Skate blade hollow and oxygen consumption during forward skating

By

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Abstract

The purpose of this study was to investigate the effect of skate blade hollow on oxygen consumption during forward skating on a treadmill. Varsity level female hockey players (n = 10, age = 21.7 yr) performed skating tests at three blade hollows (0.25 in, 0.50 in, and 0.75 in). The subjects skated for four minutes at three submaximal velocities (12, 14, and 16 km/h), separated by five minutes of passive recovery. In addition, a VO_2max test was performed on the day that the subjects skated at the 0.50 in hollow. The VO_2max test commenced at 14 km/h and increased by 1 km/h each minute until volitional exhaustion was achieved. Four variables were measured for each skating bout, volume of gas expired (V_E), volume of oxygen consumed (VO_2), heart rate (HR) and rating of perceived exertion (RPE). No significant differences ($p<0.05$) were found in any of the four test variables (V_E, VO_2, HR, RPE) across the three skate hollows. These results show that when skating on a treadmill at submaximal velocities, skate blade hollow has no significant effect on V_E, VO_2, HR or RPE.

Key Words: ice skating, skate blade hollow, skating treadmill, VO_2, women's hockey

Résumé

Cette recherche avait comme but d'étudier l'influence de l'aiguisage du patin de hockey sur la demande d'oxygène lors du patinage avant sur un tapis roulant pour patin à glace. Les sujets étaient des membres d'une équipe hockey féminin universitaire (n = 10, âge moyenne = 21.7 ans) et devaient exécuter trois séances de patinage avant avec trois différents rayons de profondeurs d'aiguisage de la lame du patin (0,25 pouce, 0,5 pouce et 0,75 pouce). Les séances consistaient en trois intervalles de quatre minutes d'intensité sous-maximale (12, 14 et 16 km/h), avec cinq minutes de repos immobile entre chaque intervalle. De plus, un test de VO_2max fut exécuté lors de la séance avec le rayon d'aiguisage de 0,5 pouce. Le test débuta à une vitesse de 14 km/h et augmenta de 1 km/h chaque minute jusqu'à l'épuisement du sujet. Quatre variables furent mesurées lors de chaque séance : le volume de gaz expiré (V_E), le volume d'oxygène consommé (VO_2), la fréquence cardiaque (FC), ainsi que l'indice de perception de la fatigue (IPF). Les résultats ne démontrèrent aucune différence considérable ($p<0.05$) pour les quatre variables lors de chaque séance. Les résultats démontrent donc que le rayon d'aiguisage du patin lors du patinage avant sur tapis roulant à une vitesse sous-maximale n'a aucune influence sur le V_E, le VO_2, la FC et/ou IPF.

Acknowledgements

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12) Photographs should be supplied as unmounted black and white, high contrast prints.

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14) Acknowledgements should be brief and must include reference to sources of financial support.

Skate blade hollow and oxygen consumption during forward skating

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Abbreviated Title

Skate blade hollow and VO_2 during ice skating

Introduction

Several authors have investigated the mechanisms for locomotion on-ice (Mendelson, 1985; Zatsiorski et al., 1987; Ingen Schenau, 1989; De Koning et al., 1992; Colbeck, 1995; Pearsall et al., 2000). All of these authors presume that the low coefficient of friction seen during skating on-ice is due to the presence of a film of water between the blade of the skate and the ice surface. Although the mechanisms for sliding have been investigated, the importance of the blade itself seems to have been overlooked.

Hockey players recognize and value the contribution to performance of a properly sharpened skate blade. However our literature review located no studies which had investigated the effects of altering any skate blade characteristics on-ice hockey performance. Lavalee (1979) and Broadbent (1983a, 1983b, 1988) have identified some of the important characteristics of the skate blade. Both authors identify skate blade radius of hollow (ROH) as a significant variable in skating performance, however, no rationale or data were provided to support these claims. Radius of hollow refers to the curvature between the outside and inside edges of the skate blade (Figure 1). This radius is created by using a curved grinding stone when sharpening the skate. For example, if the sharpener uses a stone with a 0.50 in radius curved edge, then when this stone is placed against the blade of the skate, this edge will grind a hollow of 0.50 in radius into the blade. By changing the radius of the stone, the ROH that is put onto the skate blade is altered.

There are several aspects of skating performance (agility, speed, acceleration and oxygen cost of skating) that could potentially be affected by changing the characteristics of the skate blade. Speed skaters, who are primarily concerned with speed and not with agility, prefer to skate on a blade with minimal ROH (Broadbent, 1983b). Hockey players and figure skaters however, are concerned with both speed and agility. Typically, they use a ROH ranging from 0.375 in to 1.5 in (Broadbent, 1983a).

Physical effort of ice skating has varying aerobic and anaerobic contributions depending on skating velocity. During steady state moderate exercise of short duration, oxygen consumption can be used to estimate energy expenditure since the anaerobic contribution is minimal. The purpose of this study was to examine the effect of altering ROH on oxygen consumption during forward skating.

Methods

Ten female university ice hockey players volunteered to participate in this study. These subjects were selected as they represent high level female hockey players. Informed consent was obtained, with all procedures approved by the ethics committee of the university. Anthropometric measurements of height and mass were made and percent fat was measured using a Tanita BF-350 Body Composition Analyzer (Tanita Corporation of America, Evanston, IL, US). Subjects reported to the lab in a hydrated state on the day of the body fat analysis. The Body Composition Analyzer operates by sending an electrical current through the body between two electrodes located under the feet. This method of measuring body composition is common and has been shown to be both reliable and valid in healthy adults (Nunez et al., 1997).

Subjects wore their own skates during all skating sessions. They were not aware of what ROH had been used by their skate sharpening technician. Before each session, the skates were sharpened to the desired hollow by a trained technician using an Alpha Edge skate sharpener (CMJ Marketing, Fergus Ontario, Canada). Radius of hollow and level of edges were measured using a tool described as a Hollow Depth Indicator (Edge Specialties

Inc, Alexandria, Minnesota, USA). The hollow depth indicator measures the depth of the ROH to the nearest 0.0005 in. The following data describing the subjects' skates were also collected prior to testing: skate brand, model, size, blade type, blade width and blade height. Blade width and height were measured using a slide rule caliper. These characteristics are described in Table 1.

Each subject participated in three treadmill skating sessions, 0.25 in (6.35 mm) hollow, 0.50 in (12.7 mm) hollow and 0.75 in (19.05 mm) hollow. The units of measurement for skate blade hollow used by manufacturers and technicians are traditionally inches, therefore, skate measurements will be described in inches throughout this paper. All skating sessions were performed following completion of the competitive phase of the season. The subjects were randomly assigned to the three skate blade hollow conditions. In all skating sessions, the subjects wore shorts and a T-shirt.

The skating sessions were performed on a skating treadmill (Acceleration Canada, Calgary, AB). All subjects completed a minimum of three 30 min familiarization sessions prior to the commencement of testing in order to allow them to feel comfortable and confident when skating on the treadmill. The skating treadmill has a skating surface area of 3.20 m^2 (1.80 m wide X 1.78 m long). The surface is covered with a series of polyethylene slats attached to a rubber belt which rolls over two drums. Prior to each test, the surface was sprayed with silicone oil to reduce the friction between the skate blade and the polyethylene surface. During all skating sessions, subjects wore a safety harness attached to an overhead track as a precaution in the event of a fall. The testing set-up of the treadmill, harness, and metabolic gas collection system is illustrated in Figure 2.

Oxygen consumption was measured at three skating velocities (12, 14, and 16 km/h) on each hollow condition. The velocities were performed in progressive order from slowest to fastest. Subjects skated for four minutes at each velocity with physiological data averaged over the last two minutes. Subjects had 5 minutes of passive recovery between skating bouts. On the day that the subjects were skating on the 0.50 in hollow condition, they also performed a VO_2max test. After the third skating bout, the subject was given an additional 5 minutes of passive recovery, and then performed the VO_2max test. This test commenced at 14 km/h and increased in increments of 1 km/h each minute until volitional exhaustion was reached. During all skating sessions the grade of the treadmill was 0%.

Expired air was collected and averaged every 10 seconds using a metabolic cart (Medisoft, Dinant, Belgium). Physiological data were examined to confirm that R remained below 1.00 for each submaximal skating bout and exceeded 1.10 for the VO_2max test. Heart rate (HR) data were collected and averaged every 5 seconds using a Polar Accurex Plus HR monitor (Polar Electro, Kemple, Finland).

After each skating bout, subjects were asked to rate their perceived exertion on a Borg scale ranging from 6 to 20. On this scale, 7 is described as very, very light, and 19 as very, very hard. Also, on completion of each testing condition, the subjects were asked to rate the degree to which they felt their skates bit into the surface on a 10-point Leipert scale. Upon completion of all three testing conditions, the subjects were asked to rate the hollows from best to worst in terms of the role of the sharpening to their performance. These subjective tests were completed without knowledge of the physiological results.

Two way (3 hollows x 3 velocities) repeated measures ANOVA's were performed for each of the four variables (V_E, VO_2, HR and RPE). For all statistical analysis, a probability of less than 0.05 was considered to be significant.

Results

Mean (± SD) values for the 10 female hockey players were: age = 21.7 ± 0.8 years, height = 167.3 ± 3.7 cm, mass = 65.4 ± 6.7 kg and percent fat = 21.0 ± 3.1 %. These values are typical of female varsity hockey players.

Table 2 shows the VO_2, V_E, HR and RPE results for the three skate blade hollow conditions and the three velocities. As would be expected, VO_2 ($F = 30.2$; df = 2, 81; $P < 0.001$), V_E ($F = 62.2$; df = 2, 81; $P < 0.001$), HR ($F = 44.0$; df = 2, 81; $P < 0.001$) and RPE ($F = 55.5$; df = 2, 81; $P < 0.001$) were all significantly different across the three test velocities. All four of these variables increased with increasing velocity.

The mean VO_2 values for the three radii of hollows were similar at the three velocities. At 12 km/h, mean VO_2 values were 29.4, 29.5 and 27.8 ml/kg·min respectively for the 0.25, 0.50 and 0.75 in hollows with the maximum difference being only 1.7 ml/kg·min. At 14 km/h, the values differed by 1.6 ml/kg·min, and at 16 km/h the maximum difference was 1.7 ml/kg·min. No significant differences were found for VO_2 ($F = 2.3$; df = 2, 81; $P < 0.11$), V_E ($F = 1.5$; df = 2, 81; $P < 0.221$), HR ($F = 0.26$; df = 2, 81; $P < 0.772$), or RPE ($F = 0.224$; df = 2, 81; $P < 0.800$) among the three hollow radii.

Additionally, there were no significant interaction effects between velocity and hollow for any of VO_2 ($F = 0.026$; df = 4, 81; $P < 0.999$), V_E ($F = 0.041$; df = 4, 81; $P < 0.997$), HR ($F = 0.101$; df = 4, 81; $P < 0.982$), or RPE ($F = 0.224$; df = 4, 81; $P < 0.924$).

The subjective ranking of the three hollows are summarized in Table 3. Seven of the ten subjects felt that the middle hollow (0.50 in) was the best in terms of the role of sharpening to their performance, with none selecting the 0.75 in. The 0.75 in hollow was cited by five of the skaters as the worst, with three selecting the 0.25 in, and the remaining two skaters selecting the 0.50 in hollow as the worst.

The bite scores attributed to each hollow are summarized in Table 3. These scores were not significantly different ($F = 1.376$; $df = 2, 27$; $P < 0.27$) among the three different hollow radii. When sharpening skates, body mass is a variable of consideration when ROH is placed in the skate blade. Since the standard deviation for body mass of our sample was 6.7 kg, we examined the ratings of bite scores by comparing the responses of the 5 subjects with lower mass (mean = 59.6 kg) versus the 5 subjects with higher body mass (mean = 71.2 kg). This analysis of the bite scores showed that subjects with lower body mass gave a higher score to the 0.25 in ROH whereas subjects with higher body mass gave a higher score to the 0.50 in ROH.

Discussion

The major finding of this study was skate blade radius of hollow did not have a significant effect on oxygen consumption, heart rate, ventilation and perceived exertion during submaximal forward skating on a treadmill. Treadmill skating velocities of 12, 14 and 16 km/h corresponded to 67, 75 and 82 % of VO_2max for the female varsity ice hockey players in this study. Figure 3 illustrates the linear relationship between VO_2 and forward skating using data from four studies on-ice and two studies on a skating treadmill. The on-ice studies used either a 110-m oval course (Carroll et al., 1993) or a 140-m oval course

(Ferguson et al., 1969; Montgomery and Cartwright, 1994; Nobes et al., 2003; Riby, 1994) with velocities ranging from 12.5 to 26 km/h.

Our study is the first to report VO_2 values for ice skating using female subjects. Compared to studies using male subjects, the skating velocities were lower in the current study. Nobes et al. (2003) used velocities ranging from 18 – 22 km/h for male varsity hockey players while we selected velocities of 12 – 16 km/h for female varsity hockey players. When expressed as a percentage of maximum values for ventilation, VO_2 and HR, we observed similar efforts even though the velocities were lower. For example, VO_2 was 74% of maximum at 18 km/h for male subjects (Nobes et al., 2003), and in our study VO_2 was 75% of maximum at 14 km/h. Figure 3 demonstrates the linear relationship between treadmill skating velocity and VO_2 for our female subjects and the male subjects of Nobes et al. (2003).

VO_2, HR, and stride rate are significantly greater on the treadmill than on-ice at similar submaximal velocities (Nobes et al., 2003). At 20 km/h, VO_2 was 6 ml/kg·min higher on the treadmill than on-ice. At this velocity, the intensity relative to the maximum value for each modality was 67.5% on-ice compared to 80.3% on the treadmill. HR values confirmed the higher intensity when skating on the treadmill. At 20 km/h, the HR was 16 bpm higher on the treadmill. Nobes et al. (2003) proposed two potential factors to explain the different physiological and kinematic patterns on-ice versus the treadmill. One explanation relates to the skating task. The treadmill test was performed only in a linear direction, whereas the on-ice test was performed on an oval course requiring cross over strides which may require greater energy expenditure.

The second factor relates to surface friction. On the treadmill, resistive forces increase the drag on a player's skate compared to on-ice thereby reducing the glide phase of the stride (Dreger, 1997). This results in lower stride lengths and higher stride rates at a specific velocity.

Gliding while skating on-ice is possible due to the presence of a liquid layer between the skate blade and the ice surface, which creates a low coefficient of friction. There are several theories as to the cause of this liquid layer, including pressure melting (Ingen Schenau et al., 1989), frictional heating, (Colbeck, 1995; Mendelson, 1985), and intrinsic properties of the ice surface (De Koning et al., 1992). When skating on a treadmill, there is no liquid layer formed between the skate and the surface. To reduce the resistive forces on the treadmill, silicon oil is applied to the skating surface to lower the coefficient of friction. However, these skating surfaces may be sufficiently different to warrant further on-ice investigations.

The role of skate blade sharpening in skating performance is not well understood. To date there have been no scientific publications investigating the effects of altering the characteristics of the skate blade on performance or physiological variables. We hypothesized that physiological (V_E, VO_2, HR) and psychological (RPE) variables would be affected by changes in the ROH. The ROH most commonly used by ice hockey skaters is 0.50 in (Broadbent, 1983a). Our results showed that a more concave ROH or a flatter ROH had no significant effect on VO_2, V_E, HR, and RPE in a four minute submaximal skating test. The lack of significant effects could potentially have been due to the narrow range of hollows selected, the nature of the treadmill surface or our physiological measurements. Possibly, measurements of force or coefficients of friction are needed to support an effect of ROH on skating performance.

When rating the three ROH conditions as a contributing factor in skating performance, none of the ten subjects selected the flatter (0.75 in) ROH as the best condition. The polyethylene surface of the treadmill may be such that it did not allow the skate blade to "bite" into the surface to the same extent as an ice surface. Alterations in external power output resulting from changes in ROH may be too small, and measurements of oxygen consumption are not sufficiently sensitive to measure this effect. Thus it appears that changes in ROH do not alter our physiological measurements or the rating of perceived exertion.

In summary, these results showed that at submaximal velocities, VO_2, V_E, HR, and RPE were not influenced by skate blade radius of hollow in the range of 0.25 to 0.75 in on a plastic surface. The possible psychological effects on performance cannot be discounted, however, and may account for the subjective perception that skate sharpening with 0.50 in radius of hollow was preferred versus the more concave (0.25 in) and the flatter (0.75 in) radius. This study has implications for individuals in the field who sharpen skates and for individuals involved in manufacturing skates. Because no attempt was made to evaluate the effects of ROH on maximal performance, agility maneuvers, acceleration or deceleration, these questions remain for future investigations. Also needed are investigations of the effects of different skate blade characteristics (radius of contour, blade lie and skate balance point) on these skating movements.

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Table 1 Characteristics of the subjects skates

Subject	Skate Brand	Skate Model	Skate Size	Blade Type	Blade Width (inches)	Blade Height (inches)
1	Bauer	Vapor 8	5.5	Tuuk	0.125	0.445
2	Bauer	Supreme 4000	6.5	Tuuk	0.125	0.425
3	Graf	Supra 705	5	Graf Cobra 2000	0.115	0.475
4	Bauer	Vapor 10	3.5	Tuuk C+	0.125	0.401
5	Bauer	Vapor 10	6	Tuuk C+	0.125	0.492
6	Bauer	Vapor 10	5	Tuuk C+	0.120	0.555
7	Graf	727 Cyber Flex	6	Graf Cobra NT-3000	0.110	0.500
8	Bauer	Vapor 10	6.5	Tuuk C+	0.125	0.485
9	CCM	952	5.5	Prolite 3	0.120	0.415
10	Bauer	Vapor 10	6	Tuuk C+	0.120	0.436

Table 2 V_E, VO_2, HR & RPE while skating at three blade hollows

Velocity km/h	0.25 in Mean	0.25 in S.D.	0.50 in Mean	0.50 in S.D.	0.75 in Mean	0.75 in S.D.
			V_E (L/min)			
12	57.0	6.7	58.6	8.8	53.5	10.6
14	68.0	6.8	69.4	10.6	64.3	10.4
16	85.3	11.2	84.9	11.2	81.9	10.8
Max	--	--	115.2	9.0	--	--
			VO_2 (ml/kg · min)			
12	29.4	2.9	29.5	3.2	27.8	3.5
14	32.7	3.0	32.8	3.2	31.2	3.4
16	35.6	3.1	36.1	3.3	34.4	3.3
Max	--	--	42.9	3.3	--	--
			Heart Rate (beats/min)			
12	163.2	9.8	166.0	9.4	162.0	10.2
14	174.2	8.9	175.2	7.3	174.4	6.2
16	181.3	21.2	183.9	6.9	183.4	6.8
Max	--	--	197.3	5.1	--	--
			RPE			
12	8.8	2.1	9.5	1.8	9.5	2.2
14	11.5	1.6	11.5	1.7	11.5	1.4
16	14.0	1.5	13.8	1.5	14.2	1.6

Table 3 Subjective ranking of hollows

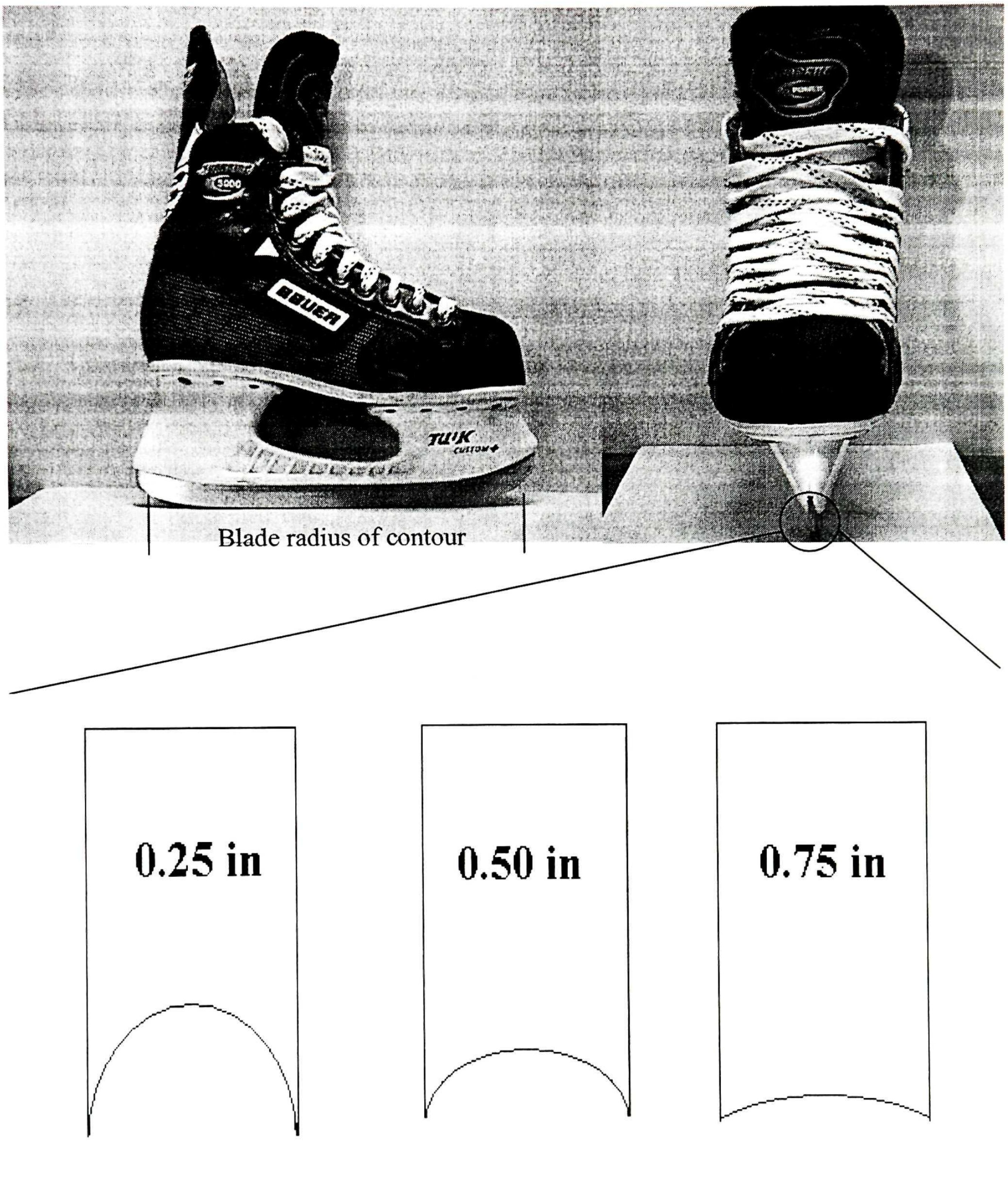
Subject #	Mass (kg)	Bite scores (Leipert scale) 0.25 in	0.50 in	0.75 in	Preferred Hollow	Worst Hollow
1	55.0	6	6	4	0.50	0.25
4	56.0	7	5	7	0.25	0.50
8	61.0	9	8	9	0.50	0.25
3	63.0	7	4	2	0.50	0.75
9	63.0	7	6	8	0.25	0.50
Mean	59.6	7.5	5.8	6.0		
10	69.0	7	6	6	0.25	0.75
5	70.5	6	6	7	0.50	0.75
6	71.0	7	8	5	0.50	0.75
2	72.0	4	8	2	0.50	0.75
7	73.5	7	9	5	0.50	0.25
Mean	71.2	6.2	7.4	5.0		

Caption for Figures

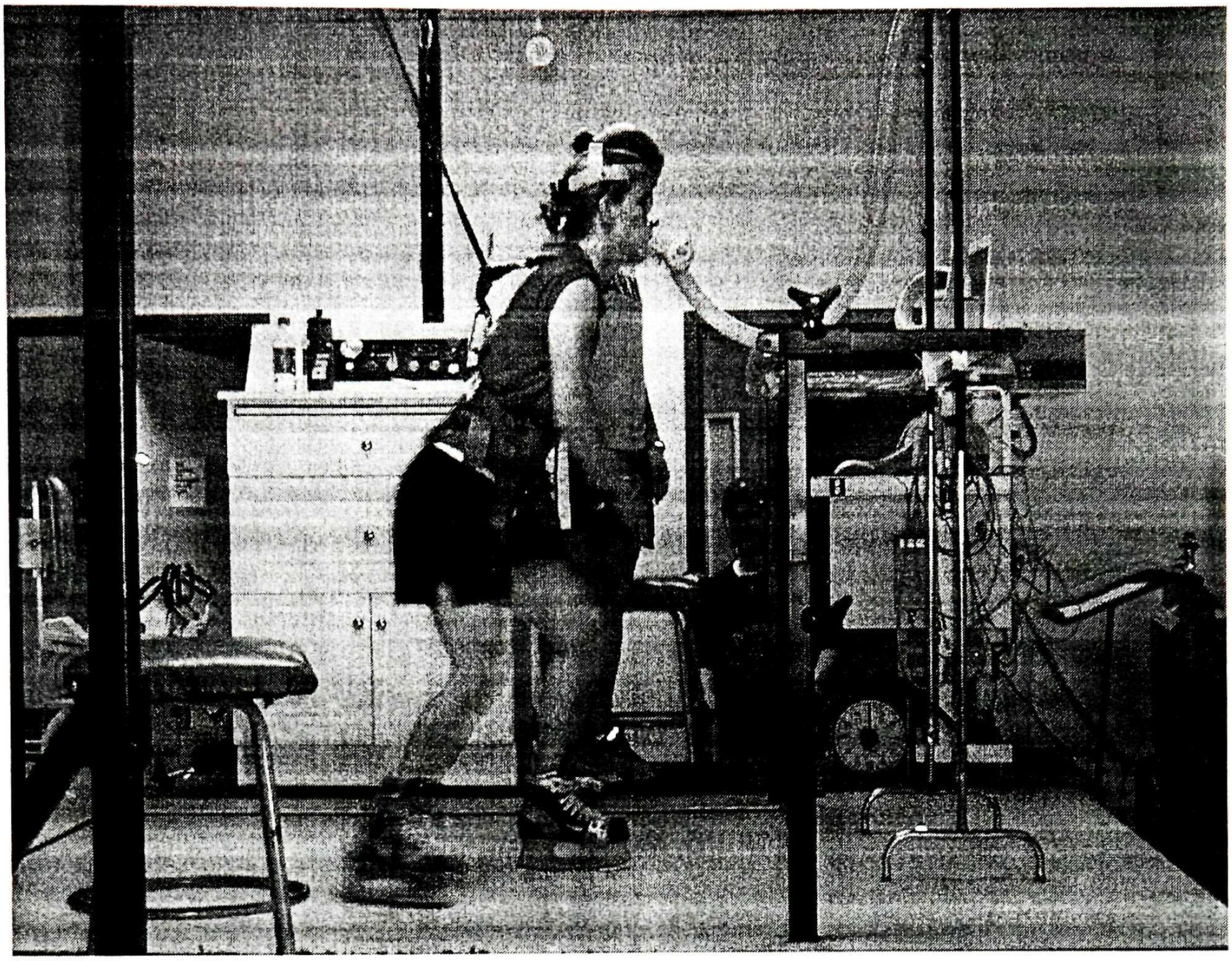
Figure 1. Skate blade characteristics.

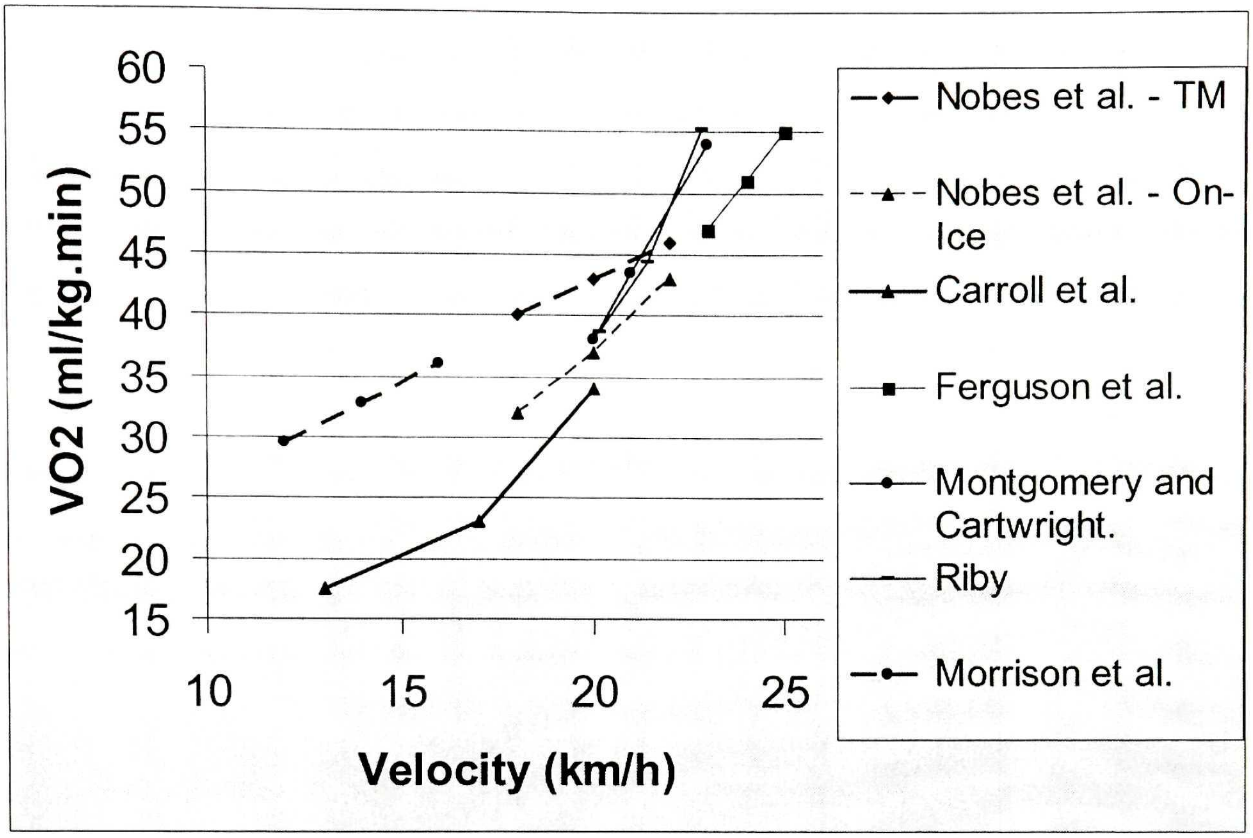
Figure 2. Experimental set-up.

Figure 3. Comparison of 6 studies measuring VO_2 on-ice and on TM.



Blade radius of hollow – not to scale





60
55
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VO2 (ml/kg.min)
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Velocity (km/h)
Nobes et al. - TM
Nobes et al. - On-Ice
Carroll et al.
Ferguson et al.
Montgomery and Cartwright.
Riby
Morrison et al.

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Appendix A

Introduction

Skate Sharpening

Properly sharpened skates are critical to hockey performance. Despite this fact, very little scientific literature has investigated the role that different skate blade characteristics play in skating performance. Although authors (Broadbent, 1983a, 1983b, 1988; Lavalee, 1979) have suggested several skate blade characteristics are important to hockey performance, there has been no scientific investigation performed to support their claims.

Broadbent (1983 a, 1983 b, 1988) suggested that radius of hollow, the bite angle formed by the flank of the skate and the tangent to the radius at the very edge of the blade, and edge levelness as being the key aspects of a properly sharpened skate. He claimed that 0.5 in is the most commonly found hollow in ice hockey skates with a range of 0.375 in to 1.5 in. Broadbent (1983b) also notes that a proper hollow centered down the width of the blade to create perfectly even edges constitutes the perfect sharpening. Lavalee (1979) agreed with Broadbent on the importance of blade hollow, but added blade profile to the list of characteristics to take into account when sharpening hockey skates. Lavalee (1979) stated that a 9 foot blade contour is sufficient for most players, but adds that defensemen may prefer a longer 10 foot or 11 foot radius for added control and increased blade contact in the execution of backwards strides, leaning and checking.

Skating Treadmill

Recently, a new tool has been developed for use in the training and assessment of skating performance. This treadmill consists of a parallel series of polyethylene slats creating a surface for subjects to skate on using their own skates. Given the fact that movements associated with skating cannot be mirrored by a running treadmill or bicycle ergometer, (Smith et al., 1982) and the importance of sport specificity to testing (MacDougall & Wegner, 1991), the skating treadmill is a useful tool in the evaluation of the aerobic power developed by ice hockey players.

The skating treadmill has several advantages when it comes to training and assessing hockey players. Firstly, since the skating motion on the treadmill is the same as that seen on-ice, the skating treadmill can be used to determine the aerobic power generated in ice hockey. Also, given the fact that the skater is stationary while skating, the treadmill can be very useful in skating instruction, as the teacher can stand next to subjects as they skate in order to evaluate and correct aspects of the subjects stride. When a mirror is placed in front of the skater, they too can see themselves as they skate, and therefore can more easily work to correct their stride without stopping.

As Nobes et al. (2003) pointed out, although after a few sessions on the skating treadmill the subject will feel it is very similar to on-ice skating, there is not enough literature yet to definitively state whether or not the skating treadmill is a reliable and valid tool for training, testing, rehabilitating and instructing hockey players.

Nature and Scope of the Problem

No research has been undertaken to date to investigate the effect that changing skate blade characteristics has on-ice hockey performance. Although authors such as Lavalee (1979) and Broadbent (1983a, 1983b, 1988) have identified some important aspects of properly sharpened skates, they did not conduct scientific research to ascertain which characteristics are the most vital to performance, nor to identify the best measures on each of the identified characteristics. This represents a significant gap in the research literature that needs to be addressed.

Similarly, there is a paucity of literature pertaining to the skating treadmill, although in its case, this is due more to the skating treadmills novelty than to a failure of the community to address the problem. Several authors have in recent years performed studies pertaining to ice hockey on the skating treadmill. Dreger (1997) identified the skating treadmill as a tool for training hockey players for speed.

Dreger and Quinney (1999) used the skating treadmill to develop a hockey specific VO_2max protocol. They used 6 male subjects who completed a skate treadmill and a cycle ergometer VO_2max protocol. The skating treadmill protocol consisted of the subjects skating at a self-selected speed (14.4 - 16.0 km/h) at 0% grade for 2 minutes. This was followed by 2 minutes of passive recovery. This procedure was repeated with the grade increased by 2 % in each session until the subjects reached volitional exhaustion. The results showed that VO_2max was not significantly different between the two testing modalities. They concluded that although both types of exercise yielded a similar physiological response, the skate treadmill was potentially more useful in studies of ice hockey players as it replicated the hockey stride.

Jacobson and Zapalo III (1997) also examined a VO_2max protocol. Each subject's anaerobic threshold was determined prior to the testing session. Subjects began skating at the speed corresponding to the threshold and a 5 % grade. Grade was then increased by 1 % every 30 seconds until volitional exhaustion. No significant difference was found between VO_2max on the skating treadmill and that which was found on a bicycle ergometer.

Nobes et al. (2003) studied the relationship between skating economy on-ice and on the skating treadmill. Subjects were 15 male varsity hockey players. The subjects skated for 4 minutes at each of three submaximal velocities (18, 20 and 22 km/h) on both the skating treadmill and ice. They then performed a VO_2max test starting at 24 km/h and increasing by 1 km/h until volitional exhaustion was reached. The results of this study indicated that at submaximal velocities, VO_2, HR and stride rate were higher on the skating treadmill than on-ice. VO_2max was similar between the two conditions, however HRmax was found to be higher in the treadmill test.

Montgomery et al. (2003) investigated the effect of a mouthguard on ventilation while skating on the treadmill. They used 12 female varsity subjects. The subjects skated at two submaximal velocities (14 and 16 km/h) for 4 minutes with and without the mouthguard. Subjects also completed a VO_2max test under both conditions. They found that at submaximal velocities, VO_2 was similar between the two conditions, however, VO_2max was significantly lower when wearing the mouthguard.

Significance of the Problem

As evidenced by Renger's (1994) study, skating is an essential component of successful hockey performance. Renger solicited professional hockey scouts opinions on the importance of a variety of hockey skills to success. The scouts identified skating as the most important aspect to hockey performance. Despite the importance of skating, there has been to date no research investigating the role that specific blade characteristics play in skating on-ice.

Several authors have suggested some of the blade characteristics that are important to ice skating (Broadbent 1983a, b, 1988; Lavalee, 1979). They identify radius of hollow, bite angle, blade profile, edge levelness, balance and lie as being important aspects to consider when sharpening skates in order to maximize performance. Broadbent (1983b) claims that having the proper size hollow centered within the width of the blade creating level edges constitutes a perfect sharpening. Assuming that the sharpener centers the hollow properly, the question that remains is what radius of hollow is necessary to allow for maximum skating performance? Broadbent (1983a) suggested that the most common radius of hollow for a hockey skate is 0.5 inches with a range from 0.375 to 1.5 inches. Lavalee (1979) stated a similar range (0.25 to 1.5 inches), but offered no opinion on what would be the most common radius.

Given this lack of scientific research into the effect of different skate blade characteristics on hockey performance, much work is needed before we can determine what the ideal sharpening is for maximizing hockey performance. Such performance variables as speed, agility, and acceleration, as well as metabolic variables such as oxygen cost should be investigated before we can make any suggestions as to what blade characteristics are important for hockey performance.

Statement of the Problem

The purpose of this study was to investigate the effect of skate blade hollow on oxygen consumption during forward skating. The investigation examined the following hypotheses:

1) Oxygen consumption (VO_2) will differ significantly between the three levels of blade hollow at a given velocity.

2) Volume of air expired (V_E) will differ significantly between the three levels of blade hollow at a given velocity.

3) Heart rate (HR) will differ significantly between the three levels of blade hollow at a given velocity.

4) Rating of perceived exertion (RPE) will differ significantly between the three levels of blade hollow at a given velocity.

A secondary aspect of this study was to attempt to identify the best radius of hollow to use when skating on the skating treadmill.

Operational Definitions:

Oxygen Uptake (VO_2): Indirect estimates of energy metabolism based on oxygen consumption at rest and/or under steady state exercise conditions.

Maximal Oxygen Uptake (VO_2max): The maximal volume of oxygen consumed per minute in absolute (L/min) or relative (ml/kg·min) terms.

Skating economy: The steady state VO_2 (ml/kg·min) required to skate at a given submaximal velocity.

Submaximal velocity: Skating at a velocity (km/h) representing an intensity less than maximum.

Skate Blade Radius of Hollow (ROH): The curvature between the outside and inside edges of a hockey skate blade created by grinding a portion of a circle onto the blade.

Limitations

This study has the following limitations:

1. The ambient room temperature in the laboratory does not simulate ice temperature conditions.
2. There is less air resistance in the laboratory compared to on-ice conditions.
3. Players will not be wearing full hockey gear while skating on the treadmill.
4. The surface properties of the skating treadmill differ from the properties of ice.

Delimitations

This study has the following delimitations:

1. The subjects for this study were 10 female varsity hockey players from the McGill University hockey team.
2. Subjects ranged in age from 21 to 23 years old.
3. Only forwards and defense were used.
4. Only three velocities were studied (12, 14, and 16 km/h).
5. Only three blade hollows were studied (0.25, 0.50 and 0.75 inches).

Appendix B

Review of Literature

Physiological Response During Skating

Two major physiological responses to skating will be discussed in the following section, heart rate telemetry and oxygen consumption during a game.

Heart Rate Telemetry

Many researchers have used heart rate to estimate the aerobic demands of playing hockey, (Montgomery, 2000). Despite this, it must be remembered that heart rate telemetry has limitations with regards to hockey. In ice hockey, heart rate can be influenced by factors not related to the energy cost of the activity. These extraneous conditions include: a) emotions, b) upper body static contractions, c) the intermittent nature of play and d) the elevation of core body temperature because hockey equipment may limit heat dissipation (Montgomery, 1988).

Seliger (1968) published the first heart rate data on-ice hockey. He measured the heart rates of 15 junior players between the ages of 16 and 20 years. The players competed three times for 90 seconds, each separated by 180 seconds of rest. The subjects had a peak heart rate of 177 beats/min and an average on-ice heart rate of 160 beats/min. Seliger et al.(1972) performed a similar investigation using 13 members of the Czechoslovakian National hockey team as subjects. In this study, the subjects played in a simulated game consisting of six sessions of 60 seconds competition, separated by 180 seconds of rest. The players had an average heart rate of 152 beats/min, corresponding to

72.5 % of their maximal heart rate. Many researchers have studied heart rate during practice and other simulated ice hockey tasks, (Green, 1978; Montpetit et al., 1979; and Romet et al., 1976).

Heart rate has been monitored during hockey games by a number of researchers. (Green et al., 1976; Peddie, 1995; and Wilson and Hedberg, 1976). These researchers found mean heart rates of 173, 165.6, and 178.3 beats/min respectively. Montgomery (1988) stated that the average on-ice heart rate is about 85 % of maximum with peak heart rate reaching in excess of 90 % of max. Several researchers (Montgomery, 1979; Paterson, 1979, and Peddie, 1995) estimated that the average on-ice intensity corresponds to between 70 and 90 % of VO_2max.

Davis (1991) monitored the heart rates of 4 members of the Calgary Flames over a 5-game period. The mean heart rate during a shift was 168 beats/min and the range was between 145 and 191 beats/min. During recovery between shifts, the heart rate dropped to 120 beats/min.

Peddie (1995) investigated the intensity of game play for three forwards and 3 defensemen from a varsity hockey team. He found the average on-ice intensity to be 82.5 % of heart rate max. During stoppages in play the heart rate dropped to 161.5 beats/min or 80.5 % heart rate max, and while the player's were recovering on the bench the heart rate fell to 138.5 beats/min, or 69.1 % of heart rate max. Green (1978) investigated a similar group of athletes and found that during recovery, heart rate dropped rapidly, but rarely fell below 125 beats/min. Both Peddie (1995) and Green (1978) concluded that heart rates did not differ between forwards and defensemen.

Oxygen Consumption During a Game

Due to the physical nature of ice hockey, collecting gas samples during an actual game is not possible. It therefore becomes necessary to either simulate game conditions in order to measure oxygen consumption, as was done by Seliger et al. (1972) or to predict oxygen consumption from heart rate data collected during actual games as was done by Green et al. (1976). Green et al. (1976) collected time motion and physiological data on 8 varsity hockey players during ten games. Based on the average heart rate from the ten games (173 beats/min) and a treadmill determination of the relationship between heart rate and oxygen consumption, on-ice energy requirements were estimated to be between 70 and 80 % of VO_2max. The authors noted however, that using heart rate to predict oxygen consumption in a non-steady-state activity where there is much upper body activity and changes in velocity, is suspect.

Seliger et al. (1972) investigated energy expenditure in 13 Czechoslovakian National team players (age = 24.4 yrs, height = 179.3 cm, weight = 81.8 kg) in a simulated game. The simulation consisted of 6 repetitions of 60 seconds of competition separated by 180 seconds of recovery. Analysis was done only on one 1.17 min shift. During this shift oxygen consumption was 32 ml/kg·min, which represented 66 % of the subjects VO_2max. Indirect calorimetry was used to measure energy metabolism. Based on these results Seliger et al. (1972) characterized ice hockey as, "an activity showing mostly submaximal metabolic rate with great participation of anaerobic metabolism (69 %), but simultaneously with high requirements for aerobic metabolism (31 %)". Several authors, (Montgomery, 1988; Green et al., 1976) have suggested that Seliger et al. (1972) may have overestimated the contribution of anaerobic energy sources and underestimated the contribution of the aerobic energy system. The investigation of Green et al. (1976) supports this notion.

Another way to estimate the work intensity of skating is to utilize the relationship between skating velocity and oxygen cost as proposed by Ferguson et al. (1969). These researchers had 17 players between the ages of 16 and 25 perform a VO_2max protocol on a 140-m oval. The subjects skated for 3 minutes at velocities of 350, 382, 401, 421, and 443 m/min. These speeds correspond to lap times of 24, 22, 21, 20 and 19 s/lap respectively. Ferguson et al. (1969) concluded that the relationship between VO_2 and submaximal skating velocity is linear. They caution however, that despite this linearity, there is still a wide range of VO_2 among the players for a given submaximal velocity. For example, at a velocity of 382 m/min the mean VO_2 was 46.7 ml/kg·min, with a range from 40.1 to 54.7 ml/kg·min. Green et al. (1976) agree that skating represents a major component of work intensity, but they feel that using the relationship between oxygen cost and skating velocity underestimates energy expenditure.

Factors Affecting Skating Performance

There are several factors that can have an affect on skating performance. This section will discuss three of these factors: the effect of added mass, ice surface coefficient of friction, and air resistance.

Effect of Added Mass

There are two ways in which a hockey player can carry added mass, in the form of adipose tissue, or in the form of the protective equipment worn. Montgomery (1982) investigated the effects of this added mass on skating performance using the Reed Repeat Sprint Skate test (RSS) developed by Reed et al. (1979). Eleven subjects were tested in mid-season under four different conditions: 1) normal body mass, 2) 5 % added body mass, 3) 10 % added body mass, and 4) 15 % added body mass. Body mass was added through the use of a weighted vest, which was secured at the shoulders and waist to prevent the vest from interfering with the subjects skating movements. Both speed and anaerobic endurance were significantly lower under the weighted conditions. Anaerobic endurance time increased by 4 % with the addition of 5 % mass. Montgomery concluded that excess body mass increases the amount of energy required to skate at a particular velocity and also reduces the time that a player can maintain the pace.

In a similar study, Chomay et al. (1982) investigated the effect of added mass by adding the extra mass to the subject's skates. In this study, the subjects (n=11) were assessed on the RSS test under three conditions: 1) normal skate weight, 2) 227 g added to each skate, and 3) 555 g added to each skate. As in the previous study, Chomay found a significant decrease in speed and anaerobic endurance with the added mass.

The effect of added mass in the form of equipment weight (7.3 kg) on aerobic skating performance was investigated by Léger et al. (1979). During the mid-season, 10 players performed a 20 m shuttle test in order to determine VO_2max. The VO_2max results were the same in both the weighted and un-weighted conditions, however; the equipment increased the energy cost of skating by 4.8 % and decreased the multistage test time by 20.3 %. The final skating speed was 7 m/min or 2.9 % lower when the players were wearing the equipment.

Larivière et al. (1976) tested 18 midget aged players with and without equipment. The test consisted of the player performing as many laps of a 100 foot course as possible in a five minute time frame. The subjects had to skate in one direction, stop with one foot over a determining line, and then change direction and return to the start. The total distance covered was significantly less with equipment (3973 ± 184 feet) as compared to without equipment (4124 ± 267 feet).

Ice Surface Coefficient of Friction

When skating on-ice, the energy produced is used to overcome two opposing forces, those being the air friction that is created as the player moves, and the ice frictional force caused by the skate blade and ice rubbing together. De Koning et al. (1992) stated that air friction is the larger of the two resisting forces. They attributed approximately 75 % of the total frictional energy loss to air friction and the remaining 25 % to ice friction when skating at 10 m/s.

The surface of ice has a very low co-efficient of friction. The reported co-efficient of friction varies between 0.003 (De Koning et al., 1992; and Kobayashi, 1973) and 0.030 (Zatsiorski et al., 1987). Although De Koning et al. and Kobayashi found a similar range of co-efficient of friction, they disagree on the optimal temperature. De Koning et al. found the optimal temperature to be in the range of -6 to -9 °C, whereas Kobayashi found a higher optimal temperature of -2.2 °C. It should be noted however that Kobayashi used a slightly weighted sled with skate blades attached which were always perpendicular to the ice surface, whereas De Koning et al. developed and used special skates to measure the ice frictional forces during actual speed skating.

There is some debate as to why there is such low frictional force between the skate blade and the ice surface. Several theories have been advanced to explain the low coefficient of friction of ice. Ingen Schenau et al. (1989) proposed one such theory. They suggested that skating is possible due to pressure melting. They stated that due to the small gliding surface of skates and the resultant large pressure under the skate (up to 20×10^6 N/m^2), a film of water develops between the skate and the ice. This thin film of water allows the skate to glide over the ice surface with very little resistance.

An alternative explanation for the low co-efficient of friction was advanced by Colbeck (1995). He claims that the pressure necessary to allow pressure melting as an explanation for the low co-efficient of friction of ice would be above the failure stress of ice. He also states that the pressure melting effect at -20 °C would have to be 2700 times atmospheric pressure. Furthermore, Colbeck (1995) states that pure water and ice cannot co-exist at any pressure if the temperature is below -20 °C. As well, at a speed of 5 m/s a liquid layer of less than 0.1 μm thickness exists over only a 15 μm length, which would be too short of a distance for the gliding phase of skating. Some researchers (Colbeck, 1995; and Mendelson, 1985) suggest that although the slipperiness of ice is caused by a melted film of water, this film is the result of frictional heating of the sliding surfaces, not of pressure melting.

According to De Koning et al. (1992) both frictional heating and pressure melting should result in the formation of a lubricating water layer during the skating stride. Colbeck et al. (1997) performed a study to ascertain which of these theories was the more likely. They directly measured the temperature between the blade and the ice surface. They found that during skating, there was nearly 100 % blade contact with the ice, which means that given the weight on the ice and the blade contact, the pressure melting temperature would have to be about -0.054 °C, which suggests that pressure melting can be ignored completely. Their findings that the temperature increases with increased speed and thermal insulation of the blade are consistent with the frictional melting theory, suggesting that this is the more likely explanation.

A third potential explanation is that the friction between the skate blade and the ice surface is an intrinsic property of the ice surface (De Koning et al., 1992). Recent research using modern surface science technology has shown that the surface of ice has a constant, thin semi-liquid layer producing low frictional interfaces. As the ice surface warms, the number of liquid layers increases. This is why colder ice (less water) is faster for skating than is warmer ice (more water), (Pearsall et al., 2000).

Air Resistance

According to Ingen Schenau et al., (1989), air friction has two major components, friction drag and pressure drag. Friction drag is caused by friction in the layers of air along the body. In speed skating, the suits worn by the athletes are designed to decrease this friction drag, thereby reducing the overall air resistance. In speed skating, friction drag is relatively small compared to pressure drag due to the effects of the body suits worn by the skaters. Pressure drag is caused when there is more pressure in front of the skater than behind the skater, due to the relative velocity of the air with respect to the skater's body. There are several factors that can influence air friction during skating including: skating position, body mass and length, active drag, and shielding (drafting). According to Ingen Schenau, (1982), air friction is strongly dependent on the air velocity.

Allinger and Van Den Begert, (1997) defined the air friction constant as being proportional to the velocity of the skater squared. In their study, they used the friction constant of 0.152 kg/m, which was taken from Ingen Schenau's 1982 study.

Aerobic Endurance

Several studies have investigated the maximal oxygen uptake of elite hockey players over the past thirty years. The results of these studies, which have used professional, national, university, and junior players are summarized in Table 4. Most of these studies were conducted using either a running treadmill or cycle ergometer to elicit the subject's maximal aerobic endurance. Several more recent studies have used the skating treadmill to assess the VO_2max of hockey players, (Dreger & Quinney, 1999; Hinrichs, 1994; Jacobson & Zapalo III, 1997; Nobes et al., 2003). Team averages for both forwards and defensemen ranged from 50.9 to 62.8 ml/kg·min when measured using a cycle ergometer with one exception. On the treadmill, team averages for both forwards and defensemen ranged from 51.2 to 65.8 ml/kg·min. Montgomery, (1988) suggests that running on a treadmill produces mean values that are 10 % higher than those found on the cycle ergometer.

Léger et al's, (1979) investigation suggests that the VO_2max values for hockey players will be the same whether they are tested on a running treadmill, on the ice while skating a 20 m shuttle course with or without equipment, or skating on a 140 m oval circuit. They compared the results of 10 hockey players of intercollegiate or equivalent level with 10 runners. They found the hockey players to be more efficient on the ice (15 %) while the runners were more efficient on the treadmill (7.9 %).

Cox et al., (1993) suggest that VO_2max in hockey players has been increasing progressively since 1980. They examined VO_2max data from 170 NHL players on 4 separate occasions between 1980 and 1991. They found that the percentage of players with a VO_2max of less than 55 ml/kg·min decreased from 58 % in 1980 to only 15 % in 1991. They concluded that these higher VO_2max results were due to improved training methods adopted by the players over this time frame.

In a more recent study, Dreger and Quinney, (1999) compared the VO_2max results of 6 elite 15 and 16 year old hockey players on a skating treadmill and on a cycle ergometer. The subjects performed a discontinuous skating treadmill protocol at a self selected speed (14.4 to 16.0 km/h) with an increase in the grade of 2 % every 2 minutes. There were no significant differences in the VO_2max values found on the skating treadmill (60.4 ± 5.09 ml/kg·min) and on the cycle ergometer (59.0 ± 8.31 ml/kg·min). These values are well within the range of values from previous studies done on elite professional, university, and junior hockey players.

Skating Economy

Daniels (1985) defined running economy as the relationship between the amount of work done and the amount of energy expended. He states that minimizing or eliminating unwanted or counter-productive muscular movement is a desirable goal for any distance runner. Daniels, (1985) also believes that within a homogenous group of runners, running economy may be the best predictor of success.

Skating economy is similar to running economy. Riby, (1994) described skating economy as the steady state VO_2 (ml/kg·min) required to skate at a given velocity. Riby

(1994) investigated the skating economy of 13 varsity hockey players. The testing took place on a 140 m oval circuit. The test consisted of three 4-minute skating sessions at velocities of 336, 357, and 381 m/min. These velocities correspond to lap times of 25.0, 23.5 and 22.0 seconds respectively. Riby (1994) believed that the four to five minute skating bouts were sufficiently long to allow for the achievement of steady state VO_2 values. The results of this study were as follows; at velocities of 336, 357 and 381 m/min, mean VO_2's were 38.6, 44.4, and 55.2 ml/kg·min respectively. Mean heart rate values were 161, 172 and 180 beats/min respectively. Riby, (1994) concluded that there exists a linear relationship between skating economy and velocity at velocities between 336 and 381 m/min. He also concluded that there is a low correlation between skating economy and skating ability.

In a recent study, Nobes et al. (2003) compared skating economy on-ice and on a skating treadmill. In this study, 15 male varsity hockey players skated for 4 min at each of 3 submaximal velocities (18, 20 and 22 km/h) on-ice and on the skating treadmill. All subjects were also tested for VO_2max in both skating environments. The results showed that at submaximal velocities, VO_2, HR and stride rate were all higher on the treadmill than they were on-ice. VO_2max was similar between the two conditions, however, HRmax was higher on the skating treadmill.

Skate Sharpening

Renger, (1994) asked NHL scouts to rank prospects on ten skills: skating, shooting/ scoring, positional play, checking, puck control, passing, hockey sense, desire/ attitude, aggressiveness/ toughness and size/ strength. For both forwards and defensemen, the scouts identified skating as the most important task requirement. Hockey players recognize and value the role of properly sharpened skates. Despite this, the interaction between the blade of a hockey skate and the ice surface has not received much attention. Lavalee (1979) points out that research has focused on biomechanics, equipment design and performance aspects of hockey and has overlooked what appears as being essential: the player's point of contact with the ice. Lavalee, (1979) continues on to ascertain that even the most expensive skates can be damaged, and their contribution to performance impaired if they are not sharpened properly.

Most of the literature on skate blade sharpening concentrates on the identification of important skate blade characteristics which must be taken into consideration when sharpening skates. Authors such as Lavalee, (1979) and Broadbent, (1983a, 1983b, 1988) have identified some of these key blade characteristics. These include, radius of hollow (ROH), bite angle, edge levelness, blade radius (sometimes referred to as rocker, or blade profile), balance, and lie.

Skate blade radius of hollow refers to the curvature between the inside and outside edges of the blade. As Lavalee explains (1979), all forms of skating require that the blade possess two separate edges, allowing the skate to penetrate the ice when turning to either side, accelerating and stopping. The question that arises is what radius of hollow is best for hockey players. Lavalee (1979) gives a range of ROH from 0.25 in to 1.5 in as being used in hockey skates, with the higher radius giving a flatter cut and less of an edge. Lavalee (1979) suggests that forwards benefit from a highly concave grind allowing them to make sharp turns and sudden stops while goaltenders will favor a practically flat grind for added stability. Broadbent (1983a) suggests that a radius of 0.50

inches is the most common profile for ice hockey blades. Lavalee (1979) points out that factors such as position played and personal preference can affect which radii are best suited to hockey performance.

Closely related to blade ROH is bite angle. The reason that the term ROH is used to identify the hollow grind is that it is the easiest shape to reproduce on the edge of the grinding wheel of the skate sharpener. A "V" cut would be just as effective in producing the edges required to skate, but the costs of producing this shape and being able to vary the angle of the "V" would be very costly (Broadbent, 1983a). Bite angle is a term coined by Broadbent , (1983a) to describe the angle formed by the flank or side blade and the tangent to the circle formed by the ROH at the very edge of the blade. If the "V" grind were used, it would be the angle formed by the side of the blade and the arm of the "V" extending down to the edge. This term is used in order to address confusion as to the proper ROH for figure skating blades which have a range of blade widths. Using blades of different widths, the same ROH would produce a different bite angle on the different blades. An example of this is illustrated by applying the same ROH to two different figure skating blades, one of 0.15 in width, and the other of 0.10 in width. If both blades were sharpened to a 3/8 in ROH, the wider blade would have a bite angle of 7 degrees, whereas the thinner 0.10 in blade would have a bite angle of only 4.6 degrees. This problem is not as important in the ice hockey skate blade as hockey blades are invariably 0.1 inches thick (Broadbent, 1983a). With a blade thickness of 0.11 inches and the most common ROH (0.50 inches), the resultant bite angle is 6.3 degrees. The range of bite angles associated with those ROH most commonly seen in hockey skate blades runs from slightly less than 2 degrees (ROH = 1.5 in) to approximately 8.5 degrees (ROH = 0.375 in) (Broadbent, 1983a).

Broadbent, (1983a) also points out that individual differences and the weight of the skater will have an affect on the ideal bite angle, as light skaters will usually benefit from a somewhat greater bite angle which would be associated with a lower ROH. He suggests that the heavier person can accept a lesser bite angle since their additional weight will cause the skate to bite more deeply into the ice surface.

The levelness of the blade edges is another characteristic that relates to ROH and bite angle (Broadbent, 1983b). Broadbent (1983b) claims that uneven edge height is the most common error when skates are sharpened. Ideally, the two edges are perfectly level so that the ROH is centered within the blade thickness, thereby producing identical bite angles on both edges. This constitutes a perfect sharpening (Broadbent, 1983b). When the ROH is misplaced from the center of the blade, the edges are no longer going to be level. This will increase the bite angle of one edge and decrease the bite angle on the other edge, resulting in a very different feeling when skating on one edge as opposed to the other edge (Broadbent, 1983b). Small differences in the levelness of the edges can produce large differences in the bite angle. Broadbent (1983b) suggests an accuracy tolerance of plus/minus ten percent of the bite angle as reasonable. Using a precision toolmaker's square with a blade extending 0.50 inches from the head of the square, the required tolerance is achieved with a gap of only 0.08 in for a skate with a blade of 0.10 in thickness and a bite angle of 9 degrees. Broadbent (1983b) states that errors in edge levelness can be virtually eliminated by checking the edges with a precision toolmaker's square. He states that using the toolmaker's square, a careful sharpener should be able to hold edge levelness to ¼ degree assuming that the blade is not bent (Broadbent, 1988).

A fourth important blade characteristic that must be taken into consideration when sharpening skates is the blade radius, or as it is sometimes called rocker or profile. Lavalee, (1979) states that blade radius and ROH are the two major elements involved in sharpening of hockey skates for performance. He states that radius profile maximizes blade control by modifying the blade curvature to suit the player's style of play. Lavalee (1979) also states that the 9 foot radius is the most common radius for hockey skates, although defensemen may prefer a 10 or 11 foot radius for increased blade contact with the ice which would be beneficial in the execution of backwards strides, leaning and checking.

Lavalee (1979) indicates that altering the blade radius can affect performance. By reducing the radius and thereby the blade-ice contact, players have more mobility but less speed. In contrast, increasing the radius increases speed and stability at the expense of mobility. On the Custom Radius Sharpening website (www.mts.net/~ghymers/Skates/cus-rad.html), it is suggested that the correct radius is a balance between maneuverability and stability resulting in maximum control and reduced muscle fatigue.

The Custom Radius Sharpening site (www.mts.net/~ghymers/Skates/cus-rad.html) also points to blade lie as being an important blade characteristic to consider when sharpening skates. The lie of a skate is the pitch of the radius. The pitch or lie controls the skater's posture. The proper lie is slightly forward, which forces the skater to bend slightly at the ankles, knees and hips.

What must be kept in mind when reading this review of skate sharpening is that none of the literature cited in this section is published in peer-reviewed scientific journals. That is to say that none of the conclusions drawn by the authors are the result of scientific experimentation. Although these documents do provide a knowledge base, there is a need for scientific investigation of these characteristics and their role in different modes of skating. Since there is a paucity of work investigating the relationship between blade characteristics and skating performance, (e.g. speed, agility, maneuverability or energy expenditure) it is difficult to say what constitutes a proper skate sharpening. Therefore, there is a need for further investigation before we can understand the relationship between the skate blade and the skating surface and maximize the effectiveness of the blade sharpening process.

Women's Ice Hockey

Women's ice hockey is one of the fastest growing sports in Canada (Boyd et al., 1997). In Canada between 1991 and 1996, participation in women's hockey increased 200%, compared to a 23% increase in men's hockey over these same six years (Boyd et. al., 1997). This rise in popularity has been mirrored in the United States. In a recent Sport's Illustrated article on High School Sports, they give information on the number of high school athletes participating in different sports in 1980-81 and in 2000-01. Over this twenty year period, participation in girl's ice hockey rose from 56 to 6442, an increase of 11403.5% (Wolff, 2002). This increase in popularity has led to increased opportunities for females to play at the university level. During the 2001-2002 season, there were 28 schools competing in women's hockey in Canadian Interuniversity Sport (CIS) leagues.

(www.universtiysport.ca/hockey/default_women.asp). In the CIS, women have been competing for a national hockey championship since the 1997-98 season (www.universtiysport.ca/hockey/default_women.asp).

The situation is much the same in the United States. As of January 2000, there were 53 institutions sponsoring women's ice hockey as a varsity sport (www.whockey.com/univ/ncaa/2000/usa_hockey.txt). American Division I schools have been competing for a national championship since the 1997-98 season through hockey USA. In the 2000-01 season, women's ice hockey teams competed for the first NCAA championship (www.whockey.com/univ/ncaa/2000/usa_hockey.txt).

Despite the rapid growth in popularity women's ice hockey has seen in the last decade, there is still little research done in this area. Specifically knowledge of the physical performance characteristics of women's ice hockey players is limited (Bracko & George, 2001). Several studies have looked at sociological and psychological issues surrounding female participation in ice hockey, such as the title IX issue in the United States (Cohen, 1995), aggression in women's hockey (Kerr & Kelly, 1982), perceptions of learning opportunities (Boyd et al., 1997) and physicality and the production of gender (Theberge, 1997).

Bracko recognized the need for investigation into the performance characteristics of female hockey players, and conducted studies in order to gain knowledge in this area. In one of these studies, the on-ice performance characteristics of 8 elite and 15 non-elite women's ice hockey players were examined in order to identify the differences between these two groups (Bracko, 2001). Seven members of the elite group were members of the Canadian National Team, with the eighth being a member of the Finnish National Team.

All subjects performed five skating tests including: 1) 6.10 m acceleration, 2) 47.85 m speed, 3) 16.3 m full speed, 4) agility cornering S-turn, and 5) Reed repeat sprint skate. The results of this test showed that the two groups were similar in height, weight, acceleration, speed from a stationary position and anaerobic power. The elite players were older, had more playing experience and performed better in the following areas: full speed, agility, drop off time and sum of six repeats in the Reed repeat sprint skate, anaerobic capacity (W/kg and W) and anaerobic power (W). Bracko concluded that the elite athletes were faster and more agile than the non-elite players. When the players were matched for age however, the only area the elite athletes remained superior was anaerobic capacity (W).

In another study, Bracko and George, (2001) attempted to identify off-ice predictors of ice-skating performance in female hockey players. Sixty-one women between the ages of 8 and 16 participated in this study. The following on-ice tests were performed: 1) 6.10 m acceleration, 2) 47.85 m speed, 3) agility cornering S turn, and 4) modified repeat skate test. Additionally, the following off-ice variables were measured: age, years of playing experience, height, body mass, predicted percent fat, sit and reach flexibility, vertical jump height, 40-yd dash time, and 1 minute timed sit-ups and push-ups. The results of this study indicated that 40-yd dash time was the strongest predictor of skating speed in women's hockey players aged 8 through 16.

In another study of elite female hockey players, Doyle-Baker, et al. (1997) monitored 20 national female team members over a one year period. The players performed three on-ice tests and were monitored over a one-year time frame. The tests were: 1) a 6.1 m and a 56.4 m sprint, 2) an anaerobic capacity test consisting of 6 backward and forward repetitions of 18.3 m and 3) 10, 15, and 20 lap all out aerobic tests. The players demonstrated improvement over the course of the year, and the difference in scores among the 20 players was reduced.

Bracko and Fellingham (2001) compared male and female adolescent players on a number of on and off ice tests. They tested 54 female and 77 male players between the ages of 10 and 15 years. The off ice testing consisted of: 1) height, 2) body mass, 3) lean body mass, 4) predicted body fat percentage, 5) 40-yard dash, 6) vertical jump, 7) pushups/min, 8) sit-ups/min, and 9) sit and reach flexibility. The on-ice testing consisted of: 1) acceleration, 2) speed and, 3) agility. The results showed similar results between the males and females in the off-ice testing, but the males consistently outperformed the females in the on-ice tests. The authors concluded that females would have difficulty competing against males of similar age because the males were superior skaters.

Women's ice hockey has grown substantially in the past ten years both in the number of women participating, and the opportunities available to women players. This was evidenced by the inclusion of women's hockey as a full medal sport for the first time at the 1998 Nagano Olympics. Clearly given the growing popularity of women's ice hockey, further investigation into this sport, and these athletes is necessary to further the development of women's hockey. As, Doyle-Baker et al. (1997) noted, women's hockey has not had access to sports sciences or external funding to assist with research. They note that women's hockey is in need of a standard conditioning program in order to gain recognition and continue developing. In order for this to be achieved, sports science must be integrated into the world of women's ice hockey.

Appendix C

Conclusions

Within the limitations and delimitations of this study, the following conclusions are warranted.

The results of this study indicate that at submaximal velocities, skate blade radius of hollow does not have a significant effect on the physiologic variables of VO_2, V_E, HR, or the psychological variable of RPE on a skating treadmill. Subjective ranking by the subjects revealed no perceived differences in the degree to which the different hollow radii "bit" into the skating surface. However, when ranking the radii from best to worst in terms of the role of the sharpening to their overall skating performance, 7 out of 10 subjects selected the 0.50 in hollow as being the best.

Although the results of this study suggest that skate blade radius of hollow does not affect the physiological response to the exercise, further investigation into the role of skate sharpening in performance is warranted. This study investigated only one skate blade characteristic, and only physiological variables. Further investigation of the role of skate sharpening on performance variables such as maximal exertion, agility, acceleration and deceleration is necessary before we can fully understand the role of skate sharpening and draw conclusions as to what constitutes a perfect sharpening.

Appendix D

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Appendix E

ADDITIONAL TABLES

Description of the Tables

Table 4 This table summarizes the VO2max results for several professional, national, university and junior level players over the past 30 years.

Table 5 This table summarizes the physical characteristics of the subjects. Each subjects age in years (21.7 ± 0.8), height in centimeters (167.3 ± 4.7), weight in kilograms (65.4 ± 6.7) and body fat as a percentage of total body mass (21.0 ± 3.1) are given. Values in brackets represent the mean and S.D. of the group.

Table 6 This table contains the data from the skating sessions performed with the 0.25 in radius condition. Heart rate (bpm), volume of air expired (L/min) and volume of oxygen consumed (ml/kg·min) data are grouped by velocity (12, 14 and 16 km/h).

Table 7 This table contains the data from the skating sessions performed with the 0.25 in radius condition. Heart rate (bpm), volume of air expired (L/min) and volume of oxygen consumed (ml/kg·min) data are grouped by velocity (12, 14 and 16 km/h).

Table 8 This table contains the data from the skating sessions performed with the 0.25 in radius condition. Heart rate (bpm), volume of air expired (L/min) and volume of oxygen consumed (ml/kg·min) data are grouped by velocity (12, 14 and 16 km/h).

Table 9 This table contains each individual's results from the VO_2 test. The subjects weight in kilograms, heart rate in beats per minute, volume of air expired in liters per minute, volume of oxygen consumed in liters per minute, volume of oxygen consumed relative to body weight, respiratory ratio, and the ratio of air expired to oxygen consumed in liters per liter are given. The mean VO_2max for the group was 42.9 ± 3.3 ml/kg·min. It should be noted that subject 1 did not perform the VO_2max test.

Table 10 This table gives the RPE data for all subjects. Each subject gave a RPE rating after each skating session. Mean values are calculated for each velocity under each hollow condition.

Table 11 Upon completion of all skating sessions, the subjects were asked to rank the three different skating conditions based on how they felt the hollow contributed to their performance. This ranking was done with no knowledge of the physiological results.

Table 12 After the last skating session under each hollow condition, the subjects were asked to rate how well they felt their skates "bit" into the skating surface on a scale from 1 to 10 with 1 representing poor, 5 representing average and 10 representing excellent. The results for each subject, as well as mean data for each hollow condition are given.

Tables 13-16. These tables summarize the results of the statistical analyses performed on the test variables. The results of the two way repeated measures ANOVA's for HR, VO2, VE, and RPE (respectively) are given in these tables.

Table 4 Maximal oxygen uptake of various teams

Group	n	Body Mass kg	VO_2max ml/kg·min	Reference
Treadmill				
National - American - 1976	22		58.7	Enos et al., 1976
University – CIAU	8	70.5	58.1	Montpetit et al., 1979
University – CIAU	10	72.8 ± 5.4	61.4 ± 6.3	Leger et al., 1979
National – Swedish	24	75.6	57.0	Forsberg et al., 1974
Junior	18	76.4	56.4 ± 4.3	Green & Houston, 1975
National – Finnish	13	77.3	61.5	Rusko et al. 1978
University – CIAU	8	77.4	61.3	Green et al., 1978
University – CIAU	19	77.6	58.9	Green et al., 1979
Junior	9	78.7	55.4	Green et al., 1979
National – Swedish – 1971	24	78.1	56.3	Wilson & Hedberg, 1976
Junior	44	78.2	55.4	Houston & Green, 1976
University – CIAU	11	79.5	56.4	Montgomery, 1982
National – Swedish – 1966	24	80.0	53.6	Wilson & Hedberg, 1976
University	9	80.9	56.3	Hutchinson et al., 1979
Professional	12	83.4	55.3	Green et al., 1979
Professional – NHL – 1981/82	27	85.9	55.6	Montgomery & Dallaire, 1986
Professional – NHL		86.4	53.6	Wilmore, 1979
Professional – NHL – Fwd	27	87.1 ± 5.6	57.4 ± 3.1	Rhodes et al., 1986
Professional – NHL – Def	40	90.3 ± 4.3	54.8 ± 3.9	Rhodes et al., 1986
Professional – NHL – Fwd	26	87.1 ± 5.6	56.3 ± 2.9	Cox et al., 1988
Professional – NHL – Def	21	90.3 ± 4.3	53.4 ± 3.4	Cox et al., 1988
Professional – NHL	27	85.6 ± 1.4	53.4 ± 0.8	Agre et al., 1988
Swedish Professional (DIF)	22	81.4	62.4	Tegelman et al., 1992
Swedish Professional (SSK)	21	82.4	65.8	Tegelman et al., 1992
Professional – NHL	1100	88.3	51.2	Dewart et al., 1999
Cycle Ergometer				
Professional – 1972/73	12	75.9	54.1	Bouchard et al., 1974
University	15	76.9	54.5	Thoden & Jette, 1975
Junior	24	77.0	58.4	Bouchard et al., 1974
University	9	77.1	53.2	Hermiston, 1975
University	18	78.1	55.2	Romet et al., 1978
National – Canadian	34	78.5	53.4	Coyne, 1975
National – Czech.	13	79.1	54.6	Seliger et al., 1972
University	5	79.5	54.3	Daub et al., 1983
University	21	79.8	58.4	Krotee et al., 1979
National – Canadian	23	81.1 ± 1.3	54.0 ± 1.2	Smith et al., 1982
National – Finnish	27	81.1	52.0	Vainikka et al., 1982
Junior	9	82.4	52.6	Green et al., 1979
Professional	38	82.3	43.5	Romet et al., 1978
Professional – 1982/83	29	86.8	51.9	Montgomery & Dallaire, 1986
Professional – For. – 1985	27	87.1 ± 5.6	53.3 ± 3.1	Rhodes et al., 1986
Professional – Def. - 1985	40	90.3 ± 4.3	51.6 ± 1.5	Rhodes et al., 1986
University – NCAA	25	80.8 ± 10.4	53.3 ± 8.6	Smith, T. et al., 1988
Professional – For.	14	87.1 ± 5.6	53.2 ± 5.2	Cox et al., 1988
Professional – Def.	6	90.3 ± 4.3	50.9 ± 1.5	Cox et al., 1988
Professional – NHL – 1980	38	85.3 ± 1.1	54.0 ± 1.1	Cox et al., 1993
Professional – NHL – 1984	38	88.2 ± 1.1	54.4 ± 0.8	Cox et al., 1993
Professional – NHL – 1988	23	91.2 ± 1.5	57.8 ± 1.2	Cox et al., 1993
Professional – NHL – 1991	75	88.4 ± 0.8	60.2 ± 0.6	Cox et al., 1993
Team Canada – 1991	55	89.3 ± 0.8	62.4 ± 0.5	Cox et al., 1993

Table 4 Continued

Group	n	Body Mass kg	VO_2max ml/kg·min	Reference
Professional		90.7 ± 4.5	62.8 ± 6.2	Koch et al., 1999
University – NCAA		81.3 ± 8.9	59.1 ± 5.5	Koch et al., 1999
Skating – On-Ice				
University	10	72.8	62.1	Leger et al., 1979
University	17	73.7	55.0	Ferguson et al., 1969
University	8	78.7	52.8	Green et al., 1978
University	5	79.5	52.1	Daub et al., 1983
University	15	83.5	54.7 ± 3.6	Nobes et al., 2003
Skating - Treadmill				
University	15	83.5	53.4 ± 2.3	Nobes et al., 2003

Table 5 Characteristics of the subjects

Subject	**Age (yrs)**	**Height (cm)**	**Mass (kg)**	**Body Fat (%)**
1	21	165.0	55.0	18.4
2	23	166.5	72.0	52.2
3	22	167.5	63.0	16.0
4	21	164.0	56.0	19.1
5	21	171.5	70.5	22.1
6	21	160.0	71.0	21.0
7	23	174.0	73.5	21.5
8	21	163.0	61.0	22.9
9	22	174.0	63.0	18.9
10	22	167.0	69.0	24.6
Mean	**21.7**	**167.3**	**65.4**	**21.0**
S.D.	**0.8**	**4.7**	**6.7**	**3.1**

Table 6 HR, VE and VO2 at 0.25 in radius of hollow condition

Subject	12 km/h			14 km/h			16 km/h		
	HR (bpm)	V_E (L/min)	VO_2 (ml/kg·min)	HR (bpm)	V_E (L/min)	VO_2 (ml/kg·min)	HR (bpm)	V_E (L/min)	VO_2 (ml/kg·min)
1	157.6	72.2	33.9	170.3	84.0	37.5	179	103.4	40.6
2	157.8	58.0	27.1	165.5	61.6	28.5	173.8	71.8	32.6
3	183.0	50.9	31.9	192.5	62.0	31.6	199.1	97.3	37.5
4	173.9	53.0	32.0	182.3	62.1	34.6	189.6	77.4	38.9
5	162.5	58.0	28.5	175.9	71.7	31.7	188.3	95.4	33.9
6	167.5	53.6	24.4	181.1	69.2	29.0	193.1	87.2	31.7
7	155.9	59.5	31.9	166.4	70.7	34.8	176.8	81.0	37.8
8	167.8	52.5	28.1	174.3	65.3	31.0	182.6	84.4	33.5
9	158.6	54.1	28.6	171.1	66.0	33.6	180.6	74.5	36.3
10	147.8	58.0	27.6	162.5	67.2	30.4	172.1	80.3	32.8
Mean	**163.2**	**57.0**	**29.4**	**174.2**	**68.0**	**32.3**	**183.5**	**85.3**	**35.6**
S.D.	**10.1**	**6.1**	**2.9**	**9.1**	**6.7**	**2.8**	**8.8**	**10.4**	**3.1**

Table 7 HR, VE and VO2 at 0.50 in radius of hollow condition

Subject	12 km/h			14 km/h			16 km/h		
	HR (bpm)	**V_E (L/min)**	**VO_2 (ml/kg·min)**	**HR (bpm)**	**V_E (L/min)**	**VO_2 (ml/kg·min)**	**HR (bpm)**	**V_E (L/min)**	**VO_2 (ml/kg·min)**
1	--	77.7	33.5	171.1	90.2	36.9	180.4	105.9	39.2
2	169.5	57.2	24.7	169.9	64.7	29.6	176.8	75.1	31.8
3	186.5	47.4	33.3	192.3	56.8	37.3	198.8	82.8	41.0
4	167.8	54.4	30.9	178.5	66.5	33.6	186.6	79.1	38.0
5	--	66.4	31.7	--	81.7	33.3	190.5	101.6	37.1
6	167	55.9	25.9	177.3	62.5	28.1	187.4	78.2	31.8
7	161.0	61.2	31.5	175.6	78.1	35.0	183.6	88.9	37.7
8	162.0	49.4	26.4	170.8	58.5	30.7	179.6	73.7	34.2
9	154.1	55.5	30.0	168.4	65.0	33.5	180.0	80.4	38.2
10	159.8	60.8	27.8	169.6	70.0	29.6	175.8	83.2	32.1
Mean	**166.0**	**58.6**	**29.6**	**174.8**	**69.4**	**32.8**	**184.0**	**84.9**	**36.1**
S.D.	**9.7**	**8.7**	**3.2**	**7.5**	**10.7**	**3.2**	**7.0**	**10.9**	**3.4**

Table 8 HR, VE and VO2 at 0.75 in radius of hollow condition

Subject	12 km/h			14 km/h			16 km/h		
	HR (bpm)	V_E (L/min)	VO_2 (ml/kg·min)	HR (bpm)	V_E (L/min)	VO_2 (ml/kg·min)	HR (bpm)	V_E (L/min)	VO_2 (ml/kg·min)
1	156.1	61.6	31.7	169	80.5	37.1	176.3	90.1	39.7
2	158.5	59.3	28.0	167.3	71.4	30.9	174.9	80.0	34.5
3	180.4	41.9	27.5	186.6	57.5	31.6	193.6	89.7	35.9
4	172.9	56.2	31.3	183.3	66.4	34.4	190.6	78.9	37.3
5	164.4	56.1	27.0	176.6	70.2	30.3	187.5	89.3	33.7
6	155.0	46.1	21.2	172.8	59.7	25.2	189	86.9	28.9
7	157.9	74.3	31.9	170.8	78.6	32.4	181.6	94.4	35.4
8	164.9	36.6	23.6	174.0	46.3	26.9	181.4	58.7	30.0
9	--	49.0	29.5	174.8	61.0	33.5	184.8	77.1	36.2
10	156.0	54.6	25.9	169.3	59.0	30.0	174.3	73.0	32.2
Mean	**162.9**	**53.6**	**27.8**	**174.5**	**65.1**	**31.2**	**183.4**	**81.8**	**34.4**
S.D.	**8.8**	**10.8**	**3.5**	**6.3**	**10.4**	**3.5**	**6.8**	**10.6**	**3.3**

Table 9 VO_2max test

Subject	Weight (kg)	HR (bpm)	V_E (L/min)	VO_2 (L/min)	VO_2 (ml/kg.min)	R	V_E/VO_2 L/L O_2
1	55.0	--	--	--	--	--	--
2	72.0	200	127.8	3.12	43.3	1.12	41.0
3	63.0	203	103.5	2.75	43.7	0.90	37.6
4	56.0	194	103.6	2.50	44.6	1.10	41.5
5	70.5	196	117.4	3.00	42.5	1.04	39.2
6	71.0	203	116.4	2.71	38.1	1.13	43.0
7	73.5	203	123.4	3.46	47.1	1.15	35.6
8	61.0	194	124.6	2.79	45.8	1.17	44.6
9	63.0	194	112.2	2.77	43.9	1.07	40.6
10	69.0	189	108.2	2.55	37.0	1.13	42.4
Mean	**65.4**	**197.3**	**115.2**	**2.85**	**42.9**	**1.09**	**40.6**
S.D.	**6.7**	**5.1**	**9.0**	**0.3**	**3.3**	**0.08**	**2.8**

***Note – 1 Subject did not complete the VO_2max test.**

Table 10 Ratings of perceived exertion for the three hollows

Hollow	0.25 in			0.50 in			0.75 in		
Velocity	12 km/h	14 km/h	16 km/h	12 km/h	14 km/h	16 km/h	12 km/h	14 km/h	16 km/h
Subject									
1	11	12	16	12	13	15	13	13	17
2	6	10	12	6	8	11	9	11	13
3	9	13	15	9	14	15	9	13	15
4	6	9	15	10	12	15	6	10	14
5	9	12	15	11	12	15	10	12	15
6	8	13	14	9	11	13	7	9	13
7	11	13	14	11	11	13	12	12	14
8	7	9	11	8	10	12	8	10	11
9	12	13	14	11	13	15	11	12	15
10	9	11	14	8	11	14	10	13	15
Mean	**8.8**	**11.5**	**14.0**	**9.5**	**11.5**	**13.8**	**9.5**	**11.5**	**14.2**
S.D.	**2.1**	**1.6**	**1.5**	**1.8**	**1.7**	**1.5**	**2.2**	**1.4**	**1.6**

Table 11 Ranking of hollows (1= best, 2= middle, 3=worst)

Subject	0.25 in	0.50 in	0.75 in
1	3	1	2
2	2	1	3
3	2	1	3
4	1	3	2
5	2	1	3
6	2	1	3
7	3	1	2
8	3	1	2
9	1	3	2
10	1	2	3

Table 12 Subjective perception of "bite" into skating surface

Subject	0.25 in	0.50 in	0.75 in
1	6	6	4
2	4	8	2
3	7	4	2
4	7	5	7
5	6	6	7
6	7	8	5
7	7	9	5
8	9	8	9
9	7	6	8
10	7	6	6
Mean	**6.7**	**6.6**	**5.5**
S.D.	**1.3**	**1.6**	**2.4**

Table 13 Two way repeated measures ANOVA (velocity x hollow) for HR

Source	SS	DF	MS	F	P
Velocity	5759.5	2	2879.7	44.0	0.001
Hollow	34.0	2	17.0	0.26	0.772
Velocity x Hollow	26.4	4	6.6	0.101	0.982
Error	5301.8	81	65.5		

Table 14 Two way repeated measures ANOVA (velocity x hollow) for VO_2

Source	SS	DF	MS	F	P
Velocity	622.1	2	311.1	30.2	0.001
Hollow	46.7	2	23.4	2.3	0.110
Velocity x Hollow	1.1	4	0.268	0.26	0.999
Error	833.5	81	10.3		

Table 15 Two way repeated measures ANOVA (velocity x hollow) for V_E

Source	SS	DF	MS	F	P
Velocity	11581.0	2	5790.5	62.2	0.001
Hollow	286.2	2	143.1	1.5737	0.221
Velocity x Hollow	15.1	4	3.773	0.041	0.997
Error	7541.5	81	93.1		

Table 16 Two way repeated measures ANOVA (velocity x hollow) for RPE

Source	SS	DF	MS	F	P
Velocity	336.4	2	168.2	55.5	0.001
Hollow	1.356	2	0.678	0.224	0.800
Velocity x Hollow	2.711	4	0.678	0.224	0.924
Error	245.3	81	3.028		

Appendix F

Subjective Ranking of the three hollows

Rank the three sessions in terms of the role of skate sharpening to your performance

Best	Session 1	Session 2	Session 3
Worst	Session 1	Session 2	Session 3

Appendix G

Daily Skating Survey

Borg Scale – Rating of Perceived Exertion

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, very hard
20	

With this sharpening, how well did you feel your skates "bite" into the surface when you were pushing off?

Poor **Average** **Excellent**

1 2 3 4 5 6 7 8 9 10

Appendix H

McGill University Ethics Approval

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MCGILL UNIVERSITY
FACULTY OF EDUCATION

CERTIFICATE OF ETHICAL ACCEPTABILITY FOR FUNDED AND NON FUNDED RESEARCH INVOLVING HUMANS

Faculty of Education Ethics Review Committee consists of 6 members appointed by the Faculty of Education inating Committee, an appointed member from the community and the Associate Dean (Academic Programs, luate Studies and Research) who is the Chair of this Ethics Review Board .

undersigned considered the application for certification of the ethical acceptability of the project entitled:

e blade hollow and oxygen consumption during forward skating

roposed by:

icant's Name Paul Morrison

Supervisor's Name Dr. David Montgomery

icant's Signature

Supervisor's Signature D Montgomery

ree / Program / Course MA

Granting Agency non-funded research

application is considered to be:

ıll Review x

An Expedited Review ✓

enewal for an Approved Project

A Departmental Level Review

Signature of Chair / Designate

review committee considers the research procedures and practices as explained by the applicant in this ication, to be acceptable on ethical grounds.

rof. Ron Stringer
of Educational and Counselling Psychology
Apr. 8/02
ature / date

4. Prof. Ada Sinacore
Department of Educational and Counselling Psychology
Signature / date

rof. Ron Morris
rtment of Culture & Values
Ron Morris March 27-02
ature / date

5. Prof. Brian Alters
Department of Educational Studies
Signature / date

rof. René Turcotte
artment of Physical Education
April 5/02
ature / date

6. Prof. Kevin McDonough
Department of Culture and Values in Education
Signature / date

ember of the Community

ature / date

/ H. Maguire Ph. D.
ir of the Faculty of Education Ethics Review Committee
ociate Dean (Academic Programs, Graduate Studies and Research)
ılty of Education, Room 230
: (514) 398-7039/398-2183 Fax: (514) 398-1527

Mary Maguire, April 9, 2002
Signature / date

dated June 2001)

Updated May 2001

MCGILL UNIVERSITY FACULTY OF EDUCATION

STATEMENT OF ETHICS OF PROPOSED RESEARCH

It is assumed that the responses to the questions below reflect the author's (or authors') familiarity with the ethical guidelines for funded and non funded research with human subjects that have been adopted by the Faculty of Education and that responses conform to and respect the Tri-council Policy Statement: Ethical Conduct for Research Involving Humans (1998).

1. Informed Consent of Subjects

Explain how you propose to seek informed consent from each of your subjects (or should they be minors, from their parents or guardian). Informed consent includes comprehension of the nature, procedures, purposes, risks, and benefits of the research in which subjects are participating. Please append to this statement a copy of the consent form that you intend to use.

Prior to testing, each subject will be issued a consent form, which will include an explanation of the nature, purpose, procedure, risks, benefits of the research, and informed rights. The graduate student (Paul Morrison) will read the consent form with the subjects emphasizing their right to withdraw from the study at any time. Testing will begin only when the signed consent forms have been completed. All subjects will be eighteen years of age or older.

2. Subject Recruitment

2.1 Are the subjects a "captive population" (e.g., residents of a rehabilitation centre, students in a class, inmates in a penal establishment)?

No. The subjects will be elite female ice hockey players, between the ages of 18 and 29 years.

2.2 Explain how institutional or social pressures will not be applied to encourage participation. (See attached guidelines)

All of the subjects will participate in the study on a volunteer basis only.

2.3 What is the nature of any inducement you intend to present to prospective subjects to persuade them to participate in your study?

The nature of the study requires sub-maximal and maximal performances on the skating treadmill and on-ice. Oxygen uptake and heart rate will be monitored. This information will provide meaningful data to the subjects on their skating economy. Prospective subjects are expected to volunteer for the educational experience and the opportunity to skate on a synthetic surface. The skating treadmill at McGill University is novel, as it is the only one in Quebec and Eastern Canada

2.4 How will you help prospective participants understand that they may freely withdraw from the study at their own discretion and for any reason?

The subjects' right to withdraw from the study at any time and for any reason will be clearly stated in the consent form. In addition, during the explanation of the procedures, subjects will be reminded of their right to withdraw from the study at their own discretion.

3. Subject Risk and Well-being

What assurance can you provide this committee (as well as the subjects) that the risks. physical and/or psychological, that are inherent to this study are either minimal or fully justifiable given the benefits that these same subjects can reasonably expect to receive?

Physical risks are those inherent to normal participation in high intensity exercise. The subjects will be healthy athletes that habitually exert themselves at intensities similar to that required during the testing sessions in this experiment. Also, when skating on the treadmill, a harness is secured to the subject to protect the subject in the event she should fall.

4. Deception of Subjects

4.1 Will the research design necessitate any deception to the subjects?

No.

4.2 If so, what assurance can you provide this committee that no alternative methodology is adequate?

Not applicable

4.3 If deception is used, how do you intend to nullify any negative consequences of the deception?

Not applicable

5. Privacy of Subjects

How will this study respect the subjects' right to privacy, that is, their right to refuse you access to any information which falls within the private domain?

Individual subject data will be analyzed using personal codes that will be available only to the principal investigators. In publications (thesis and research article), the subjects' identity will remain unknown.

6. Confidentiality/Anonymity

6.1 How will this study ensure that (a) the identity of the subjects will be concealed and (b) the confidentiality of the information, which they will furnish to the researchers or their surrogates will be safeguarded?

The lab technicians and graduate students that will participate in data collection will be advised that the results are confidential. The data will remain in a locked filing cabinet with access only available to the principal investigators. Codes will be used to store the data on the computer. Individual scores will be included without names, using personal identification codes.

6.2 If applicable, explain how data will be aggregated in such a way that even should the identity of the participants become known, no reasonable inference could be made about the performance, competence, or character of any one of these participants.
If data will not be aggregated, provide a detailed explanation.

The results will be presented in the form of means and standard deviations. No personal information will be used.

Signature of researcher: ______________________

If this project has been submitted to another ethics committee, please note the particulars:

Submit this statement to:
Office of the Associate Dean
(Academic Programs, Graduate Studies and Research)
Faculty of Education, Room 230
Tel: (514) 398-7039/2183
Fax: (514) 398-1527

Appendix I

Subject Consent Form

Consent Form For Exercise Testing

Thesis Title: Skate blade hollow and oxygen consumption during forward skating.

Investigators:
Dr. David L. Montgomery, Department of Kinesiology and Physical Education

Paul Morrison, Master's student, Department of Kinesiology and Physical Education,

Purpose of Research:

The purpose of this research is to examine the effect of skate blade hollow on oxygen consumption during forward skating.

Procedure:

Skate blade hollow is the curvature between the outside and inside edges of the hockey skate blade. (See appendix). One of the issues connected with skate sharpening is the determination of the required radius of the hollow grind and the effect that this will have on the oxygen cost of skating. The most common radius of hollow for the hockey player is 0.5 inches. This study will examine skate blades of three radii- 0.375 in, 0.5 in, and 0.625 in. to determine if changes in radii affect oxygen consumption.

This interaction between skate blade radius of hollow and oxygen consumption will be investigated using healthy, expert skaters. You will complete a PAR-Q (Physical Activity Readiness Questionnaire) in order to screen for any medical conditions that would prevent you from taking part in an exercise program. Age (yr), height (cm), weight (kg) will all be measured. Body composition will also be assessed using skinfold measurements at the following five sites: biceps, triceps, subscapular, iliac crest and medial calf. All skaters will be familiarized with the skating treadmill before commencement of data collection. This familiarization will consist of a minimum of three 30-minute sessions of skating on the treadmill.

The testing will take place on three separate days, each separated by 2-3 days of recovery. On each day, you will skate for four minutes at each of three velocities (12, 15, and 18 $km \cdot h^{-1}$). In addition, on the third day of testing, following completion of the third velocity, you will rest for five minutes and then perform a VO_2max test. The VO_2max test will commence at 18 $km \cdot h^{-1}$ with speed increased by 1 $km \cdot h^{-1}$ every minute until volitional exhaustion. During each of these skating sessions, VO_2 will be measured using a metabolic cart. You will breathe into a mouthpiece attached to the metabolic cart through a collection tube, and will also wear a nose-clip to ensure that all expired air is sent to the metabolic cart.

Costs:

There will be no costs to me for participating in this study. I understand that I will not be receiving monetary compensation for participating in this study, but I will benefit from free use of the skating treadmill.

Risks of Procedure:

There are no known medical risks associated with the procedures used in this study. Localized muscle fatigue and soreness may result from the exercise performed during the test. A harness will be worn at all times while skating to protect you in the event of a fall.

Information on Risks and Benefits:

The results of this study will have no direct impact on me but may help to advance the knowledge base on the skating treadmill and its continued use as a training tool for hockey players. I understand that the results of this study will not be formally presented to me but that I will have access to theses and publication(s) which will result from this study.

Confidentiality:

I understand that the lab technicians and graduate students that will participate in data collection will be advised that the results are confidential. The data will remain in a locked filing cabinet with access only available to the principal investigators. Codes will be used to store the data on the computer. Individual scores will be included without names, using personal identification codes. The results will be presented in the form of means and standard deviations. No personal information will be used.

Request for more information:

If I would like to discuss my concerns regarding participation in this study with a person not directly involved, I am aware that I can call Dr. Mary Maguire, Chair of the Ethics Committee (Faculty of Education.); tel.: (514) 398-7039.

Withdrawal from Study:

I understand that I am free to withdraw at any time from this study without any penalty or prejudice. I also understand that the investigators may terminate my participation in the study at any time.

Participant's Statement:

I confirm that ____________________________ has explained the purpose of the research, the procedures that I will undergo and the possible risks and discomforts. I have had the opportunity to ask questions and these have been answered to my satisfaction. Having read and understood this consent form I hereby agree to participate:

____________________	____________________	____________________
Name of subject	Signature	Date
____________________	____________________	____________________
Name of witness	Signature	Date
____________________	____________________	____________________
Name of researcher	Signature	Date

Research Protocol

The purpose of this research is to examine the effect of skate blade hollow on oxygen consumption during forward skating. Skate blade hollow is the curvature between the outside and inside edges of the hockey skate blade. (see appendix). One of the issues connected with skate sharpening is the determination of the required radius of the hollow grind and the effect that this will have on the oxygen cost of skating. The most common radius of hollow for the hockey player is 0.5 inches. This study will examine skate blades of three radii - 0.375 in, 0.5 in, and 0.625 in. to determine if changes in radii affect oxygen consumption.

Subjects

The participants will be 10 college-aged female volunteers from a population of varsity ice hockey players. All participants will be between 18 and 29 years of age. All subjects will complete an informed consent document prior to any testing. Each subject will perform a minimum of three acclimatization sessions consisting of 30 minutes of forward skating on the treadmill located within the Seagram Sports Science Centre. The skating treadmill is similar in function and design to a running treadmill. The surface is covered with a series of polyethylene slats that are attached to a rubber belt, which rolls over two drums. The skating treadmill has a skating surface of $3.20m^2$. Prior to each test. the surface will be sprayed with silicone oil to reduce friction between the skate blade and the polyethylene surface. During the test, subjects will wear a safety harness attached to an overhead track as a precaution if a fall occurs. Figure 1 illustrates the skating treadmill, safety harness, and metabolic gas collection system. Subjects will return to the lab on three occasions to perform oxygen consumption tests using blades with hollows of: 0.375 in, 0.5 in, and 0.625 in. Testing order will be random with the subjects blinded to the magnitude of the hollow radii. The sharpening of the blades will be performed by a trained technician.

Procedures

Height, weight and body fatness will be determined following the three acclimatization sessions. Standing height will be measured to the nearest 0.5 cm using a wall-mounted stadiometer. Body weight will be determined using a balance beam medical scale and recorded to the nearest 0.1 kg. To determine body composition, the procedures of the Canadian Physical Activity, Fitness and Lifestyle Appraisal will be used. Skinfold sites will include: biceps, triceps, subscapular, iliac crest and medial calf.

Subjects will perform three skating treadmill tests in a random order using their own skates that will be sharpened by a trained technician to obtain skate blade hollow with radii of 0.375 in, 0.5 in, and 0.625 in. During each test the subjects will skate for 4 minutes at each of three velocities on the skating treadmill. The velocities will be 12, 15 and 18 km/hr. The subjects will have five minutes of passive recovery between each skating velocity. Throughout the test, expired air will be analyzed continuously using a metabolic cart with the following variables being recorded: VO_2 (oxygen consumption), VCO_2 (carbon dioxide production), V_E (minute ventilation), and R (respirator exchange ratio). Heart rate will be measured using a Polar Sport Tester and recorded every minute throughout the test.

In addition to the submaximal skating tests, a VO_2max test will be performed during the last session. The VO_2max test will be initiated at 18 km/hr and the treadmill speed will be increased by 1 km/hr every minute until volitional fatigue is reached.

Expired air will be analyzed continuously throughout the test to determine the subjects VO_2max.

The dependant variables to examine the effect of skate blade hollow will be: VO_2 (ml/kg.min) and heart rate (bpm). Following data analysis, each subject will be presented with a summary of results explaining body composition, VO_2 and heart rate at the three velocities and the effect of skate blade hollow on these measurements.

Appendix J

Contribution of Co-Authors to the Research Article

Paul Morrison

Responsible for collecting data, analyzing data, and writing the final manuscript.

Dr. David Montgomery

Thesis supervisor and assisted with writing of the research article.

Dr. David Pearsall

Proofread research article.

Dr. Rene Turcotte

Proofread research article.

Dr. Kelly Lockwood

Provided skate blade measurement equipment and proofread the research article.