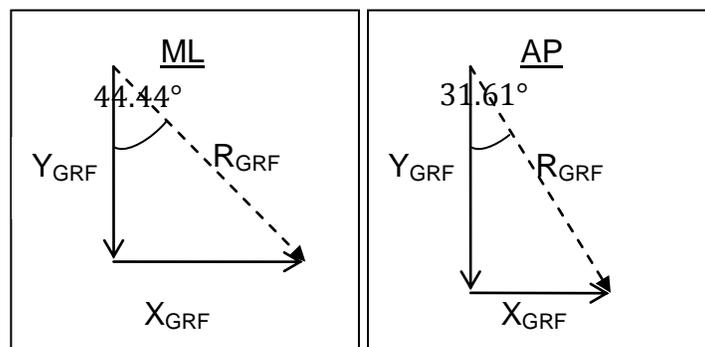
Figure 21: The resultant mediolateral (ML) and anteroposterior (AP) ground reaction force angles from the sagittal plane.

(t(138)=0.626, p=0.532, α=0.05). This indicates that the mediolateral and

anteroposterior arm swings were performed in the same amount of time during

testing. This result indicates that the time of arm swing was successfully

controlled by the use of the metronome.

Peak Upswing

Peak upswing of the mediolateral technique occurs when the dominant side arm reaches maximum abduction (Figure 22). The typical mediolateral arm swing as performed during testing consisted of 16.72° of glenohumeral extension (s=6.58), 129.82° of glenohumeral abduction (s=16.5) and 2.56° of elbow flexion (s= 2.60) at peak upswing.
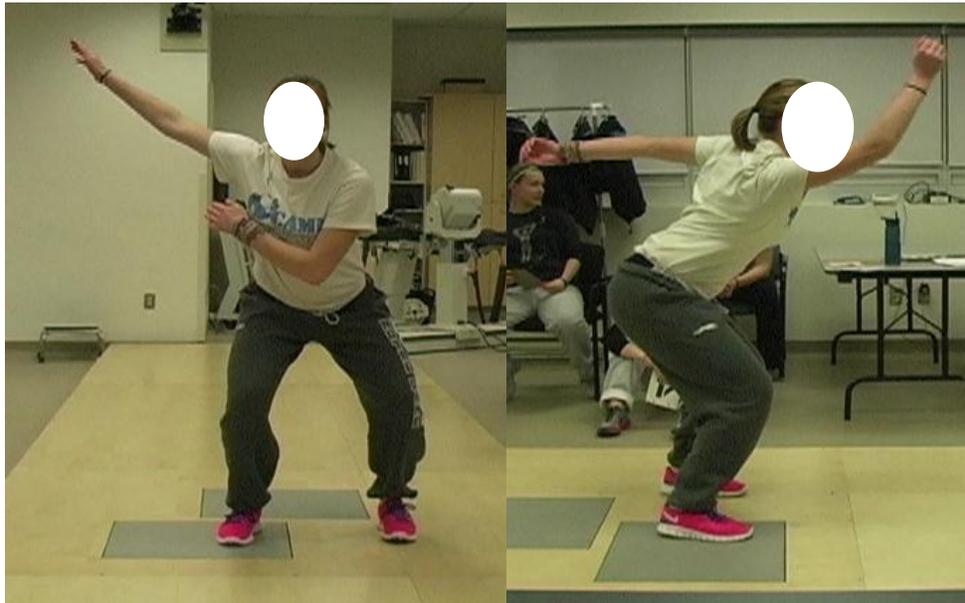
Figure 22: Peak upswing of the mediolateral (left) and anteroposterior (right) arm swing techniques.

Peak upswing of the anteroposterior technique occurs when the dominant side arm reaches maximum flexion (Figure 22). The typical anteroposterior arm swing consisted of 139.84° of glenohumeral flexion (s=10.77), 13.63° of glenohumeral abduction (2.88) and 57.80° of elbow flexion (s= 4.11) at peak upswing.

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Peak Downswing

Peak downswing of the mediolateral arm swing occurs when the dominant side arm reaches maximum adduction (Figure 23). The typical mediolateral arm swing as performed during testing consisted of 12.13° of glenohumeral flexion (s=5.90), 53.75° of glenohumeral adduction (s=4.99) and 101.66° of elbow flexion (s= 9.53) at peak downswing.

Figure 23: Peak downswing of the mediolateral (left) and anteroposterior (right) arm swing techniques for a right side dominant athlete.

The typical anteroposterior arm swing consisted of 74.35° of glenohumeral extension (s=6.03), 4.68° of glenohumeral adduction (s=4.12) and 24.66° of elbow flexion (s= 6.42) at peak downswing.

Range of Motion

Glenohumeral Flexion/Extension

The two-tailed paired t-test revealed a statistically significant difference between the glenohumeral flexion/extension range of motion between the mediolateral ($\bar{x} = 28.97, s = 8.78$) and the anteroposterior ($\bar{x} = 214.17, s = 12.12$) arm swing techniques,(t(138)=-139.51, p<0.001, α=0.05). This finding indicates that the mediolateral arm swing had a significantly smaller range of motion through glenohumeral flexion and extension than the anteroposterior arm swing (see Table 7).

The two-tailed paired t-test revealed a statistically significant difference between the glenohumeral flexion/extension angular velocities of the mediolateral ($\bar{x} = 28.87, s = 8.85$) and anteroposterior ($\bar{x} = 214.46, s = 12.50$) arm swing techniques, (t(138)=148.60, p<0.001, α=0.05. The mediolateral arm swing had significantly lower angular velocity in glenohumeral flexion and extension (see Table 8).

Glenohumeral Abduction/Adduction

The two-tailed paired t-test revealed a statistically significant difference between the abduction/adduction range of motion between the mediolateral ($\bar{x} = 183.68, s = 18.60$) and the anteroposterior ($\bar{x} = 18.38, s = 4.84$) arm swing techniques, (t(138)=102.23, p<0.001, α=0.05. This indicates that the mediolateral

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arm swing had a significantly larger range of motion through glenohumeral abduction and adduction than the anteroposterior arm swing (see Table 7).

The two-tailed paired t-test revealed a statistically significant difference between the glenohumeral abduction/adduction angular velocities of the mediolateral ($\bar{x} = 183.59, s = 18.60$) and anteroposterior ($\bar{x} = 18.33, s = 4.84$) arm swing techniques, (t(138)=-100.19, p<0.001, α=0.05. The mediolateral arm swing had significantly higher angular velocity in glenohumeral abduction and adduction (see Table 8).

Elbow Flexion/Extension

The two-tailed paired t-test revealed a statistically significant difference between elbow flexion/extension range of motion between the mediolateral ($\bar{x} = 102.71, s = 15.78$) and the anteroposterior ($\bar{x} = 82.25, s = 7.32$) arm swing techniques, (t(138)=23.37, p<0.001, α=0.05). This indicates that the mediolateral arm swing had a significantly larger range of motion through elbow flexion and extension than the anteroposterior arm swing (see Table 7).

The two-tailed paired t-test revealed a statistically significant difference between the elbow flexion/extension angular velocities of the mediolateral ($\bar{x} = 102.71, s = 15.68$) and anteroposterior ($\bar{x} = 82.55, s = 7.41$) arm swing techniques, (t(138)=-14.27, p<0.001, α0.05). The mediolateral arm swing had significantly higher angular velocity in elbow flexion and extension (see Table 8).

Table 7. The results of paired sample t-tests comparing glenohumeral (GH) and elbow ranges of motion for the mediolateral (ML) and anteroposterior (AP) arm swing techniques.

		Paired Differences					t	df	p-value (2-tailed)
		Mean difference (degrees)	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
GH Flexion/Extension	ML - AP	-185.2	15.7	1.33	-187.8	-182.6	-139.5	138	<.001*
GH Abduction/Adduction	ML - AP	165.3	18.9	1.60	162.1	168.5	103.2	138	<.001*
Elbow Flexion/Extension	ML - AP	20.5	17.3	1.47	17.6	23.4	13.9	138	<.001*

Table 8. The results of paired sample t-tests comparing glenohumeral (GH) and elbow angular velocities (ω) for the mediolateral (ML) and anteroposterior (AP) arm swing techniques.

	Paired Differences					t	df	p-value (2-tailed)
	Mean difference (degrees/second)	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
GH Flexion/Extension ω ML - AP	185.7	14.8	1.25	183.3	188.2	148.6	138	<.001*
GH Abduction/Adduction ω ML - AP	-165.2	19.6	1.65	-168.5	-162.0	-100.2	138	<.001*
Elbow Flexion/Extension ω ML - AP	-20.3	16.9	1.42	-23.1	-17.5	-14.3	138	<.001*

CHAPTER V

Discussion

This study investigated the differences between two contrasting arm swing techniques that are commonly taught to hockey players for high velocity forward skating. The analysis of the resulting ground reaction forces required that the subjects successfully learn and perform the arm swing techniques under study. It was predicted that the mediolateral arm swing would produce greater frontal plane and lower sagittal plane ground reaction forces as compared to the anteroposterior technique. It was also predicted that the magnitudes of the resultant ground reaction forces would be similar between the techniques but that the angle of the resultant from the sagittal plane would be larger in the mediolateral arm swing.

Joint Range of Motion & Angular Velocities

Prior to data collection the subjects were led through a training session with instruction on how to correctly perform the mediolateral and anteroposterior arm swing techniques. The criteria for the mediolateral technique required that the arm movements occur primarily in the frontal plane using glenohumeral abduction and adduction whereas the anteroposterior technique used primarily flexion and extension in the sagittal plane. Specific range of motion requirements were also discussed that encouraged subjects to use a large range of motion in both arm swings. The techniques were reinforced during both training and data

collection by providing verbal feedback to subjects correcting for errors in technique. Corrections were based on the predetermined inclusion criteria for successful performance of the arm swing techniques.

Kinematic analysis of the video taken during testing showed that the subjects used significantly different movement patterns to perform each arm swing technique. The mediolateral technique had significantly more frontal plane range of motion and the anteroposterior technique had significantly more sagittal plane range of motion. These results were expected based on the training provided prior to data collection.

The range of motion at the elbow through flexion and extension was also shown to be significantly different between the two techniques with the mediolateral technique using a greater range of elbow motion as compared to the anteroposterior technique. During the training session athletes were instructed specifically on glenohumeral movements and allowed to freely move the elbows in a way that felt natural to them. It is known that trained athletes who use their arms during skill performance have shown the ability to use their arms more effectively than unskilled individuals (Shetty & Etnyre, 1989). In the present study the mean reported number of years participating in structured competitive hockey was 12.17 years ($s = 2.49$). Based on the work of Shetty (1989), it could be expected that these athletes would skillfully select a movement pattern that is effective for performance. The subjects' self-selected elbow range of motion

during the mediolateral arm swing was greater than during the anteroposterior technique. The use of a greater range of motion at the elbow could produce additional ground reaction forces that could contribute to propulsion. This theory is not supported by the present study as the mediolateral technique which used a greater amount of motion at the elbow joint did not produce a significantly greater total magnitude of the resultant ground reaction forces. The use of additional elbow motion during the mediolateral arm swing may have been used to compensate for a limited ability to adduct the arm. The amount of shoulder adduction during the upswing of the mediolateral arm swing is limited by the bony structure of the shoulder girdle as well as soft tissue approximation (Magee, 2002). Though greater glenohumeral adduction may be possible with increased trunk flexion the movement is significantly more restricted than the upswing of the anteroposterior arm swing which consists of glenohumeral flexion. This restriction could be compensated for by increasing the range of motion used at the elbow.

The angular velocities of glenohumeral flexion/extension, abduction/adduction and elbow flexion/extension were all significantly different between the two arm swing techniques. The subjects performed the arm swing trials to the beat of a metronome set to 1Hz. Successful adherence to the cadence was monitored during the testing session to ensure uniformity of arm swing velocities. The angular velocity of each joint motion is very close in value to the corresponding joint range of motion because the time from peak upswing

to peak downswing was controlled during the study at 1 per second. The resulting comparisons of angular velocities are analogous to the analysis of the joint ranges of motion. The mediolateral arm swing had higher glenohumeral abduction/adduction and elbow flexion/extension angular velocities while the anteroposterior arm swing had higher glenohumeral flexion/extension angular velocity. As with on-ice hockey skating the angular velocities of the joint movements depend on skating cadence and the range of motion used. Both variables were controlled for during the present study with the use of a metronome and inclusion criteria describing acceptable minimum ranges of motion.

A further consideration would be a study of the accelerations of the arms during on-ice hockey skating to provide a proper description of the movement quality employed by the arms during high velocity skating. This would supplement the current knowledge of arm swing kinetics and how they affect performance.

Ground Reaction Forces & Movement Patterns

The results of this study confirm that the mediolateral arm swing produces lower peak sagittal plane and higher peak frontal plane ground reaction forces than the anteroposterior arm swing technique. The mediolateral arm swing occurs primarily in the frontal plane. As the hip extends and abducts during the propulsive phase the shoulder of the same side of the body flexes and adducts.

When the right leg begins the recovery phase by flexing and adducting at the hip the right shoulder extends and abducts in an opposite direction. This technique of arm swing is widely used by speed skaters during high velocity skating, see Figure 24.

Figure 24: A speed skater uses a large mediolateral arm swing to gain maximum velocity.
Consistent with Newton's third law of action and reaction the mediolateral arm swing produces a higher proportion of ground reaction forces in the frontal plane as compared with the anteroposterior technique.

The anteroposterior arm swing is advocated by many hockey and skating coaches (Glantz, 2010; Nauman, 2009; Rhoads, 2010; Stamm, 2000) and is performed using primarily glenohumeral flexion and extension. When the propulsive hip extends and abducts pushing against the ice, the ipsilateral arm flexes at the shoulder. During recovery when the right hip adducts and extends the right upper limb extends at the shoulder creating a movement pattern that occurs primarily in the sagittal plane (Figure 2). As most of the arm movement

occurs in the sagittal plane so do the greater proportion of ground reaction forces. Hockey skating coaches may tend to favor this technique on the basis that it helps to create and maintain forward momentum of the skater (Glantz, 2010; Nauman, 2009). It is believed that any motion of the arms that is not directed forward and backward is wasted energy and will negatively affect skating velocity (Rhoads, 2010). The arms alone are not able to generate momentum for the skater without somehow transferring the force that is created against the ground surface (Dapena, 1988). This suggests that the momentum that is generated by the arms should be produced in the same direction as the momentum created by the propulsion of the legs. This will help to increase forces directed through the skate and onto the ice in the same force vector as lower limb propulsion. In addition the forward and backward movement of the arms during hockey skating is in direct conflict with the movement patterns of the lower limbs that push sideways against the ice. In order to maintain balance in the body the arms should directly oppose the action in the legs by also moving in a side to side manner.

If the arm swing and leg propulsion occur in exactly the same plane of motion the ground reaction forces produced by the upswing of the arms will be directed in the same plane as the propulsive forces produced by extension and abduction of the hip. The propulsive forces of the muscles of the leg and the reaction forces from the arms will summate providing a greater amount of force acting perpendicular to the length of the skate blade helping to propel the skater

forward. In hockey because the action of the legs occurs in both the sagittal and frontal planes the arms should also swing in both the sagittal and frontal planes.

Angular momentum is produced about the longitudinal axis of the body during propulsion because the skate pushes sideways against the ice at a perpendicular distance from the axis of rotation (Figure 25). This action creates the force and moment arm that leads to torque production which tends to rotate the athlete in the opposite direction to the push.
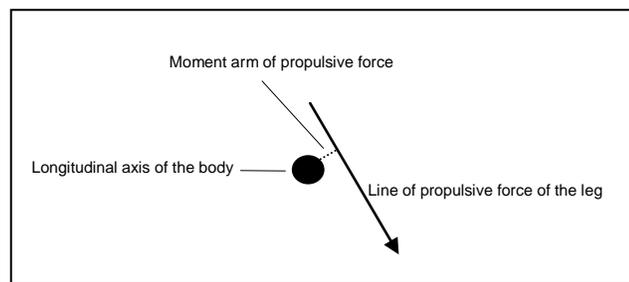
Figure 25: The propulsion of the leg acts at a distance to the longitudinal axis of the body.

In order to balance the angular momentum about the longitudinal axis of the body created by the propulsion of the legs during the hockey stride the arms should swing in an opposite direction in the same plane of motion, using a large amount of trunk rotation in the direction opposite to the push of the leg against the ice. This is similar to the technique of elite sprinters who forcefully swing their arms in the sagittal plane in a direction that is opposite of the ipsilateral leg. If there is no movement of the upper limbs to counter the angular movements of the legs unwanted angular motion about the long axis of the body can occur causing the athlete to lose balance and forward momentum.

The mediolateral arm swing can help to eliminate the unwanted torque created during propulsion by taking up the force as they swing across the body. When using the anteroposterior arm swing technique the action of flexing and extending the shoulders may increase the moment of inertia of the upper body about the longitudinal axis. As the arms are extended away from the body at peak upswing and peak downswing the general distribution of weight of the upper body is moved further from the longitudinal axis resulting in a greater moment of inertia, or resistance to change in angular motion. This could have some counterbalancing function helping to resist some of the unwanted torques created by the lateral propulsion forces.

Studies of the action of arms generally conclude that the use of an arm swing can contribute to performance by various mechanisms (Arellano et al., 1988; Ashby & Heegaard, 2002; Bhowmick &Bhattacharyya, 1988; Cheng et al., 2008; Feltner, Fraschetti, & Crisp, 1999; Hara et al., 2006; Hara et al., 2008; Harman et al., 1990; Lees, Vanrenterghem, & De Clercq, 2006; Miller et al., 2009; Ortega, Fehlman, & Farley, 2008; Shetty & Etnyre, 1989; Umberger, 2008). Hara et al. (2008) concluded that that the arm swing should be directed in the same plane of overall desired motion. During horizontal jumping the arms should swing forward when the direction of travel is forward and the arms should swing backward when the direction of travel is backward (Hara et al., 2008).

Ground reaction forces created by the action of an arm swing have been studied only in movement skills where propulsion and translation of the body occur in the sagittal plane such as walking, running, vertical jumping and backward and forward horizontal jumping. In each of these movement patterns the primary means of propulsion (generation of ground reaction forces) by the lower limbs occurs by extension of the pushing leg hip, knee and plantarflexion of the ankle. In contrast to hockey skating no abduction or adduction of the hip occurs, and there is usually very limited rotational movement about the longitudinal axis of the body. The rotational movements and the abduction and adduction of the propulsive hip require a different movement pattern in the arms in order for the arm swing to contribute to performance.

The resultant magnitude of the ground reaction forces is similar between the two arm swings, though the direction of the resultant is significantly different. In order for the forces created by the arm swing to contribute maximally to the forward velocity of a skater they should be directed along the line of push of the propulsive leg. The ground reaction forces produced by the anteroposterior arm swing are directed more posteriorly than the mediolateral technique because the upswing of the arm occurs in the sagittal plane. Due to the nature of blade to ice contact a portion of the ground reaction forces will be lost to a sliding motion and will not contribute to forward propulsion. It is recommended that skaters push off with the propulsive leg at an angle of 45 degrees to the sagittal plane (Alexander et al., 2007). The mediolateral arm swing generates ground reaction forces that

are directed very close to the recommended 45 degree angle of push and thus may contribute more efficiently to forward velocity production. Mike Bracko, author of the 1996 study *Glenohumeral Kinematics: A Comparison of Three Techniques During an Ice Hockey Acceleration Test* and director of Calgary's Institute for Hockey Research has been quoted saying "fast skaters move their arms side to side as opposed to slow skaters who move their arms back and forth" (McMurray, 2010). This statement may reflect an observation of the results of successfully directing the forces from the arm swing for maximal force production.

The current study is limited by the laboratory setting and the isolation of the arm swing from any action of the lower body. The athletes were standing stationary on the force platform with the resulting data reflecting only the action of the arms. The movement patterns produced during testing may not directly reflect what occurs in an on ice practice or game. The data does however provide a picture of the forces being produced by two opposing arm swing styles and insight into the possible contributions of each to hockey skating performance. This study shows that there are significant kinetic and kinematic differences between techniques each with their own implications for performance. Further studies should aim to collect kinetic data during on ice skating including ground reaction forces, segment accelerations and three dimensional movement analysis.

Conclusions

Both the anteroposterior and mediolateral arm swing techniques produce resultant ground reaction forces of similar magnitudes but the plane of motion of the arm movement closely reflects the plane of ground reaction forces produced. The mediolateral arm swing technique uses a movement pattern that closely opposes the action of the legs using abduction and adduction of both the glenohumeral and hip joints. This acts to counterbalance the rotation produced about the longitudinal axis of the body. The movement pattern of the anteroposterior arm swing does not directly oppose the rotation from the lower body but the extension and flexion of the arms away from the body may increase the moment of inertia of the trunk acting to resist the rotation created in propulsion. The ground reaction forces produced by the anteroposterior technique are directed at a smaller angle from the sagittal plane as compared to the mediolateral technique. The ground reaction force produced by the mediolateral arm swing closely match in direction with the angle of push of the leg against the ice which may lead to a greater contribution to skating velocity. Ice hockey skaters should perform the mediolateral arm swing to maximize the effective ground reaction forces produced with each stride.

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Appendix A

Research Ethics Approval Certificate

UNIVERSITY of MANITOBA | Ethics
Office of the Vice-President (Research)

CIBC Building
208 - 194 Dafoe Road
Winnipeg, MB R3T 2N2
Fax (204) 269-7173
www.umanitoba.ca/research

APPROVAL CERTIFICATE

September 22, 2011

TO: Julie Hayward   (Advisor M. Alexander)
Principal Investigator

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

Re: Protocol #E2011:079
"Ground Reaction Forces Resulting from Mediolateral vs. Anteroposterior Arm Swing & Theoretical Application to Forward Hockey Skating"

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

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

> Please note:
>
> - If you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to the Office of Research Services, fax 261-0325 - please include the name of the funding agency and your UM Project number. This must be faxed before your account can be accessed.
>
> - If you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.

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

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

Bringing Research to Life

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Appendix B

Subject Consent Form

Research Project Title: Ground reaction forces from two different styles of hockey skating

Principal Researcher:
Julie Hayward, BKin, CAT(C), Master's Candidate
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Research Supervisor:
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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.

Summary of Project
The contribution of the arm swing in forward hockey skating is less well understood than the contributions of the lower body due to limited research on the subject. Two styles of arm swing are commonly taught to hockey players though controversy exists as to which style is more likely to result in faster skating. The mediolateral arm swing involves mostly side to side arm motion whereas the anteroposterior arm swing is mostly front to back movement.

The role of the arm swing can be conceptually divided into two general categories; facilitation of ideal lower body mechanics, and generation of ground reaction forces. The purpose of this study is to measure and compare the

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ground reaction forces produced in the anteroposterior and mediolateral style arm swings. The secondary purpose is to theoretically relate those findings to the production of forward hockey skating velocity.

Data collection will occur over 1-2 days at the Pan Am Clinic Foundation Inc. Biomechanics Research Centre. Each participant will be asked to attend the facility for a scheduled testing session lasting approximately 90 minutes; each participant will be tested on one occasion only. Evaluation methods will include the use of participant anthropometric data, force platform measurements and video analysis to investigate the differences between each of the two arm swing styles. Prior to data collection a research assistant will record each participant's age, height, mass and reported number of years hockey experience. The participants will be assigned a number at this time and will be tracked and recorded through the data collection process by number only. A five minute training session will be conducted providing instruction and practice for participants regarding the anteroposterior and mediolateral arm swing styles. Training will include the use of a metronome to ensure subjects perform the arm swing at uniform speed approximating typical fast paced on ice skating stride rates. The metronome will also be used during data collection to keep pace.

Participants will stand on the ground mounted force platform wearing athletic shoes. They will perform 10 repetitions of the anteroposterior arm swing to the pace of the metronome. Force platform data will be collected for the duration of the 10 repetitions. Following a 20-30 second rest the subject will be instructed to repeat this procedure for a total of 3 trials. During data collection two video cameras will be set up and recording from an anterior view and a sagittal view for later analysis of upper body kinematics using Dartfish motion analysis software. On completion of 3 trials the participant will be given approximately 5 minutes rest before data collection of the mediolateral arm swing commences.

Following data collection, all trials of anteroposterior and mediolateral arm swing will be analyzed for peak scaled ground reaction force magnitudes and peak upper extremity joint angles. Each participant's data will be averaged across the 3 trials and compared across conditions. These results will be used to infer the potential contributions of each arm swing style to forward hockey skating performance.

Research Instruments

Digital Video Camcorder

Two Canon GL2 standard definition digital video camcorders will be used to film the participants performing all trials during data collection, The cameras will be set on tripods at a distance of at least 1.5 meters from the force platform to ensure there is no chance of the participants contacting the cameras and/or tripods at any time during data collection.

Force Platform

One OR-6 model Biomechanics Force Platform manufactured by Advanced Mechanical Technology Inc. will be used to collect the force data required for this study. The platform is located at the Pan Am Clinic Pan Am Clinic Foundation Inc. Biomechanics Research Centre. The ground mounted platform is level with the surrounding floor and does not pose any risk to participant of tripping or falling.

Feedback/Debriefing

Following the testing session each participant will be invited to view a sample of video analysis and force platform data. Because the raw data must be processed before it can be read and understood it will not be possible to show the participants data collected from their own trials.

Risks and Benefits

There are no risks to participants. They will be performing low intensity physical tasks that are currently part of their regular physical training regime in a controlled environment. The results of this study will benefit all participating coaches and athletes in providing evidence to be used for the attainment of improved skating performance.

Anonymity

All data collected for this study will remain anonymous and will not be marked with any personal identifiers at any time. The digital video recordings will be stored on an external computer hard drive and will only be viewed by the researcher and research advisor. The data will be kept in a locked cabinet in the University of Manitoba Sport Biomechanics laboratory and will not be used for any other purpose than the current study. After completion of the study in approximately March 2012 the digital video recordings will be destroyed. The

force plate data will be stored on the computer and will remain anonymous at all times. Sample force plate data may be stored for later teaching purposes.

Compensation

There will be no compensation offered to participants of this study.

Dissemination

The results of this study will be published as a Master's Thesis. A summary of outcomes will be distributed to participants and volunteers involved in the research. This research may be published in print or online academic and professional journals and magazines.

When the results of the study become available approximately in April of 2012 a summary of outcomes will be forwarded to the each participant.

Principal Researcher:

Julie Hayward, BKin, CAT(C), Master's Candidate
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 204-474-8675 umhaywaj@cc.umanitoba.ca

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

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

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

_____

Participant Name

_____

Participant Signature   Date

_____

Parent and/or guardian's signature (if under 18 years of age)   Date

_____

Researcher or Delegate's Signature   Date

If you would like to receive a copy of the results of this study please provide your mailing address below and a copy will be sent upon completion.

_____
_____
_____
_____

Appendix C

Subject Characteristics

Subject	Age (years)	Height (m)	Mass (kg)	# years hockey experience (years)	Leg dominance (r/l)	Shot (r/l)
High School						
0	17	1.65	64.4	14	L	L
1	16	1.60	75	11	L	R
2	16	1.64	65.9	13	R	R
3	16	1.66	65	13	R	L
4	16	1.67	62	11	R	L
5	17	1.62	67	11	L	L
6	17	1.60	69	13	L	R
7	16	1.75	75	10	R	L
8	17	1.62	67	13	R	R
9	16	1.69	53.5	12	R	L
10	17	1.76	67.5	11	R	L
11	17	1.80	81	11	R	R
12	16	1.69	63	5	R	L
13	16	1.57	62.2	9	L	L
CIS/NCAA						
14	20	1.68	71	12	L	L
15	21	1.64	79	13	L	L
16	19	1.66	66	11	R	L
17	20	1.63	67.4	14	R	L
18	19	1.70	82.5	16	R	R
19	20	1.78	79	15	R	L
20	19	1.72	64.5	14	R	L
21	20	1.72	74.5	10	R	L
22	25	1.68	74.5	12	R	R
23	23	1.70	62.5	18	R	L
					total	
mean	18.17	1.68	69.1	12.17	R=17 L=7	R=7 L=17
s	2.41	0.06	6.97	2.49		

<center>**Appendix D**</center>

<center>**Pilot Study**</center>

Introduction

The purpose of the pilot study was to collect video and force platform data from subjects performing the two different hockey skating arm swing techniques. The pilot study provided the investigator with an opportunity to test methods of data collection and analysis to be used during the thesis project including video camera setup, force platform configuration and experimental protocol. Finally the pilot study was used to determine what differences might exist between the ground reaction forces produced by different hockey skating arm swing techniques.

The pilot study took place on two occasions at the Pan Am Clinic Biomechanics Laboratory, April 19, 2011 and May 12, 2011.

Methods

Subjects

Two subjects were used for the pilot study; on April 19, 2011 a research assistant volunteered to participate and performed a number of preliminary trials. On May 12 2011, a female hockey player from Balmoral Hall School was tested; this subject represented the population of interest of the study. Test procedures were explained to the subject prior to the commencement of testing procedures.

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Experimental Procedures

Filming Technique

The same filming technique was used on both occasions of pilot study data collection. Two cameras were set up to capture the kinematics of the arm swing techniques being performed. A front view camera was set up to capture the frontal plane movements and a side view camera was set up to capture sagittal plane kinematics. All trials were recorded in this manner for later kinematic analysis of the arm swing techniques that were performed by the subjects.

Force Platform & Subject Configuration

The pilot study provided an opportunity to explore different configurations with regards to subject stance and positioning over the force plates. It was used to determine which subject stance would be most beneficial for providing clear and consistent force data for the thesis project. All force platform data collection was conducted by the technician at the David and Ruth Asper Research Centre. On April 19, 2011 three different subject configurations were performed. The first trial consisted of the subject standing on two feet evenly spaced and approximately shoulder width apart, each foot standing on an independent force platform (see Figure 1).

Figure 1: Subject configuration number one, one foot on top of each mounted force platform.

Due to the existing setup of the force plates and mounting platform it was difficult for the subject to stand in a symmetrical position while ensuring full contact between the bottom of each shoe and the force plate. For this reason the two force plate configuration was not deemed appropriate for the thesis study. The second configuration had the subject standing with only the left foot in contact with the force plate, both feet in contact with the ground evenly spaced and approximately shoulder width apart. For the third configuration the subject stood in the same position as configuration number two but with only the right foot in contact with the force platform (see Figure 2).
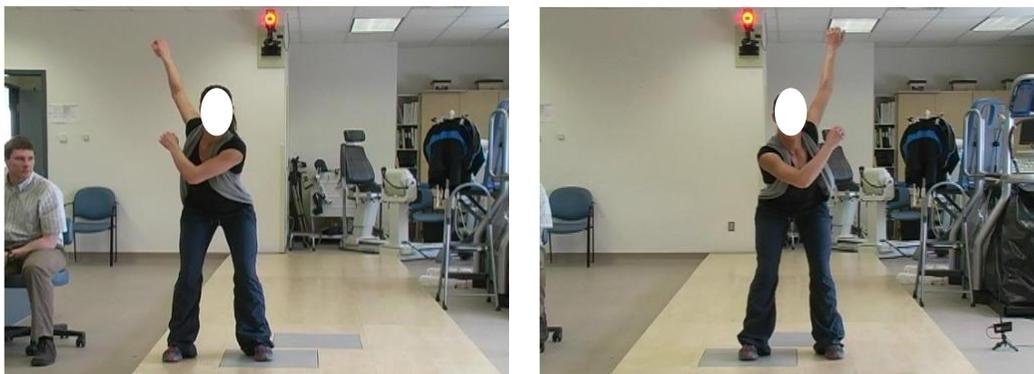
Figure 2: Subject configuration trials two (left) and three (right) with one foot in contact with the force plate.

The subject was right leg dominant; to eliminate redundancy of data it was decided to test each subject only with their dominant leg foot in contact with the force plate for the thesis data collection procedures.

During the second pilot data collection phase on May 12, 2011 the subject performed trials under three configurations including configuration number three in which the dominant leg foot was in contact with the force plate as this was found most effective during the first data collection session. Additionally the subject performed configuration number four in which a partial single leg stance was used where the dominant (right) foot was in contact with the force plate and the left foot was slightly posterior with only the toes in contact with the ground for balance, see Figure 3. It was determined that this position might create more distinct force data for analysis because most of the bodyweight would be directed through the dominant leg overtop the force plate. During this trial the subject had difficulty maintaining her balance while performing the arm swing techniques which would inevitably lead to artifact in the force data as the centre of gravity shifted during balance loss and correction.

The fourth and final subject configuration mimicked configuration number three, the most successful of trials, with the addition of 2.5lb barbell plates to add weight to the arm swing. It was hypothesized this might increase the magnitude of the resulting ground reaction forces. The subject held one barbell plate in each hand while performing the arm swing trials, see Figure 3.

Figure 3: Subject configurations four (left) and five (right) performed on May 12, 2011.

A comparison of force data collected for subject configurations three and four can be found in Figure 4 and Table 3. Although the use of the hand held weights increased the magnitude of the ground reaction forces that were measured with each arm swing technique it was decided that the thesis data would be collected without the addition of hand held weights. The measurement of the true ground reaction forces produced with the various arm swing techniques is an important aspect of this study which may aid in future research study design. Following the collection of all pilot study data it was concluded that subject configuration number three would be used for the collection of data to be included in the thesis research. This configuration was the most feasible and provided the most useful data for the purposes of this study.

Kinematic analysis from video footage

Kinematic analysis from the video footage taken during the pilot study was performed using Dartfish TeamPro software version 4.5.2.0 (2005). The video analysis focused on variables pertaining to the arm swing techniques performed

and are listed in Table 1. Only the trials consisting of subject configuration number three (as previously described) were included in the kinematic video analysis. Angular velocities of the shoulder in flexion/extension and abduction/adduction, and angular velocity of the elbow in flexion/extension were calculated.

Table 1 Kinematic variables measured for the pilot study.

Kinematic Measurement Variables
Glenohumeral flexion/extension range of motion (deg)
Glenohumeral flexion/extension angular velocity (deg/sec)
Glenohumeral abduction/adduction range of motion (deg)
Glenohumeral abduction/adduction angular velocity (deg/sec)
Elbow flexion/extension range of motion (deg)
Elbow flexion/extension angular velocity (deg/sec)
Time from peak upswing to peak downswing (sec)

Force Platform Data Analysis

Force data for the pilot study were collected using an OR-6 model Biomechanics Force Platform manufactured by Advanced Mechanical Technology Inc. (AMTI). Force platform data were amplified and recorded using the Vicon Workstation software package for later analysis.

Data from all trials was processed using Microsoft Excel software. All measurements were scaled to the subjects' body weight and analyzed for peak scaled ground reaction force magnitudes in each of the three planes. Only data collected using subject configuration numbers three and four were further analyzed for the purpose of the pilot study. After it was determined that

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configuration number three would be used for thesis data collection procedures all further analysis included only data pertaining to this configuration.

Results & Discussion

Kinematic Analysis

The kinematic analysis from video footage taken during the pilot study showed clear differences between the anteroposterior and mediolateral arm swing techniques. Table 2 shows the results of all measurement variables measured during the pilot study. The kinematic analysis showed several important differences between the arm swing styles that were tested, indicating that the subjects successfully performed two different techniques for analysis. The mean time from peak upswing to peak downswing was 0.63 and 0.68 seconds for the anteroposterior and mediolateral arm swing trials respectively. This slight difference was due to the lack of control over arm swing velocity, in order to accurately study the differences in ground reaction forces between the arm swing techniques the timing of the trials must be controlled. For this reason the investigator added the use of a metronome to the data collection procedures.

Table 2: Kinematic variables measure in the pilot study.

	Anteroposterior Arm Swing			Mediolateral Arm Swing		
	Subject 1	Subject 2	Mean	Subject 1	Subject 2	Mean
Measurement						
Time from peak upswing to peak downswing (sec)	0.60	0.66	**0.63**	0.66	0.70	**0.68**
Glenohumeral flexion/extension range of motion (deg)	165	205	**185**	146	216	**181**
Glenohumeral flexion/extension angular velocity (deg/sec)	275	292.86	**283.93**	221.21	284.21	**252.71**
Glenohumeral abduction/adduction range of motion (deg)	17	16	**16.5**	165	204	**184.5**
Glenohumeral abduction/adduction angular velocity (deg/sec)	28.33	22.86	**25.60**	250	268.42	**259.21**
Elbow flexion/extension range of motion (deg)	41	30	**35.5**	119	76	**97.5**
Elbow flexion/extension angular velocity (deg/sec)	68.33	42.85	**55.59**	180.30	100	**140.15**

The mean range of motion through flexion/extension during the anteroposterior arm swing was 185 degrees with an angular velocity of 283.93 degrees per second. This value did not differ greatly as was expected for the mediolateral arm swing which had a mean flexion/extension range of motion of 181 degrees with an angular velocity of 250.71 degrees per second. It should be noted that subject number two who was an experienced hockey player had considerably less flexion/extension range of motion during the mediolateral arm swing as compared with the inexperienced subject number 1. Given that all subjects for the thesis study will be of similar experience as subject number two it

is expected that arm swing kinematics included in the study will more closely mimic that of pilot subject number 2.

The mean range of glenohumeral abduction/adduction in the anteroposterior arm swing was 16.5 degrees with an angular velocity of 25.60 degrees per second. The mean abduction/adduction range for the mediolateral arm swing was considerably higher at 184.5 degrees with 259.21 degrees per second angular velocity. This difference was expected and indicates that the subjects successfully performed two different arm swing techniques during testing.

The kinematics of the elbow were also considerably different between the two arm swing techniques. The mean elbow range of motion during the anteroposterior arm swing was 35.5 degrees with 55.59 degrees per second, elbow motion was 97.5 degrees with 140.15 degrees per second angular velocity during the mediolateral arm swing. These results indicate that the mediolateral arm swing technique may involve more flexion and extension of the elbow, though it should be pointed out that the experienced hockey player showed decreased elbow motion values on both arm swing techniques as compared with the inexperienced pilot study subject.

Kinetic Analysis

One purpose of the pilot study was to determine the most effective subject configuration to be used for the thesis project. Following the testing sessions the

investigator had to make a decision between the two most plausible

configurations; numbers three and five (see Figures 2 and 3). It was

hypothesized that the addition of hand held weights would increase the

magnitude of the ground reaction forces without disrupting the direction, which

was confirmed upon analysis of the force platform data. Only pilot subject

number two was tested using the fifth configuration with the hand held weights,

the results of this test are summarized in Table 4 and Tigure 4. The data was first

scaled by dividing the data by the subjects' weight in Newtons. The absolute

value of the data points was used for analysis.

Table 3 Comparison of force plate summary data from subject configurations three and five performed on May 12, 2011. Forces expressed in Newtons per body mass.

	Anteroposterior Arm Swing			
	Configuration 3		Configuration 5	
	Sagittal Plane GRF	Frontal Plane GRF	Sagittal Plane GRF	Frontal Plane GRF
Peak	0.0514	0.1137	0.1342	0.1631
Mean	0.0220	0.0858	0.0608	0.1141
	Mediolateral Arm Swing			
	Configuration 3		Configuration 5	
	Sagittal Plane GRF	Frontal Plane GRF	Sagittal Plane GRF	Frontal Plane GRF
Peak	0.0487	0.1250	0.0917	0.1593
Mean	0.0145	0.0829	0.0350	0.1127

No Handheld Weights   With Handheld Weights
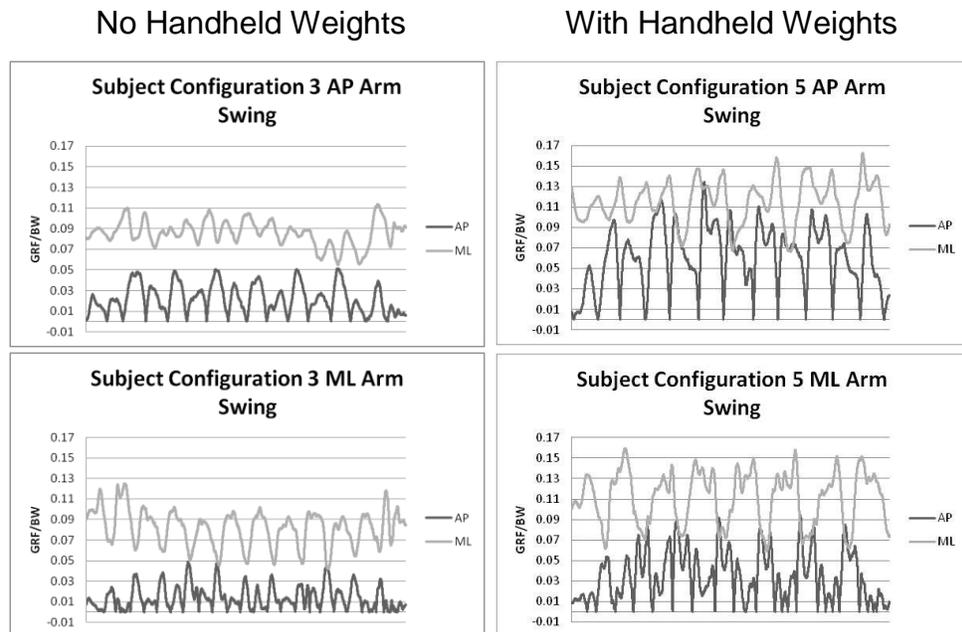
Figure 4: Comparison of force plate data for configurations three and five performed on May 12, 2011.

Sagittal plane peak scaled ground reaction forces during the anteroposterior arm swing trial increased from 0.0514 N/BW to 0.1342 N/BW with the addition of two hand held 2.5lb barbell plates. Frontal plane peak scaled ground reaction forces during the anteroposterior arm swing trial increased from 0.1137 N/BW to 0.1631 N/BW when the plates were added.

Sagittal plane peak scaled ground reaction forces during the mediolateral arm swing trial increased from 0.0487 N/BW to 0.0917 N/BW with the addition of two hand held 2.5lb barbell plates. Frontal plane peak scaled ground reaction forces during the mediolateral arm swing trial rose from 0.1250 N/BW to 0.1593 N/BW when the plates were added. Although these results support the hypothesis that ground reaction force magnitude would be increased with the

addition of the barbell plates, this adjustment was not deemed necessary for the purpose of the thesis research. Further analysis of the force platform data was conducted only for trials of the pilot study that were carried out using configuration number three, which will be used during the thesis data collection.

An analysis of the successful trials from each of the subjects shows a 12.97% reduction in sagittal plane ground reaction forces and a 20.77% increase in frontal plane ground reaction forces when subjects used the mediolateral arm swing as compared with the anteroposterior arm swing technique (see Table 4).

Table 4 Comparison of mean peak ground reaction forces in the sagittal and frontal planes for subjects performing the anteroposterior and mediolateral arm swing techniques. Forces are expressed in Newtons per body mass.

	Anteroposterior Arm Swing	
	Peak Sagittal Plane GRF (N/BW)	Peak Frontal Plane GRF (N/BW)
Subject 1	0.0750	0.0802
Subject 2	0.0534	0.1137
Mean	0.0642	0.0970
SD	0.0153	0.0237
	Mediolateral Arm Swing	
	Peak Sagittal Plane GRF	Peak Frontal Plane GRF
Subject 1	0.0630	0.1093
Subject 2	0.0487	0.1250
Mean	0.0559	0.1171
SD	0.0101	0.0112
% Change	**-12.97**	**20.77**

This data supports the investigator's hypotheses that the mediolateral arm swing would produce more frontal plane ground reaction forces and less sagittal plane ground reaction forces than the anteroposterior arm swing style, see Figure 5.
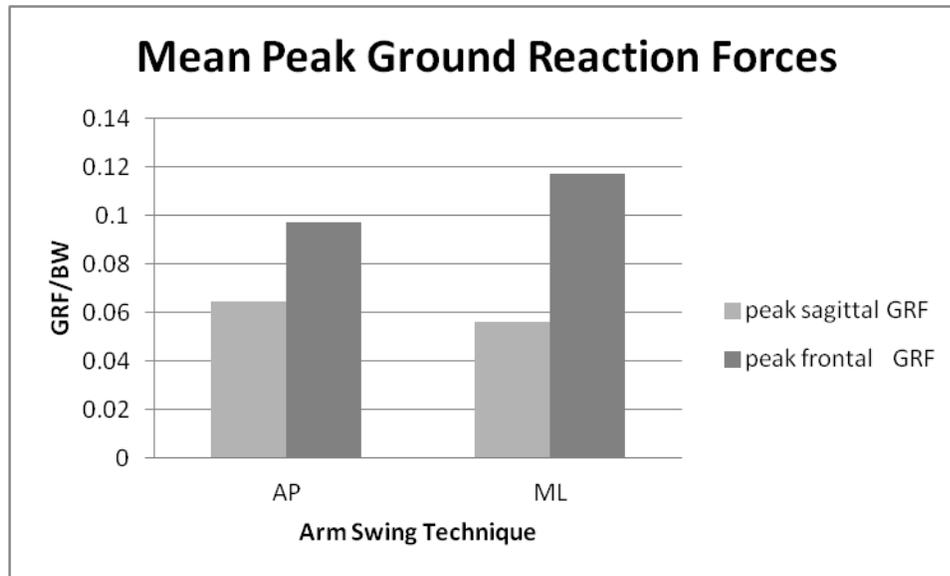
Figure 5: Mean peak ground reaction forces for the anteroposterior (AP) and mediolateral (ML) arm swing techniques, scaled to body mass (BW).

A power analysis for the calculation of required sample size for the full scale study was conducted with a significance level (alpha) of 0.05 was used with a desired power of 0.80. The minimum detected difference between GRFs of the two arm swing techniques during this pilot study of 0.01N occurred in the sagittal plane, this value was used for the sample size calculation. A standard deviation of 0.01 was used in the power analysis. This value was estimated based on the average standard deviation of the sagittal plane data. The calculation was performed based on the formula $N=4\sigma^2(z_{crit}+z_{pwr})^2/D^2$; where σ is the estimated standard deviation, z_{crit} is the critical value 1.96 (for $\alpha=0.05$), z_{pwr} is the standard normal deviate for $\beta=0.80$, and D is the minimum expected difference between two means (Hassard, 1991). The result of this calculation is a required sample size of 32 for the planned full scale study.

The purpose of the pilot study was to collect video and force data of subjects performing two different hockey arm swing techniques. The results of the study showed that subjects successfully performed the two arm swing styles intended for study and that there is a difference in the ground reaction forces resulting from each of these styles. The pilot study provided support for the hypothesis and rationale for the continuance of the thesis study investigating the difference in ground reaction forces produced with various arm swing styles used in hockey skating.