Skating Mechanics of Change of Direction Maneuvers in Hockey Players

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ABSTRACT

Ice hockey is a popular winter sport that involves many skating skills improved by coaching instruction and numerous hours of practice. Once the basic mechanics of skating have been honed, the open game context requires rapid skating transitions between skating skills so as to effectively navigate about the ice surface to evade opponents and move in strategic tandem with teammates. Consequently, a player's performance relates in large part to effective change of direction maneuvers. The purpose of this study was to observe the kinetics of change of direction maneuvers in hockey players while wearing one of two skate models: a conventional skate and a skate with enhanced ankle mobility. Eight subjects with competitive ice hockey playing experience performed 90° change of direction tasks both to their left and then right sides for both skate models. Kinetic data were collected using a portable acquisition device connected to force strain gauge transducers on the blade holder. During a change of direction maneuver, a significant difference in the force applied by the inside and outside skates was noted ($p < 0.05$). No significant differences were observed as a main effect for skate model and turn direction. Significant differences were noted when leg side (inside/outside) was compared with skate model or turn direction ($p< 0.05$). This can provide insight to ice hockey coaches for training and skill development purposes but also to ice hockey skate manufacturers for future directions related to injury prevention and skating performance.

ABRÉGÉ

Étant un sport d'hiver populaire, l'hockey sur glace englobe plusieurs tâches de patinage qui sont améliorées par l'enseignement des entraîneurs accompagné de plusieurs heures de pratique. Une fois que les bases du patinage sont maîtrisées, le contexte du jeu ouvert requière des habilitées de transition rapide à travers les aptitudes de patinage pour naviguer effectivement sur la surface glacée afin d'évader les adversaires et se déplacer de manière stratégique avec les coéquipiers. Par conséquence, la performance d'un joueur est largement reliée aux mouvements de changement de direction. L'objectif de cette étude est d'observer la kinétique des mouvements de changement de direction de joueurs d'hockey en portant soit un patin conventionnel ou un patin avec une plus grande mobilité à la cheville. Huit sujets avec de l'expérience compétitive d'hockey on performés des mouvements de changement de direction de 90° à gauche et a droite pour les deux type de patins utilises. Des données kinétiques on été collectées en utilisant un système portable d'acquisition de données connecté à des jauges de déformation situés entre la lame et la botte du patin. Durant un mouvement de changement de direction, une différence significative a été observée au niveau de la distribution du poids entre la jambe extérieure et intérieure ($p > 0.05$). Aucune différence significative n'a été notée pour les deux modèles de patin ou par rapport à la direction du virage. Des différences significatives ont été observées lorsque la jambe intérieure ou extérieure a été comparée avec le type de patin utilisé ou la direction du virage ($p > 0.05$). Ceci nous donne de l'information par rapport aux stratégies d'entrainement des joueurs d'hockey ainsi que pour la fabrication de futurs modèles de patin pour la performance et la prévention aux blessures.

CHAPTER 1 – REVIEW OF LITERATURE

1.1 ORIGINS OF HOCKEY AND ICE SKATING

Skating itself has evolved over several hundred years, first evident in northern European countries that developed skating as a possible alternative means of locomotion (Formenti and Minetti, 2008). The oldest known skates to be discovered were made of animal bones and determined by archaeologists to have originated from as far back as 2000 B.C. from countries such as the Netherlands, Finland, Sweden and Norway, possibly developed for traveling during hunting and fishing during the long winters (Formenti and Minetti, 2008).

Later, skates consisting of a wooden boot with an iron runner strapped under the bottom were used throughout the 16th and 17th centuries when ice skating began to develop as a competitive sport. The first all-steel skate called 'long blades' or 'Norwegian skates' were invented in the middle of the 19th century and became the basis for the modern speed-skate used today (de Koning et al., 2000).

Ice hockey as we know it today has certainly come a long way since its evolution from ice hurley in the 1800's by students at King's College School in Windsor, Nova Scotia who have been credited for the origins of the game (Diamond et al., 1998). Hurley (originally a stick-and-ball summer sport like brandy, shinny, cricket, and lacrosse) had been adapted for play on local skating ponds in the winter to create the new sport of ice hurley (Diamond et al., 1998). The influence of Irish, Scottish, French and English sub cultures led the game to be organized and played by the rules of ice hockey (Pearsall et al., 2000). From this template, the game has evolved as new innovations in equipment design, facilities, coaching, game strategy and training were introduced (Pearsall et al., 2000).

There are similarities between speed skating and ice hockey as to the types of movements that are performed by an athlete of either discipline. Although understanding the roots and origins of how both disciplines developed into the sports we know today , it is also equally important to understand the principles behind the movement patterns of ice skating itself, which we will address in the following section.

1.2 ICE SKATING

Ice skating, which is defined as the ability to travel on ice (Formenti and Minetti, 2008), is considered an effective method of locomotion on ice by the reactive force that is produced perpendicular to the direction of travel (de Koning et al., 1995; Pearsall et al., 2000; Upjohn et al., 2008). Due to the low friction on the ice surface, the coordination patterns of the hip extension, hip abduction, knee extension and plantar flexion are adapted to accommodate a more natural movement pattern as seen in walking or running (Pearsall et al., 2000; Upjohn et al., 2008; van Ingen Schenau et al., 1989).

Forward skating is one of the most crucial ice hockey skills a player must possess. The stride in forward skating is biphasic in motion and begins when the blade of the skate worn on the foot makes contact with the ice progressing into glide, push-off and ipsilateral-limb recovery phases (de Boer et al., 1986; de Boer el al., 1987; de Koning et al., 1991; de Koning et al., 1995; de Koning et al., 2000; Marino and Weese, 1979; Upjohn et al., 2008). Following this initial contact, the glide phase follows as the phase in the stride where no propulsion is occurring (Pearsall et al., 2000). The movement is body is steered in this glide phase through the orientation of the skate blade (Pearsall et al., 2000). When the skate blade externally rotates, this is considered the push-off phase which occurs immediately after the glide phase and rapid extension of the hip, knee and ankle is used to create propulsion (Pearsall et al., 2000). The full extension of the extending leg followed by the blade being lifted off the ice marks the end of the push-off phase (de Boer et al., 1986). As the push off is completed, the flexion of the non-weight bearing limb marks the start of the recovery phase as it is allowed to swing forward to begin the next skating stride (Pearsall et al., 2000). This forward skating pattern consists of 95-80% of all skating maneuvers performed during the duration of an entire hockey game, with an average player covering between 3 to 5 kilometers over approximately 20 minutes of ice time (Montgomery et al, 2004, Percival, 1970).

As one would suspect, in order for a player to be able to properly cover the aforementioned amount of distance over a relatively short time period; properly designed skates would be required to ensure optimal performance of these forward skating tasks with minimal encumbrance. The following section will take a closer look at the various concepts behind ice skate design, particularly for use in hockey.

1.3 ICE SKATES

Ice skates are tools primarily used to harness the frictional properties of ice to help the player control his/her movement patterns while travelling on the ice (Minetti, 2004). Modern skates used today for sporting or leisure activity have evolved and changed primarily due to trial and error in terms of skate design (Pearsall and Turcotte, 2007). Currently, the blade along a standard hockey skate as shown in Figure 1 (adapted from Stidwill et al., 2010) is curved along its length with radii of curvature of 2-3m and acts as the main interface between the skate and the ice surface during skating tasks. This blade in cross-section consists of a medial edge, a lateral edge divided by a shallow hollow between the two edges. It is one of these two edges that maintain contact with the ice surface during the gliding phase by creating a shallow channel by compression breaking into the ice surface.

Figure 1: Structural components of a modern hockey skate (adapted from Stidwill et al., 2010).

To momentarily gain leverage during the push-off phase of the stride, the blade is oriented obliquely in order to enable a reactive force. A diagram of this reactive force can be seen in Figure 2. The materials used and design characteristics of the skate can have a significant effect on medial-lateral or anterior-posterior mobility because of altered stiffness and thus boot construction can have an impact on skating performance (Pearsall et al., 2000). Because the boot is cut high above the medial malleolus it can provide additional support to the ankle in the medial-lateral direction during turning or change of direction maneuvers but may restrict plantar-dorsi flexion during push-off in forward skating depending on how the skate is fitted for the player. For optimal stability during propulsion generation at push-off, a considerable amount of force must be applied over a sufficient area within the wall of the skate boot as well as within the sole of the skate (Pearsall, 2004). Kinesthetic sense of joint position and limb orientation, accommodation for geometric anthropometrics and dynamic changes of the foot and ankle structures, and provision for effective anterior-posterior and medial-lateral alignment are the factors suggested to be taken into consideration for skate construction in order to obtain an optimally functioning hockey skate (Pearsall, 2004).

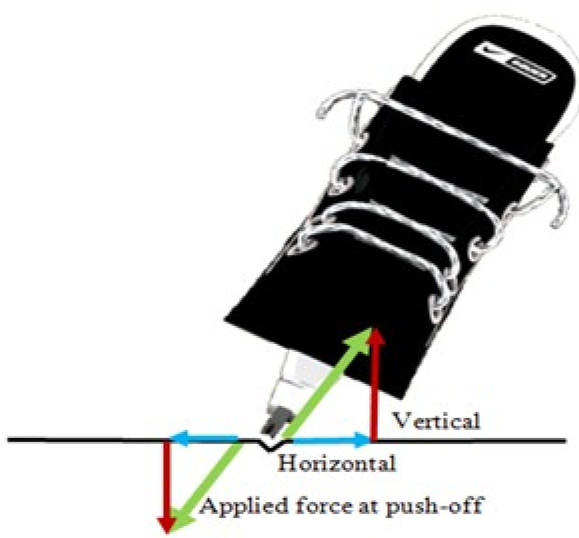

Figure 2: Orientation of skate to ice surface at push-off (adapted from Pearsall, 2007).

To aid manufacturers in evaluation of design, construction and material effects on the mechanical response to varying stresses in hockey skates, a system for measurement of stiffness properties in hockey skates has been validated (Turcotte et al., 2001). The use of pressure sensors, electrogoniometers and EMG sensors are available to develop performance and comfort improvements in skate design and functionality (Pearsall, 2004). A study that lends itself to this direction of modifying skate design for performance purposes was conducted to investigate frictional properties of three types of flared ice hockey blades compared to the frictional properties of a standard hockey blade. When compared to standard ice hockey blades, the blade angles (4°, 6° and 8°) decreased friction by 12, 21 and 22% respectively. If it is possible to enhance performance by modifying the blades, potentially other modifications to the skate's components can be made to improve performance (Federolf et al., 2008).

Because of the open nature of the sport, performance in ice hockey can be defined through so many different types of hockey skills. In the next section the nature of these skills will be discussed as they are divided into several sub-categories. A clearer understanding of the grouping of these skills will help us better determine which specific skill we would like to observe and why.

1.4 CLASSIFICATION OF HOCKEY SKILLS

Skating movement patterns comprise the primary skills for locomotion across the rink's ice surface. Similar skills may be grouped and classified (Pearsall et al., 2000). Fundamentally these skills are broken down into three sub categories: skating, stick handling and checking. Each category has a large number of sub-skills that can be identified in Figure 3 (Pearsall et al., 2000). These skill-sets required to play the game effectively are very distinct from other sports, primarily due to the environment on which ice hockey is played (Pearsall and Turcotte, 2007). These skills are considered to be 'open' in nature due to the constantly varying position and movement of the player, teammates, and the puck (Martell &

Vickers, 2004). The high variety of visual and auditory stimuli perceived by the players, forces the players to make optimally strategic decisions within a very short time frame (Martell & Vickers, 2004). These skills are not always performed consistently because of the ‘open’ and ever-changing conditions during a game of ice hockey, but also due to the many factors required for skills to be performed efficiently such as: anticipation, balance, reaction time, speed and timing (Pearsall et al., 2000). In a specific hockey task, if the factors required in the performance of the task such as with on-ice change of direction maneuvers are clearly identified, it could allow us to design an effective testing protocol for observation of the task in a more closed setting. Before doing so, we must first understand what exactly a change of direction maneuver is.

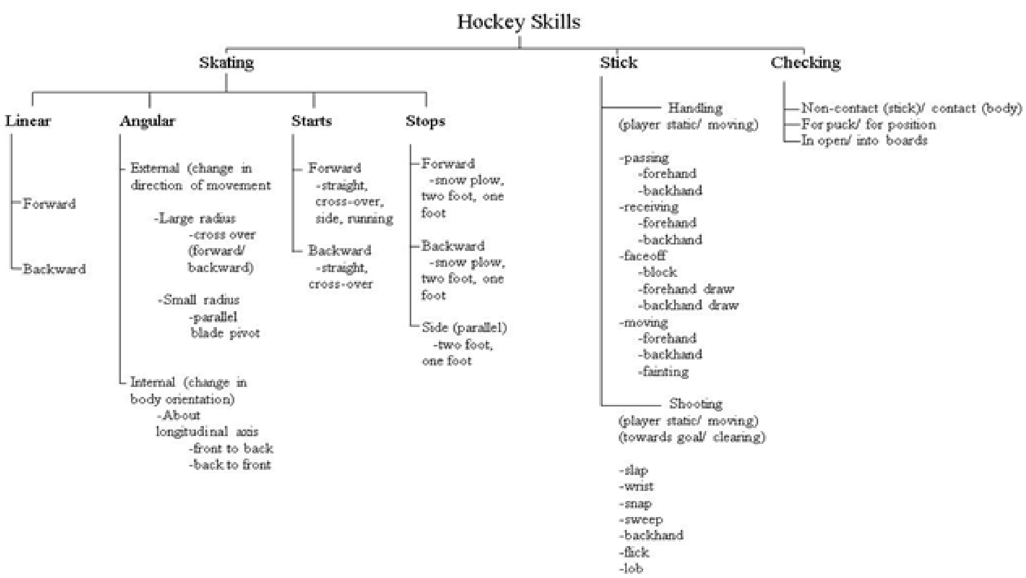

Figure 3: - Hockey's Fundamental Skills (adapted from Pearsall et al., 2000)

1.5 CHANGE OF DIRECTION MANEUVERS

The definition of the concept of agility has been highly discussed over many years mainly due to the high variability in the definitions of both agility and change of direction (COD) maneuvers. As a result the two terms are easily confused. The main consensus in modern research defines agility as a rapid-whole body movement with a change of velocity or direction in response to a stimulus (Sheppard and Young, 2006). A COD maneuver is considered a component of agility but is described as a pre-planned movement wherein no reaction to a stimulus is required (Sheppard and Young, 2006).

Attention has been given to the mechanics of COD maneuvers due to its associated links with non-contact, lower body injuries (Sanna, 2008). The injury mechanism is composed of a deceleration phase, a COD maneuver and a varus/valgus moment about the knee or internal/external rotation of the leg (Colby et al., 2000). This quick COD maneuver mechanism is often said to be the source of noncontact ACL rupture injuries (Ford et al., 2005). Larger breaking forces combined with higher muscle activation associated with different COD styles are also suspected to be factors related to increased risk of injury (Houck, 2003).

Colby's study observed EMG contraction of hamstrings and quadriceps muscles of collegiate and recreational athletes while performing COD tasks to observe implications for ACL injuries. These participants were instructed to run at what he described as 3/4 of the speed they would normally run at in a game situation where after reaching the end 8-meter runway they were instructed to plant the test limb of the contralateral side of the direction they were changing to at an angle of approximately 45°. EMG data was successfully collected for one test limb; however the other limb was left untested. It may be important to observe what is occurring in both limbs during this COD maneuver in order to improve our understanding of what occurs in both limbs during this action.

Observing both limbs during these maneuvers can help us understand the effects of dominant and non-dominant limbs on force production. In a study observing differences in landing and cutting maneuver neuromuscular strategies of female basketball and soccer athletes, ground reaction forces were collected using two forces plates spaced 8 cm apart for each foot to contact the plate (Cowley et al., 2006). The ground reaction forces for the dominant limb were seen to be 41.4% greater during the cutting maneuver, than the non-dominant limb (Cowley et al., 2006).

The speed of these COD maneuvers are said to be potentially influenced by three main factors including strength, power and reactive strength (Young and Farrow, 2006). Research attempting to observe the relationship between maximum leg strength and COD speed is lacking, and studies attempting to relate various measures of leg muscle power to some test of COD reported consistent low-to-moderate correlations (Young and Farrow, 2006). Reactive strength, defined as the ability to change from an eccentric to concentric phase quickly in a stretch-shortening cycle, was tested using a single-leg drop jump test to observe any muscle imbalances in this form of muscle power. Correlations with COD speed tests were not particularly high. However, the subjects were observed to have significantly higher reactive strength in the right leg producing a better COD speed to the left side (Young and Farrow, 2006).

Although the vertical jump test is determined to be the strongest predictor of on-ice skating sprint performance (Farlinger et al., 2007), little is known about testing for COD maneuvers in ice hockey. Agility tests such as the "On-Ice Cornering S Test" are reported to have been used to measure on-ice agility (Farlinger et al., 2007), but no emphasis is placed on the stopping phase of the COD maneuver. Additionally from a performance perspective, skate design is known to have a significant effect on performance. A study comparing the ability to make sharp turns between a CT Edge blade and a regular hockey skate blade demonstrated that the mean times for performing the tests improved on average by 1.4% (Federolf et al., 2007). Also, highest individual improvements of personal performance for acceleration, maximum speed and glide increased by 4.2%, 5.3% and 3.7% respectively.

Ground reaction forces have been shown to be an effective method of understanding the effects of dominant and non-dominant limbs on force production in COD maneuvers for sports such as soccer or basketball. In order to obtain a better understanding of COD maneuvers in ice hockey, a closer look with the use of different kinetic data collection methods can give us more insight for the design of an effective experimental protocol.

1.6 KINETICS

The term "Kinetics" is the term given to both internal and external forces that produce movement (Winter, 2005). By definition, internal forces are considered to originate from inside the body by muscle contraction or tendon stretch, while external forces come in the form of external loads such as an impact from a checking maneuver or the ground friction. Kinetic analysis of these forces can be performed in either 2D or 3D.

1.6.1 HISTORY OF KINETICS

One of the earliest methods to scientifically record the magnitude of the heel to foot contact phase in walking was a system composed of air reservoirs developed by Carlet in the 19^{th} century. An "m" shaped curve resembling a vertical force pattern that we would normally see in a modern force plate was produced using Carlet's one-dimensional analysis system (Sutherland, 2005). Using this system as a reference, Demeny and Marey were able to create the first force plate in the world able to measure the vertical component of the ground reaction forces using a pneumatic system similar to the one developed by Carlet (Sutherland, 2005). Evolutions of this system were required in order to measure forces in more than one direction. Elfman developed an unsophisticated but creative spring-calibrated system within a force plate to separate and measure ground reaction forces into components. Using strain-gauge technology, Cunningham and Brown created a force-plate platform that enabled them to divide ground reaction forces into four components for use in the clinical setting in the 1950's (Sutherland, 2005). A few decades later in 1969, the first force plate to be made commercially available was created by Wartenweiler and Sonderegger for the ETH biomechanics laboratory in Zurich, Switzerland that required it to analyze gait of humans and animals

(Nigg and Herzog, 1999). New force-plate technologies used today are created based on the very same model with additional technology such as the strain-gauge technology (Nigg and Herzog, 1999; Sutherland, 2003; Winter, 2005).

1.6.2 FORCE TRANSDUCER HISTORY

Force transducers function through changes in electrical signaling that are proportional to the amount of load applied as force on the force plate (Winter, 2005). Among force plate sensors, piezoresistive, capacitive, and spring transducers are available for use, however the two most commonly used force plate sensors are strain gauge and piezoelectric sensors (Nigg and Herzog, 1999; Winter, 2005). When the metal plate or beam that is located within the strain gauge undergoes even the slightest change in one of its physical dimensions, the mechanical change causes a change in resistance of the bridge circuits connected to the strain gauges. This change of voltage is the considered to be proportional to the applied load or force (Murray, 1992; Window, 1992; Winter, 2005). When these gauges are placed on the blade holder of a skate or on skis as in the Yoneyama (2008) study, the deformations in the mechanical properties allow us to estimate the force values generated at the location of the gauges.

Use of piezoelectric sensors within force plates measures the micro voltage changes induced by deformation (Winter, 2005). The deformation of a piezoelectric crystal structure causes changes within the electrical charge properties, where the signal can be calibrated to measure a corresponding force value (Nigg and Herzog, 1999; Winter, 2005).

1.6.3 FORCE TRANSDUCERS IN ICE SKATING KINETICS

Use of traditional biomechanics methods (i.e. force plate) for assessing kinetic measurements on ice have not been conducted because of the difficulty associated with correctly implementing a force plate into a frozen surface such as one seen on an ice hockey rink. Alternatives to measuring on-ice kinetic force values using temperature compensated strain gauge transducers have been developed for use in speed skating studies (de Boer et al., 1987; de Koning et al., 1992; Jobse et al., 1990). These three studies used an instrumented system that was composed of three subsystems: sensor-instrumented skates, a microcomputer and appropriate computer software.

Inserted between the boot and the blade of the speed skate were temperature compensated strain gauges. An electrical signal proportional to the load exerted on the strain gauge was generated by the Wheatstone bridges of the strain gauges. One of the gauges was placed in the middle of the unit to measure horizontal force caused by frictional resistance, while the other strain gauges were placed in the front and the back of the unit. This particular strain-gauge configuration permitted the measurement of force values up to 1400N in addition to a maximum of 40N to be measured in frictional force. The overall weight of the normal speed skate with the instrumentation of this strain-gauge configuration increased the weight of the skate by a total 55%. The microcomputer was wired to these skates to capture and store maximum of 40 seconds of force data for multiple strides at a frequency of 200Hz. The collected data outputted force and friction results then appeared on a hand-held display after the mean coefficient of friction had been calculated with the software. Combinations of loading were performed for calibration of the system and linear regression models were calculated using observed signal response during recording compared to the amount of force loaded onto the system.

The force values obtained were identified as a summation of the forces obtained from the front and back strain-gauges. Two peaks were identified in the normal force curve, one caused by a powerful push-off and the other by a counteraction of bodyweight during the body transfer from the push-off leg. The gliding phase of the stride was said to be equivalent to one bodyweight. The purpose of the studies by Jobse et al., (1990) and Koning et al., (1992) was to determine the frictional properties of ice during speed skating.

When this system was used in a study by de Boer et al., (1987), it was observed that the force patterns within the gauges were changing in a way that the front connection’s force pattern was increasing at the end of the stroke while the back connection’s force pattern was decreasing. In other words, the total force vector was changing origins towards the front of the skate.

A study attempting to measure vertical reaction forces during push-off using a force plate for injury prevention purposes in ice hockey was conducted by Sim and Chao (1978). Two subjects wearing a regular hockey skate on one leg (the push-off leg) with a rubber protector for additional grip and a roller skate on the other leg, performed push-off maneuvers on a force plate. With a posterior push-off force of approximately 688N and a lateral force of ~353N, vertical reaction forces of the players were observed between 1.5 to 2.5 times the players' bodyweight.

It was not until Gagnon, Lamontagne and Doré attempted to collect on-ice force data using strain-gauge technology that we were able to gain some insight on collecting on-ice force data for ice hockey as they completed the only studies directly attempting to do so specifically for ice hockey skating (Gagnon et al., 1983). Lamontagne et al. (1983) developed two systems, one with a plastic blade holder for the skates and the other with a metal blade holder. The plastic blade holder system was instrumented with pairs of 120Ω strain-gauges located in the anterior and posterior regions of the blade holder posts for compressive forces. For medial-lateral forces the frontal region of the anterior post was instrumented along with the rear area of the posterior post as displayed in Figure 4. Skating forces were discerned with this strain gauge configuration, however because the plastic structure of the plastic blade holder was too flexible when the material was strained, it could not return to its original form in a consistent manner, therefore it was not able to produce in both compressive and medial-lateral orientations, along with inconsistent force readings (Lamontagne et al., (1983).

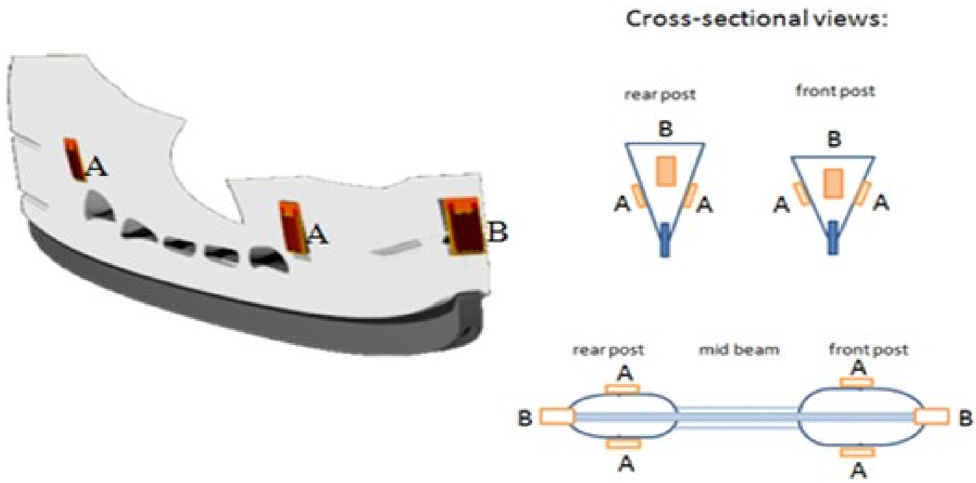

Figure 4: Depiction of gauge placement used by Lamontagne et al. (1983) (adapted from Stidwill et al., (2010)) for plastic blade holder strain gauge configuration. Letter ‘A’ represents gauges for compressive force orientation, Letter ‘B’ represents gauges in medial-lateral force orientation.

The system adapted for the metal blade holder required some custom modifications in order to get appropriate readings from the strain gauges. In the anterior and posterior columns of the blade holder holes of 1.3 and 1.5 cm^2 were punctured along with the front blade-boot column being shaved down for increased deformation in the blade holder. This configuration allowed the measurement of compressive (normal) and flexible (medial-lateral) deformations of the blade holder with the configuration of the strain gauges with a Wheatstone bridge. Loading on the skate for calibration purposes was performed with the skate locked upside-down into place on a specially constructed mount through a loading device connected to a weight that was placed on the skate blade using a pulley system. The load and deformations in the blade holder were used to calculate linear regression equations between the load and corresponding deformations. The maximum vertical load calibrated for this system was 450 N, and for the medial-lateral direction; 270 N. The reliability of the strain-force signals were determined to be within a coefficient of variation of 14% in addition to limited hysteresis (Lamontagne et al., 1983). The sampling rate of the signal during data collection was not mentioned along with other factors such as the method of strain signal collection or whether or not the subject's skating ability was encumbered while performing the skating tasks due to the length of the connective wiring or the portability of the data collection system.

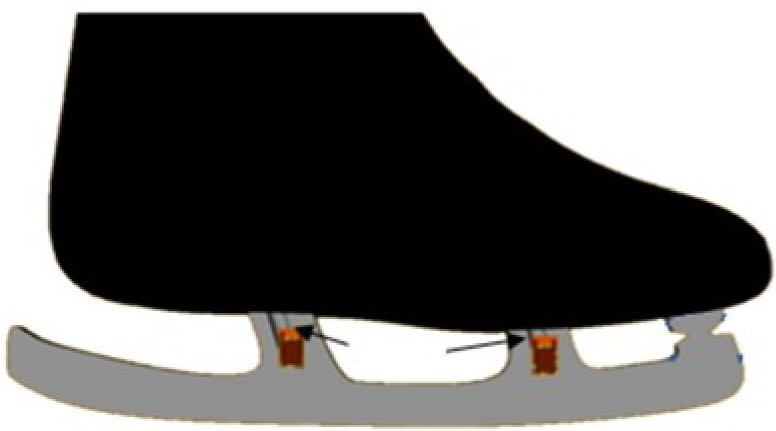

Figure 5: Example of gauge placement on metal blade holder by Lamontagne et al., 1983 (adapted from Stidwill et. al, 2010)

To determine on-ice forces for a parallel stop, strain gauge force transducers were also used in addition to sophisticated 3D measures to determine skate orientation. (Gagnon et al., 1983; Lamontagne et al., 1983). The peak forces determined by the two subjects observed were in the higher end of 900N. These measures would be much more easily obtainable for practical application of skating tasks if the data collection equipment had been more portable. A smaller, more portable instrumentation system would increase signal precision and allow further developments for on-ice testing of specific hockey skills (Lamontagne et al., 1983).

Stidwill et al. (2010) measured forces during ice skating using strain gauges bonded directly to the plastic blade holder without modification to the skate. After calibration the use of a portable signal conditioner and data logger enabled skaters to perform various hockey skating skills unencumbered and on an ice rink surface. Of note both vertical and medial-lateral forces could be directly recorded. To demonstrate the usefulness of this methodology, forward start and skating trials were conducted. For instance, peak vertical forces were found to range from 150% to 200%BW during the first six strides. Medial-lateral forces varied between subjects from low (0 to 10 %BW), mid (10 to 25 %BW) to high (25 to 50%BW) magnitudes, that may be attributed to individual skating styles. This study demonstrated the technological approach that can be applied to examine many other skating skills.

CHAPTER 2 – STUDY DESIGN

2.1 RATIONALE AND PURPOSE

From the preceding literature review, it was shown that most research regarding the mechanics of ice skating has primarily focused on forward skating (de Koning et al., 1995; Lafontaine, 2007; Marino, 1977; Marino, 1979; Marino, 1983; Marino and Weese, 1979; Upjohn, 2008; Stidwill et al., 2010). Although concepts of agility and change of direction are highly studied for sports such as basketball, soccer, rugby and other on-foot sports (Sheppard & Young, 2006; Young & Farrow, 2006; Brughelli et al., 2008), little is known about change of direction maneuvers in on-ice hockey skating. The only known studies that have attempted to assess the mechanics of skating agility were conducted over 20 years ago by the group of Lamontagne, Gagnon and Doré (Gagnon et al., 1983; Lamontagne et al., 1983). Previous technical obstacles to studies on ice have been overcome thanks to developments in technology in portable analog devices (Stidwill et al., 2010). Thus, the purpose of this study was to observe the kinetics of change of direction maneuvers for hockey players using force transducer strain gauge instrumented skates.

2.2 NOMENCLATURE - DEFINITIONS

Agility:

A rapid whole-body movement with change of velocity or direction in response to a stimulus. (Brughelli et al., 2008)

Anterior Medial-Lateral Force:

In the anterior portion of the skate blade holder, the forces acting on the blade-holder in the medial-lateral direction.

Blade holder:

The plastic part of the hockey skate which holds the skate blade.

Change of Direction (COD) maneuver:

A rapid whole-body movement with change of velocity or direction wherein no reaction to a stimulus is required. (Brughelli et al., 2008)

Cutting:

A directional change during a sprint movement (referring to the specific portion where the athlete's foot contacts the ground to initiate the change of direction)

Contact Time (Ct):

The time, in seconds, in which the skate is in contact with the ice surface.

DataLOG^{TM}:

Microprocessor controlled data acquisition device, portable data acquisition system,

Strain Gauge Force Transducers (Strain Gauges):

The type of sensor used to convert the physical deformations of the blade holder into an electrical signal (Nigg and Herzog, 1999).

Medial-Lateral Force:

The combination of the Anterior Medial-Lateral and Posterior Medial-Lateral Forces.

Posterior Medial-Lateral Force:

In the posterior portion of the skate blade holder, the forces acting on the blade-holder in the medial-lateral direction.

Total Force Impulse:

Impulse of force produced over time from the Vertical and Medial-Lateral Forces.

Vertical Force:

A force applied parallel to the vertical orientation of the skate blade.

2.3 HYPOTHESES

It is hypothesized that no significant differences will be observed between left and right turns in terms of the forces produced during the COD maneuvers; significant differences will be observed between the inside and outside legs in terms of forces produced during the COD maneuvers; and no significant differences will be observed between the modified and regular skate models in terms of the average forces produced during the COD maneuvers.

2.4 LIMITATIONS

Limitations of this study are as follows:

1) Only one type of COD maneuver was performed. To what extent these findings may be extended to other COD maneuvers is not known.
2) The tasks were performed in a non-game situation and were pre-planned; therefore, to what extent these findings are representative of unanticipated COD tasks in an open game situation needs to be determined.
3) It is also possible for a long-term habituation effect to affect performance of the COD maneuvers with regard to the two skate models which was not controlled for in this study.
4) Leg dominance and stick side of each subject was noted but not controlled for.
5) The skates were sharpened in a traditional manner before each testing period and optimal blade sharpness was not controlled for.

2.5 DELIMITATIONS

The delimitations of this study are as follows

1) While change of direction maneuvers can take place in many different directions in hockey, only 90° left and right directions will be observed

2) The subjects will not be wearing full ice hockey equipment, thus possibly affecting the kinetics of the change of direction maneuvers.
3) Only male subjects will be studied.
4) The subject pool will include only forwards and defenseman.
5) The subjects will be asked to skate at their maximum velocity prior to the change of direction maneuvers.

2.6 Research Design and independent (IV) / DEPENDANT (DV) VARIABLES

The independent variables of this study will be the skate model (regular/modified), the turn direction (left/right) and the leg side (inside/outside) (2 x 2 x 2 design). The dependant variables of this study will be vertical force, total force impulse, medial-lateral force, anterior medial-lateral force and posterior medial-lateral force and contact time.

2.7 STATISTICAL METHODS

The statistical analysis addressed the main objective of this study; to compare the kinetics generated when performing COD maneuvers. A 3 way MANOVA was used to compare all kinetic variables across each leg for both turning conditions using both kinds of skate models. A univariate F-test was performed on each of the dependent variables to interpret the results of the MANOVA (George, 2006). Statistical significance was set at $\alpha = 0.05$. All statistical analyses were performed using SPSS (v.17, Chicago, IL, USA).

CHAPTER 3 – SKATING MECHANICS OF CHANGE OF DIRECTION MANEUVERS IN HOCKEY PLAYERS

3.1 ABSTRACT

Ice hockey is a popular winter sport that involves many skating skills improved by coaching instruction and numerous hours of practice. Once the basic mechanics of skating have been honed, the open game context requires rapid skating transitions between skating skills so as to effectively navigate about the ice surface to evade opponents and move in strategic tandem with team mates. Consequently, a player's performance relates in large part to effective change of direction maneuvers. The purpose of this study was to observe the kinetics of change of direction maneuvers in hockey players while wearing one of two skate models: a conventional skate and a skate with enhanced ankle mobility. Eight subjects with competitive ice hockey playing experience performed 90° change of direction tasks both to their left and then right sides for both skate models. Kinetic data were collected using a portable acquisition device connected to force strain gauge transducers on the blade holder. During a change of direction maneuver, a significant difference in the weight distribution between the inside and outside leg was noted ($p < 0.05$). No significant differences were observed as a main effect for skate model and turn direction. Significant differences were noted when leg side (inside/outside) was compared with skate model or turn direction ($p < 0.05$). This can provide insight to ice hockey coaches for training and skill development

purposes but also to ice hockey skate manufacturers for future directions related to injury prevention and skating performance.

3.2 INTRODUCTION

Change of direction maneuvers in ice hockey have not been extensively examined mainly due to the inherent technical difficulties collecting kinetic and/or kinematic data in the ice hockey environment. In addition, previous research regarding the mechanics of ice skating has been primarily restricted to forward skating and was mainly focused on the kinematic variables influencing skating performance (de Koning et al., 1995; Lafontaine, 2007; Marino, 1977; Marino, 1979; Marino, 1983; Marino and Weese, 1979; Upjohn, 2008; Stidwill et al., 2010). The objective of the study is to adapt existing technology and kinetic data collection methods to change of direction maneuvers in ice hockey.

Previous methods of measuring force in speed skaters incorporated the use of strain gauge force transducers attached to an interconnected block assembly between the shoe and blade of the skate (de Boer et al., 1987; de Koning et al., 1992; Jobse et al., 1990). Although the purpose of these studies was to observe the frictional properties of ice during speed skating, the results proved to indicate that the use of strain gauge force transducers is an effective method to determine kinetic force values of on-ice skating. Limitations in the technology such as sensor fragility, limited capacity to display force values as well as disruption of the original skate design posed some challenges. In addition, the inability to measure medial-lateral forces due to sensor orientation would cause difficulties for analyzing more complex tasks beyond forward skating.

Using a force plate to measure vertical reaction forces of a push-off maneuver, Sim and Chao (1978), conducted an experiment on two subjects by instructing them to place their thrusting leg on a force plate and perform the push-off maneuvers with a regular hockey skate and blade with a rubber protector on the blade for additional friction on the force plate. The opposite limb wore a roller-skate to attempt to mimic the mechanics of on-ice skating as accurately as possible. The reaction force values obtained were in the regions of 1.5 to 2.5 times the participant's body weight with a posterior push off force of approximately 688N and a lateral force of approximately 353N (Sim and Chao,1978). It was not until Gagnon, Lamontagne and Doré began their on-ice studies using the strain gauge force transducer technology that true on-ice dynamics of ice hockey skating could be evaluated.

The group consisting of Gagnon, Lamontagne and Doré conducted the only known studies attempting to determine on-ice forces of a parallel stop using strain gauge force transducers attached to the skate blade (Gagnon et al., 1983; Lamontagne et al., 1983). The forces in the vertical, horizontal and medial-lateral directions of two subjects were measured using three pairs of strain gauge force transducers and demonstrated peak forces in the upward values of 900N. In order to facilitate data collection, modifications to the skate blade were required to increase signal strength. Though the feasibility of collecting force data using this method was demonstrated, the limitations in terms of portability still raise some issues in terms of practicality.

More recently in a study conducted by Stidwill et al. (2010), strain gauge force transducer instrumented skates were used to develop a portable force measurement system for the collection of kinetic data in forward skating for ice hockey.

Thus, the goal of this study was to incorporate the use of this portable force measurement system for the evaluation of COD maneuvers in both limbs using two different kinds of skate models.

It is hypothesized that no force differences between left and right COD maneuvers will be observed though asymmetric force differences between the inside and outside skate legs are expected. With regards to the modified and regular skate models no substantial force difference during the COD maneuvers are expected.

3.3 METHODS

3.3.1 SUBJECTS

Eight adult males were recruited to participate in this hockey study (7 forwards, 1 defence, 24.13 years ± 2.58, 77.51 kg ± 8.13). The participants' competitive level ranged from recreational to Midget 'AAA' and had an average of 17.13± 3.64 years of playing experience. The study was approved by the McGill University Research Ethics Committee. Each subject completed and signed an informed consent document prior to testing.

3.3.2 INSTRUMENTATION

Prior to testing, the strain gauge force transducer measurement system had to be assembled to the respective skate models. Once this was completed it had to be combined with a data recording system and calibrated. The following are the steps that were taken to complete these requirements.

3.3.2.1 INSTRUMENTED HOCKEY SKATES

Five 350Ω, 0.125" (0.3175 cm) force transducer strain gauges were placed in 5 strategic locations on the front post, the rear post, and the mid-beam of the blade holder. These strain gauges act as converters of compressive or tensile deformation of the blade holder to change microstrain signals to force estimates. The gauges were connected to bridge circuits through connective wires that were bundled together with sufficient length so that once they were connected to the bridge circuits and the DataLOG, movement was not inhibited in any way. This configuration allowed us to effectively collect an estimation of ice reaction force based on tensile strain in the Vertical, Anterior Medial-Lateral and Posterior Medial-Lateral axes of the blade holder, as this strain gauge configuration has been proven to be an effective method collecting kinetic on-ice data (Stidwill et al., 2010).

The skate models that were used for this study were an unmodified (regular) and modified version of the Nike-Bauer Supreme One95 skate. These skate models are identical except for the modified skates' have a more flexible Achilles guard, an elastic tongue and higher lacing eyelettes. These modifications were employed to improve range of motion during skating strides.

Figure 6: Picture of modified skate with elastic achilles guard

3.3.2.2 MEASUREMENT SYSTEM

Data for this study was collected at a 100Hz frequency using a portable 13 bit analog to digital data acquisition system (DataLOG model P3X8, Biometrics Ltd, Gwent, UK). The DataLOG was used to power the bridge circuits to record their signal during testing and supply a 2V ± 2% excitation voltage to force transducer strain gauges. The data is then stored in .RWX format to a Multi Media Card (MMC) flash memory card that is inserted inside the DataLOG before testing after the measurement scale has been set to 10mV with a resolution of 0.0025mV.

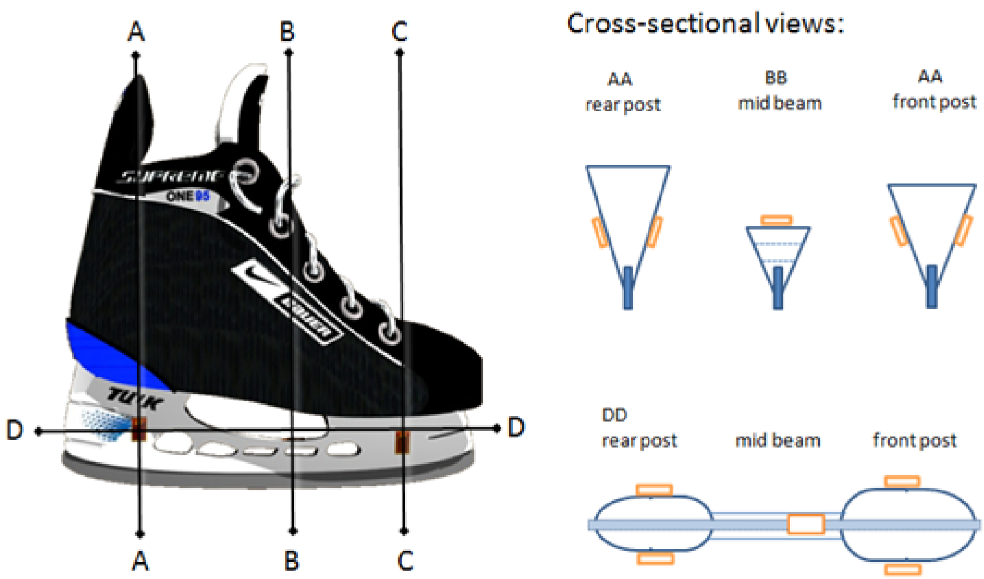

Figure 7: Representation of instrumented skate blade holder (top), and cross-sectional views of gauge locations (bottom). Gauges AML and PML are oriented vertically along each post, while gauge V is oriented longitudinally along the beam element of the blade holder. (Adapted from Stidwill et al., 2010)

3.3.2.3 STRAIN GAUGE CALIBRATION

After the skates were properly instrumented, they had to be calibrated properly using a force plate simultaneously with the DataLOG in order to ensure the micro-strain signals captured by the DataLOG from the strain gauges were well converted into force-estimates when the data were converted to be processed in Matlab. Previous calibration methods for this kind of strain gauge configuration simply required the subject to stand on a force plate with the instrumented skate and apply loads on a force plate to capture force data with the DataLOG simultaneously capturing micro-strain data (Stidwill et al., 2010). We attempted this approach but found it difficult to consistently generate calibration files with good correlation values for the vertical force gauge possibly from the lack of stability the subject had when attempting to apply the loads on the force plate while standing on one foot. As a result, a lever method was developed to accurately generate consistent vertical forces on the blade holder for vertical force calibration. Two surrogate foot levers, one for the right skate and one for the left, were created with a shape fitted to the shape of the sole within the skate (Fig 8). A level was used to ensure the foot lever was perpendicular to the vertical gauge during the loading phases (Fig 9). With the foot lever in place, it was inserted into a loading lever used to apply force loads of up to at least 1000N for calibration. For the medial-lateral force calibration of the skate, the skate blade was placed longitudinally along the force plate with the medial side of the skate facing downwards for the medial anterior and posterior calibration (Fig 10), followed by placing the lateral side of the skate facing down on the force place for the lateral anterior and posterior calibration. Before collecting data for a calibration file a few practice loads were performed with the DataLOG to warm up the strain gauges.

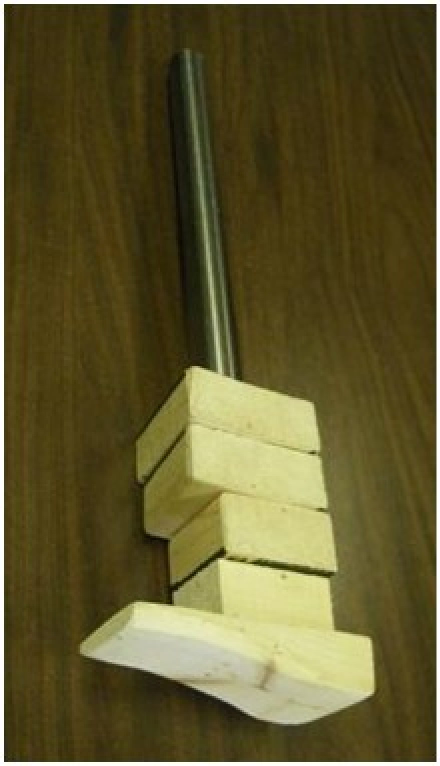

Figure 8: Example of foot lever created for the right skate

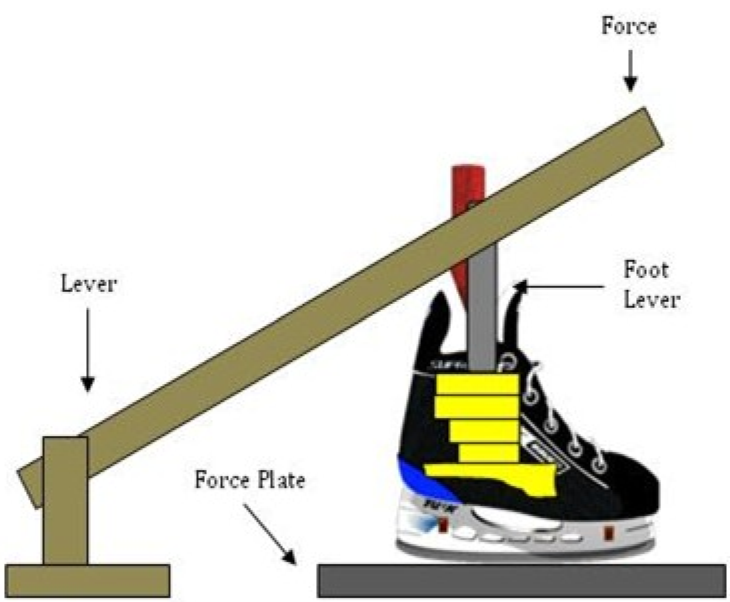

Figure 9: Skate vertical force calibration lever system

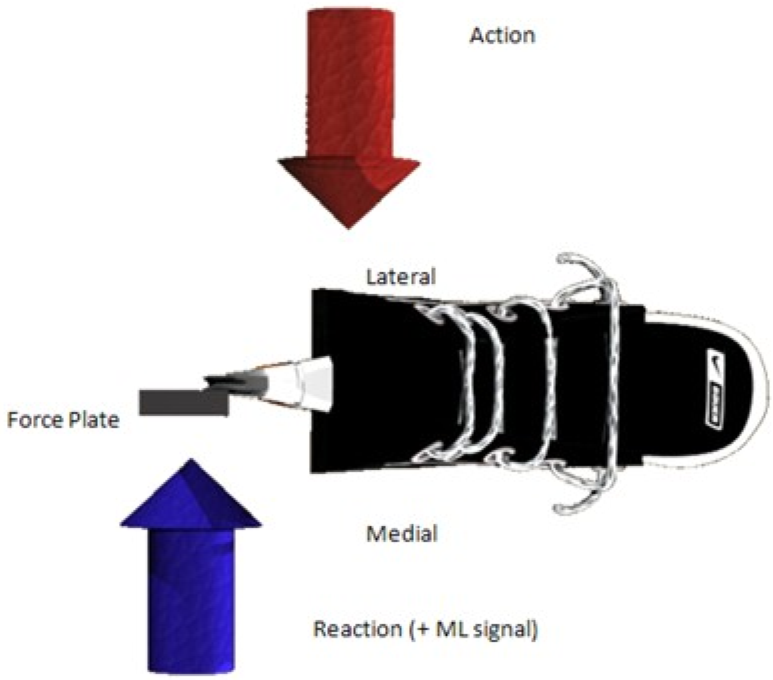

Figure 10: Example for medial calibration of skate

This approach proved to be successful in consistently generating calibration files for vertical and medial-lateral forces with excellent correlation values (include r values) for both left and right skates in both models and sizes. Appendix C indicates the calibration values obtained for both skate models, sides and sizes.

3.3.2.4 SUBJECT PREPARATION

Once the skates were properly calibrated and the blades were sharpened they were ready to be tested. Participants were asked to wear comfortable attire such as jogging pants and a sweater in order to perform the change of direction tasks with as little encumbrance as possible. Upon completing in full the attached consent form in Appendix A, participants began putting on respective skates concurrent with their skate size. The wire bundles were passed through the inside of their pant legs to avoid being tangled together during testing. The pin connectors of the wire bundles for the left and right skate were then plugged into their respective bridge circuits and the bridge circuits were connected to the DataLOG located in a backpack (<1.625 kg) to be worn by the subjects during testing (Fig 11). Subjects were also provided with a hockey helmet, gloves, and a hockey stick to their shooting side.

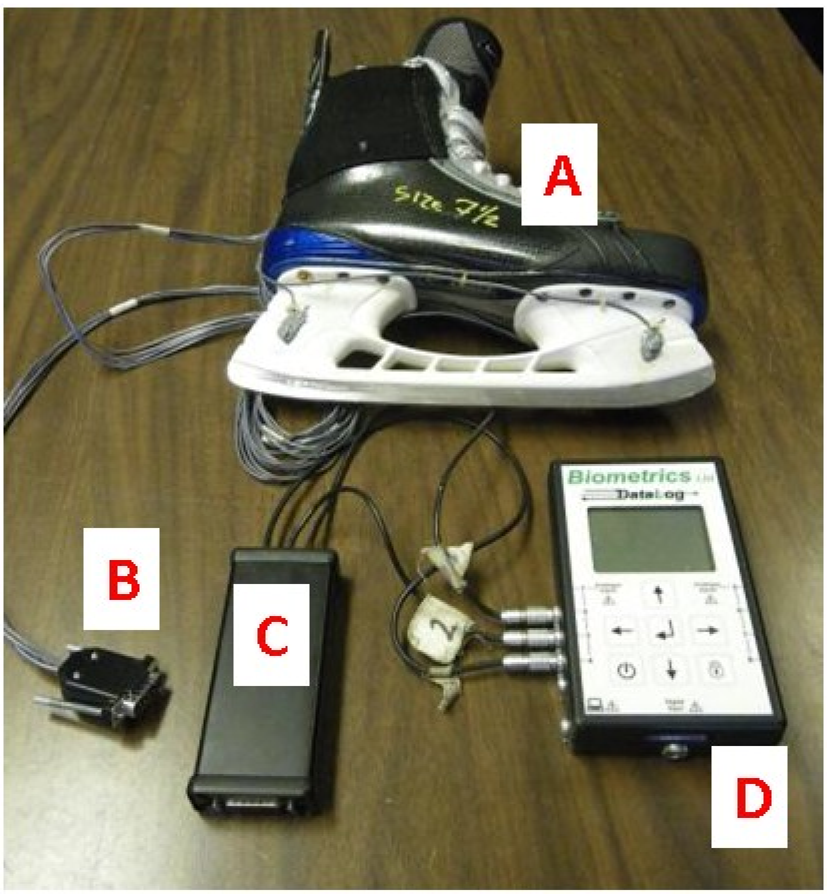

Figure 11: Equipment used for data collection: A - Instrumented Modified hockey skate, B - 15-pin connector of skate, C - Bridge Circuit Box, D- DataLOG portable acquisition device

3.3.3.1 EXPERIMENTAL PROTOCOL

Data collection sessions were broken down into four different testing sessions with two participants per session. A logbook was used to keep track of all activities performed during testing. In addition an HD video camera was set up on the ice to record data collection for a qualitative analysis post-testing. A laptop and USB card reader was set-up in the penalty box to verify after every 3 trials that the data had been collected properly and that clean peaks in the data were observed. A Zamboni was used to clean the ice before testing to maximize blade-to-ice contact.

Two pairs of cones were placed on the ice, one pair at one end of the blue line and the other ~1m behind the opposite blue line. Subjects were given ~10 minutes to warm up with their respective pair of instrumented skates and backpack. Once the warm up was finished, they were instructed to line up behind the pair of cones at one of the ends of the rink. In order to effectively collect strain data, the channels of both left and right skates were set to "Zero" in the DataLOG and one bodyweight trial was collected. The subject was asked to stand on his left foot and rise his right foot in the air without any contact on the ice surface, while this was happening the channels of the right skate in the DataLOG were set to zero. This allows a reference point to be identified in the DataLOG when there is no strain or pressure on the blade holder. Once the channels of the right skate are set to zero, the same process is repeated for the left skate, as the channels for the left skate are set to zero. After both the channels for the left and right skate are set to zero, one trial was recorded with the subject standing on his left leg followed by his right leg. These stationary force values served as a reference for the expected location of the zero axes in the collected data in post processing. If any re-zeroing was required in post-processing we would have known exactly by how much the zero axis' of the left and right skates would need to be adjusted by so they both match up in the processed data.

3.3.3.2 TASKS

The COD tasks performed by the subjects were as follows. Behind one of the two sets of cones, after the DataLOG had been started using an external trigger that was activated by the researcher, the researcher gave the signal for the subject to start skating by saying: "GO!", and the subject began to skate as fast as he could towards the pair of cones at the other end (1m behind the blue line to the other blue line or the other way around depending on the condition of the ice; Fig 12).
The subject was instructed before each trial which direction he needed to turn towards, thus making the task a COD task and not an agility task. Before reaching the cones, the subject was instructed to make a full stop, followed by a change of direction towards the left or right side, skate towards the boards and stop again once he had reached the boards. At this point the subject stopped the DataLOG data collection by pressing the external trigger once he had come to a full stop near the boards.

Each subject performed 3 consecutive "left" COD trials followed by 3 consecutive "right" COD maneuvers for each skate model type. If the subjects showed signs of fatigue, they were given a 2 minute rest period before starting the next trial. After every 3 trials collected, the subject returned to the penalty box and the MMS flash card inside the DataLOG was temporarily taken out of the DataLOG to be placed inside the Memory card reader connected to a Laptop to be viewed in the DataLOG Software (v.3.0; Biometrics Ltd., Gwent, UK). Trials were repeated if all data channels were not recorded. Once data for one skate model had been collected, the subjects changed skate models from either Regular to Modified or Modified to Regular and performed the same protocol using the alternate skate model. Subjects performing the tasks were rotated efficiently giving them enough time to rest in between tasks and skate models. Subjects were given a demonstration of the tasks by an experienced hockey player before testing commenced.

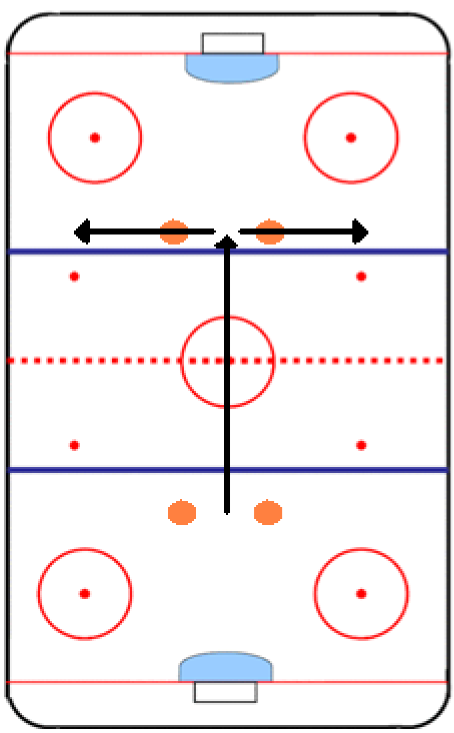

Figure 12: Diagram of left COD task and right COD task from one side of the blue lines to the other.

3.3.3.3 POST-PROCESSING METHODOLOGY

Once the data were collected, it underwent several steps to be processed into force data. First the data was converted from .RWX into a binary .log file using the DataLOG Software (v.3.0; Biometrics Ltd., Gwent, UK). The reason for doing this was because .RWX files on their own cannot be read by Matlab software, so these files were first converted into a .log file and then once loaded into Matlab, the .log file was converted to a .zoo file which we can then visually display the distribution of data in the form of a graph (Fig 13). If we were to simply look at the .zoo file we would see the graphical distribution of voltage output values that have not yet been converted to force data. The filtering stage of the data processing in Matlab was performed using a 4^{th} order Butterworth filter with a 14Hz cut-off frequency. After the data had been filtered we then converted voltage output to force data (in N) for both skate types (Modified and Regular) and both turning conditions (left/right). This gave us an indication about how much force was produced at the level of the skates for a left turn. As you can seen in the figure 13 the subject performs 6 strides before executing his change of direction maneuver which is highlighted in the green box in the figure.

In Figure 13 is an example for a processed trial of a right turn. Although the first 6 skating strides appear to be similar to a left turn, and the force values for COD maneuver highlighted in green for the right turn are similar in magnitude to the left turn, they are inversed in terms of which skate is producing the most force. It is this particular moment of the trial highlighted in the green box that we will place our focus on for data analysis as it represents the stop and force production phase of the COD maneuver being performed. The bodyweight trials that were collected at the beginning of the trial were then used as reference to determine the baseline.

After partitioning this event within the trial in Matlab and converting the force values from N (Newton) to %BW (percent bodyweight) with its corresponding video file that was taken with an HD camera, we can see what is occurring at the start, middle and end of the COD maneuver (Figure 13). From this trial we can then extract the mean vertical and medial-lateral forces produced during this COD maneuver, as well as the impulse and contact time produced for the duration of the turn. Impulse was calculated by integrating the force-time data values. After these values are calculated and extracted they are ready to be analyzed in SPSS for statistical evaluation.

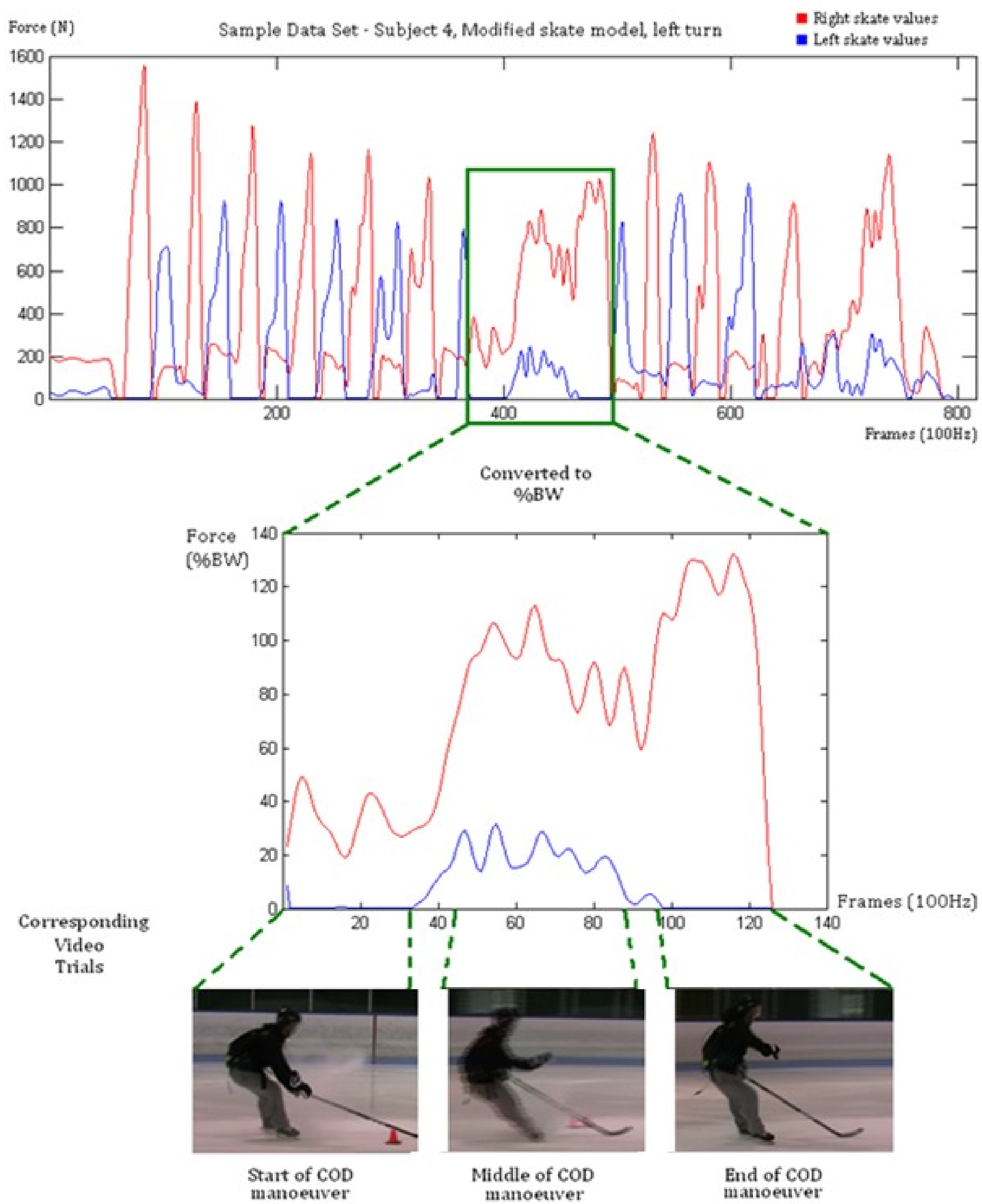

Figure 13: Example processing of sample data set for a left turn using the modified left skate model

3.3.3.4 STATISTICAL ANALYSIS

The statistical analysis addressed the main objective of this study; to compare the kinetics while performing COD maneuvers for each skate type, turning direction and between both legs. A MANOVA was used to compare all kinetic variables across all conditions. Statistical significance was set at $\alpha = 0.05$. Bonferroni post hocs were performed. All statistical analyses were performed using SPSS (v.17, Chicago, IL, USA)

3.4 RESULTS

In general, the results showed no substantial force differences between COD turn directions or between skate models (Table 1 and Figure 14A). As expected, asymmetric differences were found, such that greater average forces were exerted on the outside skate (~50 to 70%BW) versus the inside skate (~12 to 24% BW). Similar trends were found for total impulse (Figure 14B) though note that the contact times were relatively constant (1.0 to 1.1 seconds).

In terms of medial-lateral forces, a positive %BW (percent bodyweight) value represents a force value towards the lateral side of the skate blade whereas a negative value represents a force value towards the medial side of the skate blade (Figure 15). In general, the inside skate's blade pressed medially eliciting a lateral reaction force (Fig 14C) while the inverse occurred for the outside skate's blade (i.e. medial reaction force). The outside blade's forces tended to be ~2 times greater than that on the inside blade, though both were much lower (~1 to 27%BW) than the magnitude of average vertical forces. Similar trends were observed for both anterior and posterior posts of the blade holder (Fig 14D, E). In general these ML forces were not substantially different between skate models.

	Model	Turn	SideInOut	Mean	Std. Dev.
vforce_av	Modified	LeftTurn	Inside	12.7	6.0
			Outside	67.5	24.6
		RightTurn	Inside	24.0	12.2
			Outside	56.7	13.5
	Regular	LeftTurn	Inside	24.1	14.1
			Outside	69.8	11.3
		RightTurn	Inside	23.2	5.2
			Outside	51.2	16.6
totforce_impulse	Modified	LeftTurn	Inside	29.2	17.0
			Outside	72.2	18.7
		RightTurn	Inside	29.1	14.3
			Outside	54.5	21.2
	Regular	LeftTurn	Inside	42.7	26.7
			Outside	64.3	21.1
		RightTurn	Inside	31.7	7.3
			Outside	60.7	35.7
contact_time	Modified	LeftTurn	Inside	1.1	0.2
			Outside	1.0	0.2
		RightTurn	Inside	1.1	0.2
			Outside	1.1	0.2
	Regular	LeftTurn	Inside	1.0	0.1
			Outside	1.0	0.2
		RightTurn	Inside	1.0	0.3
			Outside	1.1	0.3
mlav_force	Modified	LeftTurn	Inside	11.8	7.7
			Outside	-27.0	8.3
		RightTurn	Inside	6.8	12.3
			Outside	-12.0	3.2
	Regular	LeftTurn	Inside	6.6	4.8
			Outside	-15.5	6.0
		RightTurn	Inside	1.2	6.1
			Outside	-3.8	13.7
amlav_force	Modified	LeftTurn	Inside	10.0	8.0
			Outside	-13.8	6.2
		RightTurn	Inside	4.8	8.4
			Outside	-7.6	2.9
	Regular	LeftTurn	Inside	3.5	3.7
			Outside	-8.5	5.1
		RightTurn	Inside	0.9	5.1
			Outside	-2.1	13.3
pmlav_force	Modified	LeftTurn	Inside	1.9	3.4
			Outside	-13.2	6.2
		RightTurn	Inside	2.1	4.4
			Outside	-4.3	2.0
	Regular	LeftTurn	Inside	3.1	4.8
			Outside	-6.9	3.6
		RightTurn	Inside	0.3	3.3
			Outside	-1.6	1.6

Table 1: Descriptive Statistics

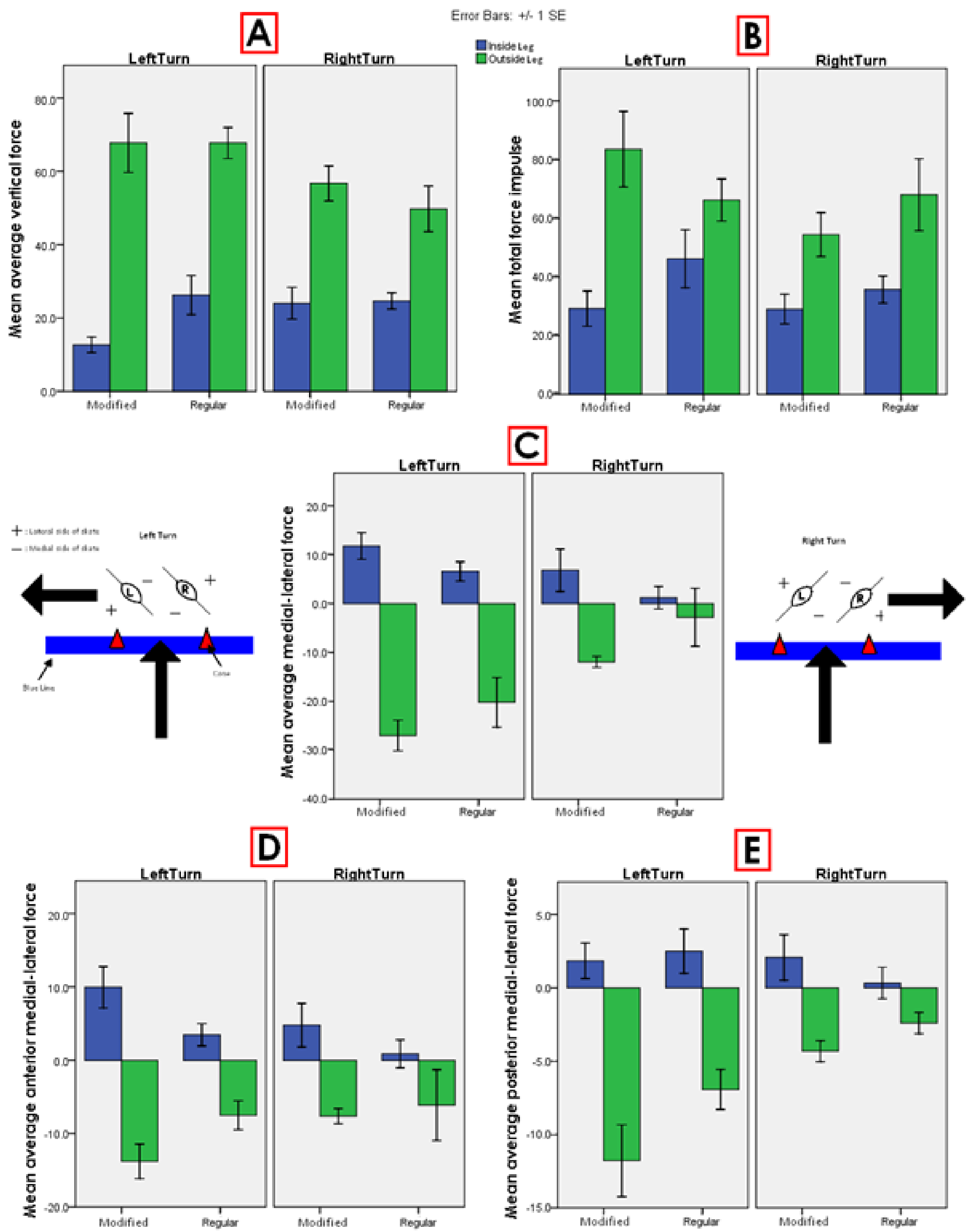

Figure 14: Graphs of average vertical force (A), force impulse (B), medial-lateral(C), ant. medial-lateral(D), post. medial-lateral forces(E). (in % BW) Adjacent to graph (C) are the diagrams of force orientations of the medial-lateral forces for a left and right turn.

The results of the multivariate test (Table 2) confirmed that no significant differences in the kinetic estimates were due to skate model or turn direction. The noted inside/outside leg differences were significant (p = 0.000). Several significant interactions were found (Table 2); that is, between skate model and leg side (p = 0.010) and turn direction compared to leg side (p = 0.000). These latter interactions were generally manifest as **lower forces for right turns** in combination with skate model or leg side than **left turn** combinations (Table 3).

Effect (Hotelling's Trace)	Value	F	Hypothesis df	Error df	Sig.
Model	0.100	0.717	6	43	0.638
Turn	0.302	2.165	6	43	0.065
SideInOut	7.406	53.077	6	43	***0.000***
Model * Turn	0.174	1.245	6	43	0.303
Model * SideInOut	0.458	3.284	6	43	***0.010***
Turn * SideInOut	0.925	6.631	6	43	***0.000***
Model * Turn * SideInOut	0.055	0.394	6	43	0.879

Table 2: Results of Multivariate tests of Skate Model, Turn Direction, Skate Leg Side and their interactions (significant differences indicated in bold and italic).

Specific differences were observed in vertical forces between inside (or right) legs of a left turn in the modified (p = 0.000) and regular (p = 0.000) skates. Similar but inversed differences between inside (or right) leg forces during outside turns in the modified (p = 0.001) and regular (p = 0.034) skates (Figure 14A).

Model by Turn by Side interactions were also seen. Specifically, these differences were shown between:

- left/outside turn directions for the inside leg of the modified skate (p = 0.000),
- the outside leg of the modified skate (p = 0.000) and
- the outside leg of the regular skate (p = 0.000).

For the mean impulse measures a similar trend to vertical forces was observed (Figure 14-B) however few significant differences were found except between:

- inside and outside legs for the left turn of a modified skate (p = 0.006),
- left and right turn for the inside leg of a modified skate (p = 0.005) and
- the modified/regular skate model and a left/right turn for the outside leg (p = 0.017).

The mean average medial-lateral forces (Figure 14-C) also showed some significant differences between inside/outside legs for:

- left turns of the modified (p = 0.000) and regular (p = 0.000) skate models; and
- right turns the modified skate (p = 0.001).

Where as differences between forces of the left/right turns were also noted for:

- the inside leg of the modified skate (p = 0.000),
- the outside leg of the modified skate (p = 0.000) and the regular skate (p = 0.012).

Differences in mean average anterior medial-lateral forces (Figure 14-D) where found in the:

- the modified skate between inside and outside legs for a left turn (p = 0.000) and for a right turn (p = 0.023).
- across left/right turning directions between the inside leg of the modified skate (p = 0.000) and for the outside leg of the modified skate (p = 0.000).

Finally for the mean average posterior medial-lateral forces (Figure 14-E), inter-leg differences were seen:

- Between the modified and regular skates during left turns (p = 0.000, p = 0.001).
- Between turn directions for the outside leg of the modified skate (p = 0.000) and regular skate (p = 0.033).

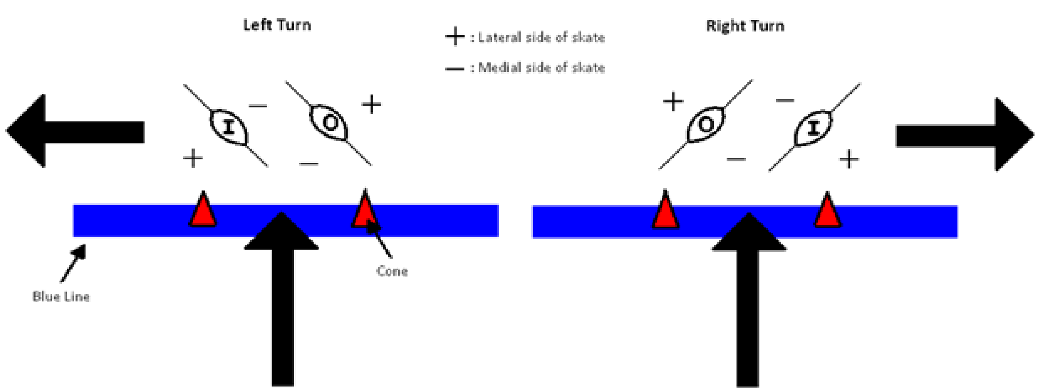

Figure 15: Diagram of medial-lateral force orientations for both types of turning conditions. The inside leg is indicated "I" and the outside leg as "O". The polarity of the force value in %BW indicates the direction of the force as towards the medial or lateral.

Table 3: Tests of Between-Subjects Effects on Dependent Variables (significant differences indicated in bold and italic).

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	vforce_av	25865.685[a]	7	3695.098	19.247	***0.000***
	totforce_impulse	14763.500[b]	7	2109.071	4.968	***0.000***
	contact_time	.030[c]	7	.004	.101	0.998
	mlav_force	8924.038[d]	7	1274.863	18.762	***0.000***
	amlav_force	3258.270[e]	7	465.467	9.655	***0.000***
	pmlav_force	1527.087[f]	7	218.155	14.067	***0.000***
Intercept	vforce_av	92657.333	1	92657.333	482.640	***0.000***
	totforce_impulse	126215.296	1	126215.296	297.328	***0.000***
	contact_time	60.461	1	60.461	1417.605	***0.000***
	mlav_force	864.151	1	864.151	12.718	***0.001***
	amlav_force	144.370	1	144.370	2.995	0.090
	pmlav_force	298.253	1	298.253	19.232	***0.000***
Model	vforce_av	46.845	1	46.845	.244	0.624
	totforce_impulse	177.398	1	177.398	.418	0.521
	contact_time	.002	1	.002	.037	0.849
	mlav_force	66.359	1	66.359	.977	0.328
	amlav_force	.104	1	.104	.002	0.963
	pmlav_force	60.808	1	60.808	3.921	0.053
Turn	vforce_av	304.596	1	304.596	1.587	0.214
	totforce_impulse	902.182	1	902.182	2.125	0.151
	contact_time	.009	1	.009	.206	0.652
	mlav_force	231.373	1	231.373	3.405	0.071
	amlav_force	19.901	1	19.901	.413	0.524
	pmlav_force	114.676	1	114.676	7.394	***0.009***
SideInOut	vforce_av	22210.101	1	22210.101	115.690	***0.000***
	totforce_impulse	12085.493	1	12085.493	28.470	***0.000***
	contact_time	.007	1	.007	.157	0.693
	mlav_force	6118.686	1	6118.686	90.048	***0.000***
	amlav_force	2235.645	1	2235.645	46.374	***0.000***
	pmlav_force	954.574	1	954.574	61.552	***0.000***

a. R Squared = .737 (Adjusted R Squared = .699)

b. R Squared = .420 (Adjusted R Squared = .336)

c. R Squared = .015 (Adjusted R Squared = -.129)

d. R Squared = .732 (Adjusted R Squared = .693)

e. R Squared = .585 (Adjusted R Squared = .524)

f. R Squared = .672 (Adjusted R Squared = .624)

Table 3 (cont.): Tests of Between-Subjects Effects on Dependent Variables (significant differences indicated in bold and italic).

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Model * Turn	vforce_av	345.447	1	345.447	1.799	0.186
	totforce_impulse	9.688	1	9.688	.023	0.881
	contact_time	.001	1	.001	.012	0.912
	mlav_force	11.581	1	11.581	.170	0.682
	amlav_force	6.841	1	6.841	.142	0.708
	pmlav_force	37.037	1	37.037	2.388	0.129
Model * SideInOut	vforce_av	162.292	1	162.292	.845	0.362
	totforce_impulse	271.394	1	271.394	.639	0.428
	contact_time	.010	1	.010	.230	0.634
	mlav_force	794.651	1	794.651	11.695	***0.001***
	amlav_force	382.150	1	382.150	7.927	***0.007***
	pmlav_force	75.428	1	75.428	4.864	***0.032***
Turn * SideInOut	vforce_av	1360.782	1	1360.782	7.088	***0.011***
	totforce_impulse	90.901	1	90.901	.214	0.646
	contact_time	.005	1	.005	.116	0.735
	mlav_force	1176.428	1	1176.428	17.313	***0.000***
	amlav_force	353.577	1	353.577	7.334	***0.009***
	pmlav_force	238.622	1	238.622	15.387	***0.000***
Model * Turn * SideInOut	vforce_av	15.459	1	15.459	.081	0.778
	totforce_impulse	528.552	1	528.552	1.245	0.270
	contact_time	.003	1	.003	.066	0.798
	mlav_force	6.962	1	6.962	.102	0.750
	amlav_force	4.541	1	4.541	.094	0.760
	pmlav_force	.265	1	.265	.017	0.896
Error	vforce_av	9215.043	48	191.980		
	totforce_impulse	20375.916	48	424.498		
	contact_time	2.047	48	.043		
	mlav_force	3261.563	48	67.949		
	amlav_force	2314.045	48	48.209		
	pmlav_force	744.407	48	15.508		
Total	vforce_av	127262.312	56			
	totforce_impulse	159502.775	56			
	contact_time	63.894	56			
	mlav_force	13010.936	56			
	amlav_force	5695.630	56			
	pmlav_force	2577.940	56			
Corrected Total	vforce_av	35080.728	55			
	totforce_impulse	35139.416	55			
	contact_time	2.077	55			
	mlav_force	12185.600	55			
	amlav_force	5572.316	55			
	pmlav_force	2271.494	55			

3.5 DISCUSSION

To the author's knowledge this is the first study of its kind to directly quantify kinetic measures during skating COD tasks. This study successfully adopted the force strain gauge transducer system developed by Stidwill et al (2010) to collect bilateral, simultaneous ground (ice) reaction forces. Clear and unambiguous skate force measures were obtained with respect to each skate's vertical and medial-lateral axes during the defined skating maneuver.

With respect to the hypotheses originally stated, first, no significant differences between the two skate models were found as proposed. The modified skate possessed greater plantar-dorsiflexion range of motion (~25°) due to strategic construction including more flexible Achilles tendon guard, more elastic tongue and greater lace compliance due to higher eyelet placement and eyelet polymer material. In general, the modified skate did not change the way forces were applied in either the vertical or medial-lateral directions during the COD task. One may interpret these results positively in that these changes intended to improve forward skating power and did not compromise the skates' medial-lateral stability for COD tasks.

The second hypothesis proposed that kinetic measures would not be affected by turning direction. However, results indicated that left turn kinetic measures were greater in general than right turns (~4 to 10 vertical % BW) but not significantly different except for posterior medial-lateral forces. Notably all subjects were right leg dominant which could have an effect on their confidence to apply forces during a turn in the left direction where the outside leg would be their right leg. Similar findings have been found in other COD studies. For example Young et al (2006) examined leg muscle imbalances in reactive strength COD speed tests. They identified subjects who possessed significantly greater reactive strength in the right leg and executed faster COD maneuvers in the left direction (Young et al, 2006). Another study by Cowly et al. (2006) found similar results during cutting maneuvers in that subjects' ground reaction forces were 41.4% greater in their dominant limb than their non-dominant limb. We can speculate then that in a game situation, right leg dominant players may be more inclined to perform a COD maneuver in the left direction which would lead them to favour certain positions on the ice i.e. being a right or left wing player.

With regards to the third hypothesis a strong significant difference was found between leg sides during the turns such that kinetic measures were in general, greater for the outside leg (skate). An obvious strategy in kinetic execution throughout the COD task was apparent in that the outside skate would sustain the majority of the body's weight (~70 to 51 %BW) whereas the inside skate would bear much less (~12 to 24% BW). A study observing forces and path radius of turning in downhill skiing displayed the forces carried by the foot of the outside ski to be larger than the forces carried by the foot of the inside ski (Yoneyama et al., 2008). Similarly, consistent medial-lateral forces (magnitude of ~1 to 27%BW) were observed where in the outside and inside skates where pressed laterally and medially, respectively, or in terms of the global environment both skates were being forced backward from the incoming skating direction and towards the new direction. As determined from the video log trials, immediately prior to the COD task, the skate to be first placed on the outside was followed rapidly (~40 ms) by the inside skate which was placed adjacent and parallel. During the COD task both skates were in full contact with the ice (~1.0 second), pivoting and ploughing under the player so as to point towards the new intended direction of travel. During execution, the inside skate moved forward in tandem with the outside skate towards the end of the task. Immediately prior to the end of the COD task the inside skate lifted and quickly stepped towards the turn direction.

The effect of leg side kinetic differences as noted above were modified by both turn direction and skate model. In general greater forces were found while turning left or while wearing the modified skate. These differences were significant for medial-lateral forces. The former left turn influence was interpreted above. How skate model affected these results is still unclear. Potentially, the modified skate provided greater dorsiflexion allowing the player greater ice contact and hence a greater sense of stability and in turn more confidence to push into the skate. Future studies including subject perception scores on these traits is necessary to confirm this speculation.

A limitation of this study is that only one type of COD maneuver was performed. To what extent these findings may be extended to other COD maneuvers is not known. Furthermore these tasks were performed in a non-game situation and were pre-planned; therefore, to what extent these findings are representative of unanticipated COD tasks in an open game situation needs to be determined. It is also possible for a long-term habituation effect to affect performance of the COD maneuvers which was not controlled for in this study. Because leg dominance appears to be a main issue in the results, a formalized testing methodology to determine the subject's true leg dominance would be beneficial to the study as well as controlling for leg dominance. Stick side of each subject was noted; however a method of examining its relationship to the performance of COD maneuvers could be developed in a future study. In terms of performance, the skates were sharpened in a traditional manner before each testing period and methods to ensure optimal blade sharpness could be taken in future studies as blade design and sharpness do affect the performance of COD maneuvers (Federolf et al., 2007).

Coaching implications of these findings can be applied to training methods for players to become better at performing these maneuvers with equal proficiency for both turning directions regardless of leg dominance. The challenge will be to define the teaching cues necessary to elicit greater outside leg force generation during the COD maneuver.

CHAPTER 4 – SUMMARY AND CONCLUSION

4.1 CONCLUSION

The results demonstrated that the use of a portable strain-gauge force transducer system can be used to assess on-ice COD maneuvers in ice hockey. Clear force asymmetry between skate sides were noted during the task. The kinetic strategies seen during skating COD tasks were similar to other sports such as alpine skiing, rugby, soccer and basketball. These findings provide a comprehensive understanding of the mechanics of these COD tasks that is relevant to athletic skill development. In addition, the ability to distinguish mechanical performance differences between the two skate models tested, further demonstrates the potential of direct force measurement as a sensitive metric to differentiate subtle glide and traction properties fundamental to skating performance. These insights may assist sporting good manufacturers in material, design and construction innovations to improve product performance. Future studies utilizing this measurement technology to more fully explore the many other skill combinations is warranted.

4.2 ACKNOWLEDGEMENT

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APPENDIX – A – CONSENT FORM

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Information and Consent document

Investigator: Antoine Fortier M.Sc. candidate

David J. Pearsall, Associate Professor, Ph.D.

René Turcotte, Associate Professor, Ph.D.

Biomechanics Laboratory,

Department of Kinesiology and Physical Education, McGill University

Statement of Invitation

You are invited to participate in a research project conducted by the above named investigator. This research project will be performed in the YMCA Hochelaga-Maisonneuve Arena, located at 2555 Bennet Ave, Montréal, Québec H1V 3N3. You are asked to come to one experimental session that will each last up to 1 hour and a half. We greatly appreciate your interest in our work.

Purpose of the Study

The purpose of this study is to compare a regular hockey skate (Bauer One95) and a prototype skate known as the DROM (highly modified Bauer One95 without a tendon guard leaving an open space in the back of the skate). The comparison will be made in two types of change of direction maneuvers. The forces obtained with strain gauges attached to both the left and right skate during the change of direction action will be examined. The force data will allow the measurement of many components of the change of direction maneuver including peak forces (vertical, medial-lateral, and total), average force, impulse and contact time.

Your participation in this study involves:

Providing informed consent prior to the experimental session, You will be asked to perform a skating agility task using two different pairs of Bauer One95 hockey skates. The procedure listed below explains the experimental session:

You will outfitted with a hockey helmet (Nike-Bauer 8500, sized accordingly) hockey skates (Nike-Bauer One95 and prototype model, sized accordingly)

You will be asked to wear shorts or track pants and a backpack

You will be outfitted with a hockey helmet, hockey skates and hockey stick (sized accordingly)

You will perform one skating change of direction task in two different directions for both skate types worn.

You will be asked to conduct up to 3 trials per task.

Risks and Discomforts

It is envisioned that you will encounter no significant discomfort during these experiments. You will be performing skating tasks that you are normally accustomed to in a regular ice hockey setting. It is anticipated that a 10-15 minute learning curve is associated when first skating with the prototype model; however, after this learning period you will feel comfortable skating with this type of skate. There is a slight risk that you could fall on the artificial ice surface; however the danger is no greater than found in regular hockey and you will be wearing a helmet in case this does occur.

Benefits

There are no personal benefits to be derived from participating in this study. Determining the kinematics and resulting forces of ice hockey skating has the ability to influence how skating is taught, as well as to influence future product designs.

Confidentiality

All the personal information collected during the study you concerning will be encoded in order to keep their confidentiality. These records will be maintained at the Biomechanics Laboratory by Dr. David Pearsall for 5 years after the end of the project, and will be destroyed afterwards. Only members of the research team will be able to access them. In case of presentation or publication of the results from this study nothing will enable your identification.

Inquiries Concerning this Study

If you require information concerning the study (experimental procedures or other details), please do not hesitate to contact *Antoine Fortier*, at the numbers or addresses listed at the top of this document.

Responsibility clause

In accepting to participate in this study, you will not relinquish any of your rights and you will not liberate the researchers nor their sponsors or the institutions involved from any of their legal or professional obligations.

Consent

Please be advised that your participation in this research undertaking is strictly on a voluntary basis, and you may withdraw at any time.

A copy of this form will be given to you before the end of the experimental session.

McGill

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Consent

I, ______________________________________, agree to voluntarily participate in the study ***SKATING MECHANICS OF CHANGE OF DIRECTION MANEUVERS IN HOCKEY PLAYERS***

I have received and read a detailed description of the experimental protocol. I am fully satisfied with the explanations that were given to me regarding the nature of this research project, including the potential risks and discomforts related to my participation in this study.

I am aware that I have the right to withdraw my consent and discontinue my participation at any time without any prejudices.

Signatures

Subject

____

(signature) (print name)

Researcher

____

(signature) (print name)

Date: __________________________

PLAYER PROFILE FORM

Name ____

Age ________________

Height ________________

Weight ________________

Position played ________________

Hockey experience (years) ________________

Highest level of competition ____

Shooting side (circle) R L

Dominant leg (circle) R L

Skate size __________________

Turning preference __________________

Skates usually worn ____

History of injuries

____

____

Health condition ____

____

____

____

APPENDIX – C – SKATE AND SUBJECT CALIBRATIONS

SKATE*	V slope	V intercept	AML medial slope	AML medial intercept	AML lateral slope	AML lateral intercept	PML medial slope	PML medial intercept	PML lateral slope	PML lateral intercept
7.5 RegularR	841	76	447	-4	585	-2	167	-30	291	-8
7.5 RegularL	1684	-99	645	5	541	17	194	-20	154	19
7.5 DROM R	761	-2	841	1	893	-6	413	-3	425	20
7.5 DROM L	1351	-67	559	11	731	26	235	-26	204	-12
8.5 RegularR	1457	18	551	-2	973	-4	167	-16	275	-3
8.5 RegularL	1860	16	838	9	1177	-2	203	-12	205	-6
8.5 DROM R	1431	19	1157	-4	997	18	263	-16	443	-23
8.5 DROM L	1213	-33	857	5	1563	0.25	134	-7	151	-5

Table 4: Skate calibrations

SUBJECT	SKATE	Weight (N)
subject1	7.5	672
subject2	8.5	883
subject3	8.5	803
subject4	8.5	780
subject5	8.5	757
subject6	7.5	712
subject7	8.5	824
subject8	7.5	646

Table 5: Subject calibrations