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ANAEROBIC PERFORMANCE IN ICE HOCKEY:
THE EFFECT OF SKATE BLADE RADIUS OF HOLLOW

Andrew Winchester

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Applied Health Sciences

Supervisor: Kelly L. Lockwood, Ph.D.

Faculty of Applied Health Sciences, Brock University
St. Catharines, Ontario

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Abstract

The purpose of the study was to investigate the effect of skate blade radius of hollow (ROH) on anaerobic performance, specifically during the acceleration and stopping phases of an on-ice skating test. Fifteen, male Junior B hockey players (mean age $19 \text{ y} \pm 1.46$) were recruited to participate. On-ice testing required each participant to complete an on-ice anaerobic performance test [Reed Repeat Skate (RRS)] on three separate days. During each on-ice test, the participant's skate blades were sharpened to one of three, randomly assigned, ROH values (0.63 cm, 1.27 cm, 1.90 cm). Performance times were recorded during each RRS and used to calculate anaerobic variables [anaerobic power (W), anaerobic capacity (W), and fatigue index (s, %)]. Each RRS was video recorded for the purpose of motion analysis. Video footage was imported into Peak Motus™ to measure kinematic variables of the acceleration and stopping phases. The specific variables calculated from the acceleration phase were: average velocity over 6 m (m/s), average stride length (m), and mean stride rate (strides/s). The specific variables calculated from the stopping phase were: velocity at initiation of stopping (m/s), stopping distance (m), stopping time (s). A repeated measures ANOVA was used to assess differences in mean performance and kinematic variables across the three selected hollows. Further analysis was conducted to assess differences in trial by trial performance and kinematic variables for all hollows. The primary findings of the study suggested that skate blade ROH can have a significant effect on kinematic variables, namely stride length and stride rate during the acceleration phase and stopping distance and stopping time during the stopping phase of an on-ice anaerobic performance test. During the acceleration phase, no significant difference was revealed in AV however significant

differences were found in SR and SL across the three selected hollows. Mean SR on the 1.27 cm hollow was significantly slower than both the 0.63 cm and 1.90 cm hollows and SL was significantly longer when skating on the 1.27 cm hollow in comparison to the 1.90 cm hollow. During the stopping phase, stopping distance on the 0.63 cm hollow ($4.12 \text{ m} \pm 0.14$) was significantly shorter than both the 1.27 cm hollow ($4.43 \text{ m} \pm 0.08$) ($p < 0.05$) and the 1.90 cm hollow ($4.35 \text{ m} \pm 0.12$) ($p < 0.05$). Mean ST was also significantly shorter when stopping on the 0.63 cm hollow then both the 1.27 cm and 1.90 cm hollows. Trial by trial results clearly illustrated the affect of fatigue on kinematic variables; AV, SR, IV decreased from trial 1 to 6. There was no significant effect on anaerobic performance variables during the RRS. Altering the skate blade ROH has a significant and practical affect on accelerating and stopping performance and will be discussed in this paper.

ACKNOWLEDGMENTS

I loved my time at Brock University, in part because it was the right place for me to be over the past eight years, but mostly because of the people involved in my life during my stay. Dr. Lockwood you have played many roles (Advisor, Boss, Friend) during my time at Brock and your ability to juggle all these roles has always amazed me. You have been the perfect blend of all of these, knowing exactly when to give me a little “pick me up” or “crack the whip” on a kid who sometimes got a little distracted or wasn’t giving his full attention to some aspect of his work. I know we are going forward from this point together, working on “stuff”, but I want you to know how much I have respected and appreciated your mentoring. Thank You.

I would like to thank my committee for their efforts during my thesis work, your ideas and editing skills helped create the readable document that follows. Thank You.

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Table of Contents

Abstract.....	ii
ACKNOWLEDGMENTS	iv
Table of Contents.....	v
List of Tables	vii
List of Figures	viii
List of Abbreviations	ix
CHAPTER 1: INTRODUCTION.....	10
CHAPTER 2: REVIEW OF LITERATURE.....	12
The Skate Blade	12
Blade Ice Interaction.....	13
Physiology of a Hockey Player.....	15
Biomechanics of Skating	15
<i>Acceleration Phase.</i>	16
<i>Stopping Phase.</i>	16
On-Ice Assessments	17
<i>Reed Repeat Skate (RRS).</i>	17
CHAPTER 3: METHODOLOGY	18
Experimental Design.....	19
On-Ice Assessments	19
<i>Reed Repeat Skate (RRS).</i>	19
<i>Blade Sharpening.</i>	20
Kinematic Analysis.....	21
Statistical Analysis.....	22
CHAPTER 4: RESULTS	24
CHAPTER 5: DISCUSSION.....	27
CHAPTER 6: CONCLUSION	32
REFERENCES	35
Glossary of Terms.....	52
Appendix A.....	54
Participant Consent Form	54
Appendix B	56
Data Collection Sheet	56
Appendix C	58

Reed Repeat Skate Calculations	58
Appendix D.....	59
Pearson Product Moment Correlation between Speed Index and Fatigue Index.....	59
Appendix E	60
Pearson Product Moment Correlation between Average Velocity and Stride Rate	60
Appendix F.....	61
Pearson Product Moment Correlation between Stopping Distance and Stopping Time	61

List of Tables

Table 1. Anthropometric measures of participants	38
Table 2. Performance variables of the RRS.....	39
Table 3. Kinematic measures during the acceleration and stopping phases of the RRS	40
Table 4. Average velocity over 6 meters during the RRS	41
Table 5. Stride rate measurements during 6 meters of the acceleration phase	42
Table 6. Stride length measurements during 6 meters of the acceleration phase	43
Table 7. Initial velocity values during the stopping phase of the RRS.....	44
Table 8. Stopping time measurements during the stopping phase.....	45
Table 9. Stopping distance measurements during the stopping phase.....	46

List of Figures

Figure 1. Skate blade radius of hollow (ROH) (frontal view).....	47
Figure 2. Skate blade radius of contour (ROC) (lateral view).....	48
Figure 3. Skate blade height (lateral view).....	49
Figure 4. Bite angle.....	50
Figure 5. Reed Repeat Skate set-up	51

List of Abbreviations

ROH: Radius of Hollow

ROC: Radius of Contour

RRS: Reed Repeat Skate

SI: Speed Index

CTT: Complete Trial Time

FI: Fatigue Index

FPS: Frames Per Second

AP: Anaerobic Power

AC: Anaerobic Capacity

BW: Body Weight

AV: Average Velocity over 6 meters

SL: Mean Stride Length

SR: Mean Stride Rate

IV: Velocity at Initiation of Stop

ST: Stopping Time

SD: Stopping Distance

CHAPTER 1: INTRODUCTION

Research in the sport of ice hockey has been primarily dedicated to the physiological demands of the sport (Reed, Hansen, Cotton, Gauthier, Jette, Thoden, and Wenger, 1979; Montgomery, 1982; Watson and Sargeant, 1986; Montgomery, Turcotte, Gamble, and Ladouceur, 1990; Cox, Miles, Verde, and Rhodes, 1995; Montgomery, 2000), the biomechanics of on-ice movement (Gagnon and Dore, 1983; Humble and Gastwirth, 1988; Pearsall, Turcotte, and Murphy, 2000; McPherson, Wrigley, and Montelpare, 2004), and the performance characteristics of the players (Marino, 1979, 1980, 1983, 1984; Naud and Holt, 1979, 1980). Although skate sharpening has been recognized as a significant factor contributing to on-ice performance, a limited number of studies have investigated the interaction between the skate blade radius of hollow (ROH) and performance (Gagnon and Dore, 1983; Morrison, Pearsall, Turcotte, Lockwood, and Montgomery, 2005).

Technical literature on skate sharpening published by Broadbent (1983, 1985, 1988) is descriptive, informative, and practical; however, it does not include research based evidence to support best practices in skate sharpening. Broadbent (1983) has questioned why, after three centuries of skating on iron and steel blades, there are no established standards for skate sharpening characteristics, and little information regarding its effect on skating performance. The lack of sharpening standards has also been identified in practical articles examining skate sharpening and skating (Gabbert, 1990, Lockwood and Winchester, 2004). It is this paucity of research examining the effects of skate blade sharpening characteristics on performance that inspired this research study. The purpose of the present study was to investigate the effect of skate blade radius of

hollow (ROH) on anaerobic performance, specifically during the acceleration and stopping phases of an on-ice skating test, the Reed Repeat Skate (RRS).

The first objective of this research was to examine the differences in RRS performance variables [speed index (SI), complete trial time (CTT), fatigue index (FI)] by the three selected ROH's (0.63 cm, 1.27 cm, 1.90 cm). The second objective was to examine the differences in RRS kinematic variables from the acceleration phase [mean stride rate (SR), mean stride length (SL), average velocity over 6m (AV)] and stopping phase [velocity at initiation of stop (IV), distance to stop (SD), time to stop (ST)] by the three selected ROH's (0.63 cm, 1.27 cm, 1.90 cm). The third objective was to examine the relationship between the RRS performance variables speed index (SI), complete trial time (CTT), fatigue index (FI)] and calculated anaerobic variables [power (W) and capacity (W)] and the three selected ROH's (0.63, etc). The fourth objective was to examine the relationship between RRS kinematic variables from the acceleration phase [mean stride rate (SR), mean stride length (SL), average velocity over 6m (AV)] and stopping phase [velocity at initiation of stop (IV), distance to stop (SD), time to stop (ST)] by the three selected ROH's (0.63 cm, 1.27 cm, 1.90 cm).

CHAPTER 2: REVIEW OF LITERATURE

The Skate Blade

The early work of Broadbent (1983, 1985) outlined the dimensions and characteristics of the skate blade. The skate blade consists of three basic dimensions: height, length, and width. When the skate blade is sharpened, these dimensions are altered. Figure 1 illustrates the radius of hollow (ROH), Figure 2 the radius of contour (length), and Figure 3 the pitch (height) of any skate. Broadbent (1985) defined the radius of hollow (ROH) as "...the hollow groove ground into the running surface of the blade during sharpening". The ROH creates a medial and lateral edge on the blade (Figure 1). A properly sharpened skate blade has edges that are symmetrical and level, meaning that the medial and lateral edges are on an even horizontal plane (Broadbent, 1983). Broadbent (1983) has described the measurement of the blade edge as the "bite angle" and defined it as; "... the non-ambiguous angular identification of the blade edge" (Figure 4). The deeper the hollow of the blade, the more acute the angle created at the blade's edge. Broadbent (1983) suggested that a measurement of bite angle is probably the most consistent method of defining the ROH of the blade.

The radius of contour (ROC) refers to the longitudinal shape of the blade and defines how much of the blade is in contact with the ice (Figure 2). A demographic analysis of skate blade geometry of the skate blades of the players of 12 NHL teams, (Lockwood, 2003) suggested that the range of ROC of forward and defensemen players was 2.44 – 3.66 m (8 – 12 ft). On a 2.44 m (8 ft) ROC, there is less blade contact with the ice than on a 3.66 m (12 ft) ROC. In theory, it is postulated that the shorter 2.44 m (8 ft)

ROC allows for greater agility due to a shorter length of blade in contact with the ice, whereas the longer 3.66 m (12 ft) ROC has more blade in contact with the ice, allowing the skater to potentially achieve greater velocity.

Finally, a difference in blade height from fore to aft of the skate blade has the potential to change the inclination or pitch angle of the skate boot (Figure 3). The pitch of the blade is altered by grinding off the height from either the fore or aft portion of the blade. The change in height can result in an anterior/posterior shift in the skater's point of balance on the blade.

Blade Ice Interaction

There are three published theories (Colbeck, 1995, 1997; Somorajia, 1996; Stanners, Gardin, and Somorajia, 1994) that define how the blade interacts with the ice surface. All three theories are based on the premise that a thin film of water is created between the skate blade and the ice surface which causes a reduction in friction. Theory I states that, the film of water is created by the pressure exerted on the ice surface by the skate blade (Colbeck, 1995). The pressure causes the ice to melt and the melted water acts a friction reducing medium between the skate blade and ice surface. Theory II states that, as the skate blade passes over the ice, the friction between the two surfaces causes the blade temperature to rise (Colbeck, 1997). Colbeck (1997) thus leading to transient melting between the blade and ice. Moreover, the melted ice would result in a reduction in the coefficient of friction between the two surfaces. Theory III is based on the assumption that the structure of ice maintains a continuous semi-liquid layer of water until a temperature of -157 °C (Somorajia, 1996; Stanners, Gardin, and Somorajia, 1994). This theory agrees with the first two theories stating that, there is a layer of water acting

as a friction reducer between the skate blade and the ice surface, but differs in the rationale for why the water exists.

Broadbent (1988) suggested that the skate blade ROH-ice interaction should change as the ice temperature changes. If the ice temperature (density) of an arena ice surface is colder (denser), then the ROH should be deeper. The deeper hollow creates a more acute blade angle, and the “keener” edge will interact with the denser ice more efficiently. Whereas, if the ice is warmer (less dense), a shallow hollow would be appropriate; the shallower hollow will not dig into the ice as aggressively as the deeper hollowed blade. Broadbent (1988) stated that, it is the blade-ice interaction and the friction between the two surfaces that can affect a skater’s energy expenditure levels during skating.

More recently, players have been using an alternative training surface to supplement their on-ice training. Synthetic or plastic ice provides a similar feel and low friction surface that simulates real ice (Turcotte, Pearsall, Montgomery, Lefebvre, Ofir, and Loh, 2004). Morrison, Pearsall, Turcotte, Lockwood, and Montgomery (2005) investigated the effect of ROH on oxygen consumption while skating on a hockey specific skating treadmill surfaced with synthetic ice. Participants skated at three different velocities to determine the influence of three different ROH’s on performance at different levels of exertion. The results indicated that the ROH had no significant effect on oxygen consumption during forward skating on the treadmill. This study is the only known peer-reviewed research paper that directly investigated the effect of ROH on physiological measures in a human model.

Physiology of a Hockey Player

Within the game of hockey, players rely on all three physiological energy systems, including alactic, lactic, and aerobic pathways (Montgomery, 2000). Aerobic conditioning of the hockey players is essential because at the elite level games can take up to 3 hours to complete with higher skilled players being active in excess of 30 minutes, compared to the average playing time of less than 16 minutes (Cox, Miles, Verde, and Rhodes, 1995). The alactic and lactic anaerobic energy systems are utilized during the intense physical play required during a shift, which ranges in length from 45-60 seconds (Cox, Miles, Verde, and Rhodes, 1995). Within each shift, a skater's activity can consist of 5-7 sprints, lasting 2-3.5 seconds in length (Montgomery, 2000). It is the dynamic nature of the game, including changes of direction and the need for periods of acceleration and deceleration that makes use of the alactic and lactic anaerobic systems (Montgomery, 2000). With four lines of players dividing ice time, each athlete spends approximately 3-5 minutes on the bench between shifts. While on the bench, the player has the opportunity to re-synthesize alactic energy and remove/eliminate lactic acid (Montgomery, 2000). The heart rates of varsity players during a shift average 85% of maximum heart rate and have been found to exceed 90% of maximum heart rate (Peddie, 1995).

Biomechanics of Skating

Several on-ice studies have used video analysis to examine the starting techniques (Naud and Holt, 1979, 1980; Marino, 1979, 1983), the stride characteristics (Marino, 1980, 1984; McPherson, Wrigley, and Montelpare, 2004), and the stopping characteristics (Gagnon and Dore, 1983) of hockey players.

Acceleration Phase. Naud and Holt (1979, 1980) conducted a biomechanical analysis of a number of starting styles. Their research identified the front start to be the most efficient and effective. It enabled the skater to create the highest initial acceleration from a stationary start position. The front start is performed from a stationary position, with the back skate perpendicular to the desired direction of motion, and the front foot parallel to the desired direction of movement. Initial forward motion is created by the back leg propulsion onto a flexed front leg allowing the skater to glide into a forward skating stride. As defined by Humble and Gastwirth (1988), there are two distinct phases of acceleration: positive acceleration and net positive acceleration. Positive acceleration is generated during the initial 3-4 strides and is almost strictly single leg support skating (Marino, 1979). After the initial positive acceleration phase, the stride changes and the ratio of double leg to single leg support increases. During the net positive acceleration phase, skaters are able to increase velocity because the stride is able to produce positive acceleration that is greater than the periods of negative acceleration. Marino (1983) performed a kinematic analysis of the start to quantify positive acceleration. He found that positive acceleration lasts an average of 1.75 seconds from a stationary position. Furthermore, Marino (1983) found three important stride characteristics that lead to high acceleration rates and the shortest skating time over 6 meters: a high stride rate, defined as short periods of single leg support, a significant forward lean, and a recovery foot that is placed under the hip of the recovery leg at the end of each single support phase. After the initial positive acceleration, the amount of time spent in double leg support increased (Marino, 1983).

Stopping Phase. Gagnon and Dore (1983) used a mechanical model to simulate

the hockey stop. They found that a deeper ROH (1.27 cm) resulted in a shorter stopping distance in comparison to a shallower ROH (3.81 cm). It is proposed that the deeper ROH causes the blade edge to carve deeper into the ice and results in a shorter stopping distance. Given that the typical game includes stopping and starting, it is possible that the depth of the ROH can affect a skater's performance. Beyond this single paper, we are unaware of any others that have explored the effect of skate blade sharpening characteristics on stopping performance.

On-Ice Assessments

Reed Repeat Skate (RRS). The RRS test has been employed by both researchers and coaches for the purpose of evaluating a player's on-ice anaerobic conditioning (Reed et al., 1979). The RRS requires that the subject skate from the first goal line to the second goal line (48.8 m), stop behind the second goal line, reverse course and skate to the second blue line (32.63 m) (Figure 5). The test consists of six trials; each trial commencing 30 seconds after the start of the previous trial.

Three performance variables obtained from RRS data; speed index (SI), complete trial time (CTT), and fatigue index (FI), . Watson and Sargeant's (1986) varsity level subjects completed a RRS, yielding values of SI ($M = 7.6$, $SD = 0.3$ s), CTT ($M = 94.6$ s), and FI ($M = 19\%$). Montgomery, Turcotte, Gamble, and Ladouceur (1990) found similar results during a RRS: SI ($M = 7.32$, $SD = 0.2$ s), CTT ($M = 89.26$, $SD = 2.70$ s), and DO ($M = 19\%$).

Anaerobic power and anaerobic capacity can be calculated to quantify a player's anaerobic fitness (Watson and Sargeant, 1986). Watson and Sargeant (1986) examined the test-retest reliability and reproducibility of the anaerobic power ($r = 0.73$, $p < 0.05$)

and capacity ($r = 0.96$, $p < 0.05$) measurements calculated from the RRS. Watson and Sargeant (1986) stated values for anaerobic power ($M = 11.5$, $SD = 1.1 \text{ W}\cdot\text{kg}^{-1}$) and anaerobic capacity ($M = 9.3$, $SD = 0.8 \text{ W}\cdot\text{kg}^{-1}$).

CHAPTER 3: METHODOLOGY

The purpose of the study was to investigate the effect of skate blade ROH on anaerobic performance, specifically during the acceleration and stopping phases of an on-ice Reed Repeat Skate test (Reed et al., 1979). RRS performance variables, power calculations, and kinematic measures were used to compare and contrast the on-ice performances while skating on three selected ROH's. RRS performance variables included speed index (s) (SI), complete trial time (s) (CTT) and fatigue index (s, %) (FI). On-ice anaerobic power (W), anaerobic capacity (W), and fatigue index (s, %) measures were calculated from the RRS data. A computer based video analysis of all RRS tests was performed to obtain kinematic variables during both the acceleration phase [mean stride rate (st/s) (SR), mean stride length (m) (SL), average hip horizontal velocity over a distance of 6 meters (m/s) (AV)] and stopping phase [velocity at initiation of stop (m/s) (IV), distance to stop (m) (SD), time to stop (s) (ST)].

Participants

Fifteen, male Junior B hockey players volunteered to participate in the study (mean age = 19 ± 1.46 y, mean weight = 77.8 ± 8.71 kg, mean height = 177.16 ± 9.70 cm). All subjects were injury free and agreed to allow specific skate blade sharpening modifications to be made to their skate blades as defined by the study. Upon completion of the study, the sharpening characteristics of the blades were returned to their original

characteristics, if the subject desired. Both participant and parental or legal guardian consent were provided prior to participation (Appendix B). The research was approved by the Brock University Research Ethics Board (File #02-187).

Experimental Design

The on-ice assessment included three testing sessions scheduled over a two-week period with a minimum of 48 hours between sessions. During each session, participants completed a RRS on one of three, double blind and randomized sharpening dimensions with ROH values of 0.63 cm, 1.27 cm, 1.90 cm. Before each on-ice test, participants were given a fifteen minute familiarization period to warm up and become acquainted with the new sharpening characteristics. All on-ice assessments were videotaped as outlined below (see *Kinematic Analysis*) to facilitate a computer based motion analysis of both the acceleration and stopping phases. Ice temperatures were recorded at the beginning and end of each testing session to be able to control for the effect of temperature on blade/ice interaction.

On-Ice Assessments

Reed Repeat Skate (RRS). The players wore their own skates (Bauer = 5, Graf = 3, Nike = 3, Rebook = 2) black tights, a black long sleeved shirt, and a helmet. The testing protocol for the RRS was modified from Reed et al. (1979). The RRS requires subjects to skate from goal line to goal line (48.8 m), stop behind the goal line, reverse course and skate to the second blue line (32.6 m). The entire test consists of six trials, each trial commencing 30s after the start of the previous trial. Two performance times for each of the RRS trials were recorded; (i) speed index (s) (SI), recorded from the beginning goal

line of the trial to the second goal line, and (ii) complete trial time (s) (CTT), recorded at the finish line (second blue line). A Tag Heuer™ HL610 photo-electric timing system (la Chaux-De-Fonds, Switzerland) was used to record times during each RRS. The RRS performance variables (SI, CTT) were used to calculate the fatigue index (s and %), the difference between the fastest and slowest complete trial. Both anaerobic variables were calculated from performance variables for each ROH condition as follows:

$$\text{Anaerobic power (W)} = \frac{\text{wt (kg)} * \text{distance (48.8 m)}}{\text{time (s)}}$$

Equation 1. Anaerobic Power

$$\text{Anaerobic capacity (W)} = \frac{\text{wt (kg)} * \text{distance (488.4 m)}}{\text{time (s)}}$$

Equation 2. Anaerobic Capacity

In both equations, wt (kg) is the subjects body weight in kilograms; distance is constant 48.8 m representing one length of the ice and 488.4 m the cumulative distance skated by the subjects during the RRS; and time represents time in seconds to skate the stated distances. Heart rate monitors (Polar™, Lake Success, NY) were used to record heart rate (beats/min) at the completion of each test. Verbal encouragement was provided during each trial to support subjects performing this maximal effort test.

Blade Sharpening. Prior to each assessment, skates were sharpened to one of three randomly assigned ROH values (0.63 cm, 1.27 cm, 1.90 cm). The ROH was produced using a Blademaster Skate Sharpener™ (Guspro, Inc. Chatham, ON). One trained technician performed all sharpening. The grinding stone was dressed prior to each sharpening to provide one of the three selected hollow depths (0.63 cm, 1.27 cm, and 1.90 cm). To verify the accuracy and precision of the ROH, measurements were taken at

three distinct points on the blade ($\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of blade length) using a Hollow Depth Indicator™ (HDI) (Edge Specialties, Inc. Alexandria, MN). The HDI is a discipline specific tool that measures hollow depth and edge levelness.

Kinematic Analysis

Two digital video cameras (Panasonic™ Palmcorder) recording at 30 frames per second (fps) were used to capture the acceleration and stopping phases of each trial. Cameras were positioned perpendicular to the path of motion at a distance of 10 m in order to capture a 6 m field of view. One camera was used to capture the acceleration phase (Figure 5); the other camera was positioned to capture the stopping phase (Figure 5). A “scaling” square (150 cm x 150 cm) was placed in the centre of the 6 m recording field of view, and video taped before and after each testing session. The video clip was used for the purpose of calibrating the field of view as part of the kinematic analysis. The cameras were manually focused prior to each testing session. The overhead arena lights were turned off and a 500 W halogen lamp was positioned beside each camera to adequately light each field of view.

Reflective markers were placed on both anatomical locations of the body and the skate boot. Body markers consisted of 1.75 cm spheres covered with 3M™ reflective tape and placed on the greater trochanter and lateral tibial condyle of the right lower extremity of each subject, to represent hip and knee joint centers. Skate markers consisted of 1.5 cm squares made of 3M™ reflective tape and were placed on the skate boot at points that represented the lateral malleolus and lateral aspect of the fifth metatarsal head. An additional marker was placed on the posterior aspect of the skate boot to measure stopping distance (m), and stopping time (s) during the stopping phase of the RRS.

Marker placement was performed by one individual, to ensure consistency of placement.

Acceleration Phase. During the acceleration phase, each participant used the “front start” technique to initiate the RRS. After completing the stop at the second goal line, the “cross-over front start” was used by the participants. At this level of hockey, the subjects were familiar with these starting techniques; however, they were reminded before each trial to use these specific starting techniques.

Stopping Phase. During the stopping phase, participants were required to come to a complete stop, using a ‘two-foot (parallel) side stop’ at the goal line. A complete stop was defined as having no positive horizontal velocity of the posterior skate boot marker.

Peak Analysis. Upon completion of all on ice testing, video footage was imported into Peak Motus software (Peak Performance Technologies Incorporated, Centennial, CO.) for digitization and analysis. Within the Peak software the sampling rate of the video was optimized by splitting each frame into two separate fields to achieve 60 Hz, resulting in a time per field of 0.0166 s. This value (0.0166 s) was used in calculating AV and ST. Procedural steps for calculating all acceleration and stopping phase variables are located in the Glossary of Terms. Raw data were filtered using a 4th order Butterworth low pass filter (6 Hz).

Statistical Analysis

All data were analyzed using the Statistical Package for the Social Sciences (SPSS) software (14.0 for Windows, Chicago, Ill.).

1. Descriptive statistics, including mean (M) and standard deviation (SD), were calculated for all variables.
2. A repeated measures ANOVA of RRS performance variables by ROH (0.63 cm,

1.27 cm, 1.90 cm) was conducted to determine if significant differences existed between the mean RRS performance measures averaged across 6 trials (SI, CTT, FI).

3. A repeated measures ANOVA of RRS kinematic variables by ROH (0.63 cm, 1.27 cm, 1.90 cm) was conducted to determine if significant differences existed between the mean RRS kinematic measures averaged across 6 trials (SL, SR, AV, IV, ST, SD).
4. A repeated measures ANOVA of trial by trial RRS kinematic variables across ROH's (0.63 cm, 1.27 cm, 1.90 cm) was conducted to determine if significant differences existed between the individual trials (1-6) for both the acceleration and stopping phases. For example, kinematic variables collected during trial 1 0.63 vs. trial 1 1.27 cm vs. trial 1 1.90 cm).
5. A repeated measures ANOVA of trial by trial RRS kinematic variables within each of the ROH's (0.63 cm, 1.27 cm, 1.90 cm) was conducted to determine if significant differences existed between trials (1-6) for both the acceleration and stopping phases. For example, RRS kinematic variables collected during trial 1 0.63 cm vs. trial 2 0.63 cm vs. trial 3 0.63 cm etc.
6. Pearson product moment correlation were computed to determine relationships among the RRS performance variables, kinematic variables collected during both the acceleration (SL, SR, AV) and stopping (IV, ST, SD) phases, and anthropometric measures (height, weight).

Significance for all analyses was set at an alpha level of < 0.05 .

CHAPTER 4: RESULTS

Descriptive data on all participants ($n=15$) are shown in Table 1. A positive correlation was seen between the height and weight of the subjects ($r = 0.67, p < 0.05$). Table 2 presents group mean values of the RRS performance variables obtained on the three selected ROH's (0.63 cm, 1.27 cm, 1.90 cm). No significant differences were revealed among the mean RRS performance variables across the three ROH's, meaning that ROH had no affect on RRS performance variables. A negative correlation was found between SI and FI (-0.55, -0.73, -0.73) ($p < 0.05$) while skating on all three selected ROH's (0.63 cm, 1.27 cm, 1.90 cm) (Appendix D).

Mean kinematic variables calculated from both the acceleration and stopping phases of the RRS performed on the three selected ROH's are reported in Table 3. During the acceleration phase, no significant difference was revealed in AV however significant differences were found in SR and SL across the three selected ROH's. Specifically, mean SR on the 1.27 cm hollow was significantly slower than on both the 0.63 cm and 1.90 cm hollows and mean SR on the 0.63 cm hollow was significantly slower than on the 1.90 cm hollow. SL was significantly longer when skating on the 1.27 cm hollow in comparison to the 1.90 cm hollow (Table 3). During the stopping phase, significant differences were found in IV, SD, and ST (Table 3). Mean IV during the stopping phase was significantly slower when performed on the 0.63 cm hollow in comparison to the 1.27 cm hollow (Table 3). Mean SD on the 1.27 cm hollow and the 1.90 cm hollow were significantly longer than the mean stopping distance on the 0.63 cm ROH (Table 3). Furthermore, mean ST was also significantly shorter when stopping on the 0.63 cm ROH than on both the 1.27 cm and 1.90 cm ROH's (Table 3).

Four repeated measures ANOVA's were conducted on the RRS kinematic variables to assess differences between hollows and between trials during both the acceleration and stopping phases across the three selected ROH's (0.63 cm, 1.27 cm, 1.90 cm). The first analysis was conducted to determine if significant differences existed across the RRS trial by trial data collected on the three selected hollows during the acceleration phase. For example, kinematic acceleration variables collected during trial 1 (0.63 cm) vs. trial 1 (1.27 cm) vs. trial 1 (1.90 cm). No significant differences across trials were revealed, meaning that kinematic variables collected during trial 1 (0.63 cm) vs. trial 1 (1.27 cm) vs. trial 1 (1.90 cm) were not significantly different (Tables 4-6). The second analysis investigated trial by trial RRS kinematic variables collected during the acceleration phase while skating on the same hollow, for example trial 1 (0.63 cm) vs. trial 2 (0.63 cm) vs. trial 3 (0.63 cm) etc. A significant difference was revealed in AV (Table 4) and SR (Table 5), but no significant difference in SL (Table 6) was seen across trials. AV decreased across trials 1 through 6 while skating on the 0.63 cm ROH. AV collected on the 1.27 cm and 1.90 cm ROH also decreased, however only through trials 2-6. A similar trend was found in SR; SR decreased from trials 1 through 4 for all three ROH's. The third analysis was conducted to determine if significant differences existed across the RRS trial by trial data collected on the three selected hollows during the stopping phase, for example trial 1 (0.63 cm) vs. trial 1 (1.27 cm) vs. trial 1 (1.90 cm). Similar to the acceleration phase, no significant differences were found (Table 7-9). The fourth analysis investigated trial by trial RRS kinematic variables collected during the stopping phase while skating on the same hollow, for example trial 1 (0.63 cm) vs. trial 2 (0.63 cm) vs. trial 3 (0.63 cm) etc. A significant difference was revealed in IV (Table 7),

ST (Table 8), and SD (Table 9). When skating on a 1.27 cm hollow, IV decreased across trials 1 through 6. While skating on the 0.63 cm and 1.90 cm hollows IV decreased across trials 2 through 6. On the 1.27 cm hollow ST was greater during trial 1 vs. trial 6. There was a significant difference in SD while skating on the 0.63 cm hollow between trials 1, 2, and 3.

Pearson product moment correlations among both RRS performance and kinematic variables revealed limited relationships. There was a significantly positive correlation ($r = 0.90$) between AV and SR for the 1.27 cm hollow and also for the 1.90 cm hollow ($r = 0.94$) (Appendix E). Significant positive correlations were also seen between ST and SD for all three hollows: 0.63 cm ($r = 0.88$), 1.27 cm ($r = 0.93$), and 1.90 cm ($r = 0.83$) (Appendix F).

Participants exhibited expected near maximal heart rates as a result of maximum effort during the RRS in a cold environment (Table 2). Ice temperatures across the five days of testing were not significantly different ranging from 24.6 – 23.8 °F.

CHAPTER 5: DISCUSSION

Montgomery (2000) characterized the sport of ice hockey as high-intensity intermittent skating, with rapid changes in direction and velocity. Being that players dedicate a significant amount of time and energy to training (physiological, biomechanical, and technical/skill related), it is essential that when the players take to the ice, their preparation is not impaired by equipment failure or specific to this study, the effect of the point of contact with the ice. Therefore, understanding how skate sharpening can affect a player's technique is paramount in on-ice sport. The purpose of this study was to investigate the effect of ROH on both performance and kinematic variables during the acceleration and stopping phases of an on-ice anaerobic skating test.

The difference in hollow dimensions is illustrated in Figure 1. The 0.63 cm ROH creates the deepest hollow and the most acute bite angle, while the 1.90 cm ROH creates the most shallow hollow with a less acute bite angle. It was hypothesized that, blade ROH has the potential to affect technical aspects of a players performance during the acceleration and stopping phases of a Reed Repeat Skate (RRS).

The study was conducted on fifteen, male Jr. B. ice hockey players. All players wore their own skates and testing was conducted on a familiar ice surface. Initial blade measures were recorded prior to the intervention. All skate blade measures with the exception of ROH were held constant across the three on-ice testing sessions conducted during the study.

The RRS is a valid and reliable on-ice assessment protocol (Watson and Sargeant, 1986). This protocol was adapted to investigate differences in performance and kinematic variables during both acceleration and stopping phases while skating on three selected

hollows. Acceleration and stopping phases were deemed important to analyze due to the dynamic nature of the game, however no studies have investigated the effect of skate sharpening on these technical aspects of performance. The three hollows used for the purpose of this study are typically classified as ‘standard’ or the most commonly used hollows by today’s players, allowing for optimal blade-ice interaction (Lockwood, 2003).

On-ice acceleration is characterized by explosive movement consisting of short, quick, running-like strides allowing the player to generate power resulting in forward motion. During the acceleration phase of this study, there were significant kinematic differences between two of the kinematic variables assessed (SR and SL) when comparing ROH’s. Specifically, when performing on the 1.27 cm hollow, the SL ($1.99 \text{ m} \pm 0.06$) was longer and SR ($2.42 \text{ strides/s} \pm 0.13$) was slower in comparison to the 1.90 cm hollow ($1.88 \text{ m} \pm 0.03$), ($2.52 \text{ strides/s} \pm 0.11$, $p < 0.05$). The shorter, quicker strides when skating on the 1.90 cm hollow (shallow) are a result of the skater not being able to maintain the blade-ice contact due to the less acute bite angle. This results in the skater shortening his stride length and increasing his stride rate. Pearsall, Turcotte, and Murphy (2000) state, “to maximize the time spent applying force, the propulsive limb should be moved through as large a range of motion as possible without compromising stride rate”. However, if the ROH is too shallow, the range of motion is compromised in an effort to maintain optimal bite angle. This translates to less time spent applying force per stride and an increase in stride rate. Short, choppy stride technique has the potential to fatigue the skater faster than a longer, slower application of force to the ice. Given that during the average shift, a player sprints 5 – 7 times, each sprint lasting 2 – 3.5s (Montgomery, 2000), it is of potential value to control for extraneous fatigue due to skate sharpening.

Further evidence that the stride length and stride rate during the 1.27 cm trial are more effective than the stride characteristics during the 0.63 cm and 1.90 cm trials was illustrated by significantly greater mean IV values during the stopping phase. This result suggests that the skater was able to achieve a greater velocity while skating on the 1.27 hollow in comparison to the other two hollows after the 6 m point of the acceleration phase. Stride rates were significantly correlated to AV over 6 meters when performing on the 1.27 cm hollow ($r = 0.904$) and 1.90 cm hollow ($r = 0.939$) ($p < 0.05$); however this relationship was not apparent during performance on the 0.63 cm hollow. This study was able to support the work of Marino (1983) in which a positive relationship was also found between SR and velocity at 6 meters ($r = 0.76$, $p < 0.05$). Overall, the effect of fatigue as a result of efforts exerted during the RRS is consistently illustrated by the AV data for all three ROH conditions. There was a significant linear decrease in AV through trials 1-6 (Table 6). This decrease is also seen in the SR data across the three ROH conditions. SR significantly decreased from trials 1-6 (Table 4). As would be expected, a positive correlation was found between AV and SR during the acceleration phase.

Due to the dynamic nature of the game, players in the game of hockey are required to stop quickly across short distances (Pearsall, Turcotte, and Murphy, 2000). Understanding how the ROH can affect stopping distance and stopping time is critical since both starts and stops are key skills in the game. Results of the present study found that mean stopping distance and mean stopping time were significantly shortened when skating on a deeper ROH. Deeper hollows are characterized by a more acute bite angle that is able to penetrate deeper into the ice surface, in comparison to the less acute angle created by the shallower ROH. With a shallower ROH, the blade has a less acute bite

angle and as a result allows for a sliding motion across the top of the ice surface. The stopping distance on the 0.63 cm hollow ($4.12 \text{ m} \pm 0.14$) was significantly shorter than on the 1.27 cm hollow ($4.43 \text{ m} \pm 0.08$) ($p < 0.05$) and the 1.90 cm hollow ($4.35 \text{ m} \pm 0.12$) ($p < 0.05$). On the 0.63 cm and 1.90 cm hollows with similar IV's, the stopping distance on the 0.63 cm hollow (deepest) was shorter than on the 1.90 cm hollow (most shallow). Furthermore, there was also a significant difference in stopping time between the 0.63 cm hollow ($0.81 \text{ s} \pm 0.01$) and 1.90 cm hollow ($0.84 \text{ s} \pm 0.02$) ($p < 0.05$). It is suggested that this is directly a result of the differences in ROH, since SD and ST were positively related during each trial. This finding supports the work of Gagnon and Dore (1983) that employed a mechanical model to analyze the stopping motion. Gagnon and Dore (1983) used a hollow difference of 2.54 cm to find that a deeper hollow resulted in a shorter stopping distance. In the current study, a hollow difference as small as 0.63 cm had an effect on stopping performance, meaning that a ROH of 0.63 cm has the potential to optimize on-ice stopping technique.

Similar to the trend found during the acceleration phase, the effect of fatigue as a result of effort exerted during the RRS was consistently illustrated by the IV data during all three ROH conditions in the stopping phase. There is a significant linear decrease in IV through trials 1-6 (Table 7). This finding also has practical implications to game play. As the game progresses and a player fatigues, a deeper hollow allows them to maintain a more acute bite angle which facilitates ease of stopping.

RRS performance data showed no significant differences among any of the performance variables (SI, CTT, FI) across the three selected hollows. The lack of significant differences could be partially explained by the homogenous skill level of the

skaters and their ability to adapt to and/or compensate for the three different ROH's by changing their performance strategies. For example, if a player felt as if he was 'spinning his wheels' during the acceleration phase, he could attempt to 'make up' for lost time by stopping more quickly and therefore, there was no significant difference found in CCT across hollows. It is also possible that the hollows selected for the purpose of this study were not different enough to elicit an effect in the mean RRS performance variables. That being said, the hollows were selected based upon 'normal' and commonly used hollows in competitive hockey (Lockwood, 2003).

The RRS performance values (SI, CTT, FI) in the present study were also compared to previous studies using the RRS. In order to do so, the SI (7.22 m/s) and CTT (6.22 m/s) variables were converted to velocities to account for differences in rink lengths and to standardize data. This resulted in the RRS (SI, CTT, FI) values of the present study being in agreement with the findings of Montgomery (1982) (6.90 m/s, 5.68 m/s), Watson and Sargeant (1986) (7.22 m/s, 5.73 m/s), and Montgomery, Turcotte, Gamble, and Ladouceur (1990) (7.50 m/s, 6.14 m/s). However, the fatigue index results calculated in the present study were lower [0.63 cm (11.6%), 1.27 cm (12.9%), 1.90 cm (11.6%)] in comparison to Montgomery (1982) (13.1%), Watson and Sargeant (1986) (19.0%), and Montgomery, Turcotte, Gamble, and Ladouceur (1990) [Team 1 (19.0%) and Team 2 (22.0%)]. The lower fatigue index reported in the present study could be due to the shorter (10%) overall skating distance.

CHAPTER 6: CONCLUSION

The present study provides information on one aspect of skate sharpening during two phases of skating; acceleration and stopping. The primary findings of the study suggests that skate blade ROH can have a significant effect on SL and SR during the acceleration phase and SD and ST during the stopping phase of an on-ice anaerobic performance test. Although there was no significant difference in mean AV during the acceleration phase, stride characteristics were distinctly different during acceleration. When skating on the 1.27 cm hollow, the skaters had longer strides compared to the shorter, choppy strides on the 1.90 cm hollow. During the stopping phase, stopping distance on the 0.63 cm hollow was significantly shorter compared to performances on both the 1.27 cm and 1.90 cm hollows.

It was somewhat unexpected to find no significant difference in the performance variables calculated from the RRS, however the performance variables are global measures or mean scores representing overall performance not specific aspects of performance. It was suspected that the level and ability of the subjects participating in the study (Jr. B hockey players) were able to adapt and compensate for the different hollows without sacrificing overall performance. For example, during the acceleration phase when skating on a shallow hollow, subjects decreased stride length and increased stride rate whereas when skating on a deep hollow, skaters increased stride length and decreased stride rate. Both strategies resulted in similar overall performance scores. In contrast during the stopping phase, the subjects were not able to compensate as well for the differences in hollows. This resulted in independent differences in both stopping distance and time, but the overall affect of ROH during the stopping phase did not change the

overall performance scores. Knowing this, overall performance scores may not have been a precise enough measure to detect differences caused by ROH. On the other hand, kinematic scores obtained from the same RRS performances allowed us to tease out the effect of ROH on acceleration and stopping independently and found significant differences.

In conclusion, this study was able to address how the ROH can effect starting and stopping performance, however further research is required to understand the effect of, and interaction between, the ROH and other blade sharpening characteristics on skating performance. Furthermore, the game of hockey includes skills beyond stopping and starting, therefore future studies should include a detailed analysis of all skills performed in a game situation. This would allow us to gain a greater perspective of the global effects of the skate blade hollow on game performance.

Potential limitations of the study include the use of human subjects, two-dimensional analysis of the video, and the recording speed of the video camera. The RRS requires a maximum effort from each subject. Given the practical nature of this test, there was no way to ensure maximum effort and motivation by the study's participants. Heart rates were recorded to assist in the interpretation of the participant's efforts. Secondly, this study was conducted using two-dimensional kinematic analyses assuming symmetry of limbs and that the majority of motion could be captured in the sagittal plane. Variables such as stride length and stopping distance are examples of movements that partially could take place in the frontal plane. Movement outside of the sagittal plane is not reflected in the current analysis and interpretation. Lastly, this researcher acknowledges the use of video recorded at 30 fps may not have been fast enough to adequately capture

the speed of movement collected during this study. Evidence of this is seen in the analysis of the stopping phase; significant differences in the stopping time variable are close to being smaller than the frame per second of the recording time.

The findings of this study contribute to the current base of scientific knowledge and understanding of skate sharpening, more specifically, the effect that the ROH has on starting and stopping performances. This information is useful to both the sport and sporting community from skaters on the ice to the sharpening technicians. It is important to realize that the sharpening a technician applies to the skater's blades can potentially affect the skater's performance. It can be suggested that if the skate blades are not appropriately sharpened, the skater may be expending more time and energy compensating or adapting to their blades as opposed to honing their skill and focusing on skating performance. Research and technician-based education on skate sharpening provides the technician with empirical evidence to support their choices in best practices in sharpening to best serve their clients. Furthermore, the results of this study can be generalized as relevant to all skaters spanning both age and ability, from recreational skaters to professional hockey players. A player can be physiologically fit, biomechanically efficient, and highly skilled, however all this could be rendered insignificant without optimal attention to the manner in which the skate blades interact with the ice surface.

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Table 1. Anthropometric measures of participants

	Mean	S.D.
Age (y)	19	1.5
Weight (kg)	77.8	8.71
Height (cm)	177.2	9.70

Data are mean \pm S.D. (n = 15)

Table 2. Performance variables of the RRS

	0.63 cm	1.27 cm	1.90 cm
Complete Trial Time (s)	78.30 ± 1.77	78.38 ± 1.85	78.90 ± 1.93
Fatigue Index(s)	1.59 ± 0.44	1.78 ± 0.42	1.61 ± 0.55
Speed Index (s)	6.73 ± 0.23	6.71 ± 0.19	6.82 ± 0.31
Anaerobic Capacity (W)	476.87 ± 54.68	476.37 ± 54.62	473.24 ± 54.40
Anaerobic Power (W)	574.45 ± 61.12	576.34 ± 64.47	567.50 ± 65.29
Max Heart Rate (beats/min)	179 ± 8.70	175 ± 9.70	182 ± 9.36

Data are mean ± S.D. (n = 15)

Table 3. Kinematic measures during acceleration and stopping phases of the RRS

	0.63 cm	1.27 cm	1.90 cm
Average Velocity over 6 meters (m/s)	3.457 ± 0.17	3.428 ± 0.17	3.448 ± 0.13
Stride Length (m)	1.924 ± 0.06	$1.986 \pm 0.06 \sim$	1.879 ± 0.03
Stride Rate (stride/s)	$2.464 \pm 0.13^{\wedge\wedge}$	$2.420 \pm 0.13^{\wedge}$	2.515 ± 0.11
Initial Velocity (m/s)	8.389 ± 0.41	$8.613 \pm 0.51^{\dagger}$	8.345 ± 0.34
Stopping Time (s)	0.812 ± 0.01	0.828 ± 0.02	$0.836 \pm 0.02^{\ddagger}$
Stopping Distance (m)	$4.120 \pm 0.13^{\diamond}$	4.433 ± 0.08	4.352 ± 0.12

Data are mean \pm S.D. (n = 15)

\sim Significantly longer SL vs. 1.90cm

\wedge Significantly slower SR vs. 1.90 cm

$\wedge\wedge$ Significantly slower SR vs. 1.90 cm

\dagger Significantly greater IV vs. 0.63 cm

\ddagger Significantly longer ST vs. 0.63

\diamond Significantly shorter SD vs. 1.27 cm and 1.90

($p < 0.05$)

Table 4. Average velocity over 6 meters during RRS

	0.63 cm	1.27 cm	1.90 cm
T1-Average Velocity (m/s)	3.65 ± 0.26 [~]	3.65 ± 0.21 [^]	3.63 ± 0.31 [†]
T2-Average Velocity (m/s)	3.47 ± 0.33	3.60 ± 0.23	3.58 ± 0.28
T3-Average Velocity (m/s)	3.49 ± 0.68	3.48 ± 0.26	3.41 ± 0.25
T4-Average Velocity (m/s)	3.42 ± 0.20	3.31 ± 0.17	3.43 ± 0.31
T5-Average Velocity (m/s)	3.23 ± 0.18	3.31 ± 0.20	3.34 ± 0.24
T6-Average Velocity (m/s)	3.31 ± .23	3.22 ± 0.17	3.29 ± 0.34

Data are mean ± S.D. (n = 15)

~ Significantly greater than T4-6 on 0.63 cm ROH

^ Significantly greater than T3-6 on 1.27 cm ROH

† Significantly greater than T3-6 on 1.90 cm ROH
($p < 0.05$)

Table 5. Stride rate measurements during 6 meters of the acceleration phase of RRS

	0.63 cm	1.27 cm	1.90 cm
T1-Stride Rate (st/s)	2.67 ± 0.37 [~]	2.64 ± 0.24 [^]	2.68 ± 0.14 [†]
T2-Stride Rate (st/s)	2.56 ± 0.21	2.50 ± 0.25	2.60 ± 0.15
T3-Stride Rate (st/s)	2.44 ± 0.15	2.42 ± 0.28	2.52 ± 0.18
T4-Stride Rate (st/s)	2.41 ± 0.24	2.32 ± 0.20	2.45 ± 0.20
T5-Stride Rate (st/s)	2.35 ± 0.17	2.30 ± 0.21	2.41 ± 0.27
T6-Stride Rate (st/s)	2.35 ± 0.19	2.36 ± 0.25	2.43 ± 0.22

Data are mean ± S.D. (n = 15)

~ Significantly faster SR then T3-6

^ Significantly faster SR then T2-6

† Significantly faster SR then T2-6

($p < 0.05$)

14

Table 1: Summary of the data set			
Variable	Unit	Range	Mean
Age	Years	18-80	45.2
Gender	Male/Female	0/1	0.48
Income	Dollars	10,000-100,000	35,000
Education	Years	12-18	15.1
Marital Status	Married/Single	0/1	0.62
Health Status	Good/Poor	0/1	0.75
Employment	Employed/Unemployed	0/1	0.85
Home Ownership	Own/Rent	0/1	0.70
Vehicle Ownership	Own/Don't Own	0/1	0.65
Travel Frequency	Times/Week	0-10	3.5
Travel Distance	Miles	0-100	25.0
Travel Cost	Dollars	0-1000	150.0
Travel Satisfaction	1-5	1-5	3.2

Table 6. Stride length measurements during 6 meters of the acceleration phase of RRS

	0.63 cm	1.27 cm	1.90 cm
T1-Stride Length (m)	1.84 ± 0.20 [~]	1.87 ± 0.25 [^]	1.85 ± 0.35 [†]
T2-Stride Length (m)	1.97 ± 0.31	2.03 ± 0.25	1.89 ± 0.34
T3-Stride Length (m)	2.00 ± 0.30	2.04 ± 0.24	1.91 ± 0.32
T4-Stride Length (m)	1.89 ± 0.23	2.02 ± 0.22	1.89 ± 0.26
T5-Stride Length (m)	1.87 ± 0.28	2.01 ± 0.30	1.90 ± 0.28
T6-Stride Length (m)	1.97 ± 0.35	1.94 ± 0.26	1.82 ± 0.22

Data are mean ± S.D. (n = 15)

~ Significantly shorter SL then T3

^ Significantly shorter SL then T2-3

† Significantly shorter then T2-3

($p < 0.05$)

Table 7. Initial velocity values during the stopping phase of RRS

	0.63 cm	1.27 cm	1.90 cm
T1-Initial Velocity (m/s)	8.86 ± 0.86	9.29 ± 0.85 [^]	9.04 ± 1.02 [†]
T2-Initial Velocity (m/s)	8.92 ± 0.76 [~]	9.18 ± 0.97	8.84 ± 0.91
T3-Initial Velocity (m/s)	8.40 ± 0.68	8.48 ± 0.85	8.48 ± 0.73
T4-Initial Velocity (m/s)	8.11 ± 0.65	8.49 ± 0.77	8.24 ± 0.60
T5-Initial Velocity (m/s)	8.01 ± 0.61	8.10 ± 0.46	8.05 ± 0.57
T6-Initial Velocity (m/s)	8.04 ± 0.76	8.12 ± 0.67	7.92 ± 0.59

Data are mean ± S.D. (n = 15)

~ Significantly greater AV then T3-6

[^] Significantly greater AV then T3-6

[†] Significantly greater AV then T3-6
(*p* < 0.05)

Table 7. Initial velocity values during the stopping phase of RRS

	0.63 cm	1.27 cm	1.90 cm
T1-Initial Velocity (m/s)	8.86 ± 0.86	9.29 ± 0.85 [^]	9.04 ± 1.02 [†]
T2-Initial Velocity (m/s)	8.92 ± 0.76 [~]	9.18 ± 0.97	8.84 ± 0.91
T3-Initial Velocity (m/s)	8.40 ± 0.68	8.48 ± 0.85	8.48 ± 0.73
T4-Initial Velocity (m/s)	8.11 ± 0.65	8.49 ± 0.77	8.24 ± 0.60
T5-Initial Velocity (m/s)	8.01 ± 0.61	8.10 ± 0.46	8.05 ± 0.57
T6-Initial Velocity (m/s)	8.04 ± 0.76	8.12 ± 0.67	7.92 ± 0.59

Data are mean ± S.D. (n = 15)

~ Significantly greater AV then T3-6

[^] Significantly greater AV then T3-6

[†] Significantly greater AV then T3-6
(*p* < 0.05)

Table 8. Stopping time measurements during the stopping phase of RRS

	0.63 cm	1.27 cm	1.90 cm
T1-Stopping Time (s)	0.83 ± 0.11	0.86 ± 0.15 [^]	0.85 ± 0.12
T2-Stopping Time (s)	0.80 ± 0.09	0.86 ± 0.12	0.81 ± 0.10
T3-Stopping Time (s)	0.81 ± 0.09 [~]	0.82 ± 0.10	0.93 ± 0.25
T4-Stopping Time (s)	0.81 ± 0.08	0.81 ± 0.11	0.80 ± 0.07
T5-Stopping Time (s)	0.80 ± 0.13	0.82 ± 0.12	0.84 ± 0.08
T6-Stopping Time (s)	0.82 ± 0.12	0.80 ± 0.12	0.84 ± 0.09

Data are mean ± S.D. (n = 15)

[^] Significantly greater ST then T6

[~] Significantly shorter SD then 1.90 cm T3

(*p* < 0.05)

Table 9. Stopping distance measurements during the stopping phase of RRS

	0.63 cm	1.27 cm	1.90 cm
T1-Stopping Distance (m)	4.37 ± 0.90~	4.52 ± 0.98	4.41 ± 0.60
T2-Stopping Distance (m)	4.02 ± 0.62	4.52 ± 0.72	4.32 ± 0.69
T3-Stopping Distance (m)	4.09 ± 0.70	4.46 ± 0.72	4.56 ± 0.65
T4-Stopping Distance (m)	4.01 ± 0.63	4.38 ± 0.77	4.21 ± 0.58
T5-Stopping Distance (m)	4.05 ± 0.79	4.39 ± 0.74	4.34 ± 0.58
T6-Stopping Distance (m)	4.17 ± 0.82	4.31 ± 0.79	4.27 ± 0.68

Data are mean ± S.D. (n = 15)

~ Significantly greater SD then T2-3
($p < 0.05$)

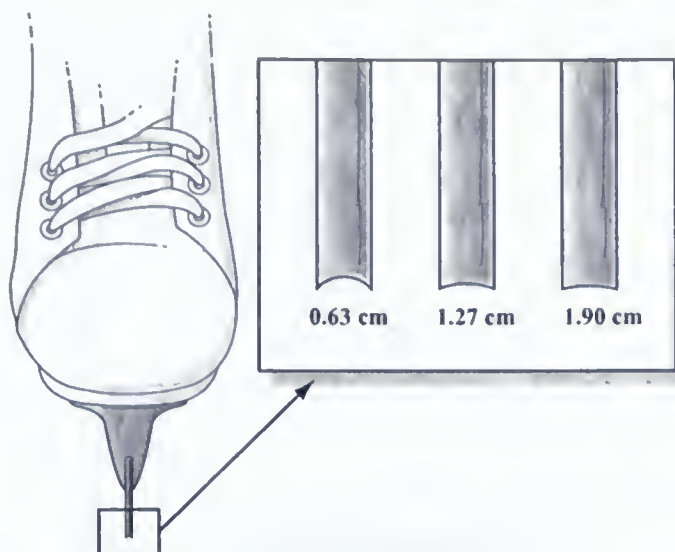


Figure 1. Skate blade radius of hollow (ROH) (frontal view).



Figure 2. Skate blade radius of contour (ROC) (lateral view)



Figure 3. Skate blade height (lateral view).

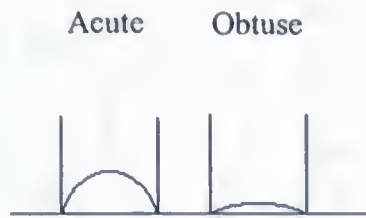


Figure 4. Bite angle

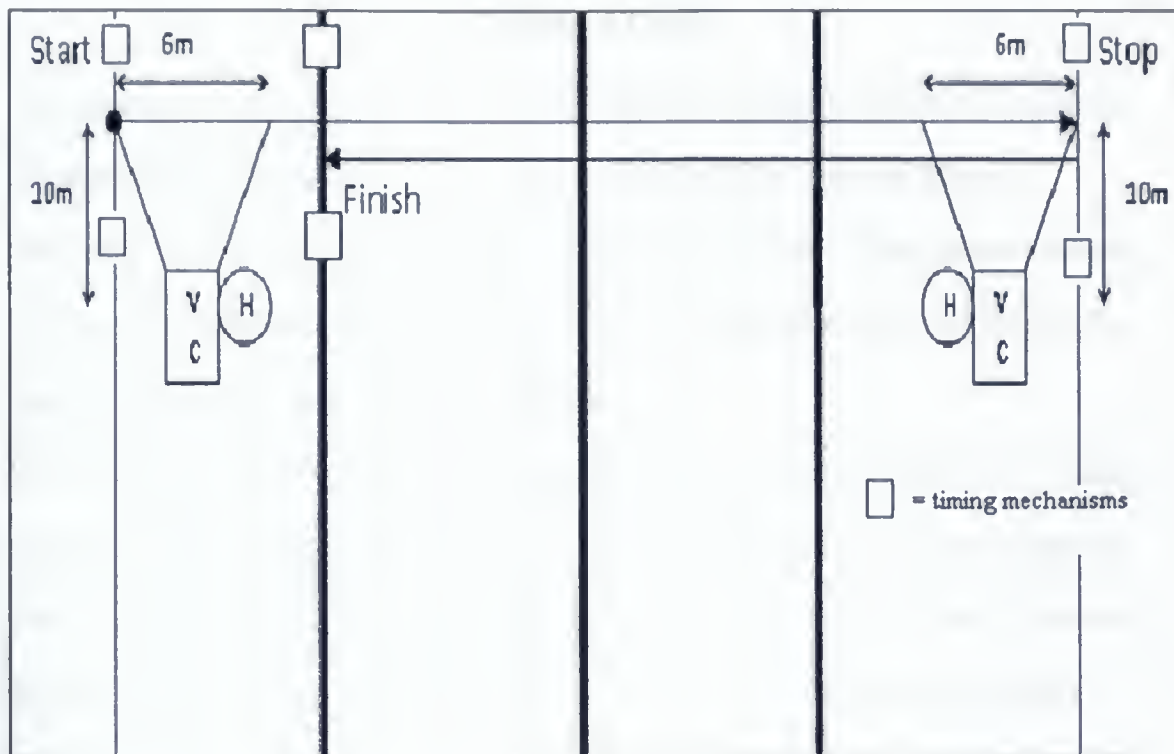


Figure 5. Reed Repeat Skate set-up

Glossary of Terms

AV: *Average Velocity of the Hip.* Calculated using the distance skated (6 m) during the acceleration phase divided by the time the participant took to skate the distance.

SR: *Mean Stride Rate.* Mean number of strides per second (st/s). Determined by dividing the number of completed strides within the 6 meters acceleration phase and dividing by the time taken to perform the completed strides.

SL: *Mean Stride Length.* Mean stride length during the acceleration phase (m). A stride is defined as toe-off of the right foot and is completed with the toe-down of the right foot. Toe-off occurs when the blade is no longer in contact with the ice. This frame is used as the first reference frame. Toe-down occurs when the blade of the same skate makes contact with the ice. This frame is used as the second reference frame, the difference between these two frames is the length of the stride. Measurement of stride length occurs during the acceleration phase. Measuring begins from the first toe-off of the initial movement and ends with the last completed stride (toe down) before 6 m. The average stride length is calculated by summing the calculated stride lengths and dividing by the number of strides.

6MT: *Time to 6 m.* Time it takes to skate 6 m (s). The displacement of the hip joint x-coordinate is used to determine both the initiation of the skate and when the participant covers the 6 m distance. The initial movement of the participant (reference frame) is the point in the data where the value of the hip x-coordinate increases by more than .004 m for 5 consecutive frames. The x-hip reference frame is used with displacement data to determine the reference frame for 6 m. Time for each participant to complete 6 m will be determined by subtracting the initial reference frame number from the 6 m reference

frame number and multiplying the difference by 0.0166 s (time per frame). For example, (6 meter reference frame (367) – initial reference frame (52) = 315 frames * 0.0166 s = 5.23 s)

IV: *Velocity at initiation of stop.* The initiation of the stopping motion will be defined as the frame in which the skater reaches peak horizontal hip velocity followed by successive frames of decreasing velocity (m/s).

SD: *Stopping distance.* Calculated from the frame number that the participant achieves peak velocity to the frame number of zero horizontal velocity of the posterior ankle marker (m). Stopping distance is determined using the displacement data of the x-coordinate of the posterior ankle marker, subtracting the displacement value at the complete stop frame from the displacement value at the initiation of the stop frame.

ST: *Time to complete stop.* Time (s) the participant takes to go from the initiation of the stopping motion to a complete stop. Time to complete stop is determined by subtracting the complete stop frame number from the initiation of the stop frame number and multiplying by 0.0166 s (time per frame).

Appendix A

Participant Consent Form

EFFECT OF RADIUS OF HOLLOW ON ANAEROBIC PERFORMANCE: A KINEMATIC EXAMINATION OF THE STRENGTH/EQUIPMENT/TECHNIQUE INTERACTION

Principal Investigator: Andrew Winchester, M.Sc. Candidate, Faculty of Applied Health Sciences, Brock University

Faculty Supervisor: Kelly Lockwood, Ph.D., Faculty of Applied Health Sciences, Brock University

Participants Name: _____

Overview of Program:

The effect skate sharpening has on skater performance has been subject to assumptions made by many of people with only limited scientific investigation of the effect. It has been shown that blade radius of hollow (ROH), radius of contour (ROC), and balance point can affect stopping distance; this study hopes to further investigate the effect ROH has on skating performance.

The study will consist of two phases of testing. In phase I, the participants will be asked to complete a Reed Repeat Skate (RRS) on four separate occasions, separated by no less than 48 hours. Before each on-ice testing session, the participants will be required to drop their skates off at the Brock University On-Ice Performance Laboratory. The skates' ROH will be altered to one of three randomly assigned ROH, $\frac{1}{4}$ ", $\frac{1}{2}$ ", $\frac{3}{4}$ ". The subject will have a different ROH during each of the first three RRS tests and for the last RRS one of the three ROH will be re-assigned to measure performance consistency. Each on ice testing session will last one hour. At the time the subject will have reflective markers placed on his right leg as well as skate boot. Before the RRS the skater will be given fifteen minutes to warm up, stretch and become familiar with the randomly assigned ROH. The RRS consists of six trials; each trial requires the skate from goal line to goal line and back to the far blue line. Each trial is to be skated as fast as possible and the skater will be given a short rest after each trial. All trials will be recorded via video camera. At the completion of the six trials the skater will be allowed a cool down skate and then must return to the dressing room to have the reflective markers removed. Appropriate apparel required for the RRS, consists of dark spandex shorts, a tight dark t-shirt, helmet, gloves, and the same skates for each trial.

Phase II will take approximately one hour to complete and asks the participant to complete two strength tests in the Brock University Physiology and Biomechanics laboratories. The first test is a maximum strength test completed on a Biodex dynamometer. The participant will warm-up on a cycle ergometer and then perform a set

of static stretches. A familiarization session, including test expectations and sub maximal trials will be performed to ensure the participant is comfortable and prepared to perform the maximum strength test. The test will require the subject to complete five repetitions at a maximum effort against the force arm of the Biodex dynamometer. The second test is a counter-movement vertical jump test that will be performed in the Biomechanics Laboratory. The test asks the participant to complete five maximum jumps while standing on a force platform. The participant will be given instruction on how to properly perform the vertical jump test. During the practice the participant must ensure they are capable of jumping and landing within the force platforms dimensions. Once comfortable with the protocol the participant will perform five trials at maximum effort with a minute rest between each trial.

I, _____,

1. Have read and understood the relevant information regarding this research project
2. Understand that I may ask questions at any given time
3. Indicate free consent to research participation by signing this research consent form
4. Understand that I am free to withdraw at any time without penalty

Participant's Signature: _____

Guardian's Name: _____

Guardian's Signature: _____

Andrew Winchester, M.Sc. Candidate
Faculty of Applied Health Sciences, Brock University
(905) 687-6583
andrewwinchester@sympatico.ca

Kelly Lockwood, Ph.D.
Faculty of Applied Health Sciences, Brock University
(906) 688-5550 ext. 3092
kelly.lockwood@brocku.ca

Appendix B

Data Collection Sheet

Effects of Radius of Hollow Study

Andrew Winchester, Candidate M.Sc.

Faculty of Applied Health Sciences

Brock University, St. Catharines, ON

Subject Data Sheet

Name: _____ Age: ____ y D.O.B.

MM/DD/YYYY

Street Address: _____ City:

Postal Code: _____ Tel:

In case of Emergency, contact: _____ Tel:

Important Medical Information:

Team/Level: _____

Test Day 1

	1	2	3	4	5	6	Total
Speed Index							
Complete Trial Time							
Max. HR							

Test Day 2

	1	2	3	4	5	6	Total
Speed Index							
Complete Trial Time							
Max. HR							

Test Day 3

	1	2	3	4	5	6	Total
Speed Index							
Complete Trial Time							
Max. HR							

Test Day 4

	1	2	3	4	5	6	Total
Speed Index							
Complete Trial Time							
Max. HR							

Appendix C

Reed Repeat Skate Calculations

Reed Repeat Skate calculations. Note: From “Laboratory and on-ice test comparisons of anaerobic power of ice hockey players,” 1986, Canadian Journal of Applied Sport Sciences, 11, 4, p. 221.

$$\text{RRS Anaerobic Power} = \frac{\text{wt(kg)} * \text{distance (49.68m)}}{\text{time (s)}}$$

Equation 1. Anaerobic Power

$$\text{RRS Anaerobic Capacity} = \frac{\text{wt(kg)} * \text{distance (479.69m)}}{\text{time (s)}}$$

Equation 2. Anaerobic Capacity

Appendix D

Pearson Product Moment Correlation between Speed Index and Fatigue Index

	QSI	QFATIGUE	HSI	HFATIGUE	TSI	TFATIGUE
QSI	1					
QFATIGUE	-0.55*	1				
HSI	0.340	0.11	1			
HFATIGUE	-0.04	-0.26	-0.73*	1		
TSI	0.36	0.01	0.72*	-0.58*	1	
TFATIGUE	-0.10	-0.15	-0.70*	0.72*	-0.73*	1

Q = 0.63cm hollow

H = 1.27 cm hollow

T = 1.90 cm hollow

* Correlation is significant at the 0.05 level

Appendix E

Pearson Product Moment Correlation between Average Velocity and Stride Rate

	QAV	QSR	HAV	HSR	TAV	TSR
QAV	1					
QSR	0.73	1				
HAV	0.77	0.94*	1			
HSR	0.75	0.96*	0.90*	1		
TAV	0.69	0.97*	0.94*	0.88*	1	
TSR	0.77	0.98*	0.96*	0.98*	0.94*	1

Q = 0.63cm hollow

H = 1.27 cm hollow

T = 1.90 cm hollow

* Correlation is significant at the 0.05 level

Appendix F

Pearson Product Moment Correlation between Stopping Distance and Stopping Time

	QSD	QST	HSD	HST	TSD	TST
QSD	1					
QST	0.88*	1				
HSD	0.27	-0.06	1			
HST	0.40	0.02	0.93*	1		
TSD	0.29	0.09	0.50	0.34	1	
TST	0.55	0.44	0.07	0.02	0.83*	1

Q = 0.63cm hollow

H = 1.27 cm hollow

T = 1.90 cm hollow

* Correlation is significant at the 0.05 level

