# A Comparison of Skating Economy On-Ice and on the Skating Treadmill

By

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## Dedication

This thesis is dedicated to the memory of Bruce Nobes, my Uncle and good friend.

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## Acknowledgments

The completion of this thesis would not have been possible without the cooperation and assistance of several very important people.

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Dad, Mom, Al, Dids, and Michelle, thank you for your unconditional love and support, you are all truly wonderful people. Dad and Mom, you are the greatest of teachers, I am eternally grateful to you for having given me the opportunity to be successful in life.

# Abstract

The purpose of this study was to compare skating economy and $VO_2max$ on-ice and on the skating treadmill (TM). Male varsity hockey players ($n = 15$, age = 21.0 yr) performed skating tests on a TM and on-ice. The subjects skated for 4 min at each of 3 submaximal velocities (18, 20, and 22 $km \cdot h^{-1}$), separated by 5 min of passive recovery. A $VO_2max$ test followed the submaximal tests and commenced at 24 $km \cdot h^{-1}$ with the velocity increasing by 1 $km \cdot h^{-1}$ every minute until volitional fatigue. $VO_2$ was 39.7, 42.9, 46.0, and 53.4 $ml \cdot kg^{-1} \cdot min^{-1}$ at 18, 20, 22, and maximum speed ($km \cdot h^{-1}$) on the TM. $VO_2$ was significantly lower ($p < .05$) 31.5, 36.9, and 42.7 $ml \cdot kg^{-1} \cdot min^{-1}$ at 18, 20, and 22 $km \cdot h^{-1}$ on-ice. The on-ice $VO_2max$ (54.7 $ml \cdot kg^{-1} \cdot min^{-1}$) was similar to TM. Kinematic data (stride rate and length) and heart rate (HR) were significantly different on-ice compared to TM. These results show that at submaximal velocities, $VO_2$, HR, and stride rate are higher on TM compared to on-ice. $VO_2max$ was similar while HRmax was higher on the skating treadmill compared to on-ice.

**Résumé**

Le but de cette étude était de comparer la dépense énergétique ainsi que le $VO_2max$ sur la glace et sur un tapis roulant conçu pour patiner. Des joueurs d'une équipe masculine universitaire de hockey (n = 15, âge = 21.0 ans) ont effecctué une épreuve de patinage sur un tapis roulant et sur la glace. Les sujets ont patiné durant quatre minutes à chacune des trois vitesses sous-maximales (18, 20 et 22 $km \cdot h^{-1}$), entrecoupées de cinq minutes de récupération passive. Suite à l'épreuve de patinage sous-maximale, un test pour évaluer le $VO_2max$ était réalisé. Celui-ci débutait à une vélocité de 24 $km \cdot h^{-1}$ et la vitesse était augmentée de 1 $km \cdot h^{-1}$ à chaque minute jusqu'à épuisement. Les $VO_2$ obtenus sur le tapis roulant étaient de 39.7, 42.9, 46.0, et de 53.4 $ml \cdot kg^{-1} \cdot min^{-1}$ à 18, 20, 22 ($km \cdot h^{-1}$) et à vitesse maximale. Le $VO_2$ était significativement plus bas sur la glace ($p = 0.05$) 31.5, 36.9 et 42.7 $ml \cdot kg^{-1} \cdot min^{-1}$ à 18, 20, et 22 $km \cdot h^{-1}$. Le $VO_2max$ sur la glace (54.7 $ml \cdot kg^{-1} \cdot min^{-1}$) était similaire à celui mesuré sur le tapis roulant. Les données cinématiques (vitesse et longueur des enjambées) ainsi que la fréquence cardiaque étaient signicativement différentes sur la glace comparativement aux résultats obtenus sur le tapis roulant. Ces résultats démontrent qu'à vitesse sous-maximale, le $VO_2$, la fréquence cardiaque ainsi que la vitesse des enjambées sont plus élevées sur le tapis roulant que sur la glace.

# A comparison of skating economy on-ice and on the skating treadmill

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## Introduction

Physiological data have been reported for ice hockey players on cycling ergometers (Cox et al., 1993; Rhodes et al., 1986), running treadmills (Cox et al., 1988; Montgomery & Dallaire, 1986), and on-ice (Carroll et al., 1993; Ferguson et al., 1969; Léger et al., 1979). Skating movements are not mirrored by either bicycle or treadmill tests and therefore may not adequately reflect the specific aerobic power developed by ice hockey players (Smith et al., 1982). When selecting a modality for testing, sport specificity is important (MacDougall & Wenger, 1991). Recently a skating treadmill (TM) has been introduced to assess the skating performance of ice hockey players. This treadmill consists of a parallel series of polyethylene slats creating a surface permitting subjects to perform wearing their own ice skates. A hockey-specific $VO_2max$ protocol was developed by Dreger & Quinney (1999). They found no significant difference in $VO_2max$ between TM and cycle ergometer protocols.

Due to the recent innovation of the TM, there is a paucity of literature describing the bioenergetics and the biomechanics of skating on this ergometer. Hinrichs (1994) examined the difference between treadmill skating and on-ice skating from a muscle activity perspective. There were few differences in EMG activity of the lower leg muscles between the two modes.

Running economy has been defined as the steady-state $VO_2$ at submaximal running velocities (Daniels, 1985). Running economy is an important correlate of successful distance running performance among individuals with comparable $VO_2max$ values (Bailey & Pate, 1991; Conley & Krahenbuhl, 1980; Daniels, 1985). A linear relationship exists between $VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) and running at submaximal velocities

(Conley & Krahenbuhl, 1980; Daniels, 1985). Skating economy is defined as the steady state $VO_2$ required to skate at a submaximal velocity (Riby, 1994). Riby concluded that there is a linear relationship between skating at velocities of 336 to 381 $m \cdot min^{-1}$ and $VO_2$. The inter-individual variability in skating at a given velocity is larger than running (Montgomery, 1988). The coefficient of variation at 20 $km \cdot h^{-1}$ has been reported at 15% during skating compared to 5 – 7% when running at similar intensities (Riby, 1994).

The purpose of this study was to compare skating economy and $VO_2max$ on-ice and on the skating treadmill.

**Methods**

Fifteen male university ice hockey players volunteered to participate in this study. Informed consent was obtained with all procedures approved by the ethics committee of the university. Anthropometric measurements of height, weight, and skinfolds (biceps, triceps, subscapula, iliac crest, chest, abdomen, thigh, medial calf) were made and percent fat was calculated (Yuhasz, 1966). Physical characteristics of the subjects are included in Table 1.

Each subject participated in two skating sessions described as TM and on-ice. Both skating sessions were performed during the competitive phase of the season with the on-ice test performed four weeks after the TM test. The availability of ice time necessitated this sequence. For both skating protocols, subjects wore the same skates (Bauer 7000 or Nike Quest), hockey gloves, track suit, and carried a hockey stick.

The TM test was performed on a skating treadmill (Acceleration Canada, Calgary, AB). Subjects performed three 30 min familiarization sessions on the skating 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 parallel 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 friction between the skate blade and the polyethylene surface. During the test, subjects wore a safety harness that was attached to an overhead track as a precaution if a fall occurred. Figure 1 illustrates the skating treadmill, safety harness, and metabolic gas collection system.

Skating economy was measured at three submaximal velocities (18, 20, and 22 $km \cdot h^{-1}$). Subjects skated for 4 min at each velocity with physiological data averaged for the last 2 min. Subjects had 5 min of passive recovery between each skating bout. Following the third skating economy test, a $VO_2max$ test was completed. The test was initiated at 24 $km \cdot h^{-1}$ with increments of 1 $km \cdot h^{-1}$ each minute until maximal volitional exhaustion was reached. Grade was 0% for the skating economy and maximal tests. Gas measurements ($V_E$, $VO_2$, R) were averaged every 20 s using a 2900 metabolic cart (SensorMedics). Physiological data were examined to confirm that R remained below 1.00 for each skating economy test and above 1.10 for the $VO_2max$ test. Heart rate (HR) data were collected every 5 s using a Polar Accurex Plus HR monitor (Polar Electro, Kempele, Finland). Temperature in the laboratory ranged from 20 to 23° C.

The on-ice test was performed on a 140-m oval track with a similar protocol that was used on the skating treadmill. The track was set using 10 pylons with 4 markers specifically positioned every 35 m for the purpose of pacing. Velocity was controlled via an audio tape system. For each velocity an audio signal was emitted at a rate of four beeps per lap. The hockey players synchronized their speed with the audio signals and the four pylons. Subjects skated for 4 min at 18, 20, 22 km·h$^{-1}$ with 5 min of recovery between each test. The $VO_2$max test was initiated at 24 km·h$^{-1}$ with increments of 1 km·h$^{-1}$ each min until maximal volitional exhaustion was reached.

The on-ice physiological data were collected using a breath-by-breath portable gas exchange system (Cosmed K4b$^2$, Italy). The K4b$^2$ system weighed 600 grams. Figure 2a and 2b illustrate the K4b$^2$ gas collection system. Gas measurements were averaged every 20 s throughout the tests. Physiological data were telemetered to a receiver located in the press box above the ice surface. The accuracy and the reliability of the K4b$^2$ system have been reported (Hausswirth et al., 1997; Palange et al., 1996). Recently, Doyon et al. (2001) observed excellent agreement between the K4b$^2$ breath-by-breath system and a mixing box system across a wide range of $VO_2$ when tested outdoors (2° C) and indoors. R remained below 1.00 for each skating economy test and exceeded 1.10 at the end of the $VO_2$max test. HRs were averaged every 5 s during the on-ice test. Temperature in the hockey arena ranged from 0 to 5° C.

During the skating economy tests, stride rate was measured by counting skating strides for approximately 60 s. A skating stride was defined as one cycle, beginning at push-off of the right skate to push-off of the same skate. This definition includes the three components of the skating stride (push-off, glide, and recovery). Stride length was calculated as:

Stride length (m·stride$^{-1}$) = Velocity (m·min$^{-1}$) / Stride Rate (strides·min$^{-1}$)

One-way repeated measures ANOVAs were used to examine differences in $VO_2$, HR, and stride rate on the 2 surfaces (TM and on-ice), and the 4 velocities (18, 20, 22 km·h$^{-1}$, and maximum). When appropriate, post hoc analyses were performed using a

Tukey honest significant difference (HSD) test. For all statistical analyses, $\alpha$ was set at $P < .05$.

## Results

Table 2 shows the $VO_2$ results for the TM and on-ice skating economy and $VO_2max$ tests. The linear relationship between $VO_2$ and velocity is illustrated in Figure 3. The on-ice submaximal $VO_2$ was significantly ($P < .01$) lower than TM values. The mean $VO_2max$ was similar on-ice (54.7 $ml \cdot kg^{-1} \cdot min^{-1}$) and TM (53.4 $ml \cdot kg^{-1} \cdot min^{-1}$).

Table 3 shows the HR results for the TM and on-ice skating economy and $VO_2max$ tests. The on-ice submaximal HRs were significantly ($P < .01$) lower than TM values. The mean HRmax was significantly lower ($P < .01$) on-ice (187.9 $beats \cdot min^{-1}$) compared to TM (193.3 $beats \cdot min^{-1}$).

Table 4 shows the kinematic results for the TM and on-ice skating economy and $VO_2max$ tests. The on-ice stride rates were significantly ($P < .01$) lower than TM values. Stride rates were similar at 18, 20, and 22 $km \cdot h^{-1}$ during the TM tests. On-ice stride rate significantly increased from 32.0 $strides \cdot min^{-1}$ at 18 $km \cdot h^{-1}$ to 39.3 $strides \cdot min^{-1}$ at 22 $km \cdot h^{-1}$.

## Discussion

Although, treadmill skating is believed to simulate on-ice skating, few studies have compared the physiological responses between the two modalities. The purpose of this study was to compare skating economy and $VO_2max$ on-ice and on the skating treadmill. Figure 3 illustrates the linear relationship between $VO_2$ and on-ice skating using data from four studies. The subjects for these studies were also male varsity hockey players. Our on-ice data using the $K4b^2$ system were similar to $VO_2$ measurements using Douglas bags (Carroll et al., 1993; Ferguson et al., 1969; Montgomery & Cartwright, 1994; Riby, 1994).

At 20 $km \cdot h^{-1}$, our $VO_2$ was 36.9 $ml \cdot kg^{-1} \cdot min^{-1}$ on-ice while Carroll et al. (1993) reported a value of 33.8 $ml \cdot kg^{-1} \cdot min^{-1}$ at this velocity. On the TM, our $VO_2$ was 6.0 $ml \cdot kg^{-1} \cdot min^{-1}$ higher. At 20 $km \cdot h^{-1}$, the intensity relative to the maximum value for each modality was 67.5% on-ice compared to 80.3% on the TM. Heart rate values confirm the higher intensity when skating on the TM compared to on-ice. At 20 $km \cdot h^{-1}$, the HR was 17 $beats \cdot min^{-1}$ higher on the TM.

Only one other study has compared TM and on-ice physiological demands during submaximal skating. The experimental design utilized by Hinrichs (1994) compared TM and on-ice heart rates as well as EMG activity while skating at three stride frequencies (42, 49.5, and 54 $strides \cdot min^{-1}$) described as slow, medium, and fast skating. At each stride frequency, the speed of the TM was significantly slower than the on-ice velocity. The "fast" condition was only 16.5 $km \cdot h^{-1}$ on the TM versus 25.0 $km \cdot h^{-1}$ on-ice. There were no significant differences in muscular activation patterns between TM and on-ice. The HR for the "fast" condition was 175 $beats \cdot min^{-1}$ on the TM. The higher HRs in the study by Hinrichs may be attributed to the protocol, which included a treadmill grade of 2.5%. By using similar stride frequencies on the TM and on-ice, Hinrichs was able to equate the physiological demands of skating on the two surfaces. In order to achieve a similar HR response our subjects skated at a higher velocity on the TM. During the skating economy test at 22 km·h$^{-1}$, the mean HR was 173.3 beats·min$^{-1}$ on the TM and 165 beats·min$^{-1}$ on-ice.

At similar velocities, stride rate and $VO_2$ were significantly greater on TM compared to on-ice. The different physiological and kinematic pattern observed on-ice versus TM might be attributed to two factors – coefficient of friction of the two skating surfaces and the manner of skating. The TM test was performed using only forward strides in a linear direction whereas the on-ice test was performed on an oval course necessitating forward crossover strides. Hinrichs (1994) also observed increased stride frequencies on the TM compared with on-ice skating. During on-ice speed skating at high velocities, the frictional component is mainly due to air resistance (deKoning et al., 1992). On the TM, surface friction is much greater while air resistance is minimal. When skating on the TM there is increased drag on the player's skate effectively reducing the glide phase of the stride compared with on-ice skating (Dreger, 1997).

Ice-skating is possible because of a low coefficient of friction. The on-ice coefficient of friction ranges from $\mu = 0.003$ (deKoning et al., 1992; Kobayshi, 1973) to $\mu = 0.030$ (Zatsiorski et al., 1987). The coefficient of friction for the artificial surface of the skating treadmill has yet to be determined and it is probably higher than that which is reported for ice. The following theories have been suggested to describe the mechanics of skating on-ice: frictional heating of the ice (Colbeck, 1995), pressure melting (van Ingen Schenau, 1989), and intrinsic properties of the ice surface (deKoning et al., 1992; Pearsall et al., 2000).

We found that $VO_2$max was similar on the TM compared to on-ice. The protocol for the TM test was continuous with grade remaining constant at 0%. Dreger and

Quinney (1999) found a similar $VO_2max$ when TM results were compared to cycle ergometer. They used a discontinuous protocol with a constant speed of 14.4 to 16.0 $km \cdot h^{-1}$ with grade increasing by 2% every 2 min. Their protocol permitted 2 min of recovery between stages.

We observed a higher maximal HR on the TM (193.3 $beats \cdot min^{-1}$) compared to on-ice (187.9 $beats \cdot min^{-1}$) despite having similar maximal oxygen uptakes. Our results are supported by Léger et al. (1979) who also tested varsity hockey players on-ice and in the laboratory. HRmax was 185.9 $beats \cdot min^{-1}$ during treadmill running and significantly lower (175.7 $beats \cdot min^{-1}$) during on-ice skating. A higher HRmax was also recorded during a TM protocol compared to a cycle ergometer test (Dreger & Quinney, 1999). Montgomery and Cartwright (1994) found lower HRs while skating on-ice compared to in-line skating at similar submaximal velocities.

Since the physiological demand was greater during submaximal skating on the TM compared to on-ice, we expected that the subjects would achieve a higher peak velocity during the maximal on-ice protocol. However, the average peak velocity during the final stage was 29.6 $km \cdot h^{-1}$ on the TM compared to 28.0 $km \cdot h^{-1}$ on-ice. We attribute the difference to two factors - the cornering effect of skating on the oval course and the procedure for measuring the oval course. On the oval course, greater physical effort is required when performing crossover strides (i.e. skating on the corners) as compared to only forward skating on the TM. Our 140-m oval was measured on the inside of the track. Using the markings on the ice we measured the total distance skated per lap. At peak velocities, the subjects traveled approximately 146 m per lap. If the maximum on-ice velocity is calculated using a 146-m oval, then the peak velocity would have been 29.1 $km \cdot h^{-1}$ compared to 28.0 $km \cdot h^{-1}$.

In summary, these results showed that at submaximal velocities, $VO_2$, HR, and stride rate were higher on the skating treadmill compared to on-ice. $VO_2max$ was similar while HRmax was higher on the skating treadmill compared to on-ice.

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**Table 1. Characteristics of the Subjects (n = 15)**

| Variable | Mean | S.D. | Range |
|---|---|---|---|
| Age (yr) | 21.0 | 1.4 | 19 - 24 |
| Height (cm) | 179.5 | 8.3 | 164.3 - 193.8 |
| Weight (kg) | 83.5 | 6.7 | 68.0 - 92.5 |
| Fatness (%) | 10.6 | 1.5 | 8.4 - 14.1 |
| Sum of 8 Skinfolds (mm) | 85.3 | 17.1 | 59.4 - 122.8 |

**Table 2. $VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) on the Skating Treadmill and On-Ice**

| Velocity | Treadmill | | On-Ice | |
|---|---|---|---|---|
| $km \cdot h^{-1}$ | Mean | S.D. | Mean | S.D. |
| 18 | 39.7 | 2.8 | 31.5 | 3.3 |
| 20 | 42.9 | 2.2 | 36.9 | 4.2 |
| 22 | 46.0 | 2.3 | 42.7 | 4.2 |
| Maximum | 53.4 | 2.3 | 54.7 | 3.6 |

The F values for the ANOVA were 430.1 for velocity, 20.2 for surface, and 40.1 for the interaction of velocity X surface with $P < .01$ for each factor.

**Table 3. Heart Rate (beats·min$^{-1}$) on the Skating Treadmill and On-Ice**

| Velocity | Treadmill | | On-Ice | |
|---|---|---|---|---|
| km·h$^{-1}$ | Mean | S.D. | Mean | S.D. |
| 18 | 159.3 | 11.3 | 134.4 | 12.9 |
| 20 | 166.5 | 11.3 | 149.5 | 13.4 |
| 22 | 173.3 | 10.8 | 165.1 | 11.1 |
| Maximum | 193.3 | 6.6 | 187.9 | 5.8 |

The F values for the ANOVA were 261.2 for velocity, 75.2 for surface, and 41.4 for the interaction of velocity X surface with $P < .01$ for each factor.

**Table 4. Kinematic Results on the Skating Treadmill and On-Ice**

| Velocity $km \cdot h^{-1}$ | Treadmill Mean | Treadmill S.D. | On-Ice Mean | On-Ice S.D. |
|---|---|---|---|---|
| | **Stride Rate ($strides \cdot min^{-1}$)** | | | |
| 18 | 46.2 | 4.5 | 32.0 | 4.1 |
| 20 | 46.7 | 4.6 | 34.6 | 4.4 |
| 22 | 47.6 | 4.4 | 39.3 | 4.4 |
| | **Stride Length ($m \cdot strides^{-1}$)** | | | |
| 18 | 6.6 | 0.6 | 9.5 | 1.2 |
| 20 | 7.2 | 0.7 | 9.8 | 1.4 |
| 22 | 7.8 | 0.8 | 9.5 | 1.1 |

The F values for the ANOVA were 49.6 for velocity, 80.2 for surface, and 13.6 for the interaction of velocity X surface with $P < .01$ for each factor.

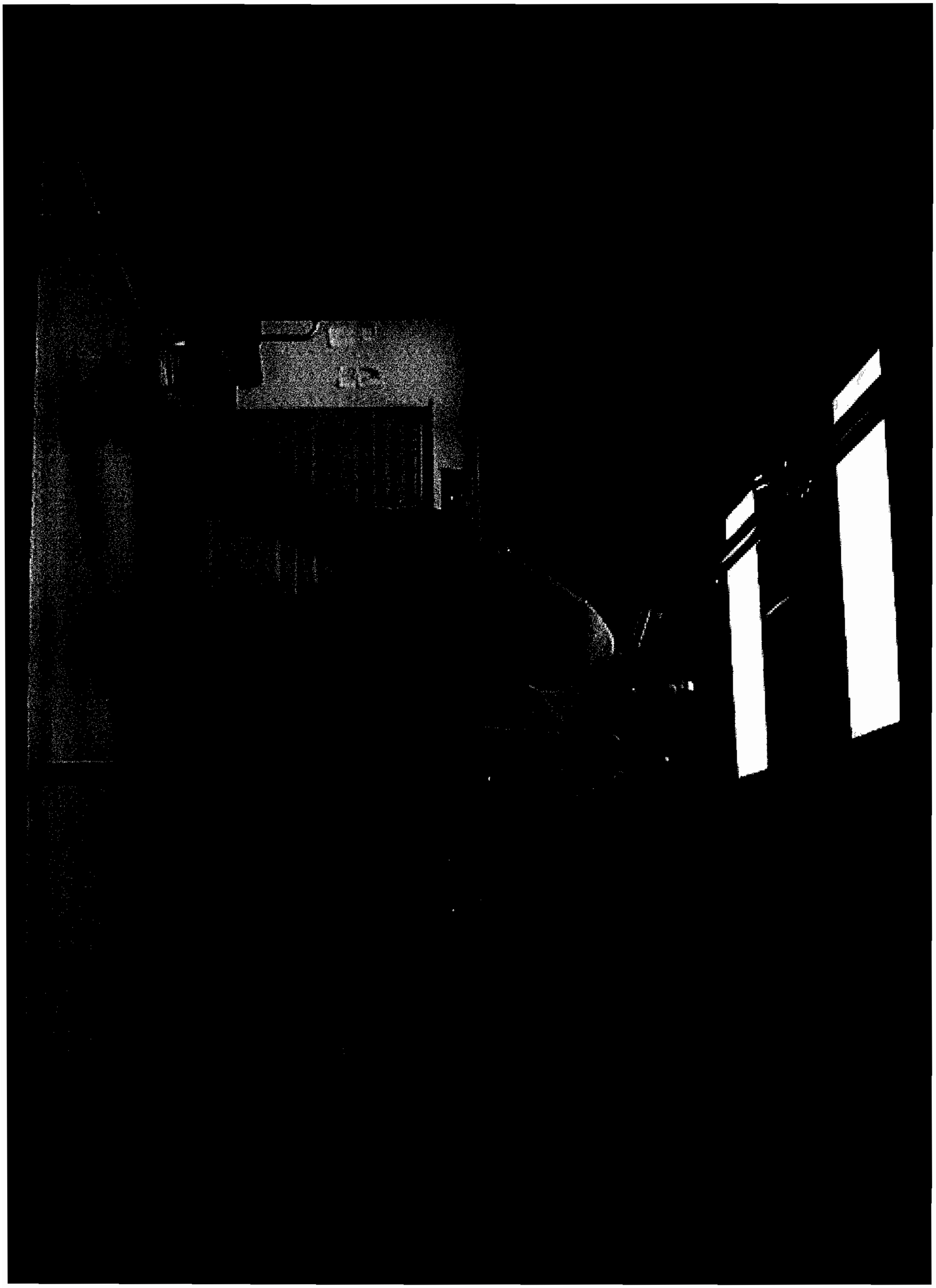
## Figure Captions

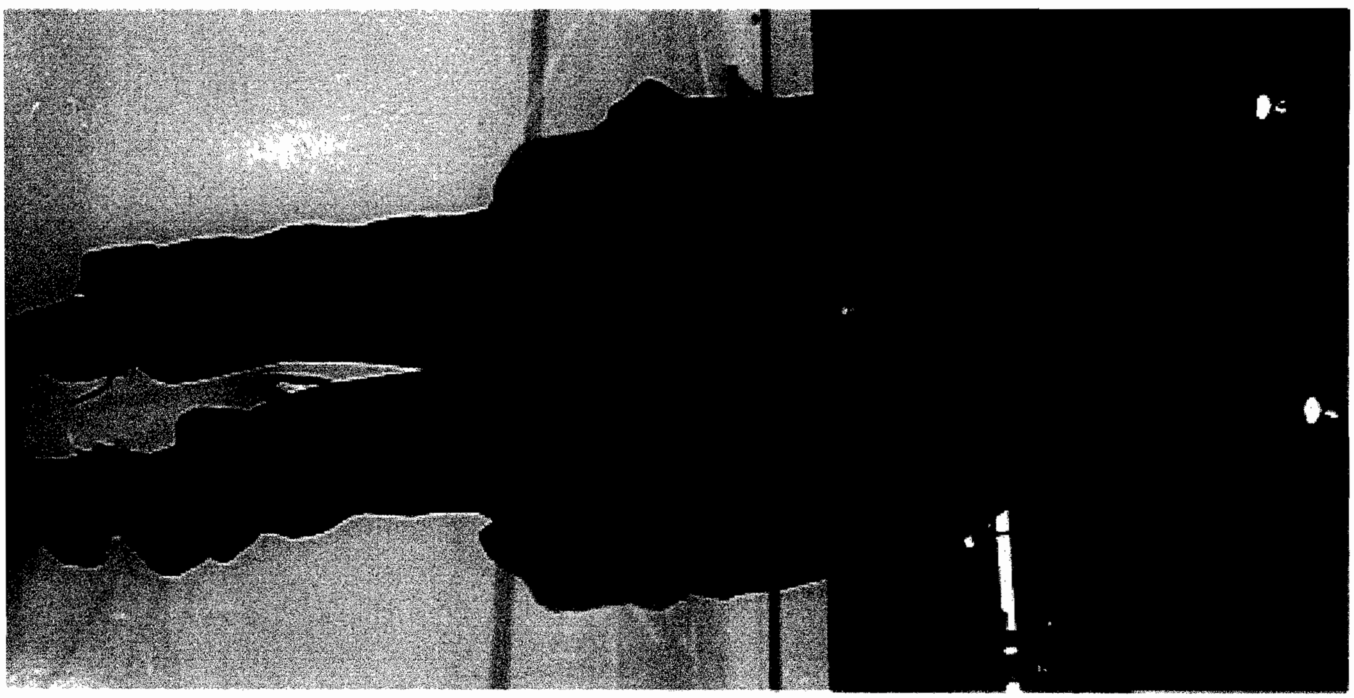
**Figure 1.** Set-up for data collection on the skating treadmill.

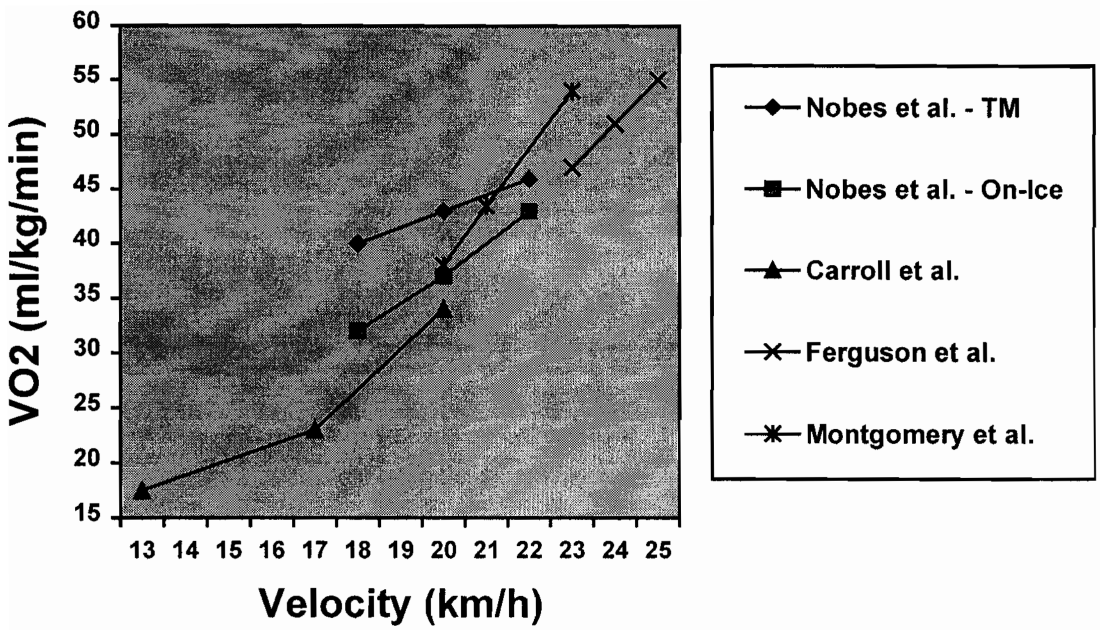
**Figure 2a.** Frontal view of $K4b^2$ metabolic system.

**Figure 2b.** Rear view of $K4b^2$ metabolic system.

**Figure 3.** Comparison of 4 studies measuring $VO_2$ on-ice and on TM.







60
55
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15
VO2 (ml/kg/min)
13 14 15 16 17 18 19 20 21 22 23 24 25
Velocity (km/h)
Nobes et al. - TM
Nobes et al. - On-Ice
Carroll et al.
Ferguson et al.
Montgomery et al.

## Appendix A

### Introduction

Skating treadmills are relatively new tools used by researchers, coaches, trainers and therapists with interests in ice hockey. They are similar in function and design to a running treadmill. The artificial surface allows players to perform a regular skating stride while wearing their ice skates.

The skating treadmill can be used for many different purposes such as: research, training, rehabilitation, instruction, and testing. Off-ice training programs can be made to improve a player's speed and/or acceleration. The range of speeds and elevations (up to 34 $km \cdot h^{-1}$ and 25% grade) that the treadmill offers can make for a wide variety of interval workouts. The treadmill can also be used as an off-ice conditioning tool (i.e. aerobic workout).

Many elite hockey teams do pre-season fitness testing of the players and most incorporate some type of aerobic and anaerobic test. $VO_2max$ is primarily influenced by the aerobic character of muscle (Saltin et al., 1976). Researchers commonly utilize either a running treadmill or a cycle ergometer to evaluate hockey players. The skating actions during training are not mirrored by either bicycle or treadmill tests and, therefore, may not adequately reflect the specific aerobic power developed by hockey players (Smith et al., 1982). The technical development of a skating ergometer should help in the assessment and analysis of aerobic endurance in elite hockey players (Smith et al., 1982). The skating treadmill is more sport specific for hockey players with the mode of performance being skating compared to traditional laboratory tests on either a running treadmill or cycle ergometer.

Another benefit of skating in the laboratory is that it is very conducive to teaching. The coach or skating instructor can stand beside the skater and offer feedback with regards to technique. A mirror mounted in front of the skating treadmill allows the skater to see their stride and make corrections as needed. This can be beneficial to both younger players and even elite players who may need to work on some element of their stride.

Some professional hockey teams are utilizing skating treadmills for the purpose of training, testing, rehabilitation, and instruction. After a session on the treadmill, most skaters will agree that it feels very similar to on-ice skating. However, there have been very few investigations done comparing treadmill skating to on-ice skating to determine if it is in fact a valid and reliable tool for the training, testing, rehabilitation, and instruction of ice hockey players.

**Nature and Scope of the Problem**

To date there have been only a few investigations using the skating treadmill. Hinrichs' (1994) Master's thesis examined the EMG activity of selected leg muscles during treadmill skating and on-ice skating. Subjects (n=14) skated at three stride frequencies on the treadmill and on-ice. The stride frequencies (42.0, 49.5, and 54.0 strides$\cdot$min$^{-1}$) resulted in faster skating speeds on-ice (21.0, 22.9, and 25.0 km$\cdot$h$^{-1}$) than on the skating treadmill (10.5, 14.0, and 16.5 km$\cdot$h$^{-1}$). He claimed these differences were due to a higher coefficient of friction and the 2.5% grade that was used on the treadmill. For the push-off phase of the stride, the EMG activity patterns between the skating treadmill and on-ice skating were not significantly different (except for one of the seven muscles). However, EMG activity patterns involved during the recovery phase of the stride showed a significant difference between the two skating surfaces. Hinrichs concluded that treadmill skating simulates on-ice skating better than any other type of training device.

Recently, Dreger and Quinney (1999) and Jacobson and Zapalo III (1997) have investigated $VO_2$max protocols using the skating treadmill. Dreger and Quinney (1999) examined differences between $VO_2$max elicited on the skating treadmill and on a bicycle ergometer. For the treadmill protocol, subjects skated at a self-selected, constant speed (14.4 to 16.0 $km \cdot h^{-1}$) and a 0% grade for 2 min, followed by 2 min of passive recovery. The treadmill was then increased by 2% and another 2 min session was completed. This protocol was followed until the subject reached volitional fatigue. They found no significant difference between the skating treadmill protocol and the bicycle ergometer protocol in terms of $VO_2$max.

Jacobson and Zapalo III (1997) also examined a $VO_2$max protocol. Prior to testing, the subjects (n=5) skated on the treadmill and their anaerobic threshold was determined. The $VO_2$max skating protocol commenced at the speed that corresponded with the subject's predetermined anaerobic threshold and a 5% grade. Elevation was increased by 1% every 30 seconds until volitional fatigue. They found no significant difference between the peak $VO_2$ found on the treadmill as compared to that on a bicycle ergometer test. Presently, nothing has been done comparing the aerobic demands of on-ice skating to that of treadmill skating.

## Significance of the Problem

There is a paucity of literature pertaining to the skating treadmill. Two studies (Dreger & Quinney, 1999; Jacobson & Zapalo III, 1997) reported on a skating treadmill protocol to determine $VO_2max$. The investigation by Hinrichs (1994) examined the difference between treadmill skating and on-ice skating from a muscle activity perspective. He concluded that there were no differences in EMG activity of the lower leg muscles between treadmill and on-ice skating. He also concluded that the heart rates of the subjects were not significantly different for three stride frequencies while skating on both surfaces. This seems to be the only research done comparing treadmill skating and on-ice skating. Clearly, more needs to be done to validate the skating treadmill as a tool for hockey research. This study will attempt to validate the skating treadmill by comparing skating economy ($VO_2$), kinematics (stride rate and length), and peak performance ($VO_2max$) on-ice and on the skating treadmill.

## Statement of the Problem

The purpose of this study was to compare skating economy on-ice and on the skating treadmill at three velocities. The investigation also compared the $VO_2max$ elicited both on-ice and on the skating treadmill.

The investigation examined the following hypotheses:

1. Oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) at a given velocity will be greater on the skating treadmill compared to on-ice.

2. Maximal oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) will be similar on-ice and on the skating treadmill.
3. Stride rate ($strides \cdot min^{-1}$) at a given velocity will be greater on the skating treadmill compared to on-ice.

**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 ($L \cdot min^{-1}$) or relative ($ml \cdot kg^{-1} \cdot min^{-1}$) terms.

**Submaximal $VO_2$:** Indirect estimates of oxygen consumption during steady state aerobic exercise, representing an intensity less than the maximal aerobic capacity.

**Skating economy:** The steady state $VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) required to skate at a given submaximal velocity.

**Skating Stride:** A full stride is defined as successive foot strikes of the same leg.

**Stride Rate**: The number of strides required to skate for one minute on the skating treadmill or for one minute around the 140-meter on-ice course.

**Stride Length:** The length in meters of one complete stride.

**Submaximal Velocity:** Skating at a velocity ($km \cdot h^{-1}$) representing an intensity less than maximum.

## Limitations

This study had the following limitations:

1. Ice conditions differed from subject to subject.
2. All subjects did the skating treadmill protocol prior to doing the on-ice protocol.
3. The ambient temperature in the arena was colder than in the laboratory.

## Delimitations

This study had the following delimitations:

1. The subjects for this study were 15 male varsity ice hockey players from the McGill University hockey team.
2. Subjects were students at McGill University
3. Subjects ranged in age from 19 to 24 years old.
4. Only forwards and defensemen were used.
5. Only three velocities were studied (18, 20, and 22 $km \cdot h^{-1}$)

## Appendix B

## Review of Literature

### Physiological Response During Skating

In this review the physiological response during skating will be discussed in three sections, described as: (1) lactate accumulation, (2) heart rate telemetry, and (3) oxygen consumption during a game.

#### Lactate Accumulation

High intensity intermittent skating, rapid changes in velocity, and frequent body contact are all characteristics specific to the sport of hockey. There is a very large contribution from anaerobic glycolysis during a hockey game (Montgomery, 1988), which in turn elevates the blood lactate above resting levels. Lactate accumulation depends on: fitness level, state of training, active muscle mass, muscle fiber composition, nutritional status, blood flow, and fatigue (Cox et al., 1995). Typically, venous blood samples are taken at the end of each period to assess the anaerobic energy contribution from glycolysis.

In order to get an indication of the anaerobic involvement, Green et al. (1976) analyzed blood samples at the end of each period for CIAU hockey players ($n = 8$). Blood lactate values were the highest following the first ($8.7\ mmol \cdot L^{-1}$) and second ($7.3\ mmol \cdot L^{-1}$) periods and then declined during the third period ($4.0\ mmol \cdot L^{-1}$). The blood lactate values were quite similar for the forwards and defense despite the fact that the forwards were skating at a higher average velocity. The similarity in lactate values was attributed to the fact that the defensemen played a greater number of shifts and had less recovery time between shifts (Green et al., 1976).

Buffone (1997) collected blood lactate samples from varsity hockey players (n=10) after each of four repetitions of the Repeat Sprint Skate (RSS) test. The four samples were intended to simulate the blood lactate profile for one period of hockey typically experienced by players at the elite level. In Green et al.'s (1976) investigation the blood lactate concentrations were single measurements taken after each period. Blood lactate concentrations after one shift of the RSS test in the Buffone (1997) study were 11.7 $mmol \cdot L^{-1}$. Watson and Sargeant (1986) and Montgomery (1988) have reported similar blood lactate concentrations of 11.5 and 10.7 $mmol \cdot L^{-1}$, respectively, after one shift of the RSS test. Following shifts 2,3,and 4 of the Buffone (1997) study, the values were 13.3, 13.5, and 13.8 $mmol \cdot L^{-1}$, respectively. During game play, Green (1978) observed lactate values ranging from 2.9 – 5.5 $mmol \cdot L^{-1}$ for varsity defensemen and forwards, respectively. Buffone (1997) explained the higher lactate values in his study compared to the Green et al. (1976) and Green (1978) studies by stating that in a game situation every shift is not a maximal effort as it is with one shift of the RSS test.

One explanation for the relatively low lactate values seen during a game as compared to the studies with simulated situations of other sports is that within a shift there is an average of two stoppages per shift (Montgomery, 2000). This pause provides sufficient time for 60 – 65% of the PC to be resynthesized and available for the next phase of the shift (Green, 1979).

After a shift, hockey players recover passively for 4 – 6 minutes on the bench waiting for their next shift (Montgomery, 2000). Researchers have evaluated the effect of active recovery conditions on blood lactate accumulation and removal with respect to ice hockey. Kaczynski (1989) had subjects (n=11) perform 6 repetitions of the RSS test with passive, skating, or cycling recovery between repetitions. Results indicated that the cycling recovery condition resulted in a significantly lower blood lactate (8.5 $mmol \cdot L^{-1}$) than the passive (10.6 $mmol \cdot L^{-1}$) and skating (10.4 $mmol \cdot L^{-1}$) conditions. In a study by Watson and Hanley (1986) bench stepping and skating as modes of recovery were superior to passive recovery for removal of lactate.

Foster and Brackenbury (1999) evaluated the degree to which fatigue from previous efforts of the RSS test was related to lactate accumulation. Collegiate hockey players (n=29) performed 6 repetitions of the RSS. Lactate was measured before and after the RSS test and after repetitions 2 and 4, from these measurements the authors calculated the effective peak blood lactate prior to each skating trial. It was shown that blood lactate increased from trial to trial (2.29, 7.18, 11.48, 14.57, 16.81, 18.01, and 18.58 $mmol \cdot L^{-1}$) and that performance in the RSS test deteriorated from repetition 1-6 (12.47, 13.06, 13.80, 14.43, 14.86, and 15.12 s). It is quite clear that either preventing or removing lactate from the muscles is an important strategy in maintaining skating performance (Foster & Brackenbury, 1999).

## Heart Rate Telemetry

Heart rate has been used by many researchers to estimate the aerobic demands of playing hockey (Montgomery, 2000). However, heart rate telemetry has limitations that should be recognized when interpreting the results. In hockey, heart rate may be influenced by conditions that do not increase the energy cost such as: (a) emotions, (b) upper body static contractions, (c) the intermittent nature of play, and (d) elevation of core 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 (age=16–20 yr) in a model match (i.e. the players competed for 90 s and then recovered for 180 s for 3 repetitions). The subjects had a peak heart rate of 177 beats·min$^{-1}$ and an average on-ice heart rate of 160 beats·min$^{-1}$. Seliger (1972) did another investigation using the Czechoslovakian National team (n=13). During a simulated match (i.e. on the ice for 60 s followed by recovery for 180 s with 6 repetitions of this pattern) the subjects had an average heart rate of 152 beats·min$^{-1}$, which corresponded to 72.5% of their max. Many researchers have studied heart rate during practices and other simulated ice hockey tasks, (Green, 1978; Montpetit et al., 1979; and Romet et al., 1976).

Heart rate has been monitored during game play of elite hockey players by Green et al. (1976), Peddie (1995), and Wilson and Hedberg (1976), and the following mean on–ice heart rates have been found; 173, 165.6, 178.3 beats·min$^{-1}$, respectively. Montgomery (1988) stated that the average on–ice heart rate is about 85% of maximum with peak heart rates in excess of 90% HRmax. Several researchers (Montgomery, 1979; Paterson, 1979; and Peddie, 1995) estimate the average on–ice intensity at 70–90% of $VO_2$max.

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$^{-1}$ with a range of

145 to 191 beats·min$^{-1}$. During recovery, the heart rates dropped to 120 beats·min$^{-1}$. Unfortunately the mean maximum heart rate was not given in this study (Peddie, 1995).

Peddie (1995) investigated the intensity of game play for varsity forwards (n=3) and defensemen (n=3). Peddie (1995) found the average on-ice intensity to be 82.5% of HRmax. During stoppages in play the heart rate dropped to 161.5 beats·min$^{-1}$ or 80.5% of HRmax and 138.5 beats·min$^{-1}$ or 69.1% HRmax when recovering on the bench. With a similar group of athletes, Green (1978) found that during recovery heart rate rapidly declined but rarely fell below 125 beats·min$^{-1}$. Peddie (1995) and Green (1978) concluded that forwards and defensemen had similar on–ice heart rates.

Oxygen Consumption During a Game

Due to the physical nature of ice hockey, it is not possible to collect gas samples during an actual hockey game. Therefore, it becomes necessary to simulate game like conditions in order to measure oxygen consumption (i.e. Seliger, 1972) or to estimate oxygen consumption from heart rate during actual game situations (i.e. Green, 1976). Green et al. (1976) collected time motion and physiological data on 8 varsity hockey players (age = 21 yr, height = 177.3 cm, weight = 75.9 kg, $VO_2max$ = 53.2 ml·kg$^{-1}$·min$^{-1}$) during 10 games. Based on the mean heart rate obtained during the games (173 beats·min$^{-1}$) and treadmill determinations of the relationship between heart rate and oxygen uptake, the authors estimated the on–ice energy requirements at 70 – 80% of $VO_2max$. However, as the authors noted, the use of heart rate to estimate energy expenditure in non–steady state circumstance, where much upper body activity is prevalent and where there are many changes in skating velocities, is suspect. (Maxfield, 1971)

Seliger et al. (1972) investigated the energy expenditure in 13 national team hockey players from Czechoslovakia (age = 24.4 yr, height = 179.3 cm, weight = 81.8 kg) in a simulated game (6 repetitions of 60 s with a 180 s recovery period). In this study, only one shift of 1.17 min was used for analysis. During this one shift the oxygen consumption was 32 $ml \cdot kg^{-1} \cdot min^{-1}$, which was equivalent to 66% of the subjects $VO_2max$. Energy metabolism was measured by indirect calorimetry method. On the basis of energy expenditure and other physiological variables, Seliger et al. (1972) characterized ice hockey as "an activity showing mostly submaximal metabolic rate with a great participation of anaerobic metabolism (69%), but simultaneously with high requirements for aerobic metabolism (31%)." Montgomery (1988) and Green et al. (1976) suggest that Seliger et al. (1972) may have overestimated the anaerobic contribution as compared to the aerobic contribution. The investigation by Green et al. (1976) supports this notion. Montgomery (1988) cites Paterson et al. (1977) who estimated oxygen uptake in excess of 80% of $VO_2max$ in young hockey players.

Another approach to estimate work intensity is to use the oxygen cost skating velocity relationship proposed by Ferguson et al. (1969). He had 17 hockey players (age = 16–25 yr) perform a $VO_2max$ skating test around a 140-m oval. The subjects skated for 3 min at velocities of 350, 382, 401, 421, and 443 $m \cdot min^{-1}$ that correspond to lap times of 24, 22, 21, 20, and 19 $s \cdot lap^{-1}$. Ferguson et al. (1969) concluded that the relationship between $VO_2$ and sub-maximal skating velocity is linear, but that the $VO_2$ for a given sub–maximal velocity varied considerably amongst the hockey players. For example, at a velocity of 382 $m \cdot min^{-1}$the mean $VO_2$ was 46.7 $ml \cdot kg^{-1} \cdot min^{-1}$ with a range from 40.1 to

$54.7\ ml \cdot kg^{-1} \cdot min^{-1}$. Green et al. (1976) agrees that skating represents a major component of work intensity but that this method underestimates energy expenditure.

## Factors Affecting Skating Performance

In this review the factors affecting skating performance will be discussed in three sections, described as: (1) effect of added mass, (2) ice surface coefficient of friction, and (3) air resistance.

### Effect of Added Mass

A hockey player may carry excess mass in the form of adipose tissue and equipment. Montgomery (1982) investigated the effect of added mass on skating performance using the Repeat Sprint Skate (RSS) test developed by Reed et al. (1979). Subjects (n=11) were tested in mid–season in each of four conditions 1) normal body mass; 2) 5% added body mass; 3) 10% added body mass; or 4) 15% added body mass. With a weighted vest, added mass was secured to the waist and shoulders so as not to interfere with skating movements. The weighted vest was designed to simulate excess body fat and/or equipment weight. Added mass resulted in a significantly slower performance on both the speed and the anaerobic endurance components of the on-ice test. With 5% excess mass, the anaerobic endurance time increased by 4%. Excess body mass increases the energy to skate at a particular velocity and also reduces the time that a player can maintain the pace.

Chomay et al. (1982) conducted a similar study in which skating performance on the RSS test was measured when the skates were weighted. Eleven subjects performed the RSS test under 3 conditions: 1) normal skate weight; 2) 227 g added to each skate;

and 3) 555 g added to each skate. During the weighted conditions there was a significantly slower time on both the speed and the anaerobic endurance components of the RSS test.

The effect of equipment weight (7.3 kg) on aerobic skating performance is evident from the results of a study by Léger et al. (1979). During mid–season, 10 hockey players performed a 20 m shuttle skating test to determine $VO_2max$. While $VO_2max$ was similar for all conditions (with and without equipment), the equipment increased the energy cost of skating by 4.8% and decreased the multistage test time by 20.3%. While wearing equipment the final skating speed decreased by 7 $m \cdot min^{-1}$ (2.9%).

In a study by Larivière et al. (1976), 18 midget hockey players were asked to skate as many laps as possible of a 100 foot course over a 5 min time period. At each turn the subject had to make a sudden stop, allowing one of his skates to cross the delimiting line before turning to skate back to the starting point. Larivière et al. (1976) tested the group with and without equipment. Results revealed that the distance covered with equipment (3973 ± 184 ft) was significantly less than without equipment (4124 ± 267 ft).

Ice Surface Coefficient of Friction

During on-ice skating, the energy produced by the athlete is used predominantly to overcome two opposing forces, those being air and ice frictional forces. According to de Koning et al. (1992), the air friction is the largest resisting force. During skating at a velocity of 10 $m \cdot s^{-1}$, the total frictional losses can be divided into 75% air friction and 25% ice friction.

The surface of ice has a very low coefficient of friction. The reported coefficient of ice friction varies between $\mu = 0.003$ (de Koning et al., 1992; and Kobayashi, 1973) and $\mu = 0.030$ (Zatsiorski et al., 1987). Researchers de Koning et al. (1992) found a similar range of coefficient but at a different optimal temperature. He suggested an optimal temperature of – 6 to –9 °C, where as Kobayashi determined a higher optimal temperature of – 2.2 °C. However, Kobayashi performed measurements using a lightly weighted sled with skate blades, which were always perpendicular to the ice surface.

There are several theories describing the physical properties of ice with regards to the relatively low coefficient of friction of ice. A study by van Ingen Schenau (1989) suggested that skating is possible due to pressure melting. The gliding surface of the skate is small and the pressure under the skate is high (up to $20 * 10^6$ N/m²), resulting in a film of water between the skate and the ice. This film of water allows the skate to glide over the ice surface with very little friction.

Colbeck (1995) has suggested an alternative reason for the low coefficient of friction. He claims that such pressures needed to achieve 'pressure melting' would cause the ice to fracture and that the pressure melting effect at – 20 °C would have to be 2700 times atmospheric pressure. As well, at speeds of 5 $m \cdot s^{-1}$ 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 authors (Colbeck, 1995; and Mendelson, 1985) suggest that the slipperiness of ice is indeed caused by a melted water film but that the melting is caused by frictional heating of the sliding surfaces, rather than by pressure melting. According to de Koning et al. (1992) both frictional heating and pressure–melting should result in the formation of a lubricant during the skating action.

There are also those who believe that the friction between ice and steel could be explained by an intrinsic property of the ice surface (de Koning et al., 1992). Recently modern surface science technology has discovered that the surface of ice has a constant, thin semi-liquid layer producing low frictional interfaces. As the ice is warmed the number of liquid layers present increase which is why colder ice (less water) is faster for ice skating than warmer ice (more water) (Pearsall et al., 2000).

## Air Resistance

According to van 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 and is dependent on, (in speed skating for example), the roughness of the suit. With regards to speed skating the friction drag is relatively small compared to the pressure drag. The relative velocity of the air with respect to the body places more pressure in front of the skater rather than behind the skater. Many variables can influence air friction including: skating position, body mass and length, active drag, and shielding (drafting). The air friction constant is strongly dependent on air velocity, (van Ingen Schenau, 1982). Allinger and van Den Begert (1997) defined the air friction constant as proportional to the velocity of the skater squared. In their study, they used the air friction constant of 0.152 $kg \cdot m^{-1}$, an average taken from subjects (n=6) in van Ingen Schenau's 1982 study.

Allinger and van Den Begert (1997) developed a simulated model of a skater, taking into account the forces of air resistance, ice friction, and gravity, and determined the skating technique that resulted in the fastest steady state speed on a straightaway. The results indicate that a range of skating techniques may be used to obtain the same skating speed. However, the range of techniques decreases as speed increases.

**Time–Motion Analysis**

Skating is the most important skill required for success in ice hockey. This notion was supported in an article by Renger (1994). Sixteen National Hockey League (NHL) scouts from the central scouting bureau were asked to provide insight regarding the relative importance of ten task requirements. Since 1982, amateur prospects for the NHL have been assessed on the following ten skills: (a) skating, (b) shooting/scoring, (c) positional play, (d) checking, (e) puck control, (f) passing, (g) hockey sense, (h) desire/attitude, (i) aggressiveness/toughness, and (j) size/strength. Renger (1994) asked the scouts to rank these requirements and to assign relative importance to the tasks by using a 100-point distribution. For both forwards and defensemen, the most important task requirement was skating with a rank of 1 and a relative weighting of 22.5 (forwards) and 20.5 (defensemen). The scouts then identified the components of skating that were similar and unique to the positions of forward and defense. Common elements were quickness, starts/stops, balance, speed, acceleration, turns, agility, and pivots. Stride and power were components of skating for the forwards only. Backward skating and mobility refer to elements of skating used to assess defensemen only. The scouts weighted quickness, speed, and acceleration more important for forwards than for defense, and pivoting as a more important skating skill for defense than for forwards.

Time–motion analysis has been used to estimate skating activity over the course of a game. Seliger et al. (1972) stated that members of the Czechoslovakian national team averaged 5160 m with a range of 4860 m to 5620 m during 18 minutes of actual playing time. He had previously reported in 1967 that juniors skated 2360 m during a game. Seliger makes reference to Yokobori's (1964) investigation which states that top performers skate 6400 m to 7200 m. Green et al. (1976) employed time-motion analysis to examine the skating activity of 10 varsity hockey players. On average the players skated 5553 m during 24.5 min of actual playing time. Average skating velocities during a shift average 227 $m \cdot min^{-1}$ (Green et al. 1976).

For professional, junior, university and many elite youth teams games are 60 min in duration split into three periods with a 15 to 20 min intermission to resurface the ice. Games extend for 150 to 170 min (Montgomery, 2000) due to stoppages in play for reasons such as: rule infractions, injuries, and television timeouts. There are generally 2–3.5 stoppages per shift lasting 20–30 s in duration (Green et al., 1976; Green et al., 1978; Montgomery & Vartzbedian, 1979.) Typically, the average NHL player receives between 15 to 20 min of actual playing time extended over 3 hours. However, star players may receive 30 to 35 min of ice time in a game (Cox et al., 1995; Montgomery, 2000).

Green et al. (1976) compared the performance of varsity forwards (n=7) and defensemen (n=3) using both videotape and direct observation. The defensemen had a longer playing time per game (28.0 compared to 20.7 min), a greater number of shifts (20.7 compared to 15.6), less playing time per shift (81.4 compared to 88.0 s), and had less recovery time between shifts (159 compared to 260.3 s). In another study using time–motion analysis Green et al. (1978) found similar values except that the defensemen in that study had a longer playing time per shift (73.1 compared to 57.9 s). The defensemen had a longer playing time per game (28.7 compared to 19.2 min), a greater number of shifts (24.3 compared to 20.2), and less recovery time between shifts (189 compared to 293 s).

Peddie (1995) did a comparison study to Green et al.'s (1976) time–motion analysis work. Using 6 varsity hockey players Peddie reported that the players, on average, had less playing time per shift (62.4 vs. 85.4 s) and had less playing time per game (18.6 vs. 24.5 min) than the players in the 1976 study.

Léger (1980) collected time–motion analysis data from 80 junior and 170 midget players. For the junior players the playing time per shift was very similar between defensemen and forwards (88.5 compared to 84.9 s). However, the defensemen spent less time recovering on the bench and had a bench time to ice time ratio of 2:1 whereas the forwards had a ratio of 2:3. It should be noted that defensemen generally skate at lower average velocities. Green et al. (1976) report a 61.6% lower skating velocity for the defensemen compared to the forwards. Thoden and Jetté (1975) reported more anaerobic activity by the forwards than by the defensemen on both an absolute and percentage basis.

Montgomery (1979) collected time–motion data on 'old timers'. An 'old timer' was defined as a player of at least 25 years of age participating in a non–contact, recreational hockey league. During a 65 min game, the players (n=12) had an average playing time of 18.9 min. The average playing time per shift was 139.1 s compared to the average playing time per shift for university players of 58 to 62 s (Green, 1978; Peddie, 1995), 87 s for junior players (Léger, 1980), and 95 s for youth players (Paterson, 1994). The ratio of bench time to playing time was lower for the recreational players than the junior, university and professional players because there are fewer players per team (Montgomery, 1988). Recreational teams generally use 2 forward lines and 3-4 defense, whereas professional, university, and junior teams use 3-4 forward lines and 5-7 defense.

Thoden and Jetté (1975) collected data on 3 QJMHL games and 1 NHL game. They reported that players would participate in 15–18 shifts per game of 70–80 s in duration and that during a shift there would be 5-7 anaerobic bursts lasting 2-3.5 s for a total of 15–20 s of anaerobic activity. Out of the 15–21 min of ice time per game the total burst time averaged 4–6 min per game.

**Physical Characteristics of the Elite Player**

In the NHL players range in age from 18-40 years old with team averages in the mid 20's. The physiological profiles for junior, university, and professional players have been extensively researched during the past thirty years and are presented in Table 5. Team averages for body mass and stature have been progressively increasing since the late 1970's. The average NHL player is taller than 185 cm and weighs more than 90 kg. Prior to this, the average professional player would be 180 cm and weigh approximately 85 kg (Montgomery, 2000). The body composition of hockey players calculated by skinfold measurement ranges between 10 and 14% (Cox et al., 1995; Montgomery, 1988). The variability can be attributed to the different equations used to calculate percent body fat (Montgomery, 2000).

Dewart et al. (1999) examined the physiological profile of a NHL team over a nineteen-year period. They examined 1100 players (aged 23 ± 4 yr) and determined that body mass increased significantly over the 19 year period. Defensemen were the heaviest

(93 ± 6 kg) followed by forwards (88 ± 7 kg) and goaltenders (84 ± 7 kg). Percent body fat reached a minimum in 1984 and remained relatively constant with forwards having the lowest at 11.1 ± 2.2% (Dewart et al., 1999).

A similar study was done by Cox et al. (1993) who collected data on several NHL teams between 1980 and 1991. Data were obtained from 170 players from 5 different teams as well as 55 recruits for the 1991 Team Canada. According to Cox et al. (1993) body mass and height increased between the years 1980 and 1991. In 1980 approximately 40% of the players weighed less than 85 kg and 71% were shorter than 180 cm in height. By 1991, only 26% of the players weighed less than 85 kg and 85% were taller than 180 cm. Body fat remained fairly constant at 13% over the 11-year period.

Data also suggests that professional players in the NHL are taller and heavier than university and junior players (Montgomery, 1988). Koch et al. (1999) also examined the physical differences between collegiate (NCAA Division I) and professional hockey players. The professional players were taller (182.1 ± 4.7 cm compared to the collegiate players at 178.4 ± 6.9 cm) and heavier than the university players (90.7 ± 4.5 kg and 81.3 ± 8.9 kg, respectively).

A physiological analysis of ice hockey positions reveals that defensemen are typically taller and heavier than forwards (Agre et al., 1988; Chovanova, 1976; Cox et al., 1988; Dewart et al., 1999; Green & Houston, 1975; Houston & Green, 1976; Montgomery & Dallaire, 1986; Rhodes et al., 1986; Smith et al., 1982; Twist & Rhodes, 1993; Smith & Quinney, 1982). However, according to Twist and Rhodes (1993) these profiles were more a result of the on-ice demands of each position and the fact that many players did not take part in off-ice conditioning. They claim that player selection and strength training are bringing players closer together in stature and physique. They analyzed 31 NHL players prior to the 1992-93 season and found the defensemen to be taller compared to the forwards (187.9 vs. 187.4 cm) and heavier (94.1 vs. 92.9 kg, respectively). This notion was also supported by Cox et al. (1988) who tested 10 NHL players over a three-year period. The selected players were put on a vigorous training program following the baseline test and were required to continue it for the three years. Results suggested that as the training program continued over the three years the 10 players (regardless of position) became more closely matched in physiology.

**Aerobic Endurance**

There have been several descriptive studies detailing the maximal oxygen uptake of elite ice hockey players over the past 30 years. The $VO_2max$ results for professional, national, university, and junior players are summarized in Table 6. Many of these studies were done using the treadmill or cycle ergometer, some were done with skating protocols, and recently there have been a few using the skating treadmill (Dreger & Quinney, 1999; Hinrichs, 1994). On the cycle ergometer, team averages for both forwards and defense ranged from 51 to 63 $ml \cdot kg^{-1} \cdot min^{-1}$, with one exception. On the treadmill team averages for both forwards and defense ranged from 51 to 66 $ml \cdot kg^{-1} \cdot min^{-1}$. Treadmill testing usually gives values that are 10% higher than cycle ergometer (Montgomery, 1988).

The results of Leger et al.'s (1979) investigation suggest that the $VO_2max$ of ice hockey players will be the same whether tested on the running treadmill, on the ice while skating a 20 m shuttle course with or without equipment, and on a continuous 140 m oval course. He compared the results of 10 hockey players (intercollegiate or equivalent) and 10 runners. Compared to the runners, the hockey players were more efficient on the ice (15%) and less efficient on the treadmill (7.9%). Other related studies have shown $VO_2max$ to be either higher or similar to treadmill running (Leger et al., 1979).

Cox et al. (1993) have suggested a progressive increase in $VO_2max$ results since 1980. They examined $VO_2max$ data from 170 NHL players on four occasions between 1980 and 1991. In 1980, 58% of the players had a $VO_2max$ less than 55 $ml \cdot kg^{-1} \cdot min^{-1}$. In 1991, only 15% were below this value. They attributed these gains to improved training regimens adopted by the players.

Dreger and Quinney (1999) compared $VO_2max$ results of 6 elite youth hockey players (age = $15.8 \pm 0.41$ yr) on a motor driven skating treadmill and a bicycle ergometer. Subjects performed a discontinuous skating treadmill protocol at a self-selected speed (14.4 to 16.0 $km \cdot h^{-1}$) with increases in grade of 2% every 2 min. The results showed no significant difference between the skating treadmill and bicycle ergometer protocols for relative $VO_2max$ values ($60.4 \pm 5.09$ versus $59.0 \pm 8.31$ $ml \cdot kg^{-1} \cdot min^{-1}$), respectively. These $VO_2max$ values are well within the same range as previous research done on elite professional, university, and junior ice hockey players.

## Skating Economy

Daniels (1985) defined running economy as "the relationship between work done and energy expended". Minimizing or eliminating unwanted or counter-productive muscular movement is a desirable goal for any distance runner". It has been reported that within a homogenous group of runners, running economy can be the greatest predictor of success (Daniels, 1985).

Skating economy has been described as the steady state $VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) required to skate at a given submaximal velocity (Riby, 1994). Riby (1994) investigated the skating economy of 13 varsity hockey players (age = 20.9 yr, height = 179.7 cm, weight = 79.9 kg, sum of 5 skinfolds = 40.0 mm, $VO_2$ max = 60.5 $ml \cdot kg^{-1} \cdot min^{-1}$). The on–ice skating economy test took place on a 140-m oval, with 10 cones being placed 14 meters apart to delineate the course. The subjects had to perform three 4 min skating bouts at velocities of 336, 357, and 381 $m \cdot min^{-1}$. These velocities correspond to lap times of 25.0, 23.5, and 22.0 s, respectively. According to Riby (1994), the four to five minute skating bouts were of sufficient duration to allow the subjects to achieve steady state oxygen consumption. Results indicated that at velocities of 336, 357, and 381 $m \cdot min^{-1}$ the mean $VO_2$'s were 38.6, 44.4, and 55.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. Mean heart rate values for the three submaximal velocities were 161, 172, and 180 $beats \cdot min^{-1}$, respectively. Mean stride rates were 79.0, 85.2, and 96.6 $strides \cdot min^{-1}$, respectively. The mean stride length values were 4.4, 4.2, and 4.0 $m \cdot stride^{-1}$. Riby concluded that skating economy at velocities between 336 and 381 $m \cdot min^{-1}$ might be described by a linear regression equation. As well, he concluded that there is a low correlation between skating economy and skating ability.

## Skating Mechanical Efficiency

Skating mechanical efficiency is an indication of the movement and energy requirements of skating at a specific velocity (Montgomery, 1988). It is calculated as:

*Mechanical Efficiency = [Velocity (*m·min$^{-1}$*) / $VO_2$ (*ml·kg$^{-1}$·min$^{-1}$*)] *100*

*- where velocity is a predetermined sub–maximal pace*

*- $VO_2$ is the achieved steady state oxygen consumption*

The mechanical efficiency of the subjects in Riby's (1994) thesis were 887.6, 815.9, and 695.9 for velocities of 336, 357, and 381 m·min$^{-1}$, respectively. The mean coefficient of variation for these velocities was 15.1, 12.3, and 9.9 %, respectively. These coefficients of variation were similar to other skating related studies, (Ferguson et al., 1969; Green, 1979; and Léger et al., 1979) but larger than those of running studies. Three running studies had coefficients of variation ranging from 3.6 – 5.7 % (Riby, 1994). The inter-individual variability in $VO_2$ (± 15%) found during skating is considerably larger than the 5 – 7 % difference found in trained and untrained runners (Montgomery, 1988).

According to Green (1979), ice-skating is a highly skilled activity requiring years of training to develop completely. It is therefore not surprising that, unlike running, there exists such a large difference between individuals in the expenditure of energy required to cover a certain distance at a certain pace.

## Appendix C

## Conclusion

In summary, these results showed that at submaximal velocities, $VO_2$, HR, and stride rate were higher on the skating treadmill compared to on-ice. $VO_2$max was similar while HRmax was higher on the skating treadmill compared to on-ice.

## Appendix D

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## Appendix E

## ADDITIONAL TABLES

**Table 5. Physical Characteristics of Professional, National, University, and Junior Ice Hockey Players**

| Level | n | Age yr | Height cm | Body Mass kg | Body Fat % | SOS mm | References |
|---|---|---|---|---|---|---|---|
| Professional - NHL - 1972 | 12 | 25.3 ± 5.3 | 175.2 ± 5.0 | 75.9 ± 5.0 | 10.0 ± 4.3 | 46.5 | Bouchard et al., 1974 |
| Professional - NHL - 1974 | 38 | 27.0 ± 3.5 | 180.0 ± 7.1 | 82.3 ± 8.0 | 10.4 ± 4.3 | | Romet et al., 1978 |
| Professional - NHL | 12 | 21.5 ± 1.6 | | 83.4 ± 4.5 | 10.5 ± 1.7 | | Green et al., 1979 |
| Professional - NHL | 54 | 24.9 ± 3.2 | | 85.8 ± 6.1 | 14.2 ± 1.4 | | Gauthier et al., 1979 |
| Professional - NHL - 1980 | 38 | | 179.4 ± 0.8 | 85.3 ± 1.1 | 12.6 ± 0.3 | | Cox et al., 1995 |
| Professional - NHL - 1980 | 20 | 25.3 ± 4.0 | 182.5 ± 5.4 | 85.8 ± 6.7 | 11.4 ± 1.3 | | Smith, D. et al., 1981 |
| Professional - NHL - 1984 | 38 | | 183.4 ± 0.9 | 88.2 ± 1.1 | 13.8 ± 0.4 | | Cox et al., 1995 |
| Professional - NHL - 1981/82 | 27 | 25.0 ± 4.2 | | 85.9 ± 7.0 | 12.4 ± 1.9 | 90.2 ± 19.8 (6) | Montgomery & Dallaire, 1986 |
| Professional - NHL - 1982/83 | 30 | 24.6 ± 3.7 | | 86.2 ± 8.0 | 9.7 ± 1.6 | 62.4 ± 16.4 (6) | Montgomery & Dallaire, 1986 |
| Professional - NHL - Def. | 27 | 24.9 ± 4.6 | 186.4 ±4.5 | 90.3 ±4.3 | 10.0 ± 2.4 | 29.8 ± 5.3 (4) | Rhodes et al., 1986 |
| Professional - NHL - For. | 40 | 23.6 ± 2.6 | 183.2 ± 4.8 | 87.1 ± 5.6 | 11.7 ± 2.3 | 30.0 ± 5.4 (4) | Rhodes et al., 1986 |
| Professional - NHL - 1988 | 23 | | 184.5 ± 1.2 | 91.2 ± 1.5 | 11.8 ± 0.4 | | Cox et al., 1995 |
| Professional - NHL - For. | 15 | 24.8 ± 0.9 | 183.5 ± 1.4 | 86.1 ± 1.9 | 7.7 ± 1.3 | hydrostatic | Agre et al., 1988 |
| Professional - NHL - Def. | 8 | 24.9 ± 1.3 | 184.7 ± 2.1 | 88.5 ± 1.9 | 12.2 ± 1.1 | hydrostatic | Agre et al., 1988 |
| Professional - NHL - For. | 40 | 23.6 ± 2.6 | 183.6 ± 4.8 | 87.1 ± 5.6 | 11.7 ± 2.3 | 3.0 ± 5.4 (5) | Cox et al., 1988 |
| Professional - NHL - Def. | 27 | 24.9 ± 4.6 | 186.4 ± 4.5 | 90.3 ± 4.3 | 9.98 ± 2.4 | 29.8 ± 5.3 (5) | Cox et al., 1988 |
| Professional - NHL - 1991 | 75 | | 185.5 ± 0.8 | 88.4 ± 0.8 | 12.1 ± 0.3 | | Cox et al., 1995 |
| Professional - NHL - For. | | 24.8 ± 4.6 | 187.4 ± 1.7 | 92.9 ± 8.4 | 10.8 ± 2.4 | 39.5 ± 5.3 | Twist & Rhodes, 1993 |
| Professional - NHL - Def. | | 24.7 ± 2.6 | 187.9 ± 1.9 | 94.1 ± 9.3 | 12.1± 2.5 | 40.4 ± 5.6 | Twist & Rhodes, 1993 |
| Professional - NHL | | 25.9 ± 2.9 | 182.1 ± 4.7 | 90.7 ± 4.5 | | | Koch et al., 1999 |
| Professional - NHL | 54 | 24.0 ± 4.3 | 186.0 ± 5.3 | 92.5 ± 6.7 | | | Wygand et al., 1999 |
| National - Czech. | 13 | 24.4 | 179.3 | 81.8 | 13.1 | | Seliger et al., 1972 |
| Elite - Czech. | 55 | 23 | 176.9 ± 4.5 | 78.0 ± 4.5 | 78.0 ± 7.6 | | Chovanova & Zrubak, 1972 |
| National - Czech. - For. | 33 | | 176.2 ± 4.3 | 76.4 ± 6.6 | | | Chovanova, 1976 |
| National - Czech. - Def. | 16 | | 178.2 ± 4.2 | 82.6 ± 7.4 | | | Chovanova, 1976 |
| National - Finnish | 13 | 22.5 ± 3.5 | 179.0 ± 5.0 | 77.3 ± 5.7 | | | Rusko et al., 1978 |
| National - Finnish | 27 | 23.9 ± 2.6 | 179.9 ± 5.0 | 81.1 ± 6.0 | 13.0 ± 2.6 | | Vainikka et al., 1982 |
| National - Canadian | 23 | 22.1 ± 2.6 | 179.8 ± 5.3 | 81.1 ± 6.2 | 10.6 ± 0.5 | | Smith, D. et al., 1982 |

**Table 5 – Continued**

| Level | n | Age y | Height cm | Body Mass kg | Body Fat % | SOS mm | References |
|---|---|---|---|---|---|---|---|
| University - CIAU / Junior | 48 | 19 | 177.8 | 78.8 | 10.1 | 69.5 (6) | Houston & Green, 1976 |
| University - CIAU | 8 | 21 | 177.3 | 75.9 | 8.6 | | Green et al., 1976 |
| University - CIAU | 18 | 21 | 178.0 ± 5.7 | 78.1 ± 6.0 | 10.5 ± 3.2 | | Romet et al., 1978 |
| University - CIAU | 17 | 20.4 ± 1.8 | 177.2 ± 7.4 | 77.1 ± 7.8 | | | Song, 1979 |
| University - CIAU | 19 | 21.5 ± 1.1 | | 77.6 ± 4.8 | 10.7 ± 2.6 | | Green et al., 1979 |
| University - NCAA | 21 | 19.2 ± | | 79.8 | 5.6 | | Krotee et al., 1979 |
| University - CIAU | 17 | 21.5 ± 2.0 | 183.2 ± 3.8 | 83.8 ± 5.9 | | | Gamble and Montgomery, 1986 |
| University - CIAU / Junior | 24 | 20.2 ± 1.6 | 183.1 ± 4.9 | 86.0 ± 6.4 | | | Watson & Sargeant, 1986 |
| University - NCAA | 25 | 20.7 ± 1.7 | 178.5 ± 8.0 | 80.8 ± 10.4 | 9.2 ± 3.0 | | Smith, T. et al., 1998 |
| University - NCAA | | 20.8 ± 1.4 | 178.4 ± 6.9 | 81.3 ± 8.9 | | | Koch et al. 1999 |
| Junior | 24 | 18.2 ± 1.1 | 177.3 ± 5.4 | 77.0 ± 6.0 | 8.6 ± 3.1 | 49.8 (6) | Bouchard et al., 1974 |
| Junior | 26 | | | 77.9 ± 6.0 | 9.0 ± 1.8 | 55.0 ± 15.5 (6) | Green & Houston, 1975 |
| Junior | 94 | 18.5 ± 1.0 | | 81.8 ± 7.2 | 13.6 ± 1.5 | | Gauthier et al., 1979 |
| Junior | 9 | 18.4 ± 0.7 | | 78.7 ± 6.0 | 8.9 ± 0.9 | | Green et al., 1979 |

able 6. **Maximal oxygen uptake of various teams**

| roup | n | Body Mass kg | $VO_2max$ ml·kg$^{-1}$·min$^{-1}$ | Reference |
|---|---|---|---|---|
| **readmill** | | | | |
| ational - American - 1976 | 22 | | 58.7 | Enos et al., 1976 |
| niversity - CIAU | 8 | 70.5 | 58.1 | Montpetit et al., 1979 |
| niversity - CIAU | 10 | 72.8 ± 5.4 | 61.4 ± 6.3 | Leger et al., 1979 |
| ational - Swedish | 24 | 75.6 | 57 | Forsberg et al., 1974 |
| unior | 18 | 76.4 | 56.4 ± 4.3 | Green & Houston, 1975 |
| ational - Finnish | 13 | 77.3 | 61.5 | Rusko et al., 1978 |
| niversity - CIAU | 8 | 77.4 | 61.3 | Green at al., 1978 |
| niversity - CIAU | 19 | 77.6 | 58.9 | Green et al., 1979 |
| unior | 9 | 78.7 | 55.4 | Green et al., 1979 |
| ational - Swedish - 1971 | 24 | 78.1 | 56.3 | Wilson & Hedberg, 1976 |
| unior | 44 | 78.2 | 55.4 | Houston & Green, 1976 |
| niversity - CIAU | 11 | 79.5 | 56.4 | Montgomery, 1982 |
| ational - Swedish - 1966 | 24 | 80 | 53.6 | Wilson & Hedberg, 1976 |
| niversity | 9 | 80.9 | 56.3 | Hutchinson et al., 1979 |
| rofessional | 12 | 83.4 | 55.3 | Green et al. 1979, |
| rofessional - NHL -1981/82 | 27 | 85.9 | 55.6 | Montgomery & Dallaire, 1986 |
| rofessional -NHL | | 86.4 | 53.6 | Wilmore, 1979 |
| rofessional - NHL - Fwd | 27 | 87.1 ± 5.6 | 57.4 ± 3.1 | Rhodes et al., 1986 |
| rofessional - NHL - Def | 40 | 90.3 ± 4.3 | 54.8 ± 3.9 | Rhodes et al., 1986 |
| rofessional - NHL -Fwd | 26 | 87.1 ± 5.6 | 56.3 ± 2.9 | Cox et al., 1988 |
| rofessional - NHL - Def | 21 | 90.3 ± 4.3 | 53.4 ± 3.4 | Cox et al., 1988 |
| rofessional - NHL | 27 | 85.6 ± 1.4 | 53.4 ± 0.8 | Agre et al., 1988 |
| wedish Professional (DIF) | 22 | 81.4 | 62.4 | Tegelman et al., 1992 |
| wedish Professional (SSK) | 21 | 82.4 | 65.8 | Tegelman et al., 1992 |
| rofessional - NHL | 1100 | 88.3 | 51.2 | Dewart et al., 1999 |
| **ycle Ergometer** | | | | |
| rofessional - 1972/73 | 12 | 75.9 | 54.1 | Bouchard et al., 1974 |
| niversity | 15 | 76.9 | 54.5 | Thoden & Jette, 1975 |
| unior | 24 | 77 | 58.4 | Bouchard et al., 1974 |
| niversity | 9 | 77.1 | 53.2 | Hermiston, 1975 |
| niversity | 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 |
| niversity | 5 | 79.5 | 54.3 | Daub et al., 1983 |
| niversity | 21 | 79.8 | 58.4 | Krotee et al., 1979 |
| National - Canadian | 23 | 81.1 ± 1.3 | 54 ± 1.2 | Smith et al., 1982 |
| National - Finnish | 27 | 81.1 | 52 | Vainikka et al., 1982 |
| unior | 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 |

'able 6 – Continued.

| ;roup | n | Body Mass kg | $VO_2max$ $ml \cdot kg^{-1} \cdot min^{-1}$ | Reference |
|---|---|---|---|---|
| Jniversity - NCAA | 25 | 80.8 ± 10.4 | 53.3 ± 8.6 | Smith , T. et al., 1998 |
| 'rofessional - For. | 14 | 87.1 ± 5.6 | 53.2 ± 5.2 | Cox et al., 1988 |
| 'rofessional - Def. | 6 | 90.3 ± 4.3 | 50.9 ± 1.5 | Cox et al., 1988 |
| 'rofessional - NHL - 1980 | 38 | 85.3 ± 1.1 | 54 ± 1.1 | Cox et al., 1993 |
| 'rofessional - NHL - 1984 | 38 | 88.2 ± 1.1 | 54.4 ± 0.8 | Cox et al., 1993 |
| 'rofessional - NHL - 1988 | 23 | 91.2 ± 1.5 | 57.8 ± 1.2 | Cox et al., 1993 |
| 'rofessional - NHL - 1991 | 75 | 88.4 ± 0.8 | 60.2 ± 0.6 | Cox et al., 1993 |
| 'eam Canada - 1991 | 55 | 89.3 ± 0.8 | 62.4 ± 0.5 | Cox et al., 1993 |
| 'rofessional | | 90.7 ± 4.5 | 62.8 ± 6.2 | Koch et al., 1999 |
| Jniversity - NCAA | | 81.3 ± 8.9 | 59.1 ± 5.5 | Koch et al., 1999 |
| **;kating - On - Ice** | | | | |
| Jniversity | 10 | 72.8 | 62.1 | Leger et al., 1979 |
| Jniversity | 17 | 73.7 | 55 | Ferguson et al., 1969 |
| Jniversity | 8 | 78.7 | 52.8 | Green, 1978 |
| Jniversity | 5 | 79.5 | 52.1 | Daub et al., 1983 |

Table 7. **Physical Characteristics of the Subjects (n=15)**

| Subject | Age yr | Height cm | Weight kg | Sum of Skinfolds mm | Fatness % |
|---|---|---|---|---|---|
| 1 | 20 | 185.7 | 89.8 | 88.4 | 10.5 |
| 2 | 21 | 172.7 | 68.0 | 79.3 | 10.2 |
| 3 | 21 | 180.3 | 87.6 | 91.1 | 11.0 |
| 4 | 20 | 174.0 | 80.3 | 67.2 | 8.9 |
| 5 | 21 | 193.8 | 87.0 | 60.8 | 8.3 |
| 6 | 24 | 164.3 | 79.9 | 102.3 | 11.9 |
| 7 | 22 | 186.2 | 88.8 | 91.2 | 11.0 |
| 8 | 20 | 191.3 | 86.6 | 87.7 | 10.6 |
| 9 | 22 | 180.3 | 85.7 | 72.2 | 9.4 |
| 10 | 19 | 175.9 | 73.9 | 59.4 | 8.4 |
| 11 | 23 | 176.5 | 87.7 | 100.3 | 12.1 |
| 12 | 20 | 167.6 | 76.5 | 96.2 | 11.5 |
| 13 | 21 | 178.6 | 81.8 | 72.3 | 9.6 |
| 14 | 22 | 188.0 | 86.1 | 88.4 | 10.9 |
| 15 | 19 | 177.8 | 92.5 | 122.8 | 14.1 |
| **Mean** | **21.0** | **179.5** | **83.5** | **85.3** | **10.6** |
| **S.D.** | **1.4** | **8.3** | **6.7** | **17.1** | **1.5** |

**Table 8. Skating Treadmill - Economy Test at 18 km·h$^{-1}$**

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ ml·kg$^{-1}$·min$^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 89.8 | 163.8 | 92.1 | 3.52 | 39.2 | 0.90 | 26.3 |
| 2 | 68.0 | 156.8 | 68.2 | 2.90 | 42.7 | 0.87 | 23.5 |
| 3 | 87.6 | 160.0 | 78.0 | 3.57 | 40.7 | 0.85 | 21.8 |
| 4 | 80.3 | 160.8 | 59.2 | 3.10 | 38.6 | 0.89 | 19.2 |
| 5 | 87.0 | 161.3 | 80.0 | 3.11 | 35.8 | 0.89 | 25.8 |
| 6 | 79.9 | 154.8 | 67.7 | 3.03 | 37.9 | 0.84 | 22.3 |
| 7 | 88.8 | 158.8 | 99.2 | 3.80 | 42.8 | 0.95 | 26.2 |
| 8 | 86.8 | 166.6 | 83.8 | 3.45 | 39.8 | 0.91 | 24.5 |
| 9 | 85.7 | 140.3 | 78.6 | 3.34 | 39.0 | 0.91 | 23.7 |
| 10 | 73.9 | 173.4 | 83.3 | 3.10 | 41.9 | 0.93 | 26.8 |
| 11 | 87.7 | 134.9 | 75.2 | 3.01 | 34.3 | 0.91 | 25.2 |
| 12 | 76.5 | 173.6 | 90.7 | 3.49 | 45.6 | 0.92 | 26.0 |
| 13 | 81.8 | 157.7 | 70.9 | 3.24 | 39.6 | 0.91 | 22.0 |
| 14 | 86.1 | 152.0 | 85.5 | 3.39 | 39.3 | 0.94 | 25.3 |
| 15 | 92.5 | 175.2 | 86.8 | 3.60 | 39.0 | 0.92 | 24.2 |
| **Mean** | **83.5** | **159.3** | **79.9** | **3.31** | **39.7** | **0.90** | **24.2** |
| **S.D.** | **6.7** | **11.3** | **10.6** | **0.26** | **2.8** | **0.03** | **2.1** |

**Table 9. Skating Treadmill - Economy Test at 20 km·h$^{-1}$**

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ ml·kg$^{-1}$·min$^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 89.8 | 167.9 | 98.7 | 3.77 | 42.0 | 0.90 | 26.3 |
| 2 | 68.0 | 163.0 | 73.5 | 3.08 | 45.4 | 0.89 | 23.8 |
| 3 | 87.6 | 165.4 | 93.7 | 3.86 | 44.0 | 0.89 | 24.4 |
| 4 | 80.3 | 170.0 | 73.0 | 3.32 | 41.4 | 0.92 | 21.8 |
| 5 | 87.0 | 167.8 | 88.7 | 3.58 | 41.2 | 0.89 | 24.8 |
| 6 | 79.9 | 163.9 | 87.5 | 3.37 | 42.2 | 0.87 | 26.0 |
| 7 | 88.8 | 163.4 | 99.1 | 4.01 | 45.1 | 0.90 | 24.8 |
| 8 | 86.8 | 174.0 | 92.8 | 3.78 | 43.6 | 0.91 | 24.7 |
| 9 | 85.7 | 148.3 | 86.7 | 3.65 | 42.6 | 0.89 | 23.8 |
| 10 | 73.9 | 183.3 | 90.1 | 3.23 | 43.7 | 0.93 | 28.2 |
| 11 | 87.7 | 143.8 | 85.3 | 3.38 | 38.6 | 0.90 | 25.5 |
| 12 | 76.5 | 179.2 | 100.7 | 3.66 | 47.8 | 0.93 | 27.5 |
| 13 | 81.8 | 168.9 | 79.8 | 3.41 | 41.7 | 0.93 | 23.4 |
| 14 | 86.1 | 156.0 | 82.5 | 3.54 | 41.1 | 0.89 | 23.3 |
| 15 | 92.5 | 183.3 | 99.8 | 3.96 | 42.8 | 0.92 | 25.3 |
| **Mean** | **83.5** | **166.5** | **88.8** | **3.57** | **42.9** | **0.90** | **24.9** |
| **S.D.** | **6.7** | **11.3** | **9.0** | **0.27** | **2.2** | **0.02** | **1.7** |

**Table 10. Skating Treadmill - Economy Test at 22 km·h$^{-1}$**

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ ml·kg$^{-1}$·min$^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 89.8 | 172.3 | 110.1 | 4.07 | 45.4 | 0.91 | 26.8 |
| 2 | 68.0 | 169.8 | 89.2 | 3.41 | 50.2 | 0.93 | 26.2 |
| 3 | 87.6 | 165.5 | 101.5 | 3.81 | 43.5 | 0.87 | 26.5 |
| 4 | 80.3 | 177.4 | 83.5 | 3.69 | 45.9 | 0.94 | 22.8 |
| 5 | 87.0 | 173.0 | 99.3 | 3.87 | 44.5 | 0.89 | 25.8 |
| 6 | 79.9 | 168.8 | 92.5 | 3.57 | 44.6 | 0.85 | 26.0 |
| 7 | 88.8 | 170.4 | 115.7 | 4.28 | 48.2 | 0.95 | 27.0 |
| 8 | 86.8 | 182.0 | 109.0 | 4.07 | 47.0 | 0.95 | 26.8 |
| 9 | 85.7 | 158.3 | 98.4 | 3.94 | 46.0 | 0.92 | 25.2 |
| 10 | 73.9 | 189.0 | 96.9 | 3.41 | 46.2 | 0.93 | 28.3 |
| 11 | 87.7 | 153.8 | 96.8 | 3.71 | 42.3 | 0.92 | 25.8 |
| 12 | 76.5 | 184.4 | 115.2 | 3.85 | 50.3 | 0.95 | 29.8 |
| 13 | 81.8 | 180.0 | 94.0 | 3.75 | 45.8 | 0.97 | 25.0 |
| 14 | 86.1 | 163.0 | 97.7 | 3.75 | 43.5 | 0.93 | 26.0 |
| 15 | 92.5 | 191.3 | 123.1 | 4.34 | 46.9 | 0.98 | 28.4 |
| **Mean** | **83.5** | **173.3** | **101.5** | **3.83** | **46.0** | **0.93** | **26.4** |
| **S.D.** | **6.7** | **10.8** | **10.9** | **0.27** | **2.3** | **0.04** | **1.6** |

**Table 11. Skating Treadmill - $VO_2$max Test**

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ ml·kg$^{-1}$·min$^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ | Velocity km·h$^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 89.8 | 190 | 172.4 | 4.66 | 51.7 | 1.13 | 37.0 | 29 |
| 2 | 68.0 | 190 | 133.9 | 3.86 | 56.7 | 1.22 | 35.0 | 30 |
| 3 | 87.6 | 190 | 186.8 | 4.79 | 54.4 | 1.10 | 39.0 | 31 |
| 4 | 80.3 | 197 | 143.9 | 4.44 | 55.3 | 1.24 | 32.0 | 31 |
| 5 | 87.0 | 199 | 140.2 | 4.70 | 54.0 | 1.13 | 30.0 | 32 |
| 6 | 79.9 | 197 | 162.0 | 4.19 | 52.4 | 1.12 | 39.0 | 30 |
| 7 | 88.8 | 188 | 189.4 | 4.89 | 55.0 | 1.18 | 39.0 | 29 |
| 8 | 86.8 | 189 | 134.2 | 4.58 | 52.8 | 1.18 | 29.0 | 28 |
| 9 | 85.7 | 189 | 181.3 | 4.76 | 55.5 | 1.17 | 38.0 | 32 |
| 10 | 73.9 | 204 | 117.7 | 3.75 | 50.8 | 1.17 | 31.0 | 29 |
| 11 | 87.7 | 184 | 187.8 | 4.49 | 51.2 | 1.17 | 42.0 | 30 |
| 12 | 76.5 | 199 | 137.0 | 4.37 | 57.2 | 1.20 | 31.0 | 29 |
| 13 | 81.8 | 202 | 143.0 | 4.36 | 53.3 | 1.17 | 33.0 | 30 |
| 14 | 86.1 | 183 | 171.2 | 4.32 | 50.2 | 1.21 | 40.0 | 27 |
| 15 | 92.5 | 199 | 131.9 | 4.67 | 50.5 | 1.12 | 28.0 | 27 |
| **Mean** | **83.5** | **193.3** | **155.5** | **4.45** | **53.4** | **1.17** | **34.9** | **29.6** |
| **S.D.** | **6.7** | **6.6** | **24.2** | **0.33** | **2.3** | **0.04** | **4.5** | **1.5** |

**Table 12. Skating Treadmill - Kinematic Results**

| Subject | Rate (strides·min$^{-1}$) | | | Length (m·stride$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 18 km·h$^{-1}$ | 20 km·h$^{-1}$ | 22 km·h$^{-1}$ | 18 km·h$^{-1}$ | 20 km·h$^{-1}$ | 22 km·h$^{-1}$ |
| 1 | 40.0 | 38.6 | 40.5 | 7.5 | 8.6 | 9.1 |
| 2 | 47.1 | 46.5 | 42.6 | 6.4 | 7.2 | 8.6 |
| 3 | 48.2 | 47.7 | 50.0 | 6.2 | 7.0 | 7.3 |
| 4 | 43.6 | 41.6 | 43.2 | 6.9 | 8.0 | 8.5 |
| 5 | 42.9 | 41.8 | 46.7 | 7.0 | 8.0 | 7.9 |
| 6 | 43.6 | 48.5 | 49.0 | 6.9 | 6.9 | 7.5 |
| 7 | 54.5 | 52.2 | 51.9 | 5.5 | 6.4 | 7.1 |
| 8 | 51.0 | 49.3 | 51.9 | 5.9 | 6.8 | 7.1 |
| 9 | 39.6 | 40.0 | 40.5 | 7.6 | 8.3 | 9.1 |
| 10 | 43.6 | 43.6 | 43.2 | 6.9 | 7.6 | 8.5 |
| 11 | 47.2 | 48.8 | 51.5 | 6.4 | 6.8 | 7.1 |
| 12 | 41.7 | 49.0 | 50.3 | 7.2 | 6.8 | 7.3 |
| 13 | 46.7 | 47.5 | 50.4 | 6.4 | 7.0 | 7.3 |
| 14 | 50.8 | 51.7 | 49.0 | 5.9 | 6.4 | 7.5 |
| 15 | 51.9 | 53.6 | 52.7 | 5.8 | 6.2 | 7.0 |
| **Mean** | **46.2** | **46.7** | **47.6** | **6.6** | **7.2** | **7.8** |
| **S.D.** | **4.5** | **4.6** | **4.4** | **0.6** | **0.7** | **0.8** |

**Table 13. On-Ice Skating Economy Test at 18 km·h$^{-1}$**

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ ml·kg$^{-1}$·min$^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 89.1 | 138.2 | 62.6 | 2.83 | 31.7 | 0.85 | 22.2 |
| 2 | 69.0 | 126.0 | 44.1 | 2.08 | 30.1 | 0.73 | 21.2 |
| 3 | 86.8 | 151.0 | 64.1 | 2.74 | 31.6 | 0.91 | 23.4 |
| 4 | 81.0 | 127.2 | 50.4 | 2.36 | 29.1 | 0.78 | 21.3 |
| 5 | 88.6 | 134.0 | 60.3 | 2.82 | 31.8 | 0.86 | 21.4 |
| 6 | 76.0 | 140.0 | 60.2 | 2.58 | 34.0 | 0.85 | 23.3 |
| 7 | 85.5 | 121.3 | 53.3 | 2.10 | 24.5 | 0.83 | 25.4 |
| 8 | 88.0 | 135.8 | 68.7 | 3.04 | 34.6 | 0.91 | 22.6 |
| 9 | 85.7 | 114.5 | 62.9 | 2.79 | 32.6 | 0.87 | 22.5 |
| 10 | 73.0 | 155.2 | 56.9 | 2.40 | 32.8 | 0.94 | 23.8 |
| 11 | 85.9 | 118.8 | 57.2 | 2.41 | 28.0 | 0.89 | 23.8 |
| 12 | 76.8 | 152.3 | 62.5 | 2.91 | 37.9 | 0.93 | 21.5 |
| 13 | 81.3 | 133.5 | 59.1 | 2.55 | 31.3 | 0.93 | 23.2 |
| **Mean** | **82.1** | **134.4** | **58.6** | **2.58** | **31.5** | **0.87** | **22.7** |
| **S.D.** | **6.5** | **12.9** | **6.4** | **0.30** | **3.3** | **0.06** | **1.2** |

**Table 14. On-Ice Skating Economy Test at 20 km·h$^{-1}$**

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ ml·kg$^{-1}$·min$^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 89.1 | 157.3 | 76.6 | 3.34 | 37.4 | 0.86 | 23.0 |
| 2 | 69.0 | 149.0 | 64.4 | 2.77 | 40.2 | 0.80 | 23.3 |
| 3 | 86.8 | 155.7 | 73.9 | 2.95 | 33.9 | 0.96 | 25.1 |
| 4 | 81.0 | 143.0 | 62.1 | 2.74 | 33.9 | 0.83 | 22.6 |
| 5 | 88.6 | 156.7 | 80.7 | 3.65 | 41.2 | 0.88 | 22.1 |
| 6 | 76.0 | 159.2 | 71.1 | 3.08 | 40.6 | 0.81 | 23.1 |
| 7 | 85.5 | 132.2 | 66.9 | 2.52 | 29.5 | 0.84 | 26.5 |
| 8 | 88.0 | 154.5 | 80.4 | 3.39 | 38.6 | 0.98 | 23.7 |
| 9 | 85.7 | 131.8 | 79.4 | 3.47 | 40.5 | 0.92 | 22.9 |
| 10 | 73.0 | 166.7 | 71.6 | 2.86 | 39.2 | 0.95 | 25.0 |
| 11 | 85.9 | 124.5 | 66.4 | 2.53 | 29.5 | 0.92 | 26.2 |
| 12 | 76.8 | 166.8 | 76.8 | 3.12 | 40.6 | 0.98 | 24.6 |
| 13 | 81.3 | 146.3 | 68.2 | 2.80 | 34.4 | 0.91 | 24.4 |
| **Mean** | **82.1** | **149.5** | **72.2** | **3.02** | **36.9** | **0.90** | **24.0** |
| **S.D.** | **6.5** | **13.4** | **6.3** | **0.36** | **4.2** | **0.06** | **1.4** |

Table 15. On-Ice Skating Economy Test at 22 km·h$^{-1}$

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ ml·kg$^{-1}$·min$^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 89.1 | 170.3 | 96.0 | 3.79 | 42.5 | 0.91 | 25.3 |
| 2 | 69.0 | 164.7 | 80.0 | 3.16 | 45.8 | 0.85 | 25.3 |
| 3 | 86.8 | 162.3 | 92.7 | 3.41 | 39.3 | 1.00 | 27.2 |
| 4 | 81.0 | 159.8 | 80.6 | 3.24 | 40.0 | 0.90 | 24.9 |
| 5 | 88.6 | 175.5 | 107.0 | 4.32 | 48.8 | 0.96 | 24.8 |
| 6 | 76.0 | 175.8 | 91.8 | 3.59 | 47.3 | 0.93 | 25.5 |
| 7 | 85.5 | 152.2 | 90.3 | 3.15 | 36.8 | 0.89 | 28.7 |
| 8 | 88.0 | 170.0 | 91.5 | 3.56 | 40.4 | 1.04 | 25.7 |
| 9 | 85.7 | 154.7 | 106.4 | 4.08 | 47.7 | 0.99 | 26.1 |
| 10 | 73.0 | 180.5 | 87.3 | 3.19 | 43.6 | 1.01 | 27.4 |
| 11 | 85.9 | 142.0 | 88.2 | 3.02 | 35.2 | 1.02 | 29.2 |
| 12 | 76.8 | 176.3 | 100.0 | 3.46 | 45.0 | 1.07 | 28.9 |
| 13 | 81.3 | 162.7 | 90.3 | 3.47 | 42.6 | 0.86 | 26.0 |
| **Mean** | **82.1** | **165.1** | **92.5** | **3.50** | **42.7** | **0.96** | **26.5** |
| **S.D.** | **6.5** | **11.1** | **8.3** | **0.38** | **4.2** | **0.07** | **1.6** |

**Table 16. On-Ice $VO_2$max Test**

| Subject | Weight kg | HR bpm | $V_E$ L/min | $VO_2$ L/min | $VO_2$ $ml \cdot kg^{-1} \cdot min^{-1}$ | R | $V_E/VO_2$ L/L of $O_2$ | Velocity $km \cdot h^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 89.1 | 186 | 150.2 | 4.91 | 55.1 | 1.09 | 30.6 | 28 |
| 2 | 69.0 | 185 | 134.3 | 4.24 | 61.5 | 1.09 | 31.7 | 28 |
| 3 | 86.8 | 186 | 142.2 | 4.48 | 51.6 | 1.28 | 31.7 | 28 |
| 4 | 81.0 | 188 | 131.0 | 4.35 | 53.7 | 1.12 | 30.1 | 28 |
| 5 | 88.6 | 195 | 152.2 | 5.04 | 56.8 | 1.20 | 30.2 | 28 |
| 6 | 76.0 | 195 | 142.8 | 4.18 | 55.0 | 1.14 | 34.2 | 28 |
| 7 | 85.5 | 180 | 128.1 | 4.43 | 51.8 | 1.12 | 28.9 | 28 |
| 8 | 88.0 | 191 | 137.0 | 4.66 | 53.0 | 1.31 | 29.4 | 27 |
| 9 | 85.7 | 183 | 173.8 | 5.22 | 60.9 | 1.29 | 33.3 | 28 |
| 10 | 73.0 | 197 | 137.1 | 4.09 | 56.0 | 1.23 | 33.6 | 28 |
| 11 | 85.9 | 178 | 156.8 | 4.19 | 48.7 | 1.14 | 37.5 | 29 |
| 12 | 76.8 | 190 | 131.9 | 4.06 | 52.9 | 1.39 | 32.5 | 28 |
| 13 | 81.3 | 189 | 142.6 | 4.40 | 54.1 | 1.00 | 32.4 | 28 |
| **Mean** | **82.1** | **187.9** | **143.1** | **4.48** | **54.7** | **1.18** | **32.0** | **28.0** |
| **S.D.** | **6.5** | **5.8** | **12.6** | **0.37** | **3.6** | **0.11** | **2.3** | **0.4** |

**Table 17. On-Ice - Kinematic Results**

| Subject | Rate (strides·min$^{-1}$) | | | Length (m·stride$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 18 km·h$^{-1}$ | 20 km·h$^{-1}$ | 22 km·h$^{-1}$ | 18 km·h$^{-1}$ | 20 km·h$^{-1}$ | 22 km·h$^{-1}$ |
| 1 | 25.6 | 24.9 | 31.9 | 11.7 | 13.4 | 11.5 |
| 2 | 36.1 | 36.9 | 43.0 | 8.3 | 9.0 | 8.5 |
| 3 | 30.1 | 34.6 | 38.7 | 10.0 | 9.6 | 9.5 |
| 4 | 26.2 | 29.0 | 31.4 | 11.5 | 11.5 | 11.7 |
| 5 | 34.9 | 34.1 | 39.5 | 8.6 | 9.8 | 9.3 |
| 6 | 37.8 | 39.9 | 42.9 | 7.9 | 8.3 | 8.6 |
| 7 | 33.1 | 37.5 | 41.7 | 9.1 | 8.9 | 8.8 |
| 8 | 33.3 | 36.2 | 40.9 | 9.0 | 9.2 | 9.0 |
| 9 | 32.9 | 37.7 | 38.4 | 9.1 | 8.8 | 9.6 |
| 10 | 29.7 | 35.8 | 44.3 | 10.1 | 9.3 | 8.3 |
| 11 | 29.3 | 32.3 | 37.1 | 10.2 | 10.3 | 9.9 |
| 12 | 29.1 | 30.7 | 35.8 | 10.3 | 10.8 | 10.3 |
| 13 | 38.0 | 40.1 | 45.3 | 7.9 | 8.3 | 8.1 |
| **Mean** | **32.0** | **34.6** | **39.3** | **9.5** | **9.8** | **9.5** |
| **S.D.** | **4.1** | **4.4** | **4.4** | **1.2** | **1.4** | **1.1** |

**Table 18. Repeated Measures ANOVA for $VO_2$**

| **Source** | **SS** | **Df** | **MS** | **F** |
|---|---|---|---|---|
| Velocity | 4958.68 | 3 | 1652.89 | 430.07 * |
| Error | 138.36 | 36 | 3.84 | |
| Surface | 473.03 | 1 | 473.03 | 20.19 * |
| Error | 281.18 | 12 | 23.43 | |
| Vel X Sur | 301.70 | 3 | 100.57 | 40.14 * |
| Error | 90.19 | 36 | 2.51 | |

* P< .01

Note: The total degrees of freedom for the ANOVA are 91, not the 103 that may have been expected. The difference of 12 degrees of freedom represents the main effect of performance for the 13 subjects. This effect was not tested in the analysis because subjects were the random factor used to compute error term.

**Table 19. Repeated Measures ANOVA for Heart Rate**

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Velocity | 27795.89 | 3 | 9265.30 | 261.20 * |
| Error | 1277.01 | 36 | 35.47 | |
| Surface | 4753.36 | 1 | 4753.36 | 75.23 * |
| Error | 758.24 | 12 | 63.19 | |
| Vel X Sur | 1429.16 | 3 | 476.39 | 41.37 * |
| Error | 414.59 | 36 | 11.52 | |

* P< .01

Note: The total degrees of freedom for the ANOVA are 91, not the 103 that may have been expected. The difference of 12 degrees of freedom represents the main effect of performance for the 13 subjects. This effect was not tested in the analysis because subjects were the random factor used to compute error term.

**Table 20. Repeated Measures ANOVA for Stride Rate**

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Velocity | 272.00 | 2 | 136.00 | 49.62 * |
| Error | 65.78 | 24 | 2.74 | |
| Surface | 2259.39 | 1 | 2259.39 | 80.24 * |
| Error | 337.88 | 12 | 28.16 | |
| Vel X Sur | 103.64 | 2 | 51.82 | 13.64 * |
| Error | 91.17 | 24 | 3.80 | |

* P< .01

**Appendix F**

# MCGILL UNIVERSITY ETHICS APPROVAL

**MCGILL UNIVERSITY**
**FACULTY OF EDUCATION**

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

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

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

A Comparison of Skating Economy On-Ice and on the Skating Treadmill

as proposed by:

Applicant's Name Kelly Nobes

Applicant's Signature Kelly Nobes

Degree / Program / Course M.A.

Supervisor's Name Dr. David L. Montgomery

Supervisor's Signature David L Montgomery

Granting Agency non-funded

The application is considered to be:

A Full Review ____________

An Expedited Review X

A Renewal for an Approved Project ____________

A Departmental Level Review ____________
Signature of Chair / Designate

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

1. Prof. Joyce Benenson
Department of Educational and Counselling Psychology

Signature / date

2. Prof. John Leide
Graduate School of Library and Information Studies
John E Leide 000925
Signature / date

3. Prof. René Turcotte
Department of Physical Education
René T 00 09 25
Signature / date

4. Prof. Lise Winer
Department of Second Language Education

Signature / date

5. Prof. Claudia Mitchell
Department of Educational Studies

Signature / date

6. Prof. Kevin McDonough
Department of Culture and Values in Education
Sept. 25/0
Signature / date

7. Member of the Community

Signature / date

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

Mary H Maguire Sept 26, 00
Signature / date

**(Updated January 2000)**

**Updated January 2000**

**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 (Kelly Nobes) 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 male ice hockey players, between the ages of 18 and 26 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 submaximal 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?

Withdrawal 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 he should fall off the treadmill.

## 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? (See guidelines on confidentiality/anonymity section).

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.
For case study research see attached guidelines, section case studies.

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

Signature of
researcher: ______________________________

## Overview of the Study

Skating treadmills are relatively new tools used by researchers, coaches, trainers and therapists with interests in ice hockey. 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. An electric motor connected to a control box adjusts the speed (0 – 32 km/h), and the grade (0 – 24.5%) of the treadmill. The purpose of this study is to determine if skating economy is similar on-ice and on the skating treadmill.

The subjects for this study will be 15 male varsity ice hockey players from McGill University. The subjects will range in age from 19 to 24 years with varying degrees of playing experience at the intercollegiate level (i.e. one to four years). Prior to testing, all subjects will read and sign a consent form.

The height and weight of each subject will be determined prior to the skate-treadmill test with the subjects dressed in shorts and socks. 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 (Detecto Scales Inc.), and recorded to the nearest 0.5 kg. To determine body composition, eight skinfolds (triceps, biceps, subscapula, chest, abdominal, iliac crest, thigh, medial calf) will be obtained with the use of skinfold calipers. Percent body fat will be estimated using the Yuhasz equation ( % Body fat = [(sum of 6 skinfolds) * 0.097] + 3.64).

The laboratory test will have subjects skate for 4 min at each of 3 velocities on the skating treadmill. The velocities will be 18, 20, and 22 km/h (300, 333, and 367$m \cdot min^{-1}$), which correspond to lap times of 28, 25, and 22 seconds, respectively. The subjects will have 5 min of recovery between each skating velocity. Upon completion of the third velocity (22 km/h), an intermittent $VO_2max$ test will be given. The $VO_2max$ test will begin at 24 km/h and the treadmill will be increased by 1 km/h every minute until volitional fatigue is reached. Subjects will attempt a supermax test at the next highest velocity, if the $VO_2$ has not reached a plateau (defined as < 150 ml/min rise in $VO_2$ when speed is increased by 1 km/h). Expired air will be analyzed continuously throughout the test using a Sensor Medics Metabolic Cart. Heart rate will be recorded using a Polar Electro Sport Tester every minute during the test. Stride rate will be measured at each velocity by visually counting the number of strides in 60 seconds.

The second test will have players skate on-ice for 4 min at the same three velocities as the skating treadmill protocol. The on-ice skating economy test will take place on a 140 m oval course set-up at the McConnell Winter Arena. Subjects will be required to skate at velocities of 18, 20, and 22 km/h (300, 333, and 367 $m \cdot min^{-1}$), which correspond to lap times of 28, 25, and 22 seconds, respectively. Expired gas will be analyzed using the Cosmed $K4b^2$ breath-by-breath portable gas exchange system. Heart rate will be collected during the entire test and stored in memory for downloading at a later time. Stride rate will be measured at each velocity by visually counting the number of strides in 60 seconds.

The dependent variables will be: $VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$), heart rate ($beats \cdot min^{-1}$), stride rate ($strides \cdot min^{-1}$), and stride length ($m \cdot stride^{-1}$).

Following data analysis, each subject will be presented with a summary of results explaining body composition, $VO_2$ and HR associated with three different skating velocities on two different skating surfaces.

## Appendix G

# SUBJECT INFORMATION AND CONSENT FORM

## CONSENT FORM FOR EXERCISE TESTING

I, ________________________________________________ (print name) authorize Dr. David Montgomery and Kelly Nobes to administer the exercise tests outlined below which will be used for research purposes. I understand that the staff conducting the tests may ask me to discontinue the tests if any indication of an abnormal response becomes apparent. I understand that I will perform the tests as listed below.

### TESTS TO BE PERFORMED

1. **Body Composition:** Age (yr), height (cm), and weight (kg) will be measured. Body composition will be assessed using skinfold measurements at the following eight sites: biceps, triceps, chest, subscapula, iliac crest, abdominal, thigh, medial calf.

2. **On-Ice Skating Economy Test:** The on-ice skating economy test will take place on a 140 m oval course set-up at the McConnell Winter Arena. Subjects will be required to skate for four minutes at velocities of 18, 20, and 22 $km \cdot h^{-1}$ (300, 333, and 367 $m \cdot min^{-1}$ ), which correspond to lap times of 28, 25, and 22 seconds, respectively. There will be a five-minute rest period interspersed between velocities. Following completion of the third velocity, a $VO_2max$ test will commence at 24 $km \cdot h^{-1}$ with speed increased by 1 $km \cdot h^{-1}$ every minute until volitional exhaustion.

3. **Treadmill Skating Economy Test:** The laboratory test will have subjects skate for 4 min at 3 different velocities on the skating treadmill. Subjects will be required to skate at 18, 20, and 22 $km \cdot h^{-1}$ (300, 333, and 367 $m \cdot min^{-1}$). The subjects will have 5 min of recovery between each skating velocity. Following completion of the third velocity, a $VO_2$ max test will commence at 24 $km \cdot h^{-1}$ with speed increased by 1 $km \cdot h^{-1}$ every minute

until volitional exhaustion. Subjects will attempt a supermax test at the next highest velocity, if the $VO_2$ has not reached a plateau.

The purpose of the study, the procedures to be used, the benefits and risks associated with my participation in this study, as well as the confidentiality of the data that will be collected during the study have been explained to me.

I have had the opportunity to ask questions concerning aspects of this study and my questions have been answered to my satisfaction.

I acknowledge that I have read and fully comprehend this information. I voluntarily accept participation in this study. I am aware that I am free to withdraw from this study at any time and for any reason without penalty.

I acknowledge that I have received a signed copy of this consent form.

| | | |
|---|---|---|
| Name of subject | Signature | Date |
| Name of witness | Signature | Date |
| Name of researcher | Signature | Date |

## Appendix H

## CONTRIBUTION OF CO-AUTHORS IN THE RESEARCH ARTICLE

**Kelly Nobes**

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

**Dr. David L. Montgomery**

Thesis supervisor and assisted with writing of the research article.

**Francois Whittom**

Provided Cosmed $K4b^2$ gas analysis system, and assisted in collection of on-ice data.

**David Pearsall**

Proofread research article.

**Rene Turcotte**

Proofread research article.

**Richard Lefebvre**

Proofread research article.