Comparisons of player calibers and skate models during an ice hockey explosive transitional maneuver

By:

Samuel Forget

Department of Kinesiology and Physical Education

McGill University, Montréal, Québec, Canada

December, 2013

A thesis submitted to McGill University in partial fulfillment of the requirement of the degree of Masters of Science

© Samuel Forget, 2013

Acknowledgements

I would like to thank God, my whole family, and friends for all their support. I would also like to thank my two supervisors, Dr. René A. Turcotte and Dr. David J. Pearsall and of course our laboratory technician Yannick Paquette for their precious advice throughout my two years spent at McGill. I would also like to thank the Bauer Hockey Company, NSERC and the McGill University for their material and financial support. The last but not the least, I would like to thank my colleagues, Charles (Marc), Robert (Cam), Leo, Lisa, Ryan, Chau, Andrew, Philippe and Lasse and the numerous undergrad students for their help and for all the great memories that they provided! Merci à tous pour les beaux souvenirs que je garderai à jamais de mes deux années à McGill!

Table of Contents

List of Tables

List of Figures

Abstract

The ground (ice) reaction force and the plantar foot pressure variables were measured during an explosive transitional maneuver, stop and go, skating task on ice using: 1) regular hockey skate and 2) a modified skate with an altered tendon guard and eyelet configuration which allows for increased dorsiflexion and plantarflexion. The objective of this study was to describe the differences in skating mechanics and kinetics between high and low caliber skaters and between the two different skate models during the specific explosive transitional, stop and go, skating task. Both the left and right skates were instrumented with a calibrated strain gauge force transducer system to measure the ground (ice) reaction force and with an insole system used to measure the plantar foot pressure variables during the stop and go skating task. Similar CoP and vertical force results were observed between the two skate models; however, high caliber skaters showed a reduction of 10.7 (inside skate) and 15.2 (outside skate) mm in total antero-posterior CoP excursion during the stop phase ($p<0.05$). In conclusion, specific postural control patterns were observed between high and low caliber skaters. However, a full body kinematic study might be needed in order to study the exact biomechanical changes.

Résumé

Les variables de la force de réaction du sol (glace) et de la pression plantaire du pied ont été mesurées pendant une manœuvre de transition explosive, ’’stop and go’’, de patinage sur glace. 1) à l'aide de patins de hockey standard et 2) des patins de hockey modifiés avec un protecteur du tendon d’Achille plus flexible et une configuration différente des œillet pour lacets permettant une plus grande flexion dorsale et plantaire de la cheville. Le but de cette étude était d’illustrer les différences de la mécanique du patinage et la cinétique entre les patineurs de haut et bas calibre et entre les deux modèles de patins pendant la tâche de patinage spécifique du ’’stop and go’’. Tant les patins de gauches et de droites ont été instrumentés avec un système d’estimation de la force calibré et avec un système de capteurs de pression en dessous de la semelle pour mesurer les variables de la pression plantaire du pied pendant la tâche de patinage du ’’stop and go’’. Les deux modèles de patin ont démontré des résultats similaires quant aux variables du Centre de Pression (CdP) et de la force verticale. Toutefois, les patineurs de haut calibre ont démontré une réduction de 10,7 (patin intérieur) et 15.2 (patin extérieur) mm concernant le déplacement total du CdP antéro-postérieur pendant la phase d'arrêt ($p < 0,05$). En conclusion, des modèles spécifiques du contrôle postural ont été observées entre les patineurs de haut et de bas niveau. Néanmoins, une étude cinématique exhaustive du corps humain serait manifestement nécessaire afin d'étudier les changements biomécaniques exacts.

Chapter 1: Introduction

1.1 Thesis outline

The main goals of this research thesis are to investigate: 1) The differences between a regular ice hockey skate to a modified ice hockey skate and 2) the effect of skill level while performing a specific explosive transitional skating task and the kinetics parameters of such task (foot regions, center of pressure and ground reaction force measurements).

In chapter 1, the thesis outline, the rationale, the objective, the hypotheses, the operational definitions, the limitations and delimitations and, the contribution that this thesis will bring to the field of biomechanics will be presented. Chapter 2 provides a review of literature on the history of ice skating and the game of ice hockey, the classification of skills in ice hockey, the skating in ice hockey, the kinematics of the skating stride, the observed ground reaction forces during forward skating, the effect of skate design and skating kinetics, the recent studies involving the modified ice hockey skate, and the plantar pressure measurements in gait analysis. Chapter 3 defines the methodology of the thesis research. This section includes the presentation of the participants, the explanation of all materials used, a complete and detailed experimental setup and protocol, the research design, a description of the data acquisition and processing, the statistical method used to investigate the data. Chapter 4 presents the results of the study.

Chapter 5 contains a discussion of the presented results and a conclusion on this research.

1.2 Rationale

It comes as no surprise that the sport of ice hockey is the most popular sport in Canada from coast to coast. After all, Canada is, as proclaimed by several historians, the birthplace of the game of ice hockey (IIHF, 2012). What makes Canadians so eager to participate in this sport year after year? The technique the players use to navigate on the ice and the low friction playing surface make this sport unique and attractive because it is considered one of the fastest team sports in the world (Biasca, Simmen, Bartolozzi, & Trentz, 1995). The survey of the International Ice Hockey Federation (IIHF) in 2011 showed that Canada had 512,411 players (men, women, amateurs and pros) registered under its associations also, 2,486 and 5,000 indoor and outdoor rinks, respectively (IIHF, 2012). These statistics place Canada well in front of the United States for player registrations and indoor rinks and ahead of Russia for the outdoor rinks. On the economic front, ice hockey industries like Bauer Hockey, registered under the name of Bauer Performance Sports Ldt. (BAU) at the Toronto Stock Exchange (TSX), represents one of the leading manufacturers of ice hockey equipment, which has generated 145.1 million US $ in profit in 2012 (Hockey, 2012). In Canada ice hockey is part of our culture and an important part of our economy.

Despite the tremendous popularity of the sport of ice hockey around the World, there have not been many studies examining the biomechanical characteristics of ice hockey skating. Ice hockey research in the past has focused mainly on the physiology of training and conditioning, skill development, safety and injury prevention (D. J. Pearsall, R. A. Turcotte, & S. D. Murphy, 2000). Nevertheless, skating is one of the most, if not the most, essential skill a hockey player may possess (M.R. Bracko, 2004). Regardless of the hockey specific task executed a player needs to skate or support himself on skates in order to effectively execute shots, passes, turns and pivots, body checks and battles for puck possession. In striving for performance improvements, manipulation of internal factors, such as the physiology of training and conditioning and, skill development of the participants are more often considered than external factors such as equipment (i.e. skate design) and sport environment. Historically, the evolution of the skate has been modified via the use of improved materials and changing the design and fit of the skate (Goodman, 1882; Minetti, 2004). The ice skate design has constantly evolved throughout history and with technological advances, improvements in skate design have become evident in recent years (Formenti & Minetti, 2007). Previous research in speed skating has demonstrated that significant improvements in skating performance can be achieved with improved skate design. The most substantial development in ice skating may be the Klapskate in long-track speed skating. The Klapskate is designed with a hinge under the anterior part of the skate boot. The development of the Klapskate has definitely revolutionized the sport of speed skating resulting in improved ice skating performance in international competitions, changing this sport forever (De Koning, Houdijk, De Groot, & Bobbert, 2000).

The studies on the Klapskate in speed skating have revealed the importance of increased ankle range of motion in skating performance (De Koning et al., 2000). One study compared push-off mechanics with a conventional fixed blade skate and a Klapskate. That study showed that the Klapskate allowed for an increase in skating velocity of 5% as a result of an increase in mean power output of 25 Watts when Klapskates were used instead of conventional skates. This increase in mean power output can be explained by an 11-Joule increase in work per stroke and an increase in stroke frequency from 1.30 to 1.36 strokes/s. The difference in work per stroke occurred during the final 50 ms of the push-off phase (Houdijk, De Koning, De Groot, Bobbert, & Van Ingen Schenau, 2000). As well, the conventional skate did not allow the skater to fully extend the knee and ankle joints before the skate was lifted at the beginning of the recovery phase. Kinematic analysis using skate models have suggested that the type of hockey skate an athlete wears can affect the range of motion of the ankle and subtalar joint during the skating stride (Baig, 2011; Fortier, 2011; Hoshizaki, Kirchner, & Hall, 1989; Robert-Lachaine, Turcotte, Dixon, & Pearsall, 2012; Stidwill, Turcotte, Dixon, & Pearsall, 2009). The conventional skate boot in ice hockey restricts range of motion at the ankle and thus, there is potential for increasing that range of motion which might result in a skate design that could improve skating biomechanics. Further studies are warranted to examine whether an increased range of motion benefits the ice hockey player’s skating performance.

Despite the fact that ice hockey and speed skating are two distinct sports, skating remains the main skill within each sport. Ice hockey involves numerous distinct skating skills and frequent changes of direction in contrast to a strictly continuous forward trajectory in speed skating. Speed skating skills can be defined as closed cyclical tasks, while in ice hockey, skating skills can be defined as more open, as hockey players also have to react to their playing environment (Montgomery, Nobes, Pearsall, & Turcotte, 2004).

The revolutionary Klapskate in long-track speed skating has motivated ice hockey companies to spend time and resources on developing new prototypes that could potentially enhance skating performance in ice hockey. The innovation brought to the Klapskate has led one hockey manufacturer (Bauer Hockey) to develop a new skate model that could similarly result in key performance enhancement features as seen in speed skating with the Klapskate (longer stride length, longer relative contact time and greater ankle plantar-flexion) (Figure 1). This new skate boot was the impetus for in-lab and on-ice studies on the skating mechanics of forward skating wearing regular and modified skate and their effects on skating performance.

Figure 1: Blade position during full leg extension push off phase of a long track speed skater skating with Klapskates (adapted from http://totallycoolpix.com/2012/01/coolest-sports-pix-of-2012-week-02/).

During forward skating in ice hockey it has been shown that the maximal plantar flexion occurs at the very end of the contact phase (Robert-Lachaine et al., 2012). Most of the propulsion is complete by the time the foot reaches maximal plantar flexion, where the blade is almost off the ice. Thus, the increased ankle ROM in an ice hockey modified skate may be important for other reasons other than achieving greater maximal kinetic forces while performing a forward skating task. Perhaps the importance of increasing the ankle sagittal ROM of an ice hockey skate could be to help the skater enhance the execution of a more explosive transitional task where the skater's center of mass (CoM) quickly shifts from one skate to the other. CoM and kinetics measures in combination could give us significant insights on postural modifications and strategies used by ice hockey players. Distinction between different levels of expertise or using different types of skates while performing a specific explosive transitional skating task could also be made using this technology. Control of CoM and kinetics may also help to establish a skilled skater's strategy during the execution of skating tasks when compared to an unskilled skater or when using different skate designs. Therefore, analyzing the plantar force and pressure components during an explosive transitional stop and go skating task may result in different kinetic output in ice hockey players of different levels of expertise and also when comparing a regular skate to the modified skate design.

1.3 Objective

The main goals of this study are to describe the differences in skating mechanics and kinetics between high and low caliber skaters and between two different skate models, a regular skate and a modified skate, which was intended specifically to increase the sagittal plane ankle range of motion, during a specific explosive transitional skating task. In the explosive transitional task at hand, the stop and go, there is an energy loading phase during the dominant parallel stop side (stop phase) which is expected to be momentarily translated into an explosive crossover start (go phase). The kinetic profile of each subsection, i.e. the parallel stop and the first stride (two steps) of the crossover start of a stop and go skating task will be all measured individually and then analyze.

1.4 Hypotheses

Based on pilot work and previous study (Le Ngoc, 2013), it is hypothesized that the modified skates will allow a smaller center of pressure excursion for both the stop and go phases, especially in the anterior-posterior direction than the regular skates as seen in previous study (Le Ngoc, 2013). The medial-lateral center of pressure should be similar in the regular and the modified skate models during the stop and go phases.

It is hypothesized, assuming that the center of pressure excursion is an indication of stability; that the high caliber group will have smaller center of pressure excursions in the antero-posterior and the medio-lateral directions than the low caliber group during the stop and go phases as seen in other sport studies (Caron, Gelat, Rougier, & Blanchi, 2000; Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Paillard et al., 2006).

It is hypothesized, assuming that high caliber players are physically fitter, well trained and better skater mechanically than the low caliber players (M. R. Bracko, 2001); the high caliber player group should present greater vertical force, impulse and lower time completion values than the low caliber player group while performing the stop and go phases.

Finally, it is anticipated to find statistically significant higher vertical force values for the inside skate of the modified skate model when compared to the inside skate of the regular skate model during the go phase. Pilot work and visual aids (video logs) predicted that the greater range of motion at the ankle joint of the modified skate should results in greater plantar flexion during the propulsion thus, helping the skaters generating more vertical forces with the inside skate. The skate design should not affect the kinetics during the stop phase.

1.5 Operational definitions

The following nomenclature, operational definitions, and abbreviations used throughout this thesis are outlined in the following section.

Center of Pressure (CoP): Instantaneous point of application of the in-boot reaction forces relative to the skate's blade.

Contact Time: The total time that the skate is in contact with the ice surface for each stride.

Dominant braking side: The player's "stick side" braking side.

Force Transducer: A device used to estimate forces based on strains exerted by an external load (Winter, 2009).

Forward Skating Stride Phases:

1) **Initial Contact:** Initial blade to skating surface contact.

2) Glide: Following initial contact, the phase of the stride in which no propulsion is occurring. The orientation of the blade of the skate on the ice is guiding the movement of the body.

3) Push-Off: Following the glide, the phase in which the blade turns outward (external rotation), creating propulsion from extension of the hip, knee, and ankle.

4) Swing: Flexion of the non-weight bearing limb, allowing it to swing forward to begin the next stride.

Impulse: The change in momentum produced by an external force, defined as the integral of force with respect to time (Winter, 2009).

Kinematics: The area of biomechanics, which describes movement without consideration of the forces leading to that motion (Winter, 2009).

Kinetics: The area of biomechanics concerned with the forces that produce given movements (Winter, 2009).

Medial-Lateral Force (ML): A force applied by a subject or skater perpendicular to the orientation of the skate's blade long axis.

Modified skate: Modified Bauer One95hockey skate including a flexible Achilles tendon guard and modified eyelet placement that increase the sagittal-plane ankle motion.

Non-dominant braking side: The player's "contra-lateral stick side" braking side.

Power: The rate at which work is performed (Power = Work / time).

Range of Motion (ROM): The difference between the maximum and minimum angle attained by a body joint.

Regular skate: Regular Bauer One95 hockey skate (Figure 2).

Skating Stride: The biphasic motion of skating, which begins when the foot contacts the ice with the blade and progresses through glide, push-off, and recovery of the ipsilateral limb (Upjohn, Turcotte, Pearsall, & Loh, 2008).

Stop and go: Skating task composed of two phases; stop and go.

Strain Gauges: Sensor used to convert the mechanical deformations of materials into an electrical signal.

Total Force (TF): The summation of vertical and medial-lateral force vectors estimated from strain gauge readings.

Vertical Force (V): A force applied by a skater parallel to the orientation of the skate's blade estimated from strain gauge readings.

Work: The amount of energy transferred by a force acting over a distance (Work = Force x Distance).

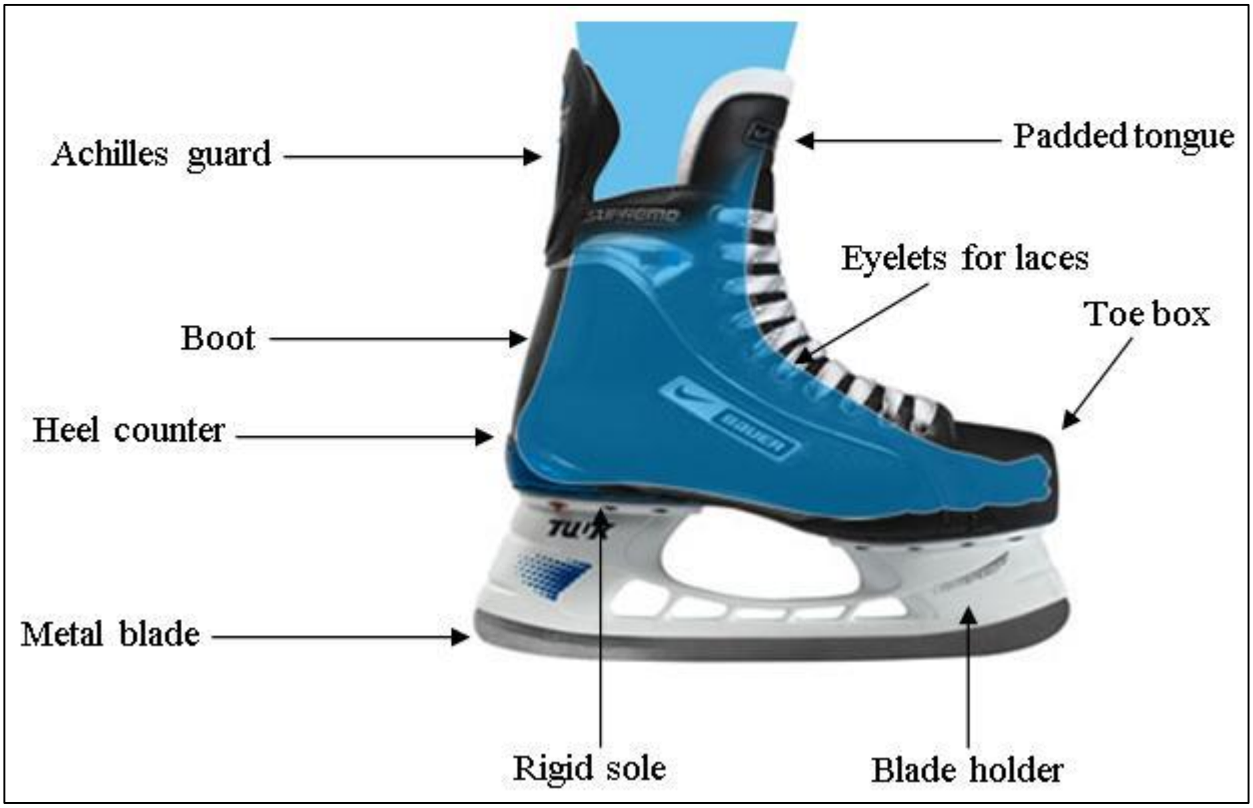

Figure 2: Structural components of a regular hockey skate (adapted from Pearsall and Turcotte, 2007).

1.6 Limitations

- The FSA sensors did not cover the whole area of the insole, thus did not measure the entire plantar pressure area of the foot.
- The strain gages did not read the vertical force at both extremities of the skate blade, thus limiting the vertical force measurement when the blade was pushing against the ice with the blade extremities.
- The ice conditions may have varied slightly between testing sessions.

1.7 Delimitations

- Only males between 18 and 35 years of age were recruited to participate in this study.
- Participants were not wearing their full ice hockey equipment.
- Participants were not wearing their own skates.
- Only participants wearing size 8.5 and 9 participated in this study.
- This study was limited to the analysis of one specific aspect of skating, an explosive transition task (stop and go).

1.8 Contribution to the Field

The current research will provide a better understanding on how a modified skate design influences ice hockey performance during a specific explosive transition skating task. It will also provide insights on skating mechanics used during a specific explosive transition skating task by different player calibers.

Chapter 2: Review of Literature

2.1 History of ice skating and the game of ice hockey

Human evolution and creativity both implicitly were the source of provision of biological and technological tools to move faster, in spite of the use of the same actuator, and to better adapt our locomotion to very different environments. Such examples are bicycles, skis and ice skates. Humans started ice skating more than 3000 years ago (Formenti & Minetti, 2007). It is hypothesized that ice skating was first developed as a more energy efficient means of locomotion. The first ice skates were made of animal bones and were discovered by archaeologists in cold North European countries such as Finland, the Netherlands, Sweden and Norway. Most of the skates were found in areas where water covers more than 5% of the land's surface (Formenti & Minetti, 2007, 2008).

Although, ice skating originated in Northern Europe, the sport of ice hockey is believed to have originated in Canada. Some oral historical accounts from the Mi'kmaq First Nation in Eastern Canada mention a hockey-like game being played. European immigrants have brought many variations to hockey-like games in Canada, such as the Irish sport of hurling, the Scottish sport of shinty and versions of field hockey in England. There are reports of hurly being played on ice ponds in Windsor, Nova Scotia, no later than 1810. A major change came in 1875 when McGill University students organized the first indoor ice hockey game at the Victoria Skating rink in Montreal (McKinley, 2006).

2.2 Classification of skills in ice hockey

Because the game of ice hockey is played under specialized conditions, most notably a low friction surface, it requires a unique set of skills compared to other team sports. The skills in ice hockey are primarily goal oriented and the timing and the movement patterns are a secondary function to the achievement of the task. To determine a player's skill, both the objectives and the player's movements have to be considered. Some skills in hockey can be considered closed while other skills can be considered open. The skills might be considered closed in that certain features of the environment are constant such as the rink dimensions and the equipment. However, the skills are more often considered open. The performance of a skill depends on the changing surroundings such as the positions of other players and whether they are moving or not. Because, ice hockey is often played in open conditions, perception, decision making and reaction time are as important as the movement in defining skills levels. Several qualities such as timing, anticipation, direction, balance, accuracy, rhythm, speed, versatility, agility and reaction time can therefore be used to define skill level in ice hockey (D. J. Pearsall et al., 2000).

General movement patterns in ice hockey include skating, stick handling and checking. Skating skills are arguably the most important and complex skills of ice hockey. Skating is also made up of many sub-set skills (Figure 3). There are a variety of skills and techniques used by hockey players which are used in an ever-changing environment. This makes ice hockey an exciting sport to play and watch (D. J. Pearsall et al., 2000).

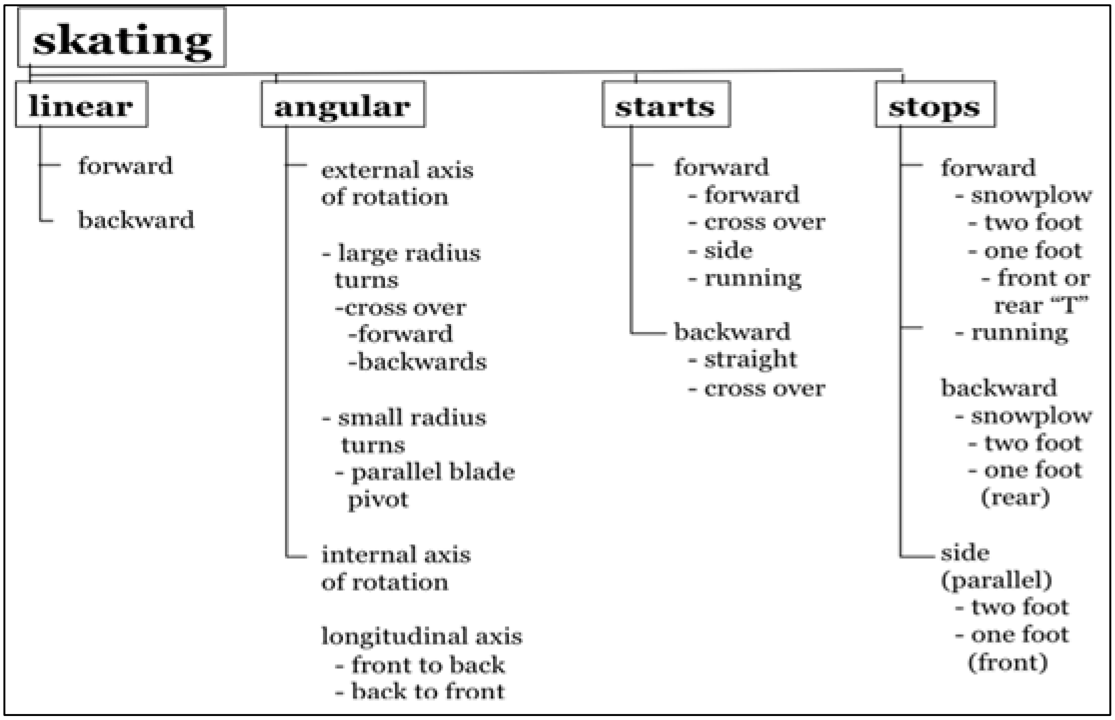

Figure 3: Classification of skating skills (adapted from Pearsall et al., 2000).

2.3 Skating in ice hockey

One of the most unique aspects of ice hockey is the method of locomotion used by the players during the game. The fact that ice hockey players are travelling with skates on the ice surface makes the sport of ice hockey one of the fastest team sports ever played. Skating in ice hockey is a complex motor skill and many experts in the field believe that skating is the most important ability a hockey player must possess to be successful at a competitive level in this sport (M.R. Bracko, 2004). Regardless of the activity in which a player is engaged he will need to skate or support himself on skates in order to effectively execute shots, passes, turns and pivots, body checks and battles for puck possession. When playing a full length hockey game, an average player skates between three and five kilometers, with the forward skating movement pattern consisting of between eighty and ninety-five percent of all skating maneuver (Montgomery et al., 2004). Similar gross motor patterns are exhibited in speed and figure skating; however, the skills executed in the context of a game and the large variety of tasks make ice hockey fundamentally different than any other on-ice skating sport. For example, an ice hockey player must start, accelerate, decelerate, stop, change direction, or turn in response to game cues, with decisions on the appropriate action often being made in an instant (D. Pearsall, R. Turcotte, & S. Murphy, 2000). There are a variety of skating skills associated with ice hockey other than forward skating. Other skating skills include skating backwards, turns, crossovers, pivots, starts, and stops, with each of these containing skill subsets and performed in a variety of game specific contexts.

2.4 Kinematics of the skating stride

The kinematics of ice skating have not been extensively studied due to difficulties associated with capturing motion on ice. The lack of accuracy and the large field of view required are some of the technical challenges that researchers have to overcome (Lafontaine, 2007; Upjohn et al., 2008). However, there are several studies investigating the kinematics of ice skating. Most of the research in kinematics has been done on lower limbs only.

Marino and colleagues published a number of studies focusing on the kinematics of the acceleration phase of skating. These studies used a video camera to derive two-dimensional data and could only offer a gross description of the forward skating movement as well as identify a few performance variables. One of these studies (G.W. Marino, 1977) using 10 skaters ranged from moderately skilled to highly skilled has examined different kinematic variables over three different skating velocities. An increase in skating velocity resulted in an increase in stride rate which corresponded to a decrease in both single and double support times. However, double support time decreased more relative to single support time. For a slow skating speed (3.75 m/s), double support time consisted of 44% of the total stride time. For a fast skating speed (6.92 m/s), double support time consisted only of 30% of total stride time. On the other hand, stride length did not change significantly. Therefore, skating velocity was more dependent on stride rate (r = 0.76) than stride velocity (r = 0.05). Close to 60% of the variation in velocity was due to the variation in stride rate (G.W. Marino, 1977).

In 1979, Marino and Weese followed this study with another to further their understanding of the kinematics of the ice skating stride. For this study, the researchers used 4 highly skilled performers. Each subject had tight fitting sweat suits and their segmental end points were marked. They performed three trials of maximal velocity skating though a designated filming area. The mean horizontal velocity for the skaters was 8.78 m/sec. The mean stride rate was 3.54 strides per second and the mean stride length was 2.48 meters. The mean single support time was .234 seconds and the mean double support time was .052 seconds. It was concluded that on average, the total time of the stride was composed of approximately 18% double support and 82% single support. The highly skilled participants were able to generate propulsion during both periods of double support and single support. Propulsion starts approximately halfway through the single support phase and lasts until the end of the subsequent double-support phase. Propulsion begins with hip external rotation and initial extension of the hip and knee and ends with full knee extension, hip hyperextension and plantar flexion (G. Marino & Weese, 1979).

In 1979 Marino and his group also observed the kinematics of forward acceleration. The acceleration pattern during the first 6 meters of skating was studied. 4 subjects ranging from moderately skilled to highly skilled were used. A typical observation was a high initial acceleration during the first 1.25 seconds. For 3 out of the 4 subjects, the acceleration levels then diminished gradually until periods of deceleration began. Overall, there was positive acceleration during the first 1.75 seconds despite alternate periods of single and double support. While this study did not have many subjects, Marino was able to confirm that propulsion could occur during both single and double support phases of the stride. They were able to maintain a positive acceleration throughout a period during which at least three strides were taken. During the first few strides, a large percentage of time is spent on single support, on average 85.3% (G. W. Marino, 1979).

The studies by Marino offered important insights on skating kinematics. However, most the research was done on the acceleration phase of skating and could only provide a gross description of the motions or identify factors that affect performance (Lafontaine, 2007). These studies were also limited because they only used two dimensional video analyses.

In addition to the studies conducted by Marino, there have been several studies conducted to identify performance variances in speed skating. In 1985 Van Ingen Schenau et al. examined elite female speed skaters during an international competition. They found that speed skaters control their speed mainly by changing their stroke frequency and not by changing the amount of work per stroke. The better skaters gained potential energy during their glide phase and showed a more horizontally directed push-off (G. J. Van Ingen Schenau, De Groot, & De Boer, 1985). De Boer et al. compared stroke mechanics between elite and trained male speed skaters. They found that better skaters showed a higher power production while having the same stroke frequency. They found several mechanical factors that could predict speed skating performance. The faster skaters reached a higher angular velocity at the knee and the time during which the knee was extended was shorter. The better push-off of the better skaters was characterized by a larger gliding time which resulted in a more effectively directed push-off force (De Boer, Schermerhorn, Gademan, De Groot, & van Ingen Schenau, 1986).

In 1989 Ingen Schenau et al. concluded that elite skaters possessed the following characteristics: a smaller pre-extension knee angle, mainly caused by a more horizontal upper leg position, a considerably higher amount of work per stroke and slightly higher stroke frequency, a higher knee extension velocity, a short lasting powerful push-off and a more horizontally directed push off (G. J. Van Ingen Schenau, De Boer, R. W., & De Groot, G. , 1989).

In a paper published in 1995, de Koning et al. described the speed skating stride as an evolution from running to gliding. 5 elite speed skaters doing all out-starts over a distance of about 50 m were used. They were filmed using 3 high-speed cameras placed near the track and three dimensional coordinates were calculated. The study compared the second stroke to the eighth stroke and it was concluded that the mechanics of the first strokes of a sprints were significantly different than the mechanics of the later strokes. The first push-offs were more similar to running. During the push-off phase, the skate was perpendicular to the intended direction of travel due to external rotation of the leg and the force was applied on a fixed location on the ice as there was little displacement of the skate, similarly to a running stride. By the eighth stride, the skate was gliding throughout the push-off phase and there was little external rotation; the push-off was more laterally directed. Gliding was defined as “the last instant when the foot moved backward relative to the body as fast as the body was moving forward relative to the ground." This occurred at a mean velocity of 6.7 m/s, after about six push-offs (De Koning, Thomas, Berger, De Groot, & Van Ingen Schenau, 1995).

The same research group revolutionized the sport of speed skating by developing the Klapskate. The Klapskate possesses a hinged skate blade holder that allows for powerful plantar flexion which helps increase the skater's impulse through a longer skating stroke (De Koning et al., 2000; Houdijk et al., 2000). The Klapskate allows for an increase in skating velocity of 5% which can be explained by an increase in work per stroke and stroke frequency. The difference in work per stroke occurs during the final 50 ms of the push-off phase (Houdijk et al., 2000). The conventional skate does not allow the skater to fully extend the knee and ankle joints before the skate have to be lifted.

Using a two dimensional system (cinematography) to evaluate three dimensional skating movements is problematic. When skaters travel the length of the ice, it is difficult to establish a properly calibrated field of view of high resolution (D.J Pearsall et al., 2001). Pearsall and his co-workers examined foot and ankle kinematics during forward ice hockey skating with electrogoniometers placed inside the skate. At the initiation of the single support phase, the skate is in 7.1º of dorsi flexion and increased to 11.8º at the beginning of the double support phase. During the swing phase, the skater quickly plantar flexed from 11.8º to 1.9º of dorsi flexion. During the glide, the foot was slightly everted and reached its maximal eversion of 7.1º in preparation for the push-off. This maximum eversion represents the need to generate a resultant force on the ice. During the swing phase the ankle underwent inversion exceeding the neutral position (Figure 4).

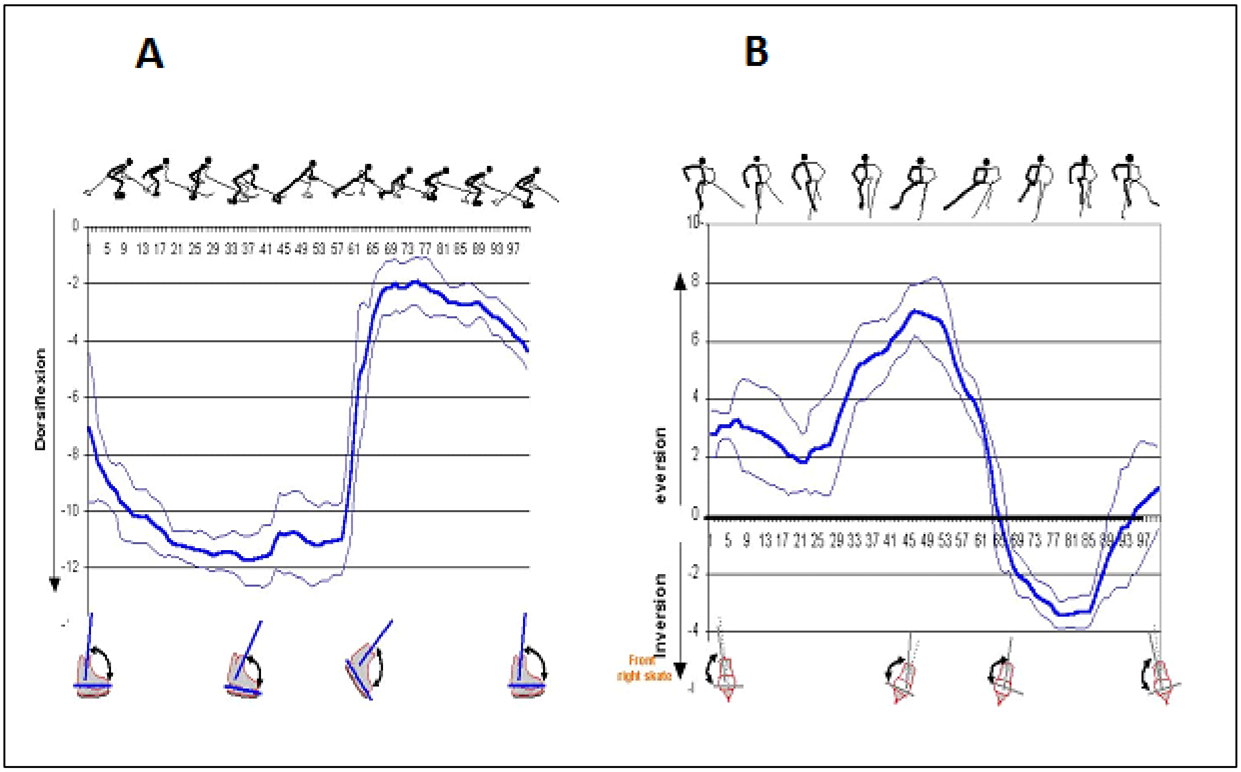

Figure 4: Ankle kinematics during forward skating: A) Plantar and dorsi flexion. B) Inversion and eversion (adapted from Pearsall et al., 2001).

The previous results differ from Dewan's (2004) study also calculating ankle kinematics with goniometry. The ankle reached higher degrees of plantar flexion 5° and dorsi flexion 18° (Dewan, Pearsall, & Turcotte, 2004). In 2009 Stidwill measured with goniometers on-ice ankle kinematics reaching 12.9° of plantar flexion and 18.6° of dorsi flexion. The different skates used in these studies might explain the discrepancies (Stidwill et al., 2009). This clearly shows the evolution in a short time of hockey skate design towards higher range of motion mostly through increased plantar and dorsal flexion. These studies also demonstrated that there are viable alternatives for capturing ice skating kinematics.

In 2007 Lafontaine was innovative in his kinematics measurement system using the traditional cameras and body markers, with one camera moving on guided rails alongside of the skater. The objective was to describe the kinematics of the knee and ankle during the first three strides of the ice hockey forward acceleration. This was done to demonstrate the usefulness of the data acquisition method and to determine if a kinematic evolution exists from the start to maximum speed during forward skating. The results showed that the range of motion for both joints progressed at every stride and increased velocities resulted from increased joint motion amplitude. The increases in knee range of motion were mainly affected by an increase in touchdown flexion angles. The ankle eversion can be linked to the blades' "angle of attack" on the ice. The results suggested that as speed increased eversion increased, thus allowing the skater to apply force in a more tangential direction on the ice surface. The author encouraged hockey players to include motions of large amplitudes in their training programmes, such as multiple-stride plyometric involving progressive knee flexion (Lafontaine, 2007).

In 2008 Upjohn et al. examined the lower body kinematic variables that discriminate high calibre hockey players from lower calibre hockey players when skating on a skating treadmill using four video camcorders. The problem of the large field of view required for skating task was removed by using a skating treadmill. Each participant completed trials of one minute at different speeds. The joint and limb segments angles were calculated. Results showed greater stride length, stride rate, knee and ankle range of motion for the high calibre skaters. The lesser range of motion of the lower calibre skaters could be attributed to the importance of maintaining stability while skating. The experienced skaters can easily keep balance, thus they can focus on the maximization of force during the push-off, which is associated with greater range of motion and stride length. Furthermore, high calibre skaters had greater limb excursion for the pelvis, thigh and foot. Thus, there was a greater lateral displacement of the lower limbs in high calibre players (Upjohn et al., 2008). In order to complete our understanding of forward hockey skating, a three-dimensional analysis of the skating stride is still needed.

2.5 Observed ground reaction forces during forward skating

Most research on ice hockey has been done on the kinematic aspects of the game; little work has been done to evaluate the kinetics of ice skating in hockey. Limited technology has made it difficult to measure kinetics while skating in ice hockey skates. The combined measurements of kinetic parameters together with joint and segment kinematics would provide researchers with a better understanding of the biomechanics of ice skating (Stidwill et al., 2009). Several studies in speed skating have used temperature compensated strain gauges as force transducers attached to an interconnected assembly block between the shoe and the blade of speed skates (De Boer et al., 1987; De Koning, De Groot, & Van Ingen Schenau, 1992; Jobse, Schuurhof, Cserep, Schreurs, & De Koning, 1990), making kinetic measurements feasible in the context of speed skating.

Regarding ice hockey, in the early 80’s the group of Lamontagne attempted to assess the kinetics of skating in ice hockey. However, major modifications of the skate blade made the application impractical (Lamontagne, Gagnon, & Doré, 1983). More recent research conducted to develop a valid, accurate, reliable and practical method of quantifying kinetics in ice hockey have recently been made possible in our research group at McGill University, at the IHRG (Ice Hockey Research Group). In 2009 Stidwill and colleagues created and validated an instrumented system to enable the measurement of forces during ice hockey skating (Stidwill et al., 2009). This strain gauge instrumented system did not require design alterations of the skate boot making it possible to obtain kinetic information from an unaltered skate during the performance of typical on-ice tasks. The wireless characteristic of the system enabled the experimenters to collect data in a real ice hockey environment without minimal constraint. The configuration of the strain gauges applied to the plastic blade holder of the skate allows simultaneous determination of vertical and medial-lateral forces. The electrical signal generated by the strain gauges is linear and was calibrated against forces generated on a force plate making force reproduction values obtained on–ice extremely valid and reproducible (Stidwill et al., 2009).

Figure 5 illustrates the forces generated by a skater in the right instrumented skate while performing a forward skating start, accelerating to maximal velocity in the first 6 strides. By examination of the strides we can clearly identify evident differences in stride mechanics. The first 3 steps showed force-time patterns similar to those found when sprinting (running motion), exhibiting short, single force peaks, evident acceleration, with the athlete pushing off against a fixed point on the ice (De Koning et al., 1995; Stidwill et al., 2009). During stride four, the skater begins a gliding push-off.

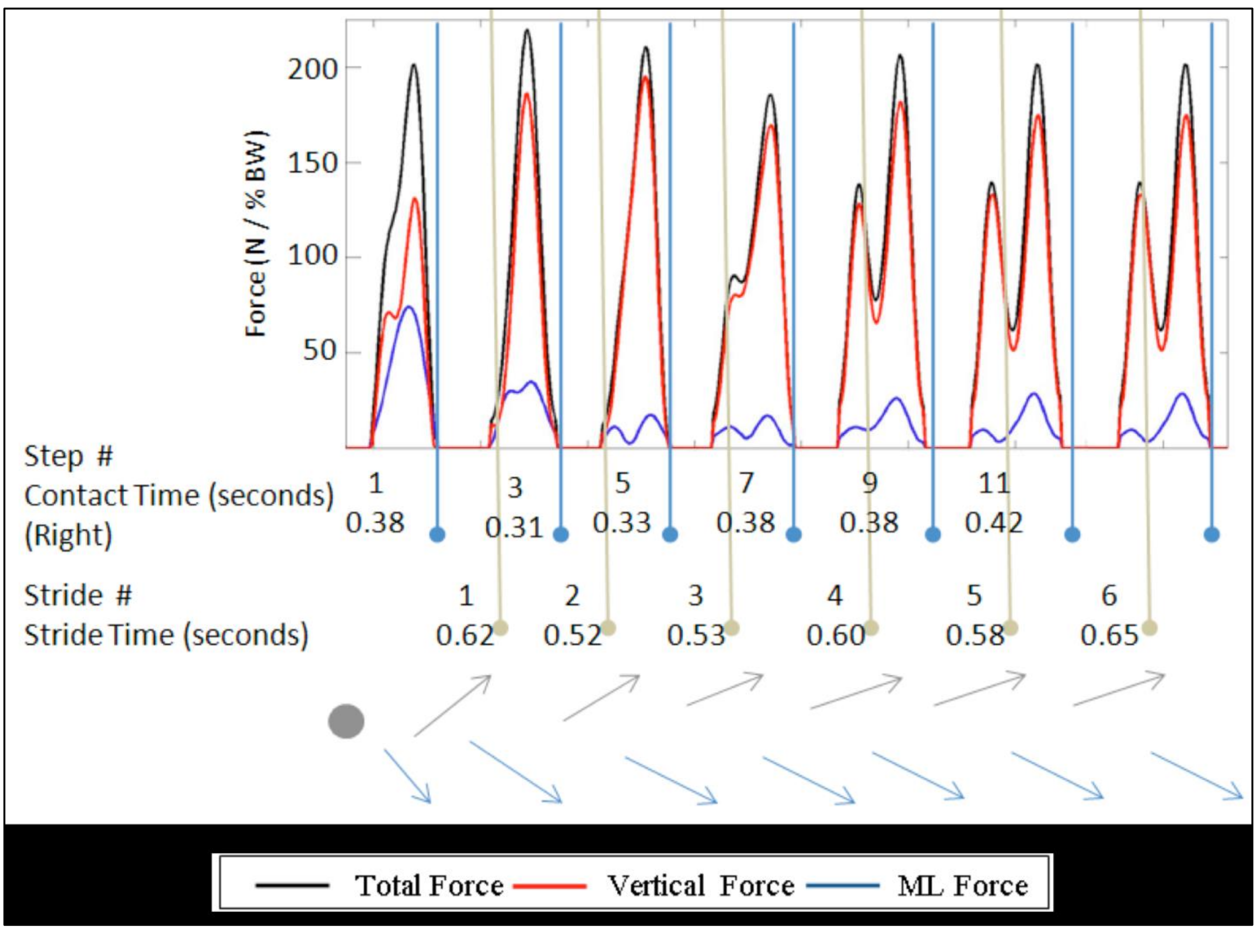

Figure 5: Kinetics of a participant for the right skate, including contact time and stride time information (adapted from Stidwill, 2009).

These results are similar to speed skating at constant velocity (De Koning et al., 1995; Jobse et al., 1990). Once constant velocity was achieved the skater initiated a bimodal skating pattern. This bimodal pattern can be explained by the sequence of the skating stride. The first peak occurs at approximately 15% of the stride and corresponds with the initial blade-ice contact. After the first peak and before the second peak there is dip in the middle of the force-time curve. This trough represents the downward acceleration of the body mass, causing the total ground reaction force (GRF) of the ipsilateral limb to fall between 50 and 70% of body weight. Finally, the second peak is indicative of the intensive push-off of the ipsilateral limb (Stidwill et al., 2009). This bimodal force pattern during skating at constant velocity is similar to the one seen in walking (Keller et al., 1996). Based on previous research (Upjohn et al., 2008), the skate is orientated at approximately 30º from the vertical during the propulsion. Assuming this approximation, the local forces with respect to the skates' local axis during the push-off phase can be seen in the Figure 6 below (Stidwill et al., 2009).

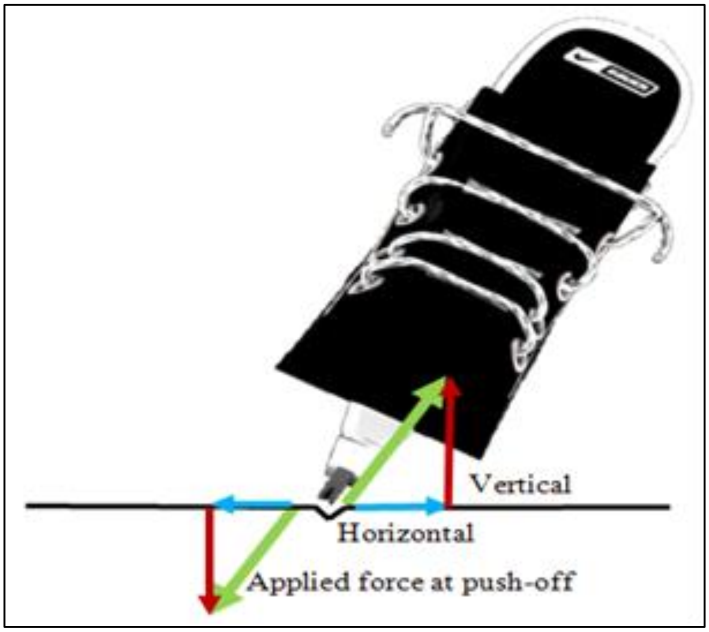

Figure 6: Representation of the resultant force and vertical and horizontal components at push-off (adapted from Pearsall et al., 2007).

2.6 The effect of skate design on the skating kinetics

The early models of ice hockey skates have undergone a tremendous evolution with the introduction of modern construction materials, design procedures and fit features used in the production of the ice hockey skate that we have come to know today. However, the manufacturing of the skate in ice hockey has remained relatively stable in past three decades, whereas in other skating sports, such as speed skating, that has not been the case. In the late 80's and early 90's, the development of a new design in the skate for speed skating demonstrated the importance of skate design on performance. In 1996, a newly designed skate, named the Klapskate (Figure 7), was introduced to the competitive world of speed skating. This new design allowed greater plantar flexion during the final portion of the stride, the propulsion, while at the same time preventing the toe of the blade from cutting into the ice and increasing friction (G. J. Van Ingen Schenau, De Groot, Wim Scheurs, Meester, & De Koning, 1996). The Klapskate led to significant improvements in speed skating performance, and contributed significantly to the many speed skating records that were broken following the 1996 season during which the new skate was introduced (Houdijk et al., 2000; Versluis, 2005). Keeping in mind that the skating requirements are much more complex and varied in ice hockey, the idea that equipment modification can enhance performance has been an intriguing consideration for companies designing ice hockey skates (D. J Pearsall & Turcotte, 2007).

Figure 7: Representation of the Klapskate allowing a greater plantar flexion (adapted from www.quebec-amerique.com).

2.7 Modified ice hockey skate; recent studies

The idea of developing a hockey skate prototype with more flexibility at the ankle sagittal plane originated from the remarkable apparition of the Klapskate in the speed skating world during the 90's and a series of pilot works on skate with modified tendon guard conditions as well. In 2008, after conducting an in lab skating pilot work mapping the pressure at the tendon guard of a skate prototype with a fixed tendon guard researchers noted significantly greater pressure on the uppermost part of the tendon guard compared to a regular skate model. This finding influenced the thinking of researchers suggesting to them that a potential ankle motion restriction was caused due to the tendon guard in the regularly designed skate. In 2009, the kinetics assessment of a modified hockey skate boot specifically designed to increase dorsi and plantar flexion during typical skating movements was made feasible due to the work of Stidwill and colleagues (Stidwill et al., 2009). In 2010 Robert-Lachaîne and colleagues (Robert-Lachaine et al., 2012) investigated the effects of an ice hockey skate that had a modified Achilles tendon guard, higher eyelet placement, and flexible material construction in the tongue of the skate boot that allowed a greater range of motion (ROM), primarily in dorsi and plantar flexion. When this skate was compared to a standard skate construction, results clearly demonstrated substantial and significant gains at the ankle ROM in dorsi and plantar flexion and net dorsi-plantar flexion ROM during a linear forward skating and forward crossovers task. Although, the modified skate demonstrated significant gains in plantar flexion and net plantar-dorsi flexion ROM in general this was not reflected in greater kinetic output. The total peak force occurred later during plantar flexion, suggesting that the increased ankle ROM resulted in a more prolonged effective force generation during a given skating stride (Robert-Lachaine et al., 2012). Furthermore in 2010, Fortier and his group analyzed the skating mechanics of a 90° change of direction maneuver in hockey players. They found that even if the modified skate possessed greater plantar-dorsi flexion ROM (~25°) due to strategic construction it did not change the way forces were applied in either the vertical or medial-lateral directions during the 90° change of direction maneuver task. Asymmetric differences were found, such that greater average forces were exerted on the outside skate (~50 to 70 % B.W.) versus the inside skate (~12 to 24 % B.W.) (Fortier, 2011). In 2010, Pearsall et al. (D.J Pearsall, Paquette, Baig, Albrecht, & Turcotte, 2012), analyzed the ankle ROM with a Biodex dynamometer and mapped the in-boot foot pressure. He found a greater ankle ROM in the sagittal plane in the modified skate when compared to the regular skate. Moreover, he found a considerably different interaction between the foot and boot when comparing the two skate models. The modified skate showed significantly lower pressure points at the tendon guard and at the instep of the boot displaying potential differences of the in-boot foot mechanics. Although, the modified skate allowed for a greater ankle ROM and a modified interaction between the feet and boot no significant kinetic differences were found in this study. In 2011, Baig found similar results regarding the increase in plantar-dorsi ROM with the modified skate boot compared to the regular skate boot using the Biodex dynamometer. He found that the ankle inversion-eversion ROM was similar in both boots, indicating that upper collar and lacing construction differences between the modified and One95 boots did not change side to side foot and ankle mobility. Once again this increase in ankle sagittal ROM did not result in greater kinetic output during the Biodex dynamometer and the linear skating trials (Baig, 2011). A 3-month familiarization pilot study performed in 2011 evaluating the skating performance demonstrated that a familiarization was not needed to maximize the modified skate skating performance benefits (unpublished results). In 2012, Culhane analyzed the bilateral forces (both right and left sides) of a modified skate and a regular skate during a linear forward skating. No statistical differences in contact time were found between the two skate models; the double and single support was 20 and 80%, respectively for both models. Similarly based on Stidwill (2009) and Robert-Lachaîne (2010) the peak plantar flexion coincided with the end of the vertical force production. The measured variables indicated that the modifications to the skate model did not influence the kinetic performance variables measured (force, acceleration and overall task completion time) (Culhane, 2013). In 2012, Le Ngoc established for the first time an in-boot plantar pressure profile during linear forward skating; a heel to toe sequence was noticed. The center of pressure (CoP) location coincided with blade position as expected. During the weight acceptance and propulsion phase the peak vertical force coincided with the CoP which was located at the lateral heel region of the skate blade moving towards the toe region on the medial side of the blade suggesting that the foot was performing a quick plantar flexion at the end of the propulsion phase. The anterior-posterior CoP excursion was 1.5 cm shorter in the modified skate compared to the regular model. A lower anterior expression of CoP resulted in a less anterior force vector orientation suggesting a different ankle and subtalar joint rotation mechanism when compared to a regular skate (Le Ngoc, 2013). Similar to previous on ice studies, no measurable kinetic performance differences were found in Le Ngoc's study. In light of the results presented in Le Ngoc's study, the CoP system used was sensitive enough to identify the in-boot plantar pressure parameters, thus giving more insight of the analysis of force generation and how force is applied while skating in ice hockey. The combination of plantar force and pressure measurement systems enabled the researchers to correlate maximal force values, for example, with specific foot sections, thus matching temporal events along the skating stride.

Since we found no kinetic performance differences in the past studies involving modified skate, but we found that the ankle ROM and plantar CoP were different between a regular and a modified skate, then a new research approach should be considered. Future research focusing on the skating kinematic differences between regular and modified skate may have more influence on getting insight on how to enhance the skating performance in ice hockey.

2.8 Plantar pressure in gait analysis

Pedobarography or foot plantar pressure is the study of the pressure field that acts between the foot and the support surface during everyday locomotion activities.

Information derived from such pressure measures is important in gait and posture research for diagnosing lower limb problems, footwear design, sport biomechanics, injury prevention and other applications (Abdul Razak, Zayegh, Begg, & Wahab, 2012). A common application is the use of plantar pressure assessment in athletic training in order to optimize sports performance. Footwear is widely believed to facilitate and enhance athletic performance (Cavanagh, Hewitt, & Perry, 1992). Numerous studies have been reported on athletic plantar pressure such as soccer specific movements (Eils et al., 2004) and forefoot loading during running (Queen, Haynes, Hardaker, & Garrett, 2007). Measurement of the plantar pressure, i.e. the distribution of force over the sole of the foot, is useful as it provides detailed information specific to each region of contact, so that a specific gait events can be attributed to a region of the foot (Rosenbaum & Becker, 1997).

Plantar pressure provides complementary information along the force analysis on how the plantar surface of the foot is loaded with respect to the supporting surface. The center of pressure (CoP) on the plantar surface is a frequently reported measure in gait analysis; it can be defined as the origin of the ground reaction force vector of external forces acting on the plantar surface of the foot. One common plantar pressure system configuration used in biomechanics research laboratory is the in-shoe system. In-shoe pressure measurements provide a means to better understand the effects of shoe design modifications on the mechanics of the foot and this has the potential to influence both shoe design and clinical practice. With the advantage of collecting multiple steps more easily than pressure platforms, in-shoe pressure system allows more robust statistical estimates of relevant parameters to be obtained and is more versatile for the study of activities other than level locomotion (such as stair climbing or sports activities) (Cavanagh et al., 1992). The measurements of in-shoe pressures may serve to evaluate the effectiveness of a given construction, or provide information that may suggest new avenues for development (Cavanagh et al., 1992).

However, several other instruments other than in-shoe pressure systems can be used to measure CoP including force plate and pressure plate. Force plates and pressure plates measure the CoP at the shoe/floor interface. On the other hand, in-shoe pressure systems allow for the calculation at the foot/shoe interface which might be more representative of typical foot function (Cavanagh et al., 1992). In-shoe pressure systems also offer the advantage of not being restricted to one area. There have been several studies assessing the characteristics of various pressure measurement systems. Several factors such as sensor accuracy and repeatability, sensor size, the number of sensors, sensor arrangement, sampling rate, and measurement context can affect the validity of calculating CoP. A recent study of the IHRG laboratory at McGill University has demonstrated the feasibility of a specific in-skate pressure system configuration to evaluate the pressure patterns, and more specifically, to measure the center of pressure during ice hockey forward skating (Le Ngoc, 2013).

In the past, several systems have been used to assess balance and postural control. These devices have typically used force plates combined with computer software to determine the movement of the center of pressure (Arnold & Schmitz, 1998). The center of pressure is the instantaneous point of application of the ground reaction force. During locomotion, this point of application usually moves in a heel-to-toe direction during the stance phase with smaller displacements observed in the medial-lateral direction (De Cock, Vanrenterghem, Willems, Witvrouw, & De Clercq, 2008). Balance could be described as the process of maintaining the position of the body's center of gravity vertically over the base of support and relies on rapid, continuous feedback from visual, vestibular and somatosensory structures and then executing smooth and coordinated neuromuscular actions (Hrysomallis, 2011). During stance, the center of pressure can be used to measure the movement of the individual's center of gravity over the foot. Thus, the center of pressure can be used to index the amount of movement or sway of the center of gravity during stance. The research literature has establish that the center of pressure is a reliable measure to evaluate balance and postural control (Chesnin, Selby-Silverstein, & Besser, 2000).

Sport training enhances the ability to use somatosensory and vestibular information, which improves postural capabilities (Paillard et al., 2006). As each sport requires high movement's specificity, postural changes are different according to the sport practiced (Davlin, 2004). Each sport develops very specific postural adaptations that are not necessarily transferable to other usual daily postures. Ice hockey requires a unipedal posture to perform different technical movements (skating, shooting, passing, and checking). The stability of the supporting foot is critical to perform these specific tasks as efficiently as possible. For example, the crossover start in ice hockey is described by Naud and Holt as a position that could potentially place the athlete off balance and in a very unstable position due in part to the crossover limb itself and in part to the elevation of the center of gravity and suspension of the body in the air for a short period of time (Naud & Hold, 1979). However, as far as we know, no study has yet been carried out comparing postural performance and strategy and its effect on the center of pressure excursion in ice hockey players of different levels of expertise and/or skating with two different skate models while performing a specific transitional explosive skating task.

2.9 Motor skill acquisition; expert versus novice

Human behavior is enormously adaptive to environmental demands. The most important changes in behavior are attributed to learning, as are changes in cognition, brain function, and many other modifications of the human body. Some adaptive changes, such as an increase in muscle volume in response to exercise, are commonly observed and are accepted as a natural result of training activities. Research in developmental biology shows that physical adaptation is more far-reaching than is commonly believed. For example, the shape of the eye is affected by an individual’s visual activity; the increased incidence of near-sightedness in Western cultures appears to be an adaptive reaction to watching TV, reading, and other activities requiring sustained focus on nearby objects (Wallman, 1994). Nevertheless, the adaptability of human behavior represents an interesting challenge for researchers who search to identify characteristics and to propose general theories that describe all forms of behavior adaptations. A valuable approach to describe those characteristics and theories is the analysis of extreme cases of maximal adaptation and learning, such as the behavior of experts. Expert performers dedicate most of their lives to attaining the highest levels of performance in highly constrained activities. Regardless of the field they are performing in, they often start training at very young ages, and the duration and intensity of their sustained training far exceed the range for other activities pursued by individuals in the normal population or novice performers (Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson & Lehmann, 1996). Athletes represent a good specimen of expert performers in the whole field of sports. Athletes are well known to exhibit tremendous motor skills during sporting activities.

Skills motor performance includes an enormous range of human activities other than sport skills, including work tasks, recreational chores, entertainment performances, and the actions of everyday life. Although, in this thesis we will consider skills in sport only, broadly defining sport as situations in which individuals or teams compete against one another through the medium of physical action, with one of the competitors being declared a winner. Motor skills are considered in terms of two components: Clearly, sport experts are better able to execute the motor skills of their particular fields than are less skilled performers; sport experts excel in performing appropriate movements. In addition, sport experts have greater cognitive skills in their particular areas than do other performers; sport experts have superior knowledge of their domain (Allard & Starkes, 1991).

Every person practicing a sport or learning a new sport goes through a learning process to acquire and optimize his or her athletic skills. In order to understand the differences of a novice and an expert we should first understand the components that characterize skilled performers from unskilled performers. A skilled individual has the ability to bring about some end result with greater certainty and a minimum outlay of energy or time. A novice could conceivably execute a flawless motor skill, yet not be able to perform it consistently, or with as little effort relative compared to an expert performer (Guthrie, 1952). Guthrie’s influential definition of skill performer has probably been the most widely used in the field of motor behavior.

We know that sport expertise has been defined as the ability to consistently demonstrate superior athletic performance (Janelle & Hillman, 2003; Starkes & Allard, 1993). Although superior performance by sport experts is readily apparent on observation, the perceptual-cognitive mechanisms that contribute to the expert advantage are less evident. Perceptual-cognitive skill refers to the ability to identify and acquire environmental information for integration with existing knowledge such that appropriate responses can be selected and executed (Marteniuk, 1976).

When compared to an expert performer, a novice performer has to manage more information when learning a new motor skill and therefore possesses less attentional capacity to react to different surrounding situations. Thus, novices are more likely to experience anxiety when encountering unfamiliar situations than expert performers. Emotional arousal can narrow the attentional field and decrease the ability to respond o peripheral stimuli (Boutcher, 1992). Expert performers are more likely able to perform optimally at a higher arousal level than novice performers (Abernethy, Maxwell, Masters, van der Kamp, & Jackson, 2007). The demands on expert perceptual-motor performance in sports nearly always include requirements for speed, very precise motor responses, or both. As the level of competition increases in sports requiring speeded responses, the available time to produce responses decreases because of the greater strength and speed of elite opponents. Elite athletes have to select responses on the basis of advance perceptual cues. When confronted with representative situations, elite athletes can produce the required reactions faster and make anticipatory movements earlier than less skilled athletes (Helsen & Pauwels, 1993). Numerous researchers have demonstrated that experts possess extensive practical knowledge of their own specific field that enables them to use important information from the environment to anticipate and predict future events (French, Spurgeon, & Nevett, 1995; French & Thomas, 1987; McPherson, 1999, 2000). Experts are typically more talented at making decisions and possess an incomparable ability to foreshadow or predict future events and outcomes given them superior temporal advantages over the novice performers (Holyoak, 1991; Starkes & Allard, 1993; Williams, Davids, & Williams, 1999). Furthermore, expert performers possess superior perceptual-cognitive skills, such as effective attention allocation and cue utilization, each of which have been demonstrated across sporting and other domains.

It is generally assumed that outstanding human achievements reflect some varying balance between training and experience (nurture or acquired skills) on one hand and innate differences in capacities and talents (nature or innate skills) on the other (Ericsson & Lehmann, 1996). The nature-nurture controversy has long and polarized history (Yarrow, Brown, & Krakauer, 2009). One view, typically associated in the literature with Galton's work (1869-1979), holds that individual differences reflect innate basic capacities that cannot be modified by training and practice (Galton, 1869). The second and more recent view, typically associated with de Groot (1946-1978) and with Chase & Simon (1973), is that expert's knowledge and task-specific reactions must have been acquired through experience (Chase & Simon, 1973; De Groot, 1978).

These two views define mutually exclusive domains corresponding roughly to the popular distinction between hardware and software in computer-based metaphors for human information processing (Ericsson & Lehmann, 1996). All performers, even the most "talented," need around 10 years (approximately 10,000 hours) of intense involvement before they reach an international level in established sports, sciences, and arts. Indeed, one can consider any skilled professional as a person who has had the motivation to practice one thing far more than most people could endure. Most elite individuals take considerably longer to reach that level. The necessity for years and even decades of required engagement in domain-related activities is the most compelling evidence for the crucial role of experience required to attain high levels of performance (Ericsson et al., 1993). A great example of genetic advantage in skill acquisition is the celebrated Finnish cross-country skier and triple-Olympic champion, Eero Mäntyranta, was born with a rare genetic mutation in the gene encoding erythropoietin (EPO) receptor that causes an increase in oxygen-rich red blood cells and consequently promotes enhanced oxygen supply to the brain and muscles. This mutation made Mäntyranta almost invincible in the heyday of his career. Throughout his career in the 1960's Mäntyranta was suspected of blood doping because his red blood count was 20% higher than that of other athletes. Thirty years later, scientists tested 200 members of his family and discovered that 50 of them, including Mäntyranta himself, were born with the same rare genetic mutation (McCrory, 2003). However, the relative importance of genetic variation in skill development remains controversial. Structural and functional brain imaging studies have also looked at patterns of change within individuals across periods of training on motor tasks. The expert-novice differences found were unambiguously the product of training (Yarrow et al., 2009). Clearly expert and novice athletes use their brains differently, but precisely interpreting these differences in terms of their functional roles seems some way off at present.

As we have seen, elite athletes show not only increased precision in execution but also superior performance at the level of perception, anticipation and decision making. In regards of the literature on the topic this superior performance expressed by the expert performers is task specific and is dependent on extensive practice and, to some degree, innate inter-individual differences (Yarrow et al., 2009).

Research on ice hockey skating is very limited in terms of the number of studies that have been performed up to this point regarding the skill level differences between skaters. In regards to the motor skill acquisition, the sport literature has established the performance superiority of the athletes compared to the novice performers. Acknowledging this superiority in motor skill acquisition, it would be interesting from a biomechanics point of view to analyze the performance differences between high caliber skaters and low caliber skaters during a specific skating task. Determining particular performance characteristics used during a specific explosive transitional ice hockey skating task and combining this information with the current data in the hockey literature may help to establish what a skilled skater in ice hockey is doing during the execution of the skating task that an unskilled skater is not. Once this information is discovered, it would make it possible to develop guidelines for ice hockey players to improve their skating abilities.

Chapter 3: Methods

3.1 Participants

A sample of 14 healthy young males (19-29 years of age) varying in hockey skill from high to low caliber, were recruited to voluntarily participate in this study. All participants had the Canadian citizenship. High caliber participants were recruited from the McGill University men's varsity ice hockey team and from other equal or higher caliber teams, while the low caliber participants were recruited from the intramural and recreation leagues at McGill University via posters placed at the McConnell Arena and ads in the McGill University online classifieds or players recruited from any similar league. All participants were screened prior to the study. Participants who have had a significant knee, ankle injury or any serious lower body injury that has prevented them from playing within the past year were excluded from the sample. Informed consents were obtained from all participants and ethics was approved prior to their involvement in the study.

The sample population recruited was carefully divided into two distinct groups based on their hockey playing experience (low caliber vs. high caliber). Also, visual inspection of the skater's abilities to perform the task both during testing and by inspection of the video logs, helped the experimenter insure that all the participants were assigned to the correct group based on their overall technique and level of comfort executing the task.

The number of participants tested to reach a statistical power of 0.8 or greater was determined by a sample power analysis (Faul, Erdfelder, Lang, & Buchner, 2007). A total sample of size of 14 participants; 7 high calibers: (Avg. age: 25.6 years; avg. height: 178.2 cm; avg. weight 82.7 kg; avg. playing experience: 20.4 years) and 7 low calibers: (Avg. age: 23.1 years; avg. height: 182.4 cm; avg. weight 77.1 kg; avg. playing experience: 12.7 years) was determined as necessary from the power analysis and previous similar studies. See Table 1 for demographic information of the participants.

Table 1: Demographic information of the participants.

Demographic Information					
Participants	Citizenship	Age	Highest Level	Playing Years	Shooting Side
High Calibers					
1	Canada	24	Junior A	16	Left
2	Canada	25	Magnus	21	Left
3	Canada	24	ECHL	20	Left
4	Canada	25	Junior B	20	Right
5	Canada	29	Midget AA	26	Right
6	Canada	24	LNAH	20	Right
7	Canada	28	CIS	20	Left
Low Calibers					
1	Canada	21	Midget A	16	Left
2	Canada	28	Recreational	17	Left
3	Canada	23	High School	18	Left
4	Canada	21	Recreational	8	Left
5	Canada	27	Bantam A	9	Right
6	Canada	23	Recreational	8	Left
7	Canada	19	Midget A	13	Right

3.2 Materials

The success of this study depended on two distinct data collection systems; a force transducer system and a pressure array based system. The pressure measurement system consisted of two skate insoles with 16 force sensitive array (FSA) pressure sensors taped under each insole. The FSA sensors (ISS-O) (Vista Medical, Winnipeg, Manitoba) were thin, flexible piezo-resistive force sensors, 1.7 cm x 1.5 cm in dimension with an active sensing area of 0.64 cm x 0.64 cm. A 32-channel amplifier was developed and linked to a data acquisition device (DAQ) monitoring the pressure voltages at a frequency of 1000 Hz. The amplifiers were customized in house in which the FSA sensors' leads were connected via a ribbon cable (UL Style 2651 300 Volt Max, Phalo Corporation, Manchester, NH). In turn, the amplifier was in series with a data acquisition device (cDAQ-9174, National Instruments, Austin, TX) linked by a Wi-Fi connection to a computer using custom programmed interfaces (LabVIEW™ 2010,National Instruments®, Austin, Texas) to monitor the sensors' voltages. This system was previously validated and calibrated for on ice usage from previous work from Le Ngoc (Le Ngoc, 2013).

The second system was utilized for ice ground reaction forces measurement. The left and right skate blade holders (Tuuk) were each instrumented with five force transducing CEA-series strain gauge (CEA-06-125UW-350). The five strain gauges from each blade holder were connected to a Wheatstone bridge circuit connected to a data logger, DataLOG MWX8 (Biometrics, Ltd, New Port, UK). The data were collected at

100Hz using a portable 14 bit analog to digital data acquisition system. The data logger was used to power the Wheatstone bridge circuits, supply a 5V +/- 2% excitation voltage to the force transducer strain gauges and record the output signal throughout the task. This system was previously validated and calibrated for on-ice usage (Fortier, 2011; Robert-Lachaine et al., 2012; Stidwill et al., 2009). Both systems were mounted on a pair of shoulder pads which was worn by each participant during the execution of the skating task (Figure 8).

Figure 8: Representation of both skate models instrumented with both wireless systems (top right) with the shoulder pads configuration (bottom right) and the shoulder pads configuration during testing (left).

3.3 Experimental setup

All testing sessions were done at the McGill University McConnell arena. The ice surface was freshly resurfaced with an ice resurfacing machine, Zamboni®, prior to each data collection session to insure consistent and optimal skating conditions. Each participant was weighed on a scale prior any equipment setup to establish baseline bodyweight measure (in Newton). Inside the locker room the participants were asked to first put on the pair of instrumented regular or modified skate model (Figure 9), in a randomized order, and were fitted with the instrumented shoulder pads system. The participants would wear size 8.5 or size 9 skates, corresponding to shoe size 10-10.5 with the instrumented insoles placed in the skates. Additionally, the participants had to wear; a hockey helmet, hockey gloves for protection and a hockey stick increase external validity of the results. Prior to go on the ice, the participants had to read and sign an inform consent which clearly stated the testing protocol and ethical issues.

Figure 9: Both skate models, the regular skate model (left) and the modified skate model (right) (adapted from Culhane, 2012).

Once on the ice, the participants were allowed a 5-minute period to warm up and familiarize with the skates and testing equipment. When the participant was ready and comfortable with the equipment, the experimenter would explain the specific sequence of commands regarding the task execution to the participant.

3.4 Experimental protocol

The task, stop and go, and signal synchronization begun with the participant standing on the starting point indicated by the first pylon; on the experimenter's GO command the participant would jump (to exhibit signal peaks in both systems to be used for synchronization purposes), executed a front start, skated forward as fast as possible to a second pylon, performed a side parallel stop at the second pylon facing their dominant side, performed a crossover start and skated as fast as possible back to the same first pylon and stopped with a side parallel stop on their non-dominant side, performed a second crossover start and skated as fast as possible to the same second pylon, stopped and on the experimenter's STOP command jumped once again to end the task. From the first pylon to the second pylon the participant skated a total distance of 19.51 meters or 64 feet (Figure 10). After performing 4 trials (during 1 trial the participant executed a parallel stop on each braking side: dominant and non-dominant braking side) with the first skate model, after the participant returned to the locker room to put on the second skate model and performed the same protocol as with the first pair of skates. A testing session (ice location) of 2 hours was sufficient to test 2 participants (half an hour per skate model including the equipment setup).

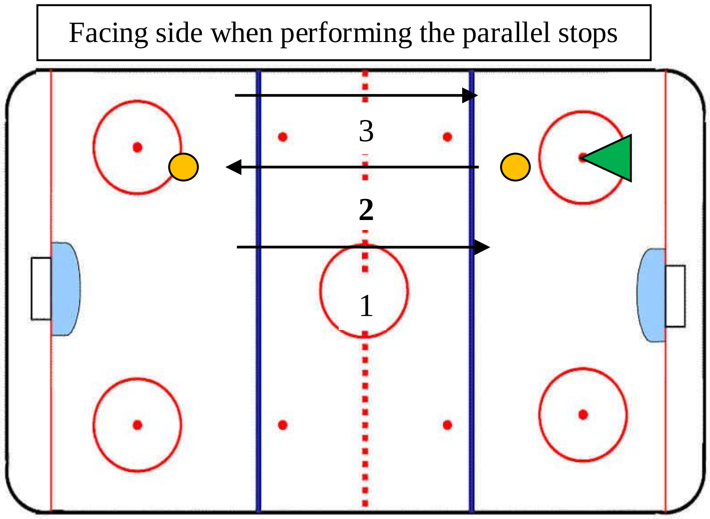

Figure 10: Representation of the stop and go skating task. The black arrows indicate the skating direction, the orange circles the pylons and the green triangles the camera positions.

3.5 Research design

This study was conducted to compare the skate models and the player calibers separately during 1) a stop and 2) a go, only analyzing the dominant parallel stop. The independent variables included; the skating task (stop and go), the skate model (regular, modified skate), player caliber (high, low). The first set of dependant variables measured was the time measure variables; time of each phase (in second), contact time (in second), air time (in second). The second set of dependent variables represented the kinetics obtained from the ice ground reaction forces and pressure systems; average force within the heel, mid and toe foot regions, maximum, minimum and delta center of pressure excursions, average and maximum vertical force and impulse. The dependent variables were calculated for the stop and for the go respectively. A complete description of the independent and dependent variables is presented in Table 2. See Figures 11, 12 and 13 for visual representations of the measurement methods of the dependent variables such as: Foot regions, center of pressure and vertical force.

Table 2: List of the independent and dependent variables.

Variable	**Type**	**Scale**	**Definition**
Skating task	Independent	Categorical	Stop Go
Player caliber	Independent	Categorical	High Low
Skate model	Independent	Categorical	Regular Modified
Braking side	Independent	Categorical	Dominant
Time measure	Dependent	Continuous	Contact time, time in air, time of each phases
Kinetics	Dependent	Continuous	CoP (A-P and M-L) maximum, minimum and delta excursions Pressure sensor: heel, mid, toe (average) Vertical force (maximum and average) Impulse

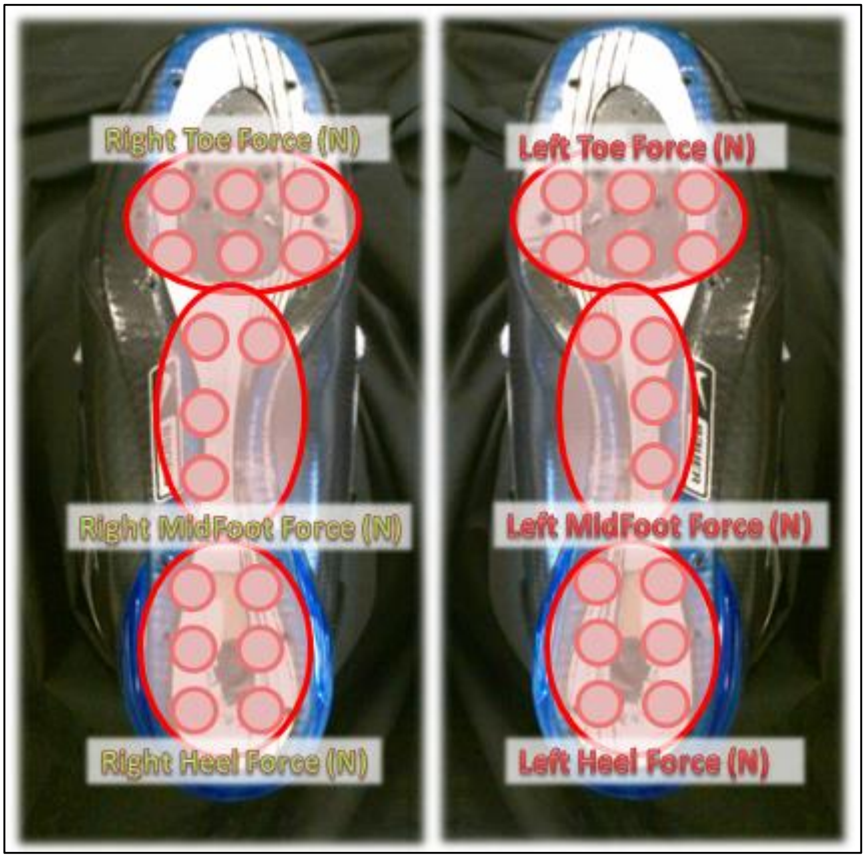

Figure 11: Layout of the 16 sensors defining the three foot regions (heel, mid and toe).

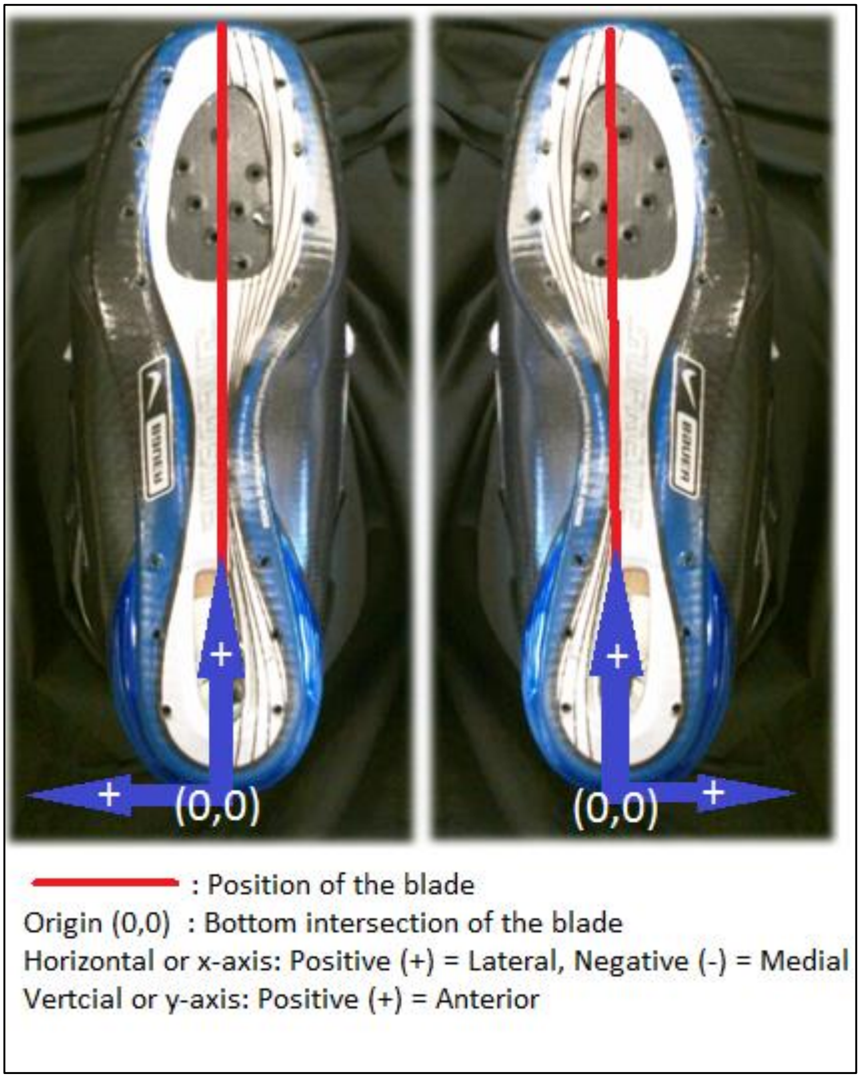

Figure 12: Axes definition and Cartesian coordinates of the center of pressure excursion measurements relative to the skate's blade.

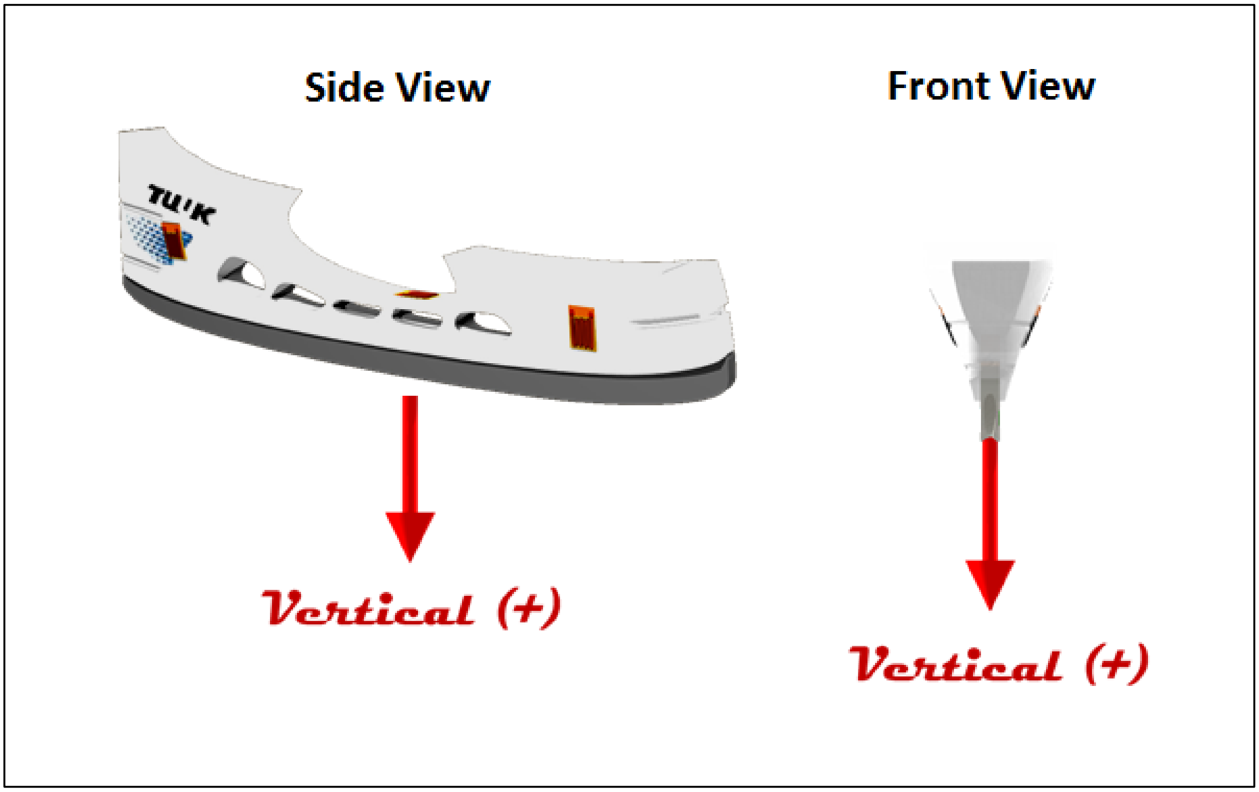

Figure 13: Emplacement the strain gauge on the blade holder measuring the vertical force variable (adapted from Stidwill, 2009).

3.6 Data acquisition, processing and analysis

LabVIEW™ Version 2010 (National Instruments®, Austin, Texas) software was used to collect the FSA pressure system data. Biometrics™ version 8 analysis software (Biometrics, Ltd, New Port, UK) was used to collect the Strain gages system data and also to activate the external synchronization trigger. MATLAB™ (7.10.0, R2010a, MathWorks, Inc., Massachusetts, U.S.A.) software was used to post-process the data, including re-sampling, filtering, and calculation of all the dependent variable using custom routines. SPSS™ (IBM Corporation, Somers, U.S.A.) was used to perform the appropriate statistical analyses on the dependant variables. Several univariate tests of variance (ANOVA) were conducted to compare the differences between the skate models and the player calibers while performing the stop and go skating task on the dominant braking side. Statistical significance was set at $\alpha = 0.05$.

Figure 14 illustrates the standardization nomenclature used to identify the inside and outside skates of right handed shooters and left handed shooters during their respective dominant braking side. For right handed shooters the inside skate was the right skate while the left skate was identified as the outside skate. For left handed shooters the inside skate was the left skate and the right skate was identified as the outside skate.

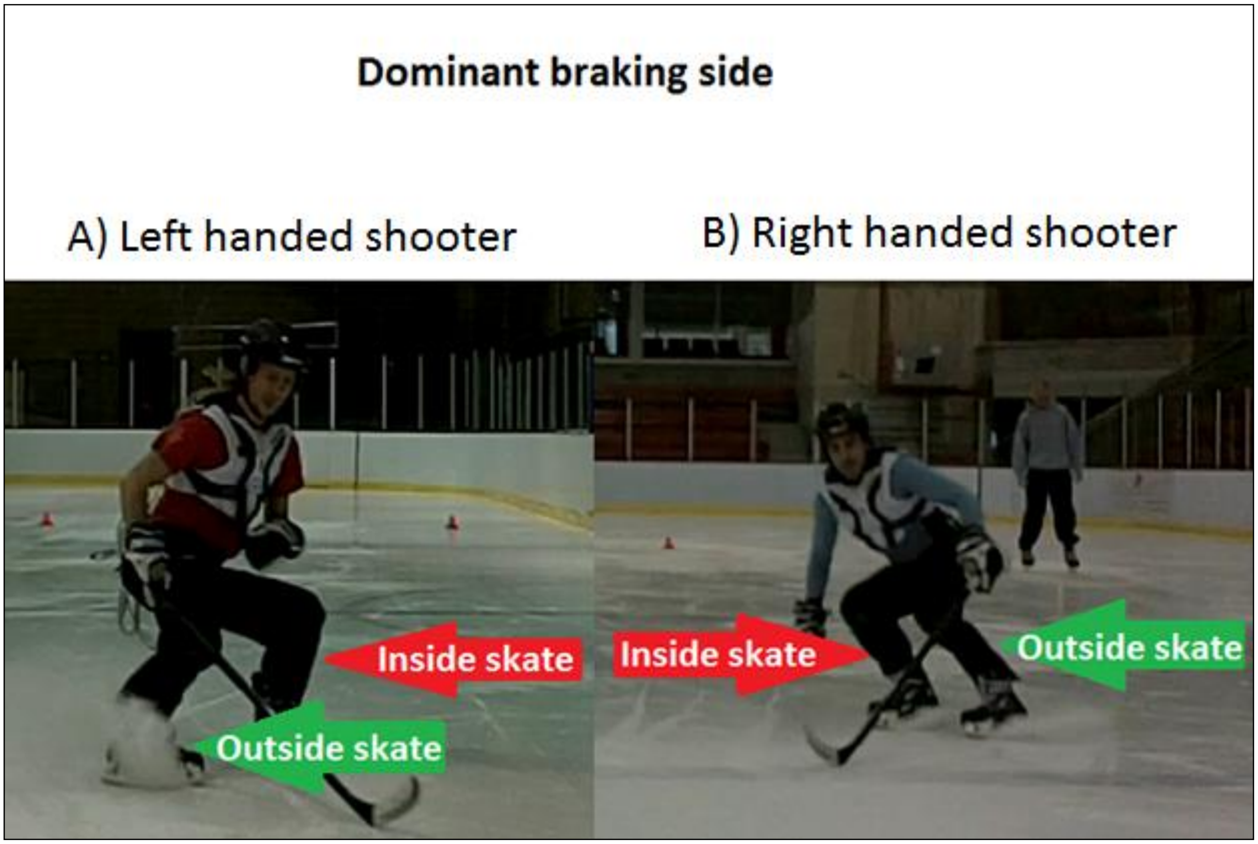

Figure 14: Illustrates the inside and outside skates for A) left handed shooters and B) right handed shooters while performing their parallel stop both on their dominant braking side.

All trials were divided into two distinct phases: 1) stop and 2) go. The stop phase initiation was defined at the instant the outside skate was starting to brake (gradual increases in vertical force). The go phase was initiated when the inside skate started executing the first push-off after the stop. Figure 15 shows the start and end of each phase; stop and go. Phase definition was performed post-hoc using the skate vertical forces to identify the start of both distinct phases (stop, go).

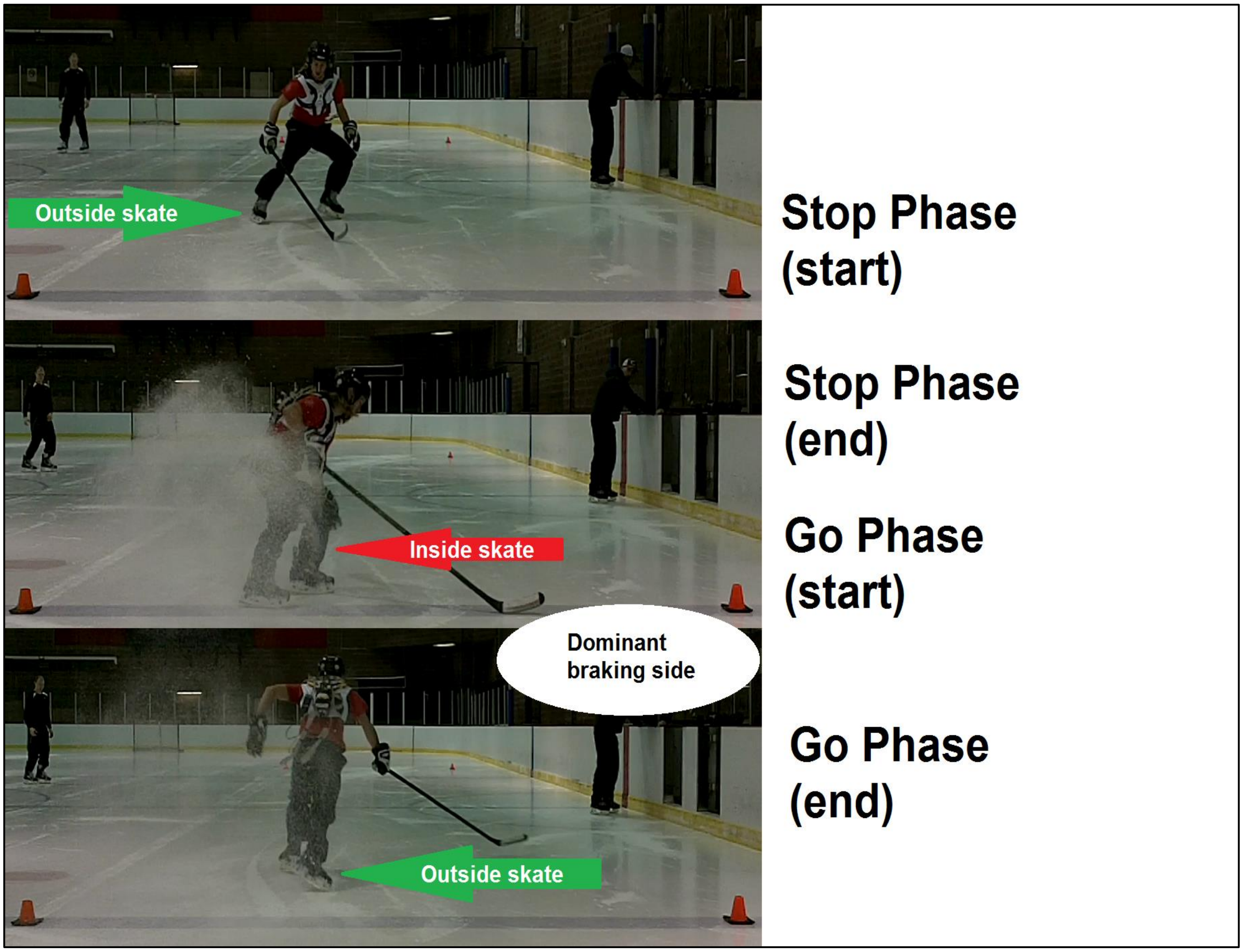

Figure 15: The sequence of the stop and go phases, from top to bottom: Frame 1; start of the stop phase, frame 2; end of the stop phase and start of the go phase, frame 3; end of the go phase.

Figure 16 shows the tagging or identification process of each phase for one sample trial. This identification process was executed using the inside and outside vertical force variables from the force transducer system. The manual identification (tagging) of each phase was performed in MATLAB™ (7.10.0, R2010a, MathWorks, Inc., Massachusetts, U.S.A.) by the same experimenter.

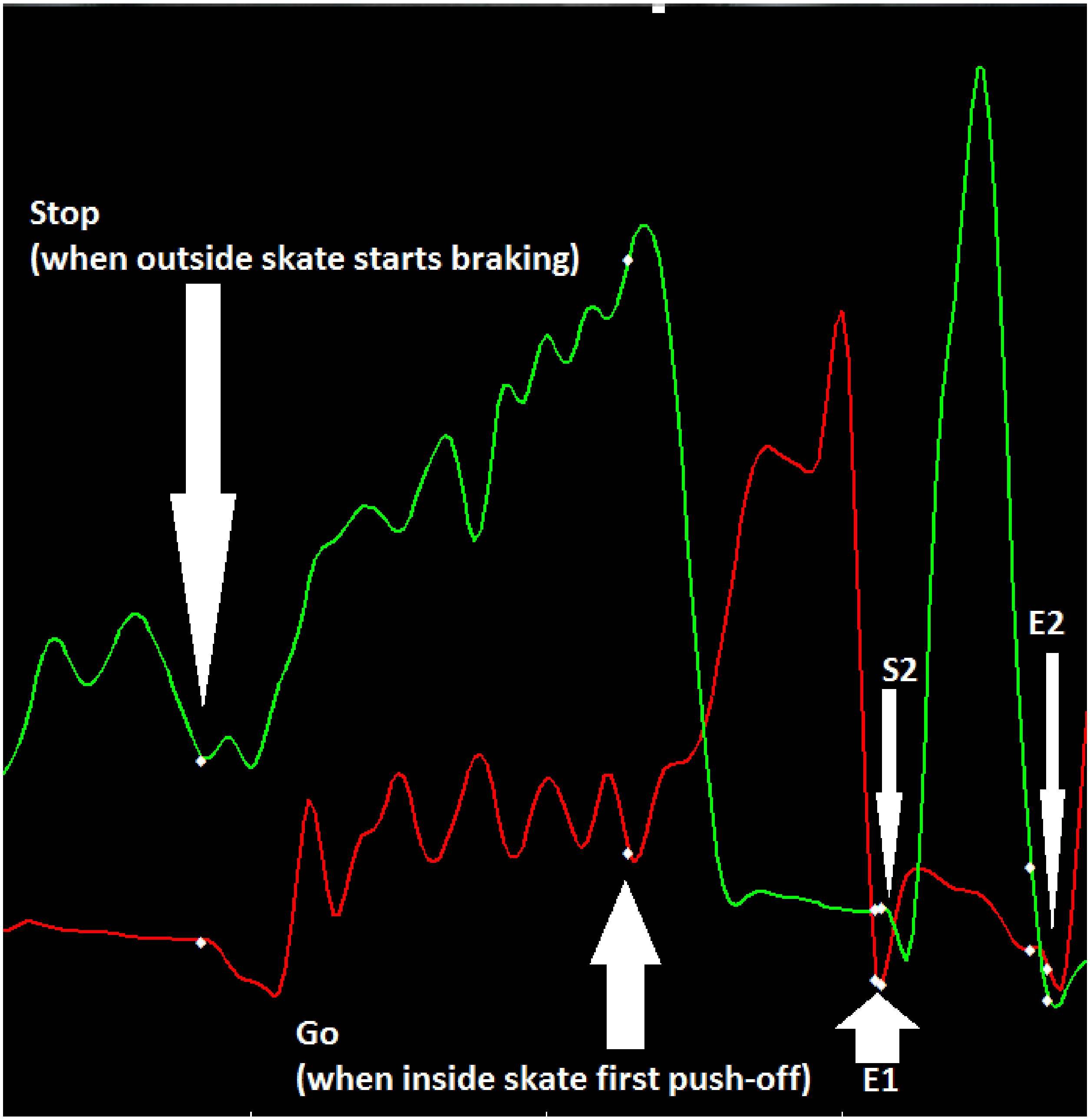

Figure 16: Stop starts when outside skate starts braking and stop when go starts, go starts when the inside skate first push-off, E1 is the end of the first step, S2 and E2 are the boundaries of the second step of the go stride. The inside skate (red) and the outside skate (green) vertical force.

The values of the outside and inside skates obtained from the FSA sensors of the pressure system were divided by foot sections (heel, mid, toe) (Figure 11). The values obtained by the strain gages of the force system were represented as the vertical force exerted by the skate on the ice. Each of the dependent variables mentioned previously in Table 2 were calculated in MATLAB™ (7.10.0, R2010a, MathWorks, Inc., Massachusetts, U.S.A.) from the two recorded and processed signals.

Chapter 4: Results

Descriptive and inferential statistics of the dependant variables are presented below in graphical and table format including means, standard errors (SE) and p-values. Significant differences (set at $p<0.05$) are identified in the graphs and tables with an asterisk sign (*). Vertical force data from the strain gages, foot regions and center of pressure data from the insole system, and time measure data were collected successfully on 14 participants (7 high calibers and 7 low calibers) on both left and right skates.

The results are reported in two distinct sections: 1) the stop phase and 2) the go phase. Each section includes the following sub-sections: foot regions, CoP and kinetics (including time measures) results.

4.1 Stop phase

The subsequent graphs and tables describe the foot regions, center of pressure, kinetics and time measure results obtained during the stop phase.

4.1.1 Foot region kinetics

The following section includes the results of the average forces at each of the three regions of the foot (heel, mid, toe) during the stop phase (Figure 11).

When considering the overall average forces for all foot regions in both skates, the high caliber players displayed greater values than the low caliber players. The high caliber group had significantly ($p<0.05$) higher average forces for both inside and outside skates in the heel foot region and for the inside leg for the mid foot region. No significant difference was found between caliber levels for both skates at the toe region. Moreover, no significant differences were observed for all foot regions between the regular and modified skates (Figure 17 and Table 3).

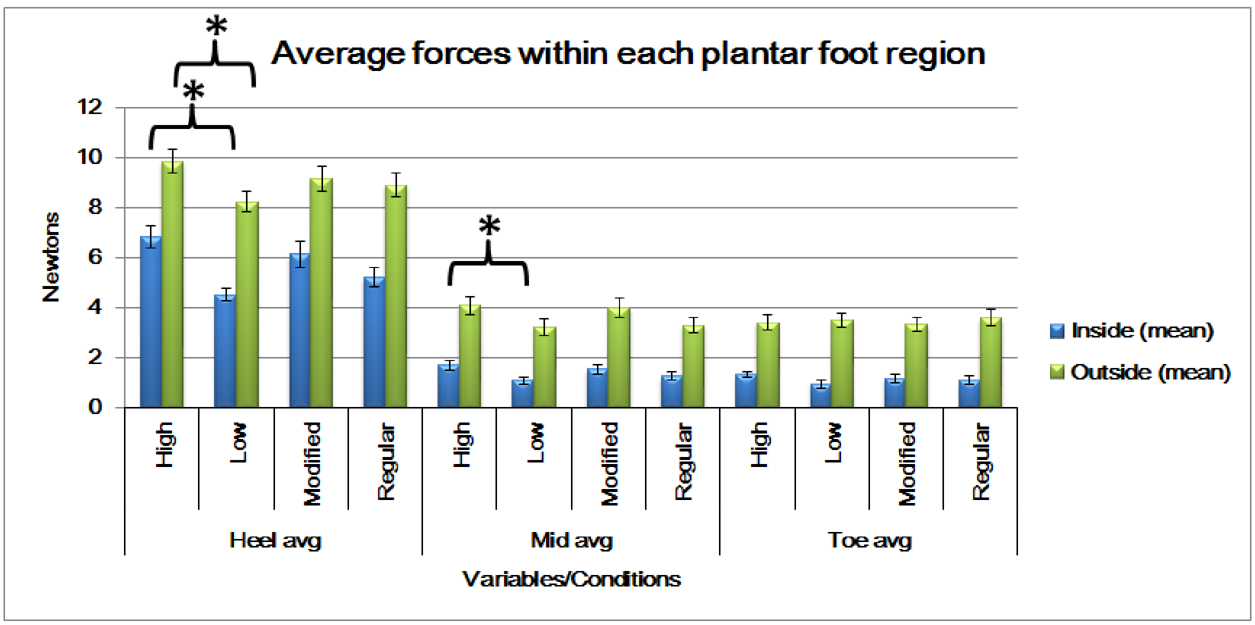

Figure 17: Stop phase average forces within each plantar foot region.

Table 3: Descriptive statistics of the stop phase foot region variables.

Descriptive statistics							
Foot side		Inside			Outside		
Variables	Conditions	Mean	Std. error	p-value	Mean	Std. error	p-value
Heel avg (Newton)	High	6.8	0.4	* p = .000	9.8	0.5	* p = .019
	Low	4.5	0.2		8.2	0.4	
	Modified	6.1	0.5	p = .068	9.2	0.5	p = .673
	Regular	5.2	0.4		8.9	0.5	
Mid avg (Newton)	High	1.7	0.2	* p = .019	4.1	0.4	p = .084
	Low	1.1	0.1		3.2	0.3	
	Modified	1.5	0.2	p = .261	4.0	0.4	p = .166
	Regular	1.2	0.2		3.3	0.3	
Toe avg (Newton)	High	1.3	0.1	p = .083	3.4	0.3	p = .804
	Low	0.9	0.2		3.5	0.3	
	Modified	1.2	0.2	p = .722	3.3	0.3	p = .510
	Regular	1.1	0.1		3.6	0.3	

4.1.2 Center of pressure

This section contains the results of the medio-lateral and antero-posterior center of pressure variables during the stop phase.

Figure 18 shows the center of pressure delta excursion in the medio-lateral direction (ΔCoPx), in millimeters, of the inside and outside skates. Positive values represent the lateral side of the blade and the negative values the medial side of the blade (Figure 12). No significance differences were found between the high and low caliber and between the modified and regular skate. It was interesting to observe that for all the conditions the outside leg ΔCoPx was more lateral to the blade than was the case for the limb on the inside skate; however, the magnitude of differences was small (< 2 mm) (Table 4).

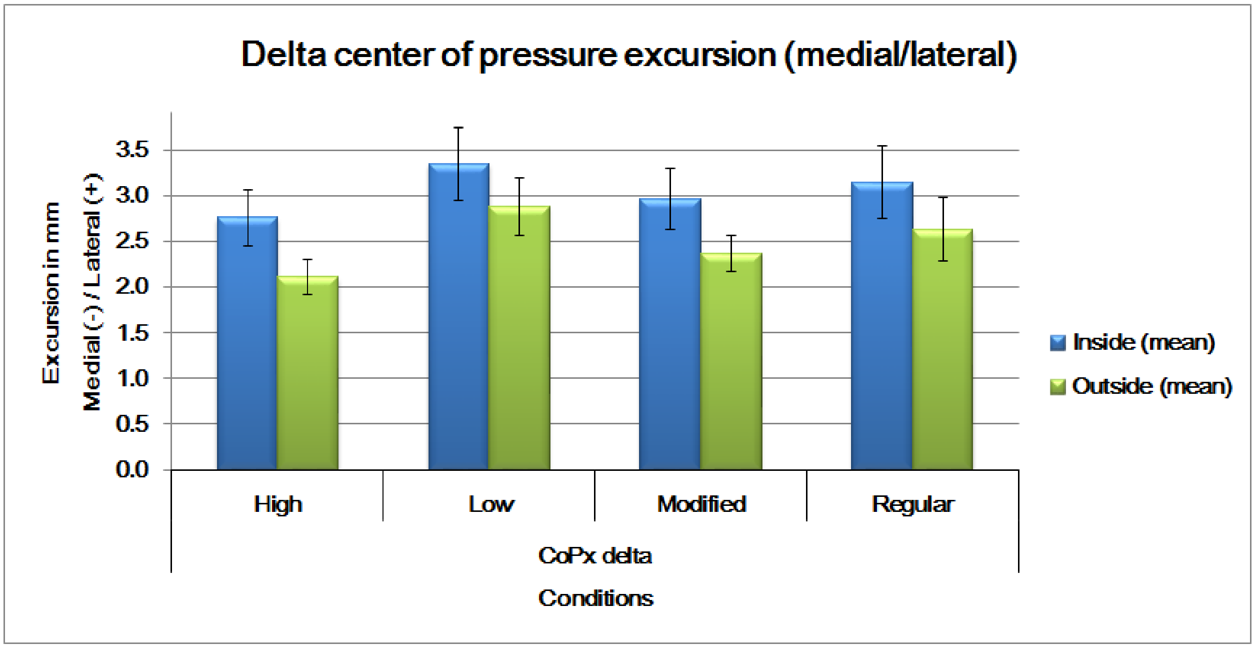

Figure 18: Stop phase medio-lateral delta center of pressure excursion.

Figure 19 demonstrates the center of pressure delta excursion in the antero-posterior direction (ΔCoPy), in millimeters, of the inside and outside skates. The more positive meant the more anterior the center of pressure along the blade related to the heel (Figure 12). The center of pressure maximum excursion in the antero-posterior direction ($CoPy_{max}$) between the high (Mean: 106.4; SE: 3.5) and low (Mean: 117.5; SE: 3.9) caliber was significantly different ($p<0.05$) for the outside skate. The low caliber players' ΔCoPy for the inside and outside skates was significantly ($p<0.05$) higher than the high caliber by ~ 1.1 cm and ~ 1.5 cm respectively (Table 4).

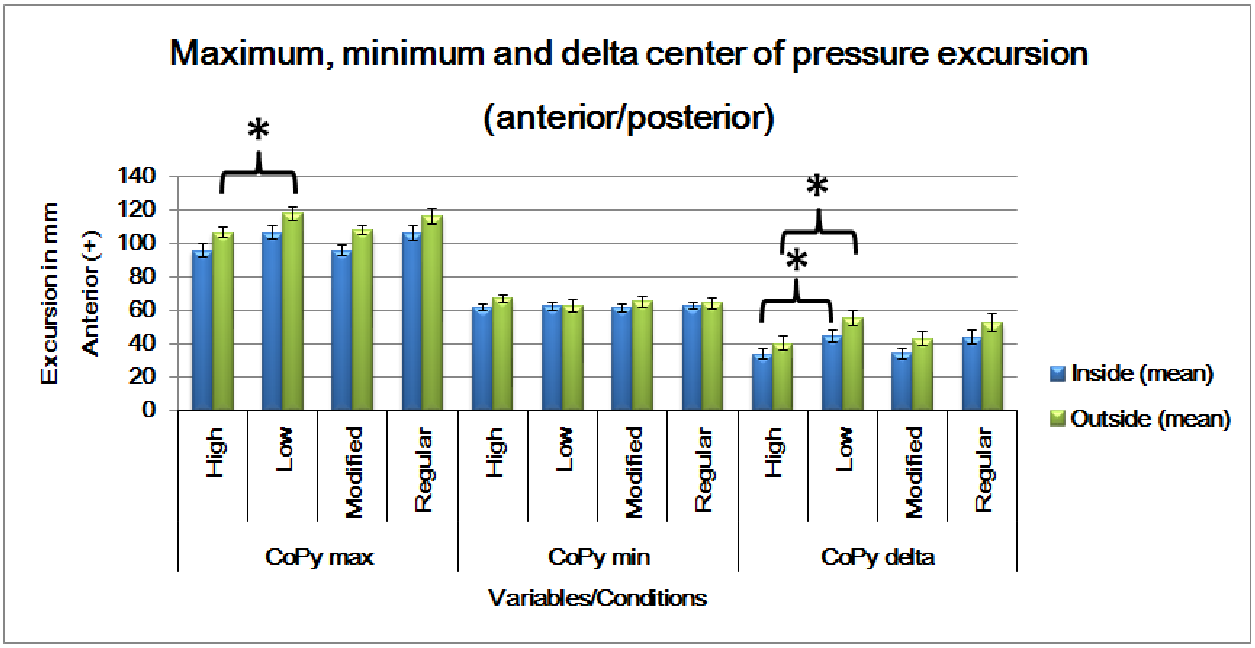

Figure 19: Stop phase antero-posterior maximum, minimum and delta center of pressure excursions.

Table 4: Descriptive statistics of the stop phase center of pressure variables.

Descriptive statistics							
Foot side		Inside			Outside		
Variables	Conditions	Mean	Std. error	p-value	Mean	Std. error	p-value
CoPx delta (mm)	High	2.8	0.3	p = .269	2.1	0.2	p = .057
	Low	3.3	0.4		2.9	0.3	
	Modified	3.0	0.3	p = .727	2.4	0.2	p = .509
	Regular	3.1	0.4		2.6	0.3	
CoPy max (mm)	High	95.3	4.0	p = .060	106.4	3.5	*** p = .038**
	Low	106.2	4.1		117.5	3.9	
	Modified	95.5	3.1	p = .067	107.6	2.9	p = .099
	Regular	106.1	4.8		116.3	4.5	
CoPy min (mm)	High	61.8	1.8	p = .940	66.5	2.3	p = .366
	Low	62.0	2.3		62.4	3.7	
	Modified	61.3	2.2	p = .707	64.8	3.1	p = .872
	Regular	62.5	1.9		64.1	3.1	
CoPy delta (mm)	High	33.5	3.3	*** p = .045**	39.9	4.0	*** p = .018**
	Low	44.2	4.0		55.1	4.6	
	Modified	34.2	3.2	p = .074	42.8	3.8	p = .130
	Regular	43.6	4.2		52.2	5.3	

4.1.3 Kinetics and time measures

Figure 20 displays the maximum and average vertical forces, expressed as a percentage of body weight, during the stop phase. In general, one can notice that the outside skate, for all the conditions, had higher values than the inside skate. We can observe four significant differences. Looking at the maximum vertical forces, the regular skate inside and outside skates were significantly ($p<0.05$) higher by 10 to 20% respectively than the modified inside and outside skates. Looking at the average vertical forces, the high caliber players and the regular skate outside skates were significantly ($p<0.05$) higher than the low calibre players' outside skates and the modified outside skate by 9 and 17% respectively (Table 5).

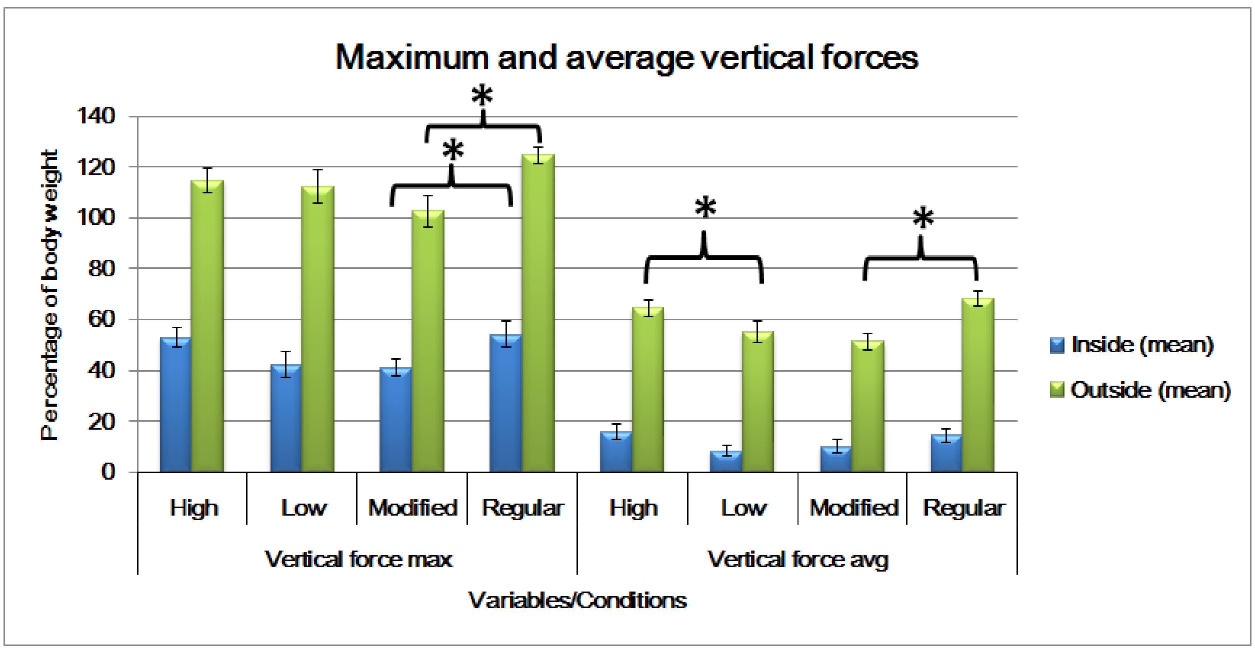

Figure 20: Stop phase maximum and average vertical forces.

For the absolute duration in seconds of the stop phase, the low caliber players showed longer stopping time than the high caliber skaters. The high caliber players took significantly ($p<0.05$) less time (high caliber: 0.88 seconds vs. low caliber: 1.06 seconds) than the low caliber players to complete the stop phase (Figure 21 and Table 6).

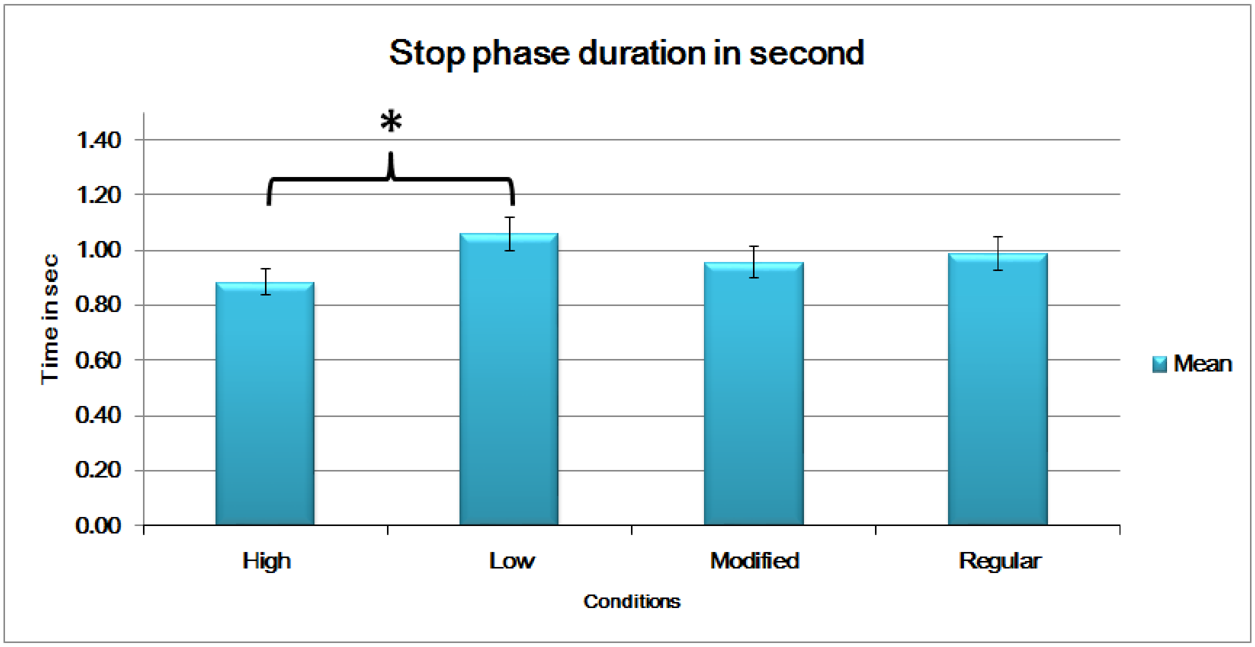

Figure 21: Stop phase duration in seconds.

The next graph (Figure 22) shows the impulse, or change in momentum, of the stop phase. The outside skate clearly showed a greater impulse than the inside skate. The regular outside skate impulse (Mean: 67.6; SE: 4.9) was significantly higher ($p<0.05$) than the modified outside skate (Mean: 48.8; SE: 4.1). No other significant differences were seen between the skate models (Table 5).

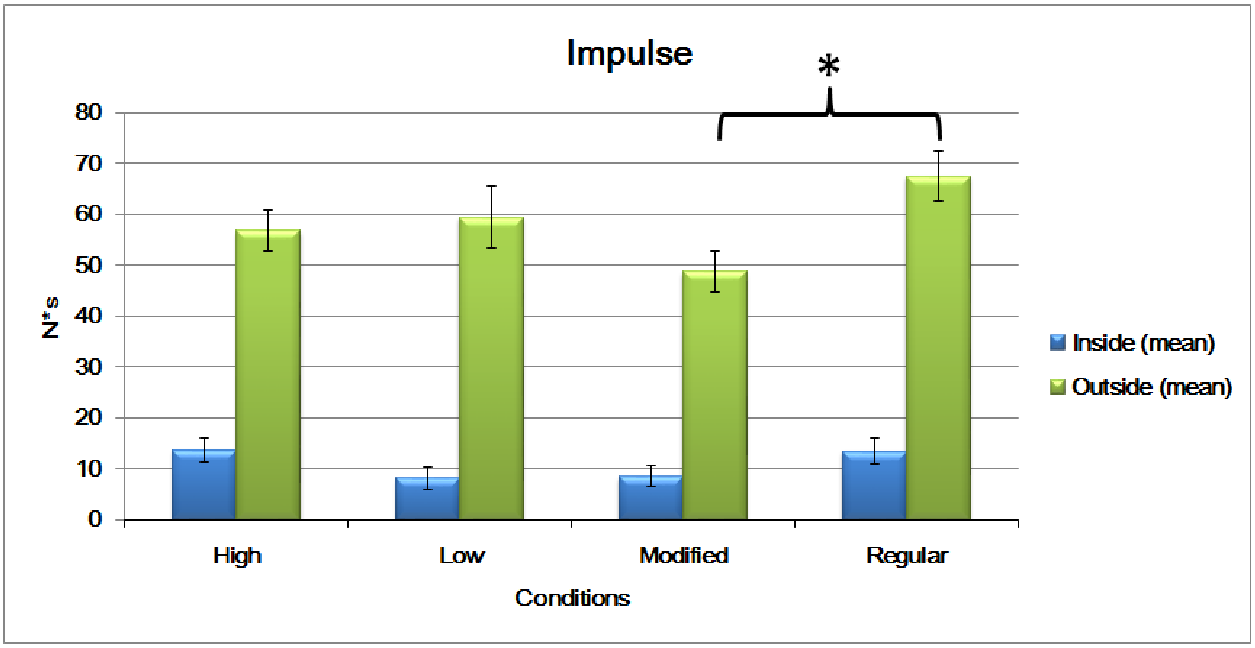

Figure 22: Stop phase impulse.

Table 5: Descriptive statistics of the stop phase kinetics variables.

Descriptive statistics							
Foot side		Inside			Outside		
Variables	Conditions	Mean	Std. error	p-value	Mean	Std. error	p-value
Vertical force max (% B.W.)	High	52.9	3.8	p = .085	114.9	4.7	p = .725
	Low	42.3	4.9		112.4	6.5	
	Modified	41.2	3.3	* p = .038	102.6	6.1	* p = .004
	Regular	54.1	5.1		124.8	3.1	
Vertical force avg (% B.W.)	High	16.1	2.9	p = .051	64.5	3.2	* p = .041
	Low	8.5	2.3		55.4	4.2	
	Modified	10.0	2.7	p = .236	51.4	3.4	* p = .001
	Regular	14.5	2.8		68.4	2.9	
Impulse (N*s)	High	13.7	2.3	p = .107	56.9	3.9	p = .695
	Low	8.2	2.3		59.5	6.2	
	Modified	8.5	2.1	p = .144	48.8	4.1	* p = .009
	Regular	13.4	2.5		67.6	4.9	

Table 6: Descriptive statistics of the stop phase time measure variable.

Descriptive statistics				
Variables	Conditions	Mean	Std. error	p-value
Stop duration (second)	High	0.88	0.0	* p = .038
	Low	1.06	0.1	
	Modified	0.96	0.1	p = .681
	Regular	0.99	0.1	

4.2 Go phase

The subsequent graphs and tables describe the foot regions, center of pressure, kinetics and time measure results obtained during the go phase.

4.2.1 Foot region kinetics

The following section summarizes the results of the average forces of the three regions of the foot (heel, mid, toe) during the go phase (Figure 11).

Regarding the average force values (by foot regions), the high caliber players showed greater average forces, ($p<0.05$), than their low caliber counterpart for; the inside skate at the heel region, the inside skate at the mid region and the outside skate at the toe foot region. For the skate model condition, the inside leg at the heel foot region of the modified skate was significantly higher ($p<0.05$) than the regular skate (Figure 23 and Table 7).

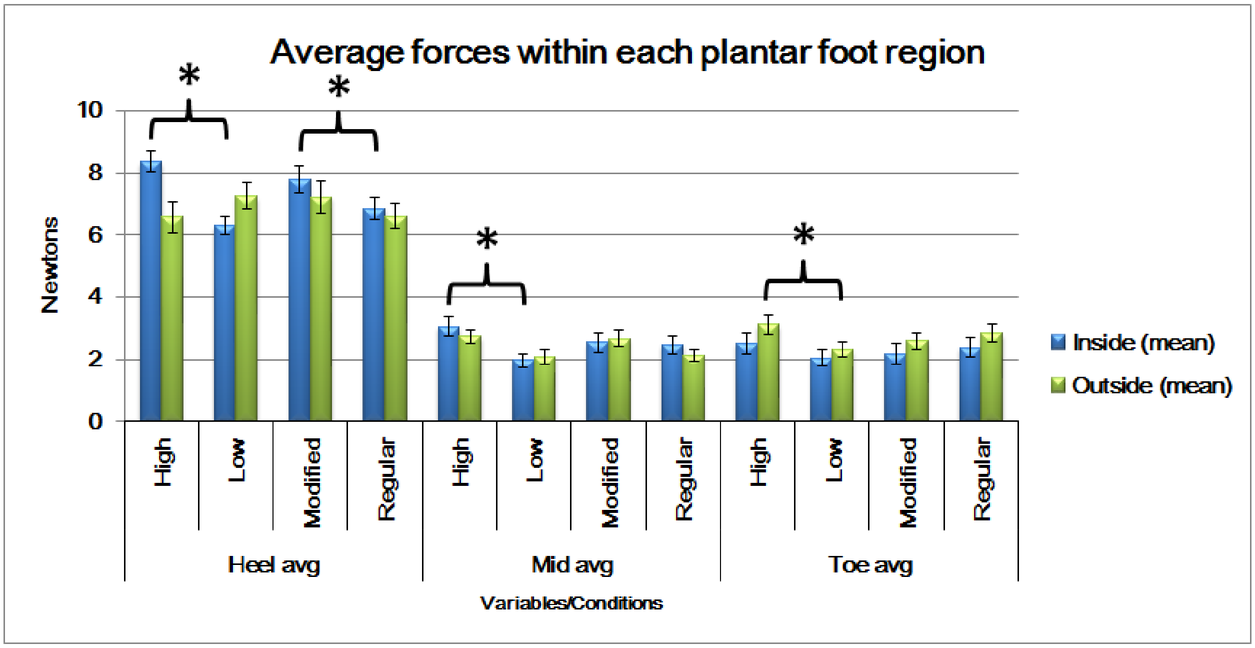

Figure 23: Go phase average forces within each plantar foot region.

Table 7: Descriptive statistics of the go phase foot region variables.

Descriptive statistics							
Foot side		Inside			Outside		
Variables	Conditions	Mean	Std. error	p-value	Mean	Std. error	p-value
Heel avg (Newton)	High	8.4	0.3	* p = .000	6.6	0.5	p = .327
	Low	6.3	0.3		7.3	0.4	
	Modified	7.8	0.4	* p = .032	7.2	0.5	p =. 361
	Regular	6.9	0.4		6.6	0.4	
Mid avg (Newton)	High	3.1	0.3	* p = .012	2.7	0.2	p = .055
	Low	2.0	0.2		2.1	0.2	
	Modified	2.6	0.3	p = .830	2.7	0.3	p = .109
	Regular	2.5	0.3		2.1	0.2	
Toe avg (Newton)	High	2.5	0.3	p = .306	3.1	0.3	* p = .047
	Low	2.1	0.3		2.3	0.2	
	Modified	2.2	0.3	p = .647	2.6	0.3	p = .505
	Regular	2.4	0.3		2.8	0.3	

4.2.2 Center of pressure

This section contains the results of the medio-lateral and antero-posterior center of pressure excursion variables during the go phase.

When analyzing the center of pressure delta excursion in the medio-lateral direction (ΔCoPx) we noticed that, during the go phase, the ΔCoPx for the outside skate of the low caliber players was significantly ($p<0.05$) higher than in the high caliber players. No differences were observed between the skate models for the ΔCoPx (Figure 24 and Table 8).

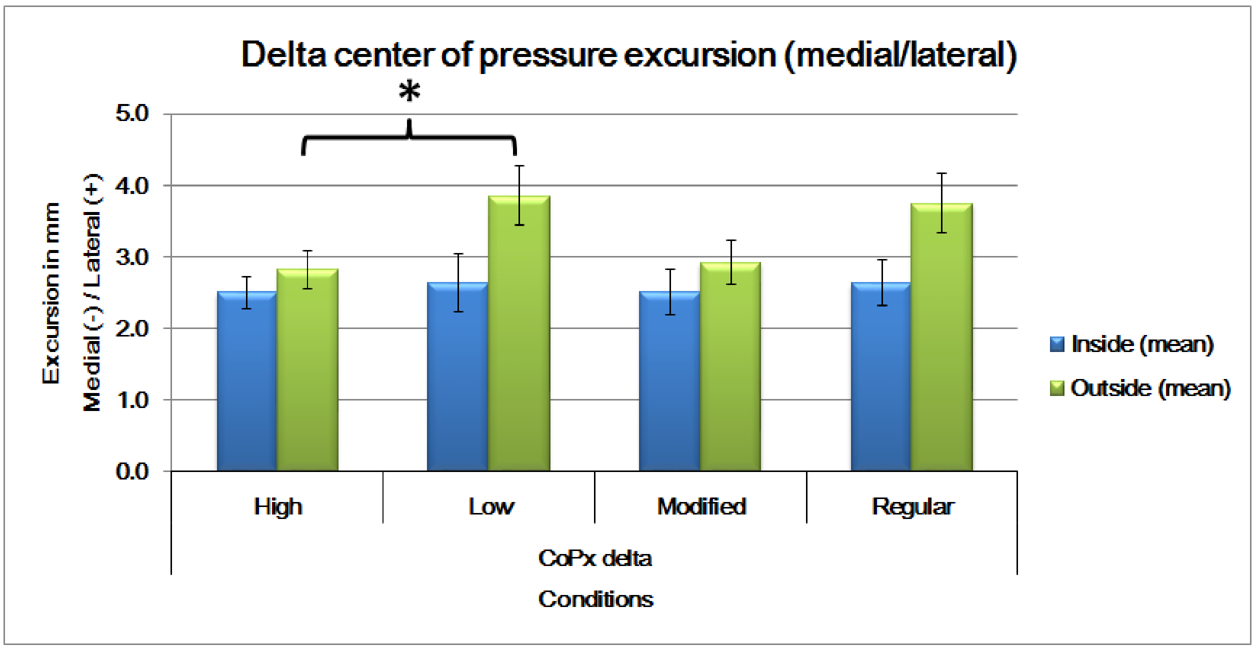

Figure 24: Go phase medio-lateral delta center of pressure excursion.

The center of pressure maximum, minimum and delta excursions ($CoPy_{max}$, $CoPy_{min}$ and ΔCoPy) were, for both the inside and outside skates and across all the independent variables, similar as no significant differences were observed (Figure 25 and Table 8).

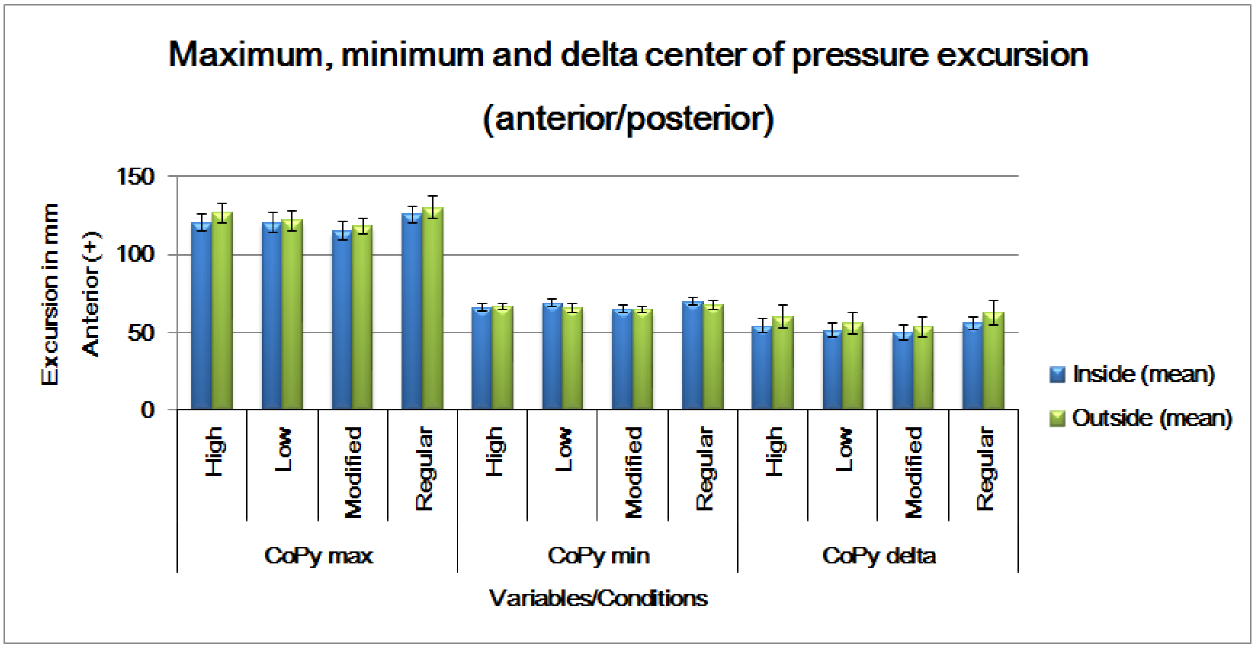

Figure 25: Go phase antero-posterior maximum, minimum and delta center of pressure.

Table 8: Descriptive statistics of the go phase center of pressure variables.

Descriptive statistics							
Foot side		Inside			Outside		
Variables	Conditions	Mean	Std. error	p-value	Mean	Std. error	p-value
CoPx delta (mm)	High	2.5	0.2	p = .769	2.8	0.3	* p = .045
	Low	2.6	0.4		3.9	0.4	
	Modified	2.5	0.3	p = .797	2.9	0.3	p = .105
	Regular	2.6	0.3		3.8	0.4	
CoPy max (mm)	High	120.5	5.2	p = .993	126.7	6.4	p = .597
	Low	120.4	6.3		121.9	6.4	
	Modified	115.2	6.0	p = .209	118.3	5.1	p = .197
	Regular	125.7	5.1		130.2	7.1	
CoPy min (mm)	High	66.1	2.4	p = .427	66.6	1.9	p = . 806
	Low	69.0	2.5		65.7	3.1	
	Modified	65.2	2.3	p = .185	64.7	2.1	p = .439
	Regular	69.9	2.5		67.6	2.9	
CoPy delta (mm)	High	54.4	4.4	p = .659	60.1	7.5	p = .706
	Low	51.5	4.8		56.2	6.7	
	Modified	50.1	5.0	p = .383	53.7	6.2	p = .386
	Regular	55.8	4.1		62.7	7.7	

4.2.3 Kinetics and time measures

This section contains the results of the kinetics and time measure variables of the go phase.

In the Figure 26 the outside skate's average and maximum vertical forces were all greater than the inside skate (Table 9). The inside skate values were significantly ($p<0.05$) greater for the regular skate in both the average and maximum vertical force variables than the modified skate.

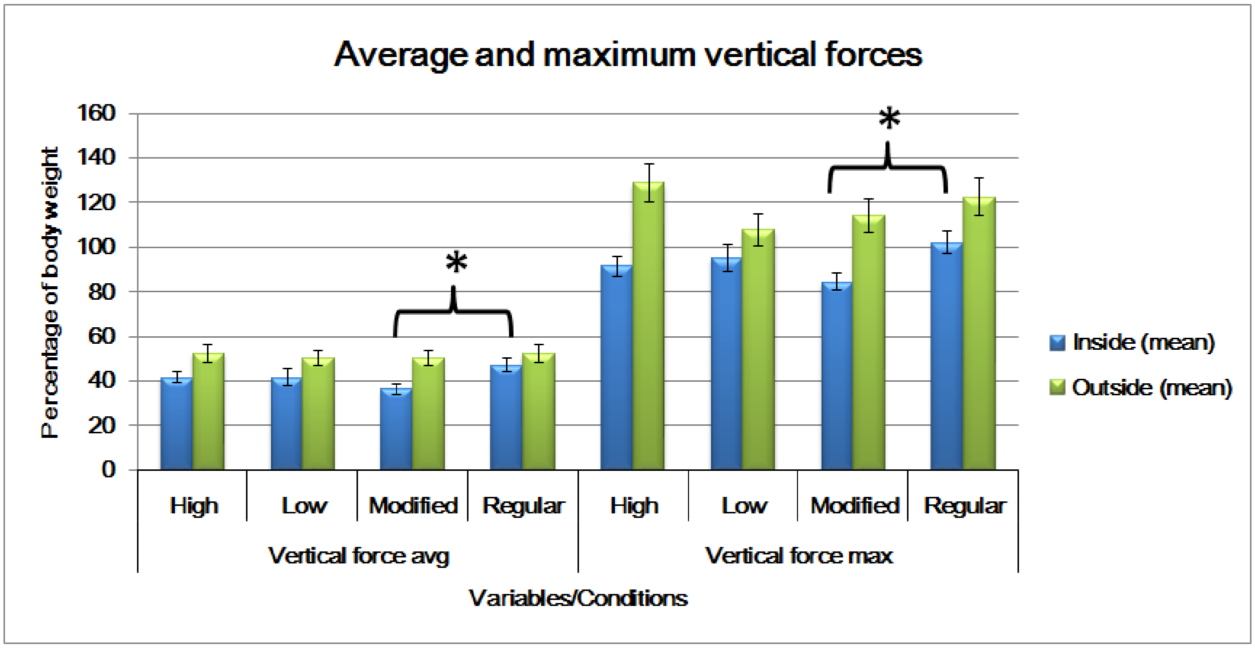

Figure 26: Go phase average and maximum vertical forces.

Similarly to the stop phase, it took less time for the high caliber players to complete the go phase than their respective low caliber counterparts. The high caliber players took significantly ($p<0.05$) less time than the low caliber players. No significant differences were found comparing the go durations between the skate models (Figure 27 and Table 10).

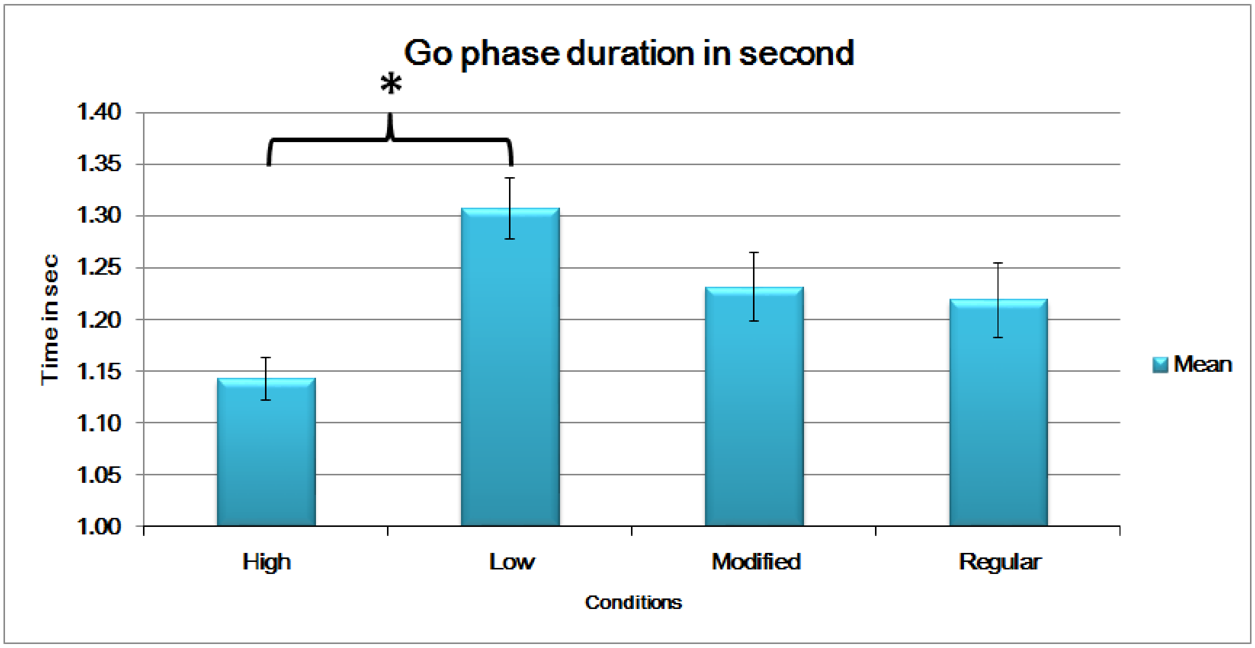

Figure 27: Go phase duration in second.

Although, no significant difference was observed in the impulse during the go phase, we can observe that the inside leg of the regular skate impulse was greater (p=.056) than the modified skate impulse (Figure 28 and Table 9).

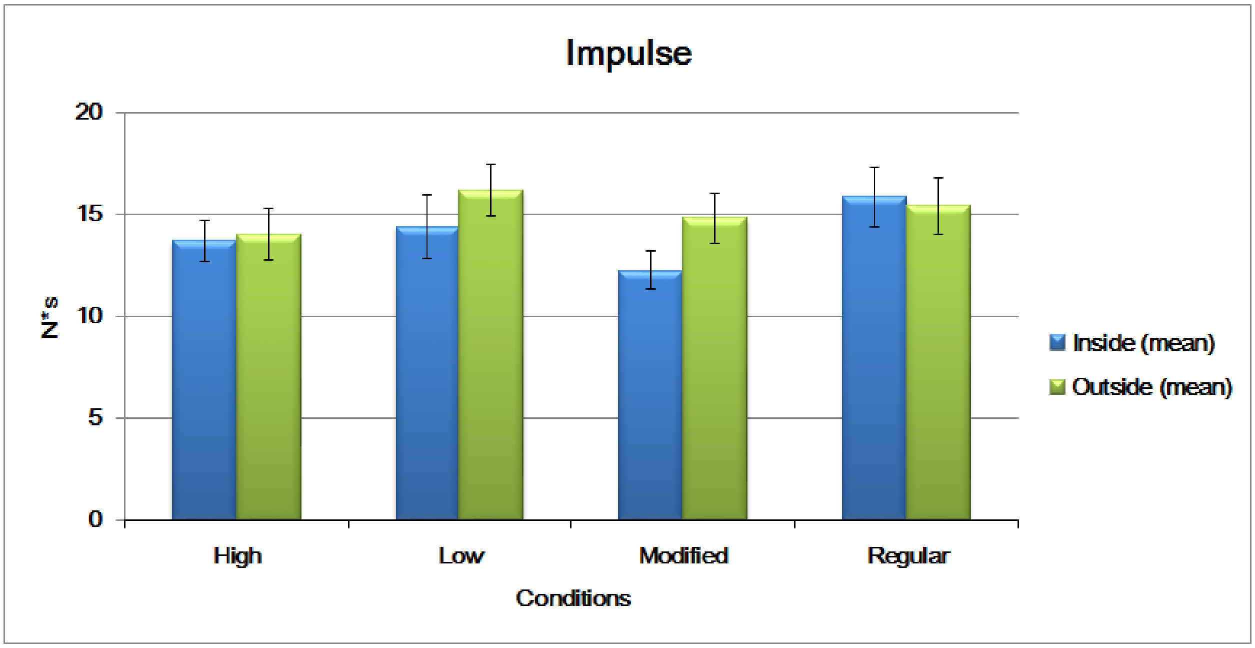

Figure 28: Go phase impulse.

Table 9: Descriptive statistics of the go phase kinetics variables.

Descriptive statistics							
Foot side		Inside			Outside		
Variables	Conditions	Mean	Std. error	p-value	Mean	Std. error	p-value
Vertical force avg (% B.W.)	High	41.5	2.3	p = .984	52.3	4.1	p = .670
	Low	41.6	3.9		49.9	3.3	
	Modified	36.2	2.4	* p = .016	50.2	3.4	p = .737
	Regular	47.0	3.2		52.0	4.1	
Vertical force max (% B.W.)	High	91.4	4.2	p = .576	128.9	8.3	p = .069
	Low	95.1	5.9		107.7	6.9	
	Modified	84.4	3.7	* p = .013	114.1	7.7	p = .461
	Regular	102.1	5.3		122.5	8.5	
Impulse (N*s)	High	13.7	1.0	p = .692	14.0	1.3	p = .254
	Low	14.4	1.6		16.2	1.3	
	Modified	12.3	1.0	p = .056	14.8	1.2	p = .751
	Regular	15.9	1.5		15.4	1.4	

Figure 29 represents the absolute contact time, in seconds, between the skate's blade and the ice surface of the inside skate. This indicates the length of time the inside skate was in the push-off action during the go phase. All the conditions were similar showing no significant differences (Table 10).

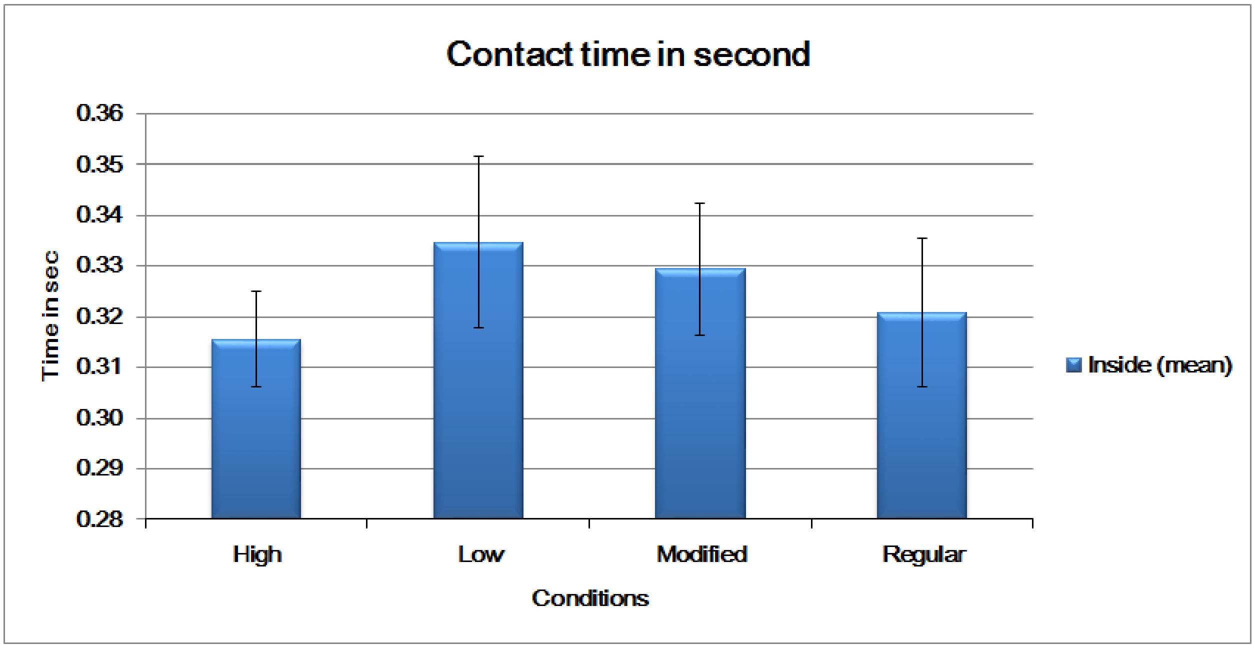

Figure 29: Go phase inside skate contact time.

Figure 30 characterises the time spent in air for the outside skate. This indicates how long the outside skate was in the crossover movement during the go phase. All the conditions were similar showing no significant differences (Table 10).

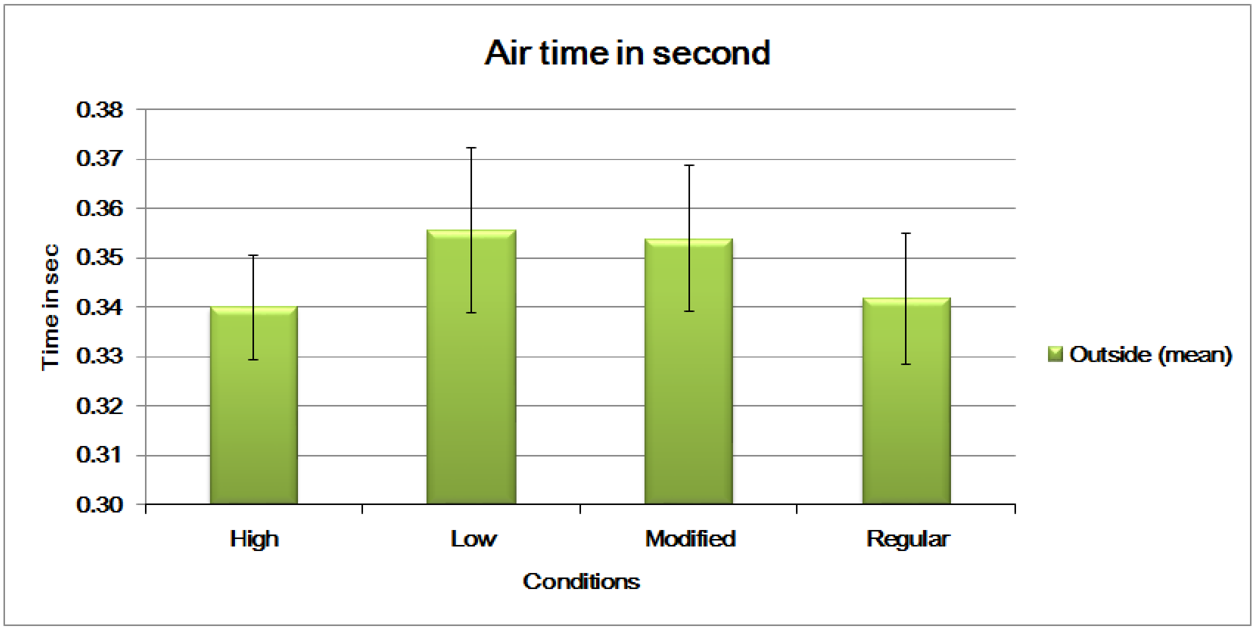

Figure 30: Go phase outside skate air time.

Table 10: Descriptive statistics of the go phase time measure variable.

Descriptive statistics				
Variables	**Conditions**	**Mean**	**Std. error**	**p-value**
Go duration (second)	High	1.14	0.0	* p = .000
	Low	1.31	0.0	
	Modified	1.23	0.0	p = .736
	Regular	1.22	0.0	
Contact time (second)	High	0.32	0.08	p = .347
	Low	0.33	0.09	
	Modified	0.33	0.09	p = .669
	Regular	0.32	0.09	
Air time (second)	High	0.34	0.09	p = .451
	Low	0.36	0.10	
	Modified	0.35	0.09	p = .559
	Regular	0.34	0.09	

Chapter 5: Discussion

To the author's knowledge this is the first study of its kind to directly quantify kinetic measures during an explosive transitional skating task in ice hockey. The experimenter was successful in achieving the purpose of this study by investigating the kinetic measures differences 1) between high and low caliber players and 2) between two different skate designs, a regular skate and a modified skate, during a specific explosive stop and go transitional skating task. The modified skate design was intended to increase the sagittal plane ankle motion due to strategic construction including a more flexible Achilles tendon guard, a more elastic tongue and greater lace compliance due to higher eyelet placement and different polymer material. The explosive transitional task at hand, the stop and go, was expected to create an energy loading phase during the dominant parallel stop (stop phase) which was anticipated to be momentarily translated into an explosive crossover start (go phase). The kinetic profiles of each subsection, i.e. the parallel stop and the first stride (first two steps) of the crossover start of a stop and go skating task were measured individually and then analyzed.

Previous research in long-track speed skating has shown that significant improvements in skating performance could be achieved with improved skate design, allowing for greater blade/ice contact times due to greater plantar-flexion freedom allowed by such a design (De Koning et al., 2000). However, such performance increase results are still lacking in an ice hockey skating setting. Both level of expertise (high and low) and skate models (regular and modified) were compared on the vertical force applied on the ice by the skater through the use of strain gauges, the in-boot center of pressure and the discrete plantar foot pressures through the use of instrumented insoles. This research successfully adopted: 1) The force strain gauge transducer system developed by Stidwill and colleagues (Stidwill et al., 2009) to collect bilateral, simultaneous ground (ice) reaction forces and 2) the plantar foot pressure transducer system developed by Le Ngoc (Le Ngoc, 2013) to collect bilateral, simultaneous plantar foot pressure variables. Clear and unambiguous skate force and plantar pressure measures were obtained with respect to each skate's vertical axis and plantar foot regions during the investigated skating maneuver as defined in Chapter 3 Methods.

The previous outcomes of the stop and go task seen in Chapter 4 Results will be separately discussed in this section by 1) the level of expertise of the skaters recruited (high vs. low caliber) and 2) the skate design (regular vs. modified).

5.1 Stop: Level of expertise differences (high versus low caliber)

When comparing expert (high caliber) and novice (low caliber) performers in a given sport it is expected that greater performance achievements will be observed in the expert cohort than the novice and the establishment of such contrast groups allow for identification of key performance parameters, as seen in the literature for sports such as ice hockey, soccer and in rifle shooters (M. R. Bracko, 2001; Caron et al., 2000; Era et al., 1996; Paillard et al., 2006).

Regardless of the level of expertise of skaters, a global strategy in kinetic execution was observed in most participants throughout the stop phase: the outside skate would sustain the majority of the body weight (B.W.) whereas the inside skate would bear a lot less. The vertical force average difference between the inside and outside (16.1% and 64.5% B.W. respectively) skate of the high caliber players represented a difference of 48.4% B.W. Likewise, the vertical force average values between the inside and outside skates (8.5 % and 55.4% B.W. respectively) of the low caliber players represented a difference of 46.9% B.W. In accordance to these results, Fortier found similar results in his research between the inside and outside skate of ice hockey skaters during a change of direction skating task (Fortier, 2011). These differences clearly indicate, independently of the player skill level, that the outside skate sustained the majority of the B.W. during the execution of the stop phase. Therefore, the results show that the outside skate and the inside skate had two distinct functions with regard to the execution of the parallel stop.

The video logs suggest that during the braking phase of the task that the outside skate was in contact with the ice surface on the inside edge of the skate blade and the skater would achieve this by pronating the foot (pushing on the ice with the hallux) and applying enough force with the inside edge of the skate blade to stop completely. On the other hand, the inside skate applied just enough force on the outside edge of the skate blade to maintain proper balance during the execution of the parallel stop and the skater would achieve this by supinating the foot (pushing on the ice with the fifth toe). In almost all cases the skaters lifted the inside skate from the ice prior to applying the necessary vertical force to the outside skate to initiate the stop phase. The inside limb may perhaps play a more important role, in maintaining the stability of the skater while performing a parallel stop, than the outside limb which main role is to apply enough force to enable the skater to stop.

Regarding the stability strategies between the high and low caliber the results show that the high caliber players tend to lean more on their heel than the low caliber players. Inversely, the CoP excursion in the antero-posterior direction also indicated that the low caliber players were more prone to an anterior lean as their CoP excursion values were more anterior to the heel than the high caliber players. Perhaps, the low caliber players, in order to maintain balance, have to lean more on their toes compared to high caliber players who lean more on their heels. This suggests that the low caliber players exerted anticipatory postural adjustments, prior to voluntary limb movement, in order to maintain postural stability thus compensating for destabilising forces associated with the braking movement. Related to the literature, one of the most important biomechanical constraints on balance control involves controlling the body Center of Mass (CoM) with respect to its base of support. The main types of movement strategies normally used to return the body to equilibrium involve keeping the feet in place with a small amount of sway to maintain balance. A sway can either be performed at the level of the ankles or at the levels of the hips in order to quickly move the body CoM (Horak, 2006).

A full body kinematic analysis could help to identify the specific postural control strategies adopted by the high and low caliber players during the stop and go skating task. Also noticeable from the average forces within each plantar foot region was the greater plantar foot pressure under the outside skate. This likely represents a weight transfer, from the inside to the outside skate, a strategy explaining the much higher force applied by the outside skate. This suggests that the main benefit of this weight transfer for the skater is to be able to apply enough force with the outside skate to execute the parallel stop. Similar to the above results, a study observing the forces while performing a similar parallel stop displayed the forces carried out by the foot of the outside skate to be larger than the forces carried by the foot of the inside skate (Fortier, 2011). During the stop phase the main stopping skate was the outside skate as seen with the greater amount of vertical forces and plantar foot pressures found for the outside skate in comparison to the inside skate values.

As seen in the literature (M. R. Bracko, 2001), the high caliber players showed greater kinetic outcomes compared to the low caliber players. The high caliber players applied significantly ($p<0.05$) more average vertical force (9%) with the main stopping skate, the outside skate, than the low caliber players. Without reaching significance at the 0.05 alpha level set ($p = .051$) the high caliber players applied more average vertical force (7.6%) with the inside skate than the low caliber players. Additionally, it took significantly ($p<0.05$) less time (0.18 seconds) for the high caliber players to complete the stop phase than the low caliber skaters. These results suggest that the high caliber players were skating into the stop phase with greater velocities, thus generating more average vertical forces throughout the stop phase and resulting in a shorter period of time to execute the stop phase. The reason the impulse variable was not significantly ($p>0.05$) different between the level of expertise might be explained by the fact that the impulse variable was calculated as the product of the average vertical force and the stop phase duration. As the low caliber players took significantly more time to execute the stop phase, the impulse values were similar to those seen in the high caliber players group.

As seen in the literature (Caron et al., 2000; Era et al., 1996; Paillard et al., 2006), the CoP excursion is a valid method to assess balance during physical activity and larger CoP excursions would represent poor postural stability performance. Paillard and colleagues assessed postural performance and strategy of soccer players by measuring their CoP excursion during a specific kicking task characteristic of soccer. They found that the elite players exhibited lower CoP excursion than their novice counterparts (Paillard et al., 2006). Another study discriminating top-level and recreational rifle shooters found similar results (Era et al., 1996). Thus, it was expected that there would be greater CoP excursions in the low caliber players during both the stop and go phases. Looking at the medio-lateral delta CoP excursion (ΔCoPx), no significant differences ($p>0.05$) were found between the player calibers. The magnitude of the ΔCoPx between the high and low caliber for the inside and outside skates was between 2.1 and 3.3 mm.

A typical ice hockey skate blade has a uniform thickness of approximately 3.2 mm (Federolf, Mills, & Nigg, 2008). This suggests that the foot and the skate boot are acting as an unique system that balance out on top of the blade and that very little movement of the center of pressure in the medio-lateral axis is needed in order to maintain balance during the stop and go phase.

When looking at the average forces within each plantar foot region, it is interesting to notice that the high caliber players displayed significantly ($p<0.05$) higher values in both the inside and outside skates at the heel region then the low caliber players. Additionally, without reaching statistical significance ($p>0.05$) the average forces at the toe region for the outside skate were slightly greater for the low caliber players than the high caliber players (3.5 vs. 3.4 N respectively). It is interesting to note that the toe region was the only foot region where the low caliber players showed greater plantar foot pressures than the high caliber players. This suggests that in order to maintain proper balance the high caliber players were able to shift their center of mass (CoM) closer to the heel regions than the low caliber players. In contrast, the low caliber players maintained their CoM more anteriorly in order to maintain their balance compared to the high caliber players.

These results are in consistent with the outcomes found with the antero-posterior center of pressure (CoPy) variables. When looking at the CoPy variables the low caliber players maintained their CoP more anteriorly during the stop phase than the high caliber players. This is supported by the $CoPy_{max}$ variable of the outside skate being significantly

($p<0.05$) higher by 1.1 cm for the low caliber players than the high caliber players. With the posterior values ($CoPy_{min}$) being similar between the high and low caliber players it suggests that the significant differences ($p<0.05$) found for both the inside and outside skate by the resultant center of pressure excursion variable ($\Delta CoPy$) resulted from a more anterior than posterior shifting of the CoP. Similar results were found with soccer players and riffle shooters regarding their CoP excursions during specific tasks related to their respective sport. The specific tasks were selected in order to assess the athlete's postural stability. (Era et al., 1996; Paillard et al., 2006).

The kinetic differences found during the stop phase suggest that the skaters will express postural balance strategies in accordance with their level of play in order to complete the task inside their own skill boundaries. The fact that the high caliber players were able on average to apply more vertical force with their outside skate during the stop phase had functional implications as perhaps maintaining proper balance in a more efficient way with a strategic lower limb placement resulting in a significantly higher ($p<0.05$) time completion for the low caliber skaters regarding the stop phase compared to the high caliber skaters. The results suggest that the low caliber players have different postural strategies than the high caliber players resulting from different postural positions. Once again related to the video logs and the results the low caliber players lean more forward over their toes to maintain equilibrium. On the other hand, the high caliber players tend to lean more backward on their heel to maintain stability. The different postural positions of the low caliber skaters versus the high caliber skaters during the stop phase could have direct impact regarding the stability and postural balance of the go phase that could in turn have an influence on the performance.

5.2 Go: Level of expertise differences (high versus low caliber)

Ice hockey is characterized by high-intensity intermittent skating and rapid changes in direction and velocity with frequent body contact (Montgomery et al., 2004). Among the important criteria of power skating in hockey is the ability to accelerate quickly. Of paramount importance is the ability to accelerate from a standing start or from a state of minimal velocity to a relatively high velocity in a short period of time (Marino, 1983). Related to the early literature, four different starting styles are used by hockey players during a hockey game: Front start, side start, side start crossover, and running start (Thiffault, 1969). Roy and colleagues investigated the biomechanical features of different starting positions and skating strides. Both kinetic and kinematic data were collected through the use of force platforms and cinematography. Results indicated that the crossover and front starts were superior to the running start and side start for generating a high magnitude of impulse during the start (Roy, 1978).

In the present study the stop phase was instantaneously followed by the performance of a crossover start called the go phase. Regarding the importance and the number of occurrence of transitions in ice hockey the analysis of the go phase was imperative. The go phase was initiated by the push-off action of the inside skate, the first portion of the go phase coincided with the end of the stop phase as a rapid transition of the stop and go task from stop to go. After executing the stop phase the two skate blades were found to be quasi-parallel to the identified stopping line. As described in the literature (Naud & Hold, 1979), the go transition involved the crossing of the outside foot in front of the inside foot (crossover stride) then rotating the body 90^0 and skating forward as quickly as possible toward the initial start point. While the outside skate is crossing over the inside skate, the inside skate is performing a quick push-off action potentially to transfer the subject's weight from the outside to the inside skate. At the end of that quick propulsion the inside skate leaves the ice as well. Then for a short period of time both the inside and outside skates are off the ice at the same time creating a jumping action, suspending the body in the air for a short period of time, which was defined as the air time variable.

The results suggest that during the crossover action of the go phase a weight transfer from the outside skate to the inside skate was occurring. During the go phase the results indicate the increased amount of plantar foot pressure in the inside skate with concurrent decrease of plantar foot pressure in the outside skate. Thus, this suggests that the skaters transferred their weight from the outside skate to the inside skate in order to perform the crossover start. Similar to the stop phase results, most of the plantar foot pressure was found under the heel region for both the high and low caliber players. However, as expected, the high caliber players displayed significantly greater plantar foot pressure values ($p<0.05$) than the low caliber players. The significant differences observed between skill levels in plantar foot pressure did not however result in a significant increase in the vertical force or impulse variables for the high caliber skaters when compared to the low caliber skaters. However, the low caliber players showed a significantly ($p<0.05$) higher time to completion for the go phase than the high caliber players (1.31 vs. 1.14 seconds, respectively). This performance difference could be explained by a faster and more efficient transition in the high caliber players following the crossover portion of the go phase or, alternatively, could simply be the result of differences in postural balance strategies seen during the stop phase. The postural strategy of the high caliber skaters during the stop phase has functional implications such as a more suitable lower limb position for a more efficient execution of the crossover (i.e. less time) during the go phase and this is one index of better task performance in the high caliber players. The latter, illustrates the importance of a fluid transition between the stop and go phase of the investigated task in this study. A complete kinematic analysis is warranted in order to better understand the kinematics differences between different skill level hockey players during a transitional crossover start.

Center of Pressure data also indicate that the low caliber players had a significantly ($p<0.05$) higher $\Delta CoPx$ excursion for the outside skate than the high caliber players. As seen in the literature (M. R. Bracko, 2001), this suggests that the low caliber players were not as stable as the high caliber skaters while entering the go phase from the stop phase and could result from a loss of balance or a different postural strategy such as a more leaning forward position over their toes during the stop phase and had repercussion over the go phase as well. Unfortunately, although the kinetic results do suggest that the players had differing kinematics and postural strategies during the execution of the task, it is only possible to speculate on the postural/kinematic differences between skill levels since kinematic analysis was not conducted in this study.

5.3 Stop: Skate design differences (regular versus modified)

In this study, a regular ice hockey skate (One95 Bauer) was compared to a modified ice hockey skate of the same model. The modified skate design was intended to increase the sagittal plane ankle range of motion (ROM) with greater dorsi/plantar flexion (overall ROM of ~25^{o}) (Robert-Lachaine et al., 2012) due to strategic construction including a more flexible Achilles tendon guard, more elastic tongue and greater lace compliance due to higher eyelet placement and different polymer material. Despite the fact that previous studies have found significant differences regarding the ankle ROM in the sagittal plane between the two skate models, as of today no significance differences related to the on ice performance between the regular and the modified ice hockey skates have been found (Culhane, 2013; Fortier, 2011; Le Ngoc, 2013; Robert-Lachaine et al., 2012). To the author’s knowledge, the on-ice performance analyzed during this research between the regular and the modified skates during an explosive transition skating task was novel.

With regard to the average forces applied to each plantar foot regions, no significant differences were found comparing the two different skate models. Similar to the results between the skill levels, for both skate models, most of the plantar foot pressure was found under the heel region during the stop phase for both the inside and outside skate. Most of the plantar foot pressure was found on the outside skate. Furthermore, the same strategy in kinetic execution throughout the stop phase was apparent in both skates; the outside skate sustained the majority of the body weight (B.W.) whereas the inside skate would bear much less of the B.W. for both skate models tested, as seen in previous related studies of change of direction in ice hockey (Fortier, 2011) and 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, Scott, Kagawa, & Osada, 2008). The results showed that the skaters when wearing the regular skate model produced significantly ($p<0.05$) greater maximum vertical forces for the inside and outside skates by 12.9% and 22.2% respectively when compared to the modified skate. Also the players when skating with the regular skate model produced significantly ($p<0.05$) greater average vertical force for the outside skate (17% higher) when compared to the modified skate. No significant differences were found between the skate models regarding the center of pressure for both axes. The similarity between the skate models regarding the CoP excursions suggest that the postural strategies were not affected by the skate model worn. Moreover, no significant differences were found regarding the duration of the stop phase.

Thus no apparent kinetic performance advantages were found between the two skate models for the parallel stop. Perhaps, the modifications brought to the skate design of the modified skate did not modified the biomechanics of the skaters during the execution of the parallel stop. However, a kinematic study of the lower limb and upper body combined with kinetic values will be required to truly evaluate the performance differences between the two skate models during a specific skating task such as a parallel stop.

5.4 Go: Skate design differences (regular versus modified)

During the go phase no performance benefit was observed with regard to the time completion of the go phase comparing the regular skate to the modified skate model. However, the vertical maximum and average force values were both significantly ($p<0.05$) higher for the regular inside skate than the modified inside skate by 17% and 11%, respectively. From the video logs we were able to observe that the foot underwent plantar flexion during the push-off or propulsion of the inside skate. In a previous study it was shown that the modified skate's flexible tendon guard allows an overall greater range of motion at the ankle joint, particularly allowing greater plantar flexion than afforded by the regular skate's rigid tendon guard (Robert-Lachaine et al., 2012). Another study found that the design modification likewise altered the manner in which the foot and lower limb interfaced with the boot to create the necessary leverage to actively move the skate boot (D.J Pearsall et al., 2012). These two findings taken together may explain why higher vertical forces were found for the inside skate of the regular model. Interestingly, even though the skaters created more vertical force with the regular skate model than with the modified skate model, the go phase duration variable was the same for the two skate models. Logically, greater force generation in the regular skate would have been thought to show a faster time to task completion than the modified skate if they produced more force. However, the results are suggest that the modified skate may not require as great a force production as the regular skate to complete the task as quickly. The results of this study combined with previous results found in previous studies from the same laboratory (D.J Pearsall et al., 2012; Robert-Lachaine et al., 2012) suggest that the higher vertical force values found for the regular inside skate during the go phase might be due to a greater leveraging effect in the regular skate, due to pushing with the lower limb against the rigid tendon guard creating a level arm and thus generating greater vertical force values. Furthermore, when analyzing the pressure within each plantar foot region we notice that the modified skate model had significantly ($p<0.05$) higher pressure at the heel foot region for the inside skate than the regular skate. Thus, these results are highly suggestive of a different method of force application in the skate models. Once again, it would appear that full body kinematic analysis would help determine more clearly the differences in behavior in the two different skate models.

5.5 Future directions

The above findings provide a comprehensive understanding of the mechanics of this explosive transitional task that is relevant to athletic skill development. In addition, the ability to distinguish mechanical performance differences between the different skate models and between skill levels tested in this study, further demonstrates the potential of direct force and pressure measurements as a sensitive means to distinguish distinct push and slide properties fundamental to skating performance. These insights may assist sporting goods manufacturers, like Bauer Hockey, with material, design and construction innovations to improve product performance and also to develop new skates that will improve the performance of the players during real game situations and have a direct impact on the game. As well as helping coaches and athletes to better understand the unique and diverse mechanics of ice skating in hockey, especially during explosive transitional skating maneuvers like the stop and go. Perhaps, in modifying the coaching approaches to the youth for a superior development of the skating technique. There is still information that is missing in order to get a more complete picture. In addition to these findings, it would be interesting to be able to measure pressure in all the areas around the foot, including the back of the foot and at the top of the foot.

The results of this study may provide insights that could help athletes, coaches and hockey manufactures better understand the mechanics of ice skating. However, in order to truly determine the skill level's benefit and exact changes in the skater's technique during a stop and go skating task, a kinematic study of the lower limb and upper body combined with kinetic values will be required.

5.6 Conclusion

It was shown that the modifications on the modified skate did not have an impact on the center of pressure during both phases of the stop and go skating task. It was expected that there would be similarities between the skate models regarding the medio-lateral center of pressure as seen in previous study (Le Ngoc, 2013). The results regarding the antero-posterior center of pressure excursion did not show a reduction as was anticipated. However, although not significantly different ($p>0.05$) the results were in accordance with the hypothesis that the modified skate model would show a reduction in total antero-posterior center of pressure excursion when compared to the regular skate model, characterized by a smaller displacement towards the anterior part of the skate during both the stop and go phase.

It was demonstrated that the modifications on the modified skate did not have an impact on the generation of vertical force by the inside skate during the go phase. The modified inside skate showed a decrease in the vertical force when compared to the regular inside skate.

It was shown that in overall the level of expertise did not have an impact on the center of pressure during the stop phase in the medio-lateral direction and during the go phase in the antero-posterior direction. During the stop phase the high caliber players showed a reduction in total antero-posterior center of pressure excursion, characterized by smaller displacement towards the anterior part of the skate. Also, during the go phase the high caliber players showed a reduction in total medio-lateral center of pressure excursion. These center of pressure excursion reductions illustrate that the high caliber players produced the best postural performances during the stop phase in the antero-posterior direction and during the go phase in the medio-lateral direction. The results suggest that the skaters used different postural control strategies for each portion of the stop and go phases of the stop and go skating task. This also illustrates the specificity of each portion of the task. Thus, it seems that high caliber players' postural control was better than the low caliber players during each phase of the stop and go task.

As anticipated, the high caliber players showed greater vertical average force values for the main stopping skate, the outside skate, during the stop phase. The high caliber players also had a lower time completion for the stop phase. However, during the go phase high caliber players had a lower time completion without showing any vertical forces or impulse performance advantages. The results show that skill level influences the skater's center of pressure and postural control strategies.

From the above results, this study has shown that the use of a portable strain-gauge force transducer system and foot pressure transducer system can be used to evaluate on-ice explosive transitional maneuvers, like a stop and go, in ice hockey. Clear postural control and kinetic strategies were noted during the task. The center of pressure and postural control strategies seen during the execution of an explosive transitional skating task were similar to other sports such as alpine skiing, soccer and rifle shooting. These findings deliver a comprehensive understanding of the mechanics of the explosive transitional stop and go skating task that is relevant to athletic skill development. Additionally, the capacity to discriminate mechanical performance variances between the two player calibers and the two skate models tested, further establishes the potential of direct force and pressure measurements as sensitive metrics to differentiate subtle glide and traction properties essential to skating performance. Upcoming studies utilizing these measurement technologies with the combination of kinematic measurements to more fully explore the many other skill combinations is necessary.

References Literature Cited

Abdul Razak, A. H., Zayegh, A., Begg, R. K., & Wahab, Y. (2012). Foot Plantar Pressure Measurement System: A Review. *Sensors, 12*(7), 9884-9912.

Abernethy, B., Maxwell, J. P., Masters, R. S., van der Kamp, J., & Jackson, R. C. (2007). Attentional processes in skill learning and expert performance. *Handbook of sport psychology, 3*, 245-263.

Allard, F., & Starkes, J. L. (1991). Motor-skill experts in sports, dance, and other domains. *Toward a general theory of expertise: Prospects and limits*, 126-152.

Arnold, B. L., & Schmitz, R. J. (1998). Examination of balance measures produced by the Biodex Stability System. *Journal of Athletic Training, 33*(4), 323.

Baig, Z. A. (2011). *Functional Mechanical Assessment of Foot and Ankle Stiffness and Work Production in Ice Hockey Skate Boots.* Masters thesis, McGill University, Montréal, Québec, Canada.

Biasca, N., Simmen, H., Bartolozzi, A., & Trentz, O. (1995). Review of typical ice hockey injuries. Survey of the North American NHL and Hockey Canada versus European leagues. *Der Unfallchirurg, 98*(5), 283.

Boutcher, S. (1992). Attention and athletic performance: An integrated approach. *Advances in sport psychology*, 251-265.

Bracko, M. R. (2001). On-ice performance characteristics of elite and non-elite women's ice hockey players. *The Journal of Strength & Conditioning Research, 15*(1), 42-47.

Bracko, M. R. (2004). Biomechanics powers ice hockey performance.

Caron, O., Gelat, T., Rougier, P., & Blanchi, J. (2000). A comparative analysis of the center of gravity and center of pressure trajectory path lengths in standing posture: an estimation of active stiffness. *Journal of Applied Biomechanics, 16*(3), 234.

Cavanagh, P. R., Hewitt, F., & Perry, J. (1992). In-shoe plantar pressure measurement: a review. *The foot, 2*(4), 185-194.

Chase, W. G., & Simon, H. A. (1973). The mind's eye in chess.

Chesnin, K. J., Selby-Silverstein, L., & Besser, M. P. (2000). Comparison of an in-shoe pressure measurement device to a force plate: concurrent validity of center of pressure measurements. *Gait & posture, 12*(2), 128-133.

Culhane, L. (2013). *Acceleration characteristics of forward skating.* Masters thesis, McGill university, Montréal, Québec, Canada.

Davlin, C. D. (2004). DYNAMIC BALANCE IN HIGH LEVEL ATHLETES 1. *Percept Mot Skills, 98*(3c), 1171-1176.

De Boer, R., Cabri, J., Vaes, W., Clarijs, J., Hollander, A., De Groot, G., & van Ingen Schenau, G. (1987). Moments of force, power and muscle coordination in speed-skating. *Int J Sports Med, 8*(6), 371-378.

De Boer, R., Schermerhorn, P., Gademan, J., De Groot, G., & van Ingen Schenau, G. (1986). Characteristic stroke mechanics of elite and trained male speed skaters. *Int. J. Sports Biomech, 2*, 175-186.

De Cock, A., Vanrenterghem, J., Willems, T., Witvrouw, E., & De Clercq, D. (2008). The trajectory of the centre of pressure during barefoot running as a potential measure for foot function. *Gait & posture, 27*(4), 669-675.

De Groot, A. (1978). Thought and choice in chess (Revised translation of De Groot, 1946. *The Hague: Mouton Publishers*.

De Koning, J. J., De Groot, G., & Van Ingen Schenau, G. J. (1992). Ice friction during speed skating. *Journal of Biomechanics, 25*(6), 565-571. doi: 10.1016/0021-9290(92)90099-m

De Koning, J. J., Houdijk, H., De Groot, G., & Bobbert, M. F. (2000). From biomechanical theory to application in top sports: The Klapskate story. *Journal of Biomechanics, 33*(10), 1225-1229. doi: 10.1016/s0021-9290(00)00063-4

De Koning, J. J., Thomas, R., Berger, M., De Groot, G., & Van Ingen Schenau, G. J. (1995). The start in speed skating: From running to gliding. *Medicine and Science in Sports and Exercise, 27*(12), 1703-1708.

Dewan, C., Pearsall, D., & Turcotte, R. (2004). *Dynamic pressure measurement about the foot and ankle*.

Eils, E., Streyl, M., Linnenbecker, S., Thorwesten, L., Völker, K., & Rosenbaum, D. (2004). Characteristic plantar pressure distribution patterns during soccer-specific movements. *The American Journal of Sports Medicine, 32*(1), 140-145.

Era, P., Konttinen, N., Mehto, P., Saarela, P., & Lyytinen, H. (1996). Postural stability and skilled performance—a study on top-level and naive rifle shooters. *Journal of Biomechanics, 29*(3), 301-306.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological review, 100*(3), 363.

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual review of psychology, 47*(1), 273-305.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods, 39*(2), 175-191.

Federolf, P. A., Mills, R., & Nigg, B. (2008). Ice friction of flared ice hockey skate blades. *Journal of Sports Sciences, 26*(11), 1201-1208.

Formenti, F., & Minetti, A. E. (2007). Human locomotion on ice: the evolution of ice-skating energetics through history. *Journal of Experimental Biology, 210*(10), 1825-1833.

Formenti, F., & Minetti, A. E. (2008). The first humans travelling on ice: an energy-saving strategy? *Biological Journal of the Linnean Society, 93*(1), 1-7.

Fortier, A. (2011). *Skating Mechanics of Change of Direction Maneuvers in Hockey Players.* Masters thesis, McGill University, Montréal, Québec, Canada.

French, K. E., Spurgeon, J. H., & Nevett, M. E. (1995). Expert-novice differences in cognitive and skill execution components of youth baseball performance. *Research Quarterly for Exercise and Sport, 66*(3), 194-201.

French, K. E., & Thomas, J. R. (1987). The relation of knowledge development to children's basketball performance. *Journal of sport psychology*.

Galton, F. (1869). *Hereditary genius*: Macmillan and Company.

Goodman, N. (1882). *Handbook of fen skating, by N. and A. Goodman*. London: Low, Marston, Scarle and Rivington

Guthrie, E. R. (1952). The psychology of learning (Rev.

Helsen, W., & Pauwels, J. (1993). A cognitive approach to skilled performance and perception in sport.

Hockey, B. (2012). Annual Report Retrieved November 2012, 2012, from http://phx.corporate-ir.net/phoenix.zhtml?c=242945&p=irol-reportsAnnual

Holyoak, K. J. (1991). Symbolic connectionism: toward third-generation theories of expertise. *Toward a general theory of expertise: Prospects and limits*, 301.

Horak, F. B. (2006). Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age and ageing, 35*(suppl 2), ii7-ii11.

Hoshizaki, T., Kirchner, G., & Hall, K. (1989). Kinematic analysis of the talocrural and subtalar joints during the hockey skating stride. *Safety in ice hockey, Philadelphia: ASTM*, 141-149.

Houdijk, H., De Koning, J. J., De Groot, G., Bobbert, M. F., & Van Ingen Schenau, G. J. (2000). Push-off mechanics in speed skating with conventional skates and klapskates. *Medicine and Science in Sports and Exercise, 32*(3), 635-641.

Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports Medicine, 41*(3), 221-232.

IIHF. (2012). International Ice Hockey Federation Retrieved 2012, 2012, from http://www.iihf.com/iihf-home/home.html

Janelle, C. M., & Hillman, C. H. (2003). Expert Performance in Sport. *Expert performance in sports: Advances in research on sport expertise*, 19-47.

Jobse, H., Schuurhof, R., Cserep, F., Schreurs, A., & De Koning, J. (1990). Measurement of push-off force and ice friction during speed skating. *Int. J. Sport Biomech, 6*, 92-100.

Keller, T., Weisberger, A., Ray, J., Hasan, S., Shiavi, R., & Spengler, D. (1996). Relationship between vertical ground reaction force and speed during walking, slow jogging, and running. *Clinical Biomechanics, 11*(5), 253-259.

Lafontaine, D. (2007). Three-dimensional kinematics of the knee and ankle joints for three consecutive push-offs during ice hockey skating starts. *Sports Biomechanics, 6*(3), 391-406.

Lamontagne, M., Gagnon, M., & Doré, R. (1983). Development, evaluation and application of a dynamometric system of skates. *Canadian journal of applied sport sciences. Journal canadien des sciences appliquées au sport, 8*(3), 169.

Le Ngoc, C. (2013). *Force and center of pressure measurements during forward ice hockey skating with a regular hockey skate and a modified hockey skate.* Masters thesis, McGill University, Montréal, Québec, Canada.

Marino. (1983). Selected mechanical factors associated with acceleration in ice skating. *54*, 234.

Marino, G., & Weese, R. (1979). *A kinematic analysis of the ice skating stride*.

Marino, G. W. (1977). Kinematics of Ice Skating at Different Velocities. *Research quarterly, 48*(1), 93-97.

Marino, G. W. (1979). Acceleration-time relationships in an ice skating start. *Research quarterly, 50*(1), 55-59.

Marteniuk, R. G. (1976). *Information processing in motor skills*: Holt, Rinehart and Winston New York.

McCrory, P. (2003). Super athletes or gene cheats? *British journal of sports medicine, 37*(3), 192-193.

McKinley, M. (2006). *Ice Time: The Story of Hockey*: Tundra Books.

McPherson, S. L. (1999). Tactical differences in problem representations and solutions in collegiate varsity and beginner female tennis players. *Research Quarterly for Exercise and Sport, 70*(4), 369-384.

McPherson, S. L. (2000). Expert-novice differences in planning strategies during collegiate singles tennis competition. *Journal of Sport & Exercise Psychology*.

Minetti, A. E. (2004). Passive tools for enhancing muscle-driven motion and locomotion. *Journal of Experimental Biology, 207*(8), 1265-1272.

Montgomery, D. L., Nobes, K., Pearsall, D. J., & Turcotte, R. A. (2004). Task analysis (hitting, shooting, passing and skating) of professional hockey players. *ASTM SPECIAL TECHNICAL PUBLICATION*, 288-296.

Naud, R. L., & Hold, L. (1979). A comparison of selected hockey skating starts. *Canadian journal of applied sport sciences. Journal canadien des sciences appliquées au sport, 4*(1), 8.

Paillard, T., Noe, F., Riviere, T., Marion, V., Montoya, R., & Dupui, P. (2006). Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *Journal of Athletic Training, 41*(2), 172.

Pearsall, D., Turcotte, R., & Murphy, S. (2000). Biomechanics of ice hockey. *Exercise and sport science, 1*, 675–692.

Pearsall, D. J., Paquette, Y. M., Baig, Z., Albrecht, J., & Turcotte, R. A. (2012). Ice hockey skate boot mechanics: Direct torque and contact pressure measures. *Procedia Engineering, 34*, 295-300.

Pearsall, D. J., & Turcotte, R. A. (2007). Design and Materials in Ice Hockey *Materials In Sports Equipment* (Vol. 2, pp. 203-224). Cambridge England: Woodhead Publishing Ltd.

Pearsall, D. J., Turcotte, R. A., Lefebvre, R., Bateni, H., Nicolaou, M., Montgomery, D. L., & Chang, R. (2001). *Kinematics of the foot and ankle during forward ice hockey skating.* Paper presented at the Proceedings from XIX international symposium on biomechanics in sports. San Francisco, USA, ISBS.

Pearsall, D. J., Turcotte, R. A., & Murphy, S. D. (2000). Biomechanics of ice hockey. *Exercise and sport science, 1*, 675–692.

Queen, R. M., Haynes, B. B., Hardaker, W. M., & Garrett, W. E. (2007). Forefoot loading during 3 athletic tasks. *The American Journal of Sports Medicine, 35*(4), 630-636.

Robert-Lachaine, X., Turcotte, R. A., Dixon, P. C., & Pearsall, D. J. (2012). Impact of hockey skate design on ankle motion and force production. *Sports Engineering, 15*(4), 1-10. doi: 10.1007/s12283-012-0103-x

Rosenbaum, D., & Becker, H. P. (1997). Plantar pressure distribution measurements. Technical background and clinical applications. *Foot and Ankle Surgery, 3*(1), 1-14.

Roy, B. (1978). *Biomechanical features of different starting positions and skating strides in ice hockey.* Paper presented at the Biomechanics VI: proceedings of the Sixth International Congress of Biomechanics, Copenhagen, Denmark.

Starkes, J., & Allard, F. (1993). *Cognitive issues in motor expertise* (Vol. 102): Access Online via Elsevier.

Stidwill, T. J., Turcotte, R. A., Dixon, P., & Pearsall, D. J. (2009). Force transducer system for measurement of ice hockey skating force. *Sports Engineering, 12*(2), 63-68.

Thiffault, C. (1969). *A comparative study of ice hockey starts with the puck under control.* Springfield College.

Upjohn, T., Turcotte, R., Pearsall, D. J., & Loh, J. (2008). Three-dimensional kinematics of the lower limbs during forward ice hockey skating. *Sports Biomechanics, 7*(2), 206-221.

Van Ingen Schenau, G. J., De Boer, R. W., & De Groot, G. . (1989). Biomechanics of speed skating. *Biomechanics of Sport*, 121-167.

Van Ingen Schenau, G. J., De Groot, G., & De Boer, R. W. (1985). The control of speed in elite female speed skaters. *Journal of Biomechanics, 18*(2), 91-96.

Van Ingen Schenau, G. J., De Groot, G., Wim Scheurs, A., Meester, H., & De Koning, J. J. (1996). A new skate allowing powerful plantar flexions improves performance. *Medicine and Science in Sports and Exercise, 28*(4), 531-535.

Versluis, C. (2005). Innovations on thin ice. *Technovation, 25*(10), 1183-1192.

Wallman, J. (1994). Nature and nurture of myopia.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport*: Taylor & Francis.

Winter, D. A. (2009). *Biomechanics and motor control of human movement*: John Wiley & Sons Inc.

Yarrow, K., Brown, P., & Krakauer, J. W. (2009). Inside the brain of an elite athlete: the neural processes that support high achievement in sports. *Nature Reviews Neuroscience, 10*(8), 585-596.

Yoneyama, T., Scott, N., Kagawa, H., & Osada, K. (2008). Ski deflection measurement during skiing and estimation of ski direction and edge angle. *Sports Engineering, 11*(1), 3-13.

Appendix I

McGill

Department of Kinesiology and Physical Education
McGill University
475 Pine Avenue West
Montreal, Quebec H2W 1S4

Département de kinésiologie et d'éducation physique
Université McGill
475 avenue des Pins Ouest
Montréal, Québec H2W 1S4

Tel./Tél.: (514) 398-4184 x0583
Fax/Télécopieur (514) 398-4186

INFORMATION AND CONSENT DOCUMENT

Investigator: Samuel Forget, M.Sc. candidate
David J. Pearsall, Associate Professor, Ph.D.
René Turcotte, Associate Professor, Ph.D.
Biomechanics, Ice Hockey Research Group, 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 investigators. This research project will be performed at the McConnell Arena, located at 3883 University Street, Montreal, Québec, H2W 1S4. You are asked to come to one experimental session that will each last up to 1-2 hours. We greatly appreciate your interest in our work.

Purpose of the Study

The purpose of this study is to analyze and quantify kinetic variables in ice hockey specific skating tasks. A comparison will be made between a Regular hockey skate (Bauer One95) and a prototype skate known as the DROM (highly modified Bauer One95 without a tendon guard leaving an opened space in the back of the skate). The study aims to measure the plantar center of pressure, the total force generated at the skate during on-ice skating tasks. The results of this study will lead to a better understanding of the movements and forces generated at the skate during ice hockey skating. Coaching ameliorations for technique, further development in hockey equipment for injury prevention as well as providing hockey players an alternative selection in terms of skate design depending on their skating style can be provided from the results we will gather in this study.

Your participation in this study involves:

1. Providing informed consent prior to the experimental session.
2. You will be asked to perform a specific skating task using two different pairs of Bauer One95 hockey skates. The procedure listed below explains the experimental session:
   a. You will be outfitted with a hockey helmet (Nike-Bauer 8500, sized accordingly), hockey skates (Nike-Bauer One95 and prototype model, sized accordingly) and hockey stick.

b. You will be asked to wear shorts or track pants and a backpack.
c. You will perform a series of skating tasks in both skate types.
d. You will be asked to conduct up to 3-5 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 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 kinetic and kinematics differences between the two skate models 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 concerning you will be encoded in order to keep their confidentiality. These records will be maintained at the Biomechanics, Ice Hockey Research Group, 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 *Samuel Forget,* 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.

Department of Kinesiology and Physical Education
McGill University
475 Pine Avenue West
Montreal, Quebec H2W 1S4

Département de kinésiologie et d'éducation physique
Université McGill
475 avenue des Pins Ouest
Montréal, Québec H2W 1S4

Tel./Tél.: (514) 398-4184 x0583
Fax/Télécopieur (514) 398-4186

CONSENT

I, ______________________________________, AGREE TO VOLUNTARILY PARTICIPATE IN THE STUDY ***KINEMATIC AND KINETIC DIFFERENCES BETWEEN TWO SKATE MODELS DURING SKATING IN ICE HOCKEY***

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

Participant

_________________________________ _________________________________
(signature) (print name)

Researcher

_________________________________ _________________________________
(signature) (print name)

Date: ________________________

PARTICIPANT/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 __________________ Shoe size __________________

Skates usually worn ______________________________________

History of injuries ____

____

Health condition ____

____

____

Appendix II

Foot Regions Descriptive Statistics					
Variables/ Conditions			Mean	Std. Deviation	N
inheel_stop_avg	High	Modified	7.39	1.96	7.00
		Regular	6.25	1.09	7.00
		Total	6.82	1.64	14.00
	Low	Modified	4.85	0.70	7.00
		Regular	4.13	1.04	7.00
		Total	4.49	0.93	14.00
	Total	Modified	6.12	1.93	14.00
		Regular	5.19	1.50	14.00
		Total	5.66	1.76	28.00
inheel_s1_avg	High	Modified	8.88	1.37	7.00
		Regular	7.82	0.86	7.00
		Total	8.35	1.23	14.00
	Low	Modified	6.68	1.05	7.00
		Regular	5.87	1.02	7.00
		Total	6.28	1.08	14.00
	Total	Modified	7.78	1.63	14.00
		Regular	6.85	1.35	14.00
		Total	7.31	1.55	28.00

inmid_stop_avg	High	Modified	1.82	0.85	7.00
		Regular	1.55	0.68	7.00
		Total	1.68	0.75	14.00
	Low	Modified	1.22	0.53	7.00
		Regular	0.93	0.43	7.00
		Total	1.07	0.49	14.00
	Total	Modified	1.52	0.75	14.00
		Regular	1.24	0.63	14.00
		Total	1.38	0.69	28.00
inmid_s1_avg	High	Modified	3.07	1.18	7.00
		Regular	3.03	1.23	7.00
		Total	3.05	1.16	14.00
	Low	Modified	2.04	0.99	7.00
		Regular	1.90	0.70	7.00
		Total	1.97	0.83	14.00
	Total	Modified	2.55	1.18	14.00
		Regular	2.47	1.12	14.00
		Total	2.51	1.13	28.00
intoe_stop_avg	High	Modified	1.38	0.58	7.00
		Regular	1.26	0.39	7.00
		Total	1.32	0.48	14.00
	Low	Modified	0.94	0.59	7.00

		Regular	0.92	0.67	7.00
		Total	0.93	0.61	14.00
	Total	Modified	1.16	0.61	14.00
		Regular	1.09	0.55	14.00
		Total	1.12	0.57	28.00
intoe_s1_avg	High	Modified	2.39	1.35	7.00
		Regular	2.63	1.18	7.00
		Total	2.51	1.22	14.00
	Low	Modified	1.96	1.10	7.00
		Regular	2.13	1.08	7.00
		Total	2.05	1.05	14.00
	Total	Modified	2.18	1.20	14.00
		Regular	2.38	1.12	14.00
		Total	2.28	1.14	28.00
outheel_stop_avg	High	Modified	9.94	1.96	7.00
		Regular	9.72	1.59	7.00
		Total	9.83	1.72	14.00
	Low	Modified	8.38	1.58	7.00
		Regular	8.05	1.59	7.00
		Total	8.22	1.54	14.00
	Total	Modified	9.16	1.89	14.00
		Regular	8.89	1.76	14.00

		Total	9.02	1.80	28.00
outheel_s1_avg	High	Modified	6.88	2.33	7.00
		Regular	6.26	1.45	7.00
		Total	6.57	1.89	14.00
	Low	Modified	7.58	1.71	7.00
		Regular	6.93	1.61	7.00
		Total	7.25	1.63	14.00
	Total	Modified	7.23	1.99	14.00
		Regular	6.59	1.51	14.00
		Total	6.91	1.76	28.00
outmid_stop_avg	High	Modified	4.48	1.48	7.00
		Regular	3.64	1.11	7.00
		Total	4.06	1.33	14.00
	Low	Modified	3.46	1.44	7.00
		Regular	2.91	1.04	7.00
		Total	3.19	1.24	14.00
	Total	Modified	3.97	1.50	14.00
		Regular	3.28	1.10	14.00
		Total	3.62	1.34	28.00
outmid_s1_avg	High	Modified	3.03	0.96	7.00
		Regular	2.44	0.68	7.00
		Total	2.73	0.86	14.00

	Low	Modified	2.32	1.05	7.00
		Regular	1.84	0.67	7.00
		Total	2.08	0.88	14.00
	Total	Modified	2.67	1.03	14.00
		Regular	2.14	0.72	14.00
		Total	2.40	0.91	28.00
outtoe_stop_avg	High	Modified	3.43	1.21	7.00
		Regular	3.35	1.31	7.00
		Total	3.39	1.21	14.00
	Low	Modified	3.16	0.87	7.00
		Regular	3.83	1.20	7.00
		Total	3.50	1.06	14.00
	Total	Modified	3.29	1.02	14.00
		Regular	3.59	1.23	14.00
		Total	3.44	1.12	28.00
outtoe_s1_avg	High	Modified	3.06	1.09	7.00
		Regular	3.16	1.20	7.00
		Total	3.11	1.10	14.00
	Low	Modified	2.10	0.63	7.00
		Regular	2.52	1.00	7.00
		Total	2.31	0.83	14.00
	Total	Modified	2.58	0.99	14.00

		Regular	2.84	1.11	14.00
		Total	2.71	1.04	28.00

Foot Regions Univariate Tests (Caliber)						
Dependent Variables		Sum of Squares	df	Mean Square	F	Sig.
inheel_stop_avg	Contrast	37.94	1.00	37.94	22.91	0.00
	Error	39.74	24.00	1.66		
inheel_s1_avg	Contrast	29.98	1.00	29.98	25.35	0.00
	Error	28.38	24.00	1.18		
inmid_stop_avg	Contrast	2.60	1.00	2.60	6.34	0.02
	Error	9.87	24.00	0.41		
inmid_s1_avg	Contrast	8.15	1.00	8.15	7.45	0.01
	Error	26.23	24.00	1.09		
intoe_stop_avg	Contrast	1.05	1.00	1.05	3.28	0.08
	Error	7.72	24.00	0.32		
intoe_s1_avg	Contrast	1.53	1.00	1.53	1.09	0.31
	Error	33.53	24.00	1.40		
outheel_stop_avg	Contrast	18.11	1.00	18.11	6.35	0.02
	Error	68.45	24.00	2.85		
outheel_s1_avg	Contrast	3.25	1.00	3.25	1.00	0.33
	Error	77.98	24.00	3.25		

outmid_stop_avg	Contrast	5.35	1.00	5.35	3.24	0.08
	Error	39.58	24.00	1.65		
outmid_s1_avg	Contrast	2.98	1.00	2.98	4.08	0.05
	Error	17.54	24.00	0.73		
outtoe_stop_avg	Contrast	0.08	1.00	0.08	0.06	0.80
	Error	32.24	24.00	1.34		
outtoe_s1_avg	Contrast	4.43	1.00	4.43	4.40	0.05
	Error	24.14	24.00	1.01		
The F tests the effect of Condition High=1, Low=2,. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.						

Foot Regions Univariate Tests (Skate)						
Dependent Variables		Sum of Squares	df	Mean Square	F	Sig.
inheel_stop_avg	Contrast	6.03	1.00	6.03	3.64	0.07
	Error	39.74	24.00	1.66		
inheel_s1_avg	Contrast	6.09	1.00	6.09	5.15	0.03
	Error	28.38	24.00	1.18		
inmid_stop_avg	Contrast	0.55	1.00	0.55	1.33	0.26
	Error	9.87	24.00	0.41		
inmid_s1_avg	Contrast	0.05	1.00	0.05	0.05	0.83
	Error	26.23	24.00	1.09		

intoe_stop_avg	Contrast	0.04	1.00	0.04	0.13	0.72
	Error	7.72	24.00	0.32		
intoe_s1_avg	Contrast	0.30	1.00	0.30	0.21	0.65
	Error	33.53	24.00	1.40		
outheel_stop_avg	Contrast	0.52	1.00	0.52	0.18	0.67
	Error	68.45	24.00	2.85		
outheel_s1_avg	Contrast	2.81	1.00	2.81	0.87	0.36
	Error	77.98	24.00	3.25		
outmid_stop_avg	Contrast	3.37	1.00	3.37	2.05	0.17
	Error	39.58	24.00	1.65		
outmid_s1_avg	Contrast	2.03	1.00	2.03	2.78	0.11
	Error	17.54	24.00	0.73		
outtoe_stop_avg	Contrast	0.60	1.00	0.60	0.45	0.51
	Error	32.24	24.00	1.34		
outtoe_s1_avg	Contrast	0.46	1.00	0.46	0.46	0.51
	Error	24.14	24.00	1.01		
The F tests the effect of Condition Modified=1, Regular=2,. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.						

Center of Pressure Descriptive Statistics					
Variables/ Conditions			Mean	Std. Deviation	N
incopx_stop_delta	High	Modified	2.54	0.87	7.00
		Regular	2.97	1.41	7.00
		Total	2.76	1.15	14.00
	Low	Modified	3.38	1.46	7.00
		Regular	3.32	1.65	7.00
		Total	3.35	1.50	14.00
	Total	Modified	2.96	1.23	14.00
		Regular	3.14	1.48	14.00
		Total	3.05	1.34	28.00
incopx_s1_delta	High	Modified	2.29	0.96	7.00
		Regular	2.72	0.66	7.00
		Total	2.50	0.83	14.00
	Low	Modified	2.74	1.47	7.00
		Regular	2.55	1.65	7.00
		Total	2.64	1.51	14.00
	Total	Modified	2.51	1.22	14.00
		Regular	2.64	1.21	14.00
		Total	2.57	1.19	28.00
incopy_stop_max	High	Modified	90.79	12.85	7.00

		Regular	99.89	16.30	7.00
		Total	95.34	14.87	14.00
	Low	Modified	100.20	8.87	7.00
		Regular	112.28	18.57	7.00
		Total	106.24	15.32	14.00
	Total	Modified	95.49	11.68	14.00
		Regular	106.08	17.97	14.00
		Total	100.79	15.82	28.00
incopy_stop_min	High	Modified	61.37	7.61	7.00
		Regular	62.22	6.01	7.00
		Total	61.79	6.60	14.00
	Low	Modified	61.31	9.28	7.00
		Regular	62.74	8.61	7.00
		Total	62.02	8.63	14.00
	Total	Modified	61.34	8.16	14.00
		Regular	62.48	7.14	14.00
		Total	61.91	7.54	28.00
incopy_stop_delta	High	Modified	29.42	9.99	7.00
		Regular	37.67	14.03	7.00
		Total	33.54	12.46	14.00
	Low	Modified	38.89	12.40	7.00
		Regular	49.54	16.21	7.00

		Total	44.21	14.92	14.00
	Total	Modified	34.16	11.88	14.00
		Regular	43.60	15.81	14.00
		Total	38.88	14.54	28.00
incopy_s1_max	High	Modified	112.27	21.78	7.00
		Regular	128.75	13.63	7.00
		Total	120.51	19.44	14.00
	Low	Modified	118.15	24.69	7.00
		Regular	122.72	24.26	7.00
		Total	120.44	23.63	14.00
	Total	Modified	115.21	22.57	14.00
		Regular	125.74	19.16	14.00
		Total	120.47	21.23	28.00
incopy_s1_min	High	Modified	64.63	9.61	7.00
		Regular	67.63	9.01	7.00
		Total	66.13	9.08	14.00
	Low	Modified	65.69	8.45	7.00
		Regular	72.22	9.85	7.00
		Total	68.96	9.45	14.00
	Total	Modified	65.16	8.71	14.00
		Regular	69.93	9.38	14.00
		Total	67.54	9.21	28.00

incopy_s1_delta	High	Modified	47.64	18.68	7.00
		Regular	61.13	11.69	7.00
		Total	54.38	16.52	14.00
	Low	Modified	52.46	19.49	7.00
		Regular	50.50	17.69	7.00
		Total	51.48	17.91	14.00
	Total	Modified	50.05	18.51	14.00
		Regular	55.81	15.42	14.00
		Total	52.93	16.97	28.00
outcopx_stop_delta	High	Modified	1.96	0.45	7.00
		Regular	2.26	0.95	7.00
		Total	2.11	0.73	14.00
	Low	Modified	2.77	0.76	7.00
		Regular	2.99	1.58	7.00
		Total	2.88	1.19	14.00
	Total	Modified	2.37	0.74	14.00
		Regular	2.62	1.31	14.00
		Total	2.50	1.05	28.00
outcopx_s1_delta	High	Modified	2.33	0.55	7.00
		Regular	3.31	1.16	7.00
		Total	2.82	1.01	14.00
	Low	Modified	3.52	1.33	7.00

		Regular	4.20	1.83	7.00
		Total	3.86	1.58	14.00
	Total	Modified	2.93	1.16	14.00
		Regular	3.76	1.54	14.00
		Total	3.34	1.40	28.00
outcopy_stop_max	High	Modified	104.27	12.25	7.00
		Regular	108.60	14.15	7.00
		Total	106.43	12.91	14.00
	Low	Modified	110.99	8.88	7.00
		Regular	123.93	16.65	7.00
		Total	117.46	14.47	14.00
	Total	Modified	107.63	10.85	14.00
		Regular	116.26	16.84	14.00
		Total	111.95	14.58	28.00
outcopy_stop_min	High	Modified	66.97	9.05	7.00
		Regular	66.10	9.20	7.00
		Total	66.53	8.78	14.00
	Low	Modified	62.67	14.35	7.00
		Regular	62.05	14.22	7.00
		Total	62.36	13.73	14.00
	Total	Modified	64.82	11.74	14.00
		Regular	64.08	11.70	14.00

		Total	64.45	11.51	28.00
outcopy_stop_delta	High	Modified	37.31	11.96	7.00
		Regular	42.49	17.76	7.00
		Total	39.90	14.79	14.00
	Low	Modified	48.33	15.31	7.00
		Regular	61.88	17.55	7.00
		Total	55.10	17.31	14.00
	Total	Modified	42.82	14.39	14.00
		Regular	52.18	19.72	14.00
		Total	47.50	17.60	28.00
outcopy_s1_max	High	Modified	117.60	16.94	7.00
		Regular	135.78	27.44	7.00
		Total	126.69	23.86	14.00
	Low	Modified	119.09	22.17	7.00
		Regular	124.71	26.76	7.00
		Total	121.90	23.79	14.00
	Total	Modified	118.34	18.97	14.00
		Regular	130.24	26.67	14.00
		Total	124.29	23.50	28.00
outcopy_s1_min	High	Modified	65.34	6.20	7.00
		Regular	67.82	8.07	7.00
		Total	66.58	7.03	14.00

	Low	Modified	63.97	9.65	7.00
		Regular	67.35	13.82	7.00
		Total	65.66	11.58	14.00
	Total	Modified	64.66	7.82	14.00
		Regular	67.59	10.87	14.00
		Total	66.12	9.41	28.00
outcopy_s1_delta	High	Modified	52.26	20.08	7.00
		Regular	67.96	33.81	7.00
		Total	60.11	27.93	14.00
	Low	Modified	55.11	27.59	7.00
		Regular	57.36	24.22	7.00
		Total	56.23	24.97	14.00
	Total	Modified	53.68	23.23	14.00
		Regular	62.66	28.79	14.00
		Total	58.17	26.07	28.00

Center of Pressure Univariate Tests (Caliber)						
Dependent Variables		Sum of Squares	df	Mean Square	F	Sig.
incopx_stop_delta	Contrast	2.42	1.00	2.42	1.28	0.27
	Error	45.45	24.00	1.89		
incopx_s1_delta	Contrast	0.14	1.00	0.14	0.09	0.77
	Error	37.60	24.00	1.57		
incopy_stop_max	Contrast	831.70	1.00	831.70	3.89	0.06
	Error	5125.64	24.00	213.57		
incopy_stop_min	Contrast	0.37	1.00	0.37	0.01	0.94
	Error	1526.33	24.00	63.60		
incopy_stop_delta	Contrast	796.97	1.00	796.97	4.47	0.05
	Error	4279.61	24.00	178.32		
incopy_s1_max	Contrast	0.04	1.00	0.04	0.00	0.99
	Error	11149.60	24.00	464.57		
incopy_s1_min	Contrast	55.92	1.00	55.92	0.65	0.43
	Error	2051.79	24.00	85.49		
incopy_s1_delta	Contrast	58.94	1.00	58.94	0.20	0.66
	Error	7069.65	24.00	294.57		
outcopx_stop_delta	Contrast	4.16	1.00	4.16	3.99	0.06
	Error	25.02	24.00	1.04		
outcopx_s1_delta	Contrast	7.55	1.00	7.55	4.45	0.05

	Error	40.68	24.00	1.70		
outcopy_stop_max	Contrast	851.05	1.00	851.05	4.82	0.04
	Error	4237.43	24.00	176.56		
outcopy_stop_min	Contrast	122.10	1.00	122.10	0.85	0.37
	Error	3448.35	24.00	143.68		
outcopy_stop_delta	Contrast	1617.85	1.00	1617.85	6.47	0.02
	Error	6005.65	24.00	250.24		
outcopy_s1_max	Contrast	161.02	1.00	161.02	0.29	0.60
	Error	13485.63	24.00	561.90		
outcopy_s1_min	Contrast	5.94	1.00	5.94	0.06	0.81
	Error	2325.20	24.00	96.88		
outcopy_s1_delta	Contrast	105.09	1.00	105.09	0.15	0.71
	Error	17368.35	24.00	723.68		
The F tests the effect of Condition Elite=1, Rec=2,. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.						

Center of Pressure Univariate Tests (Skate)						
Dependent Variables		Sum of Squares	df	Mean Square	F	Sig.
incopx_stop_delta	Contrast	0.24	1.00	0.24	0.13	0.73
	Error	45.45	24.00	1.89		
incopx_s1_delta	Contrast	0.11	1.00	0.11	0.07	0.80
	Error	37.60	24.00	1.57		
incopy_stop_max	Contrast	785.32	1.00	785.32	3.68	0.07
	Error	5125.64	24.00	213.57		
incopy_stop_min	Contrast	9.19	1.00	9.19	0.14	0.71
	Error	1526.33	24.00	63.60		
incopy_stop_delta	Contrast	624.58	1.00	624.58	3.50	0.07
	Error	4279.61	24.00	178.32		
incopy_s1_max	Contrast	775.56	1.00	775.56	1.67	0.21
	Error	11149.60	24.00	464.57		
incopy_s1_min	Contrast	158.95	1.00	158.95	1.86	0.19
	Error	2051.79	24.00	85.49		
incopy_s1_delta	Contrast	232.30	1.00	232.30	0.79	0.38
	Error	7069.65	24.00	294.57		
outcopx_stop_delta	Contrast	0.47	1.00	0.47	0.45	0.51
	Error	25.02	24.00	1.04		
outcopx_s1_delta	Contrast	4.81	1.00	4.81	2.84	0.11

	Error	40.68	24.00	1.70		
outcopy_stop_max	Contrast	521.01	1.00	521.01	2.95	0.10
	Error	4237.43	24.00	176.56		
outcopy_stop_min	Contrast	3.83	1.00	3.83	0.03	0.87
	Error	3448.35	24.00	143.68		
outcopy_stop_delta	Contrast	614.11	1.00	614.11	2.45	0.13
	Error	6005.65	24.00	250.24		
outcopy_s1_max	Contrast	991.51	1.00	991.51	1.76	0.20
	Error	13485.63	24.00	561.90		
outcopy_s1_min	Contrast	59.91	1.00	59.91	0.62	0.44
	Error	2325.20	24.00	96.88		
outcopy_s1_delta	Contrast	563.96	1.00	563.96	0.78	0.39
	Error	17368.35	24.00	723.68		

The F tests the effect of Condition DROM=1, One95=2, . This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Kinetics and Time Measures Descriptive Statistics					
Variables/ Conditions			Mean	Std. Deviation	N
invforce_stop_max	High	Modified	45.44	9.35	7.00
		Regular	60.39	15.18	7.00
		Total	52.92	14.38	14.00
	Low	Modified	36.87	13.92	7.00
		Regular	47.82	21.38	7.00
		Total	42.34	18.24	14.00
	Total	Modified	41.16	12.23	14.00
		Regular	54.10	18.97	14.00
		Total	47.63	16.99	28.00
invforce_stop_avg	High	Modified	13.22	11.55	7.00
		Regular	18.93	9.91	7.00
		Total	16.07	10.76	14.00
	Low	Modified	6.84	8.04	7.00
		Regular	10.11	9.30	7.00
		Total	8.47	8.53	14.00
	Total	Modified	10.03	10.12	14.00
		Regular	14.52	10.30	14.00
		Total	12.27	10.28	28.00
invforce_stop_time	High	Modified	0.87	0.16	7.00

		Regular	0.90	0.20	7.00
		Total	0.88	0.18	14.00
	Low	Modified	1.04	0.25	7.00
		Regular	1.08	0.22	7.00
		Total	1.06	0.23	14.00
	Total	Modified	0.96	0.22	14.00
		Regular	0.99	0.23	14.00
		Total	0.97	0.22	28.00
invforce_stop_impulse	High	Modified	10.77	8.77	7.00
		Regular	16.57	8.36	7.00
		Total	13.67	8.77	14.00
	Low	Modified	6.21	6.96	7.00
		Regular	10.24	10.04	7.00
		Total	8.23	8.56	14.00
	Total	Modified	8.49	7.97	14.00
		Regular	13.40	9.46	14.00
		Total	10.95	8.94	28.00
invforce_go_time	High	Modified	1.15	0.07	7.00
		Regular	1.14	0.09	7.00
		Total	1.14	0.08	14.00
	Low	Modified	1.32	0.11	7.00
		Regular	1.30	0.13	7.00

		Total	1.31	0.11	14.00
	Total	Modified	1.23	0.12	14.00
		Regular	1.22	0.13	14.00
		Total	1.22	0.13	28.00
invforce_ct1	High	Modified	0.32	0.03	7.00
		Regular	0.31	0.04	7.00
		Total	0.32	0.03	14.00
	Low	Modified	0.34	0.06	7.00
		Regular	0.33	0.07	7.00
		Total	0.33	0.06	14.00
	Total	Modified	0.33	0.05	14.00
		Regular	0.32	0.05	14.00
		Total	0.33	0.05	28.00
invforce_s1_avg	High	Modified	37.77	4.30	7.00
		Regular	45.30	10.73	7.00
		Total	41.54	8.77	14.00
	Low	Modified	34.65	12.48	7.00
		Regular	48.60	13.69	7.00
		Total	41.62	14.51	14.00
	Total	Modified	36.21	9.11	14.00
		Regular	46.95	11.94	14.00
		Total	41.58	11.77	28.00

invforce_s1_max	High	Modified	85.06	11.11	7.00
		Regular	97.65	18.10	7.00
		Total	91.35	15.84	14.00
	Low	Modified	83.68	16.75	7.00
		Regular	106.52	22.07	7.00
		Total	95.10	22.24	14.00
	Total	Modified	84.37	13.67	14.00
		Regular	102.08	19.93	14.00
		Total	93.23	19.04	28.00
invforce_s1_imp	High	Modified	12.26	1.89	7.00
		Regular	15.13	4.72	7.00
		Total	13.70	3.76	14.00
	Low	Modified	12.25	4.89	7.00
		Regular	16.58	6.35	7.00
		Total	14.42	5.89	14.00
	Total	Modified	12.26	3.56	14.00
		Regular	15.86	5.43	14.00
		Total	14.06	4.86	28.00
outvforce_stop_max	High	Modified	105.03	18.22	7.00
		Regular	124.85	10.87	7.00
		Total	114.94	17.70	14.00
	Low	Modified	100.17	27.74	7.00

		Regular	124.67	13.36	7.00
		Total	112.42	24.48	14.00
	Total	Modified	102.60	22.69	14.00
		Regular	124.76	11.70	14.00
		Total	113.68	21.00	28.00
outvforce_stop_avg	High	Modified	56.25	9.61	7.00
		Regular	72.72	8.10	7.00
		Total	64.49	12.08	14.00
	Low	Modified	46.60	13.98	7.00
		Regular	64.10	12.21	7.00
		Total	55.35	15.54	14.00
	Total	Modified	51.43	12.57	14.00
		Regular	68.41	10.91	14.00
		Total	59.92	14.43	28.00
outvforce_stop_time	High	Modified	0.87	0.16	7.00
		Regular	0.90	0.20	7.00
		Total	0.88	0.18	14.00
	Low	Modified	1.04	0.25	7.00
		Regular	1.08	0.22	7.00
		Total	1.06	0.23	14.00
	Total	Modified	0.96	0.22	14.00
		Regular	0.99	0.23	14.00

		Total	0.97	0.22	28.00
outvforce_stop_impulse	High	Modified	49.49	14.19	7.00
		Regular	64.24	11.98	7.00
		Total	56.86	14.76	14.00
	Low	Modified	48.11	17.63	7.00
		Regular	70.86	23.82	7.00
		Total	59.49	23.34	14.00
	Total	Modified	48.80	15.39	14.00
		Regular	67.55	18.44	14.00
		Total	58.18	19.21	28.00
outvforce_go_time	High	Modified	1.15	0.07	7.00
		Regular	1.14	0.09	7.00
		Total	1.14	0.08	14.00
	Low	Modified	1.32	0.11	7.00
		Regular	1.30	0.13	7.00
		Total	1.31	0.11	14.00
	Total	Modified	1.23	0.12	14.00
		Regular	1.22	0.13	14.00
		Total	1.22	0.13	28.00
outvforce_s1_avg	High	Modified	51.92	16.72	7.00
		Regular	52.67	15.41	7.00
		Total	52.30	15.46	14.00

	Low	Modified	48.42	8.36	7.00
		Regular	51.42	16.25	7.00
		Total	49.92	12.51	14.00
	Total	Modified	50.17	12.83	14.00
		Regular	52.04	15.23	14.00
		Total	51.11	13.85	28.00
outvforce_s1_max	High	Modified	123.58	35.03	7.00
		Regular	134.21	28.44	7.00
		Total	128.89	31.15	14.00
	Low	Modified	104.66	19.00	7.00
		Regular	110.70	32.67	7.00
		Total	107.68	25.87	14.00
	Total	Modified	114.12	28.80	14.00
		Regular	122.46	31.85	14.00
		Total	118.29	30.10	28.00
outvforce_s1_imp	High	Modified	13.58	5.26	7.00
		Regular	14.48	4.56	7.00
		Total	14.03	4.75	14.00
	Low	Modified	16.06	3.84	7.00
		Regular	16.36	5.84	7.00
		Total	16.21	4.75	14.00
	Total	Modified	14.82	4.61	14.00

		Regular	15.42	5.13	14.00
		Total	15.12	4.79	28.00
outvforce_airtime	High	Modified	0.35	0.04	7.00
		Regular	0.33	0.04	7.00
		Total	0.34	0.04	14.00
	Low	Modified	0.36	0.07	7.00
		Regular	0.35	0.06	7.00
		Total	0.36	0.06	14.00
	Total	Modified	0.35	0.06	14.00
		Regular	0.34	0.05	14.00
		Total	0.35	0.05	28.00

Kinetics and Time Measures Univariate Tests (Caliber)						
Dependent Variables		Sum of Squares	df	Mean Square	F	Sig.
invforce_stop_max	Contrast	782.28	1.00	782.28	3.23	0.08
	Error	5814.47	24.00	242.27		
invforce_stop_avg	Contrast	404.22	1.00	404.22	4.22	0.05
	Error	2297.11	24.00	95.71		
invforce_stop_time	Contrast	0.22	1.00	0.22	4.83	0.04
	Error	1.07	24.00	0.04		
invforce_stop_impulse	Contrast	207.53	1.00	207.53	2.80	0.11
	Error	1776.75	24.00	74.03		
invforce_go_time	Contrast	0.19	1.00	0.19	19.26	0.00
	Error	0.24	24.00	0.01		
invforce_ct1	Contrast	0.00	1.00	0.00	0.92	0.35
	Error	0.07	24.00	0.00		
invforce_s1_avg	Contrast	0.05	1.00	0.05	0.00	0.98
	Error	2859.75	24.00	119.16		
invforce_s1_max	Contrast	98.17	1.00	98.17	0.32	0.58
	Error	7312.31	24.00	304.68		
invforce_s1_imp	Contrast	3.62	1.00	3.62	0.16	0.69
	Error	539.99	24.00	22.50		
outvforce_stop_max	Contrast	44.38	1.00	44.38	0.13	0.72

	Error	8388.60	24.00	349.53		
outvforce_stop_avg	Contrast	584.06	1.00	584.06	4.65	0.04
	Error	3016.08	24.00	125.67		
outvforce_stop_time	Contrast	0.22	1.00	0.22	4.83	0.04
	Error	1.07	24.00	0.04		
outvforce_stop_impulse	Contrast	48.29	1.00	48.29	0.16	0.69
	Error	7338.49	24.00	305.77		
outvforce_go_time	Contrast	0.19	1.00	0.19	19.26	0.00
	Error	0.24	24.00	0.01		
outvforce_s1_avg	Contrast	39.56	1.00	39.56	0.19	0.67
	Error	5106.34	24.00	212.76		
outvforce_s1_max	Contrast	3150.03	1.00	3150.03	3.64	0.07
	Error	20786.92	24.00	866.12		
outvforce_s1_imp	Contrast	33.26	1.00	33.26	1.37	0.25
	Error	584.07	24.00	24.34		
outvforce_airtime	Contrast	0.00	1.00	0.00	0.59	0.45
	Error	0.07	24.00	0.00		
The F tests the effect of Condition High=1, Low=2,. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.						

Kinetics and Time Measures Univariate Tests (Skate)						
Dependent Variables		Sum of Squares	df	Mean Square	F	Sig.
invforce_stop_max	Contrast	1173.43	1.00	1173.43	4.84	0.04
	Error	5814.47	24.00	242.27		
invforce_stop_avg	Contrast	141.28	1.00	141.28	1.48	0.24
	Error	2297.11	24.00	95.71		
invforce_stop_time	Contrast	0.01	1.00	0.01	0.17	0.68
	Error	1.07	24.00	0.04		
invforce_stop_impulse	Contrast	168.78	1.00	168.78	2.28	0.14
	Error	1776.75	24.00	74.03		
invforce_go_time	Contrast	0.00	1.00	0.00	0.12	0.74
	Error	0.24	24.00	0.01		
invforce_ct1	Contrast	0.00	1.00	0.00	0.19	0.67
	Error	0.07	24.00	0.00		
invforce_s1_avg	Contrast	807.07	1.00	807.07	6.77	0.02
	Error	2859.75	24.00	119.16		
invforce_s1_max	Contrast	2195.87	1.00	2195.87	7.21	0.01
	Error	7312.31	24.00	304.68		
invforce_s1_imp	Contrast	90.80	1.00	90.80	4.04	0.06
	Error	539.99	24.00	22.50		
outvforce_stop_max	Contrast	3435.30	1.00	3435.30	9.83	0.00

	Error	8388.60	24.00	349.53		
outvforce_stop_avg	Contrast	2018.46	1.00	2018.46	16.06	0.00
	Error	3016.08	24.00	125.67		
outvforce_stop_time	Contrast	0.01	1.00	0.01	0.17	0.68
	Error	1.07	24.00	0.04		
outvforce_stop_impulse	Contrast	2461.47	1.00	2461.47	8.05	0.01
	Error	7338.49	24.00	305.77		
outvforce_go_time	Contrast	0.00	1.00	0.00	0.12	0.74
	Error	0.24	24.00	0.01		
outvforce_s1_avg	Contrast	24.49	1.00	24.49	0.12	0.74
	Error	5106.34	24.00	212.76		
outvforce_s1_max	Contrast	486.56	1.00	486.56	0.56	0.46
	Error	20786.92	24.00	866.12		
outvforce_s1_imp	Contrast	2.50	1.00	2.50	0.10	0.75
	Error	584.07	24.00	24.34		
outvforce_airtime	Contrast	0.00	1.00	0.00	0.35	0.56
	Error	0.07	24.00	0.00		
The F tests the effect of Condition Modified=1, Regular=2,. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.						