The effect of surface, wheel, and bearing type on the physiological response of in-line skating

by

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ABSTRACT

The purpose of this study was to determine the physiological response of an in-line submaximal skate on two surfaces using two wheel types and two bearing types. The variables measured were VO_2 and HR. Ten male varsity hockey players volunteered as subjects. The subjects, after being assigned one of two wheel types with varying durometers, skated the submaximal test twice for each surface (concrete and asphalt) using a different type of bearing (precision and semi-precision) each time. These results were compared to a similar on-ice submaximal skating test session.

Results revealed no significant difference between in-line skating with wheels of 78 and 82 Shore A durometers ($p < .05$) with both VO_2 and HR as markers. A significant difference was found between in-line skating with precision and semi-precision bearings with VO_2 as a marker ($p < .05$), however, not with HR as a marker ($p = 0.31$). On-ice skating was significantly different from in-line skating on concrete and asphalt surfaces for both physiological markers. In-line skating on asphalt and concrete surfaces resulted in similar physiological responses. It was concluded that hockey players training with in-line skates obtain the same training benefits using either wheel durometers, but will have greater oxygen costs when training with semi-precision bearings than training with precision bearings.

Résumé

Le but de cette étude était d'établir les demandes physiologique de deux types de roues et deux types de roulement à billes pour un test de patinage à roues alignées sous-maximal sur deux surfaces différentes. La fréquence cardiaque et le VO_2 étaient les variables de cette étude. Dix joueurs de hockey universitaires masculins se sont portés volontaires. Les sujets ont été divisés par groupe selon la durité duromètre de roues et ont complété le test de patinage sous-maximal à deux reprises pour chaque surface (asphalte et béton) utilisant un type différent de roulement à billes (précision et semi-précision) à chaque reprise. Ces résultats ont ensuite été comparés à un test semblable de patin sur glace. Les résultats ont démontré qu'il n'y avait aucune différence significative pour le test de patinage à roues alignées avec les roues d'une dureté duromètre de 78 et 82 ($p<.05$) quand la f.c. et le VO_2 étaient utilisés comme variables. Il y a eu une différence significative pour le patinage à roues alignées entre les roulements à billes semi-précision et précision en terme de VO_2 ($p<.05$), mais pas pour la f.c. ($p=0.31$). Le VO_2 et f.c. obtenus pour le patinage sur glace étaient significativement différents que ceux obtenus pour le patinage à roues alignées sur le béton et l'asphalte. Les demandes physiologiques étaient semblables pour le patinage à roues alignées sur surface en béton ou asphalte.

Il fut conclu que des joueurs de hockey s'entraînant avec des patins à roues alignées obtiennent les mêmes bénéfices d'entraînement en utilisant des roues d'une duromètre ou de l'autre, mais que la demande de consommation d'oxygène sera plus élévée en s'entraînant avec des roulements à billes semi-précision que des roulement à billes précision.

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Chapter 1

Introduction

In-line skating, more commonly known as rollerblading, is becoming more popular among people of all ages. Young children enjoy using in-line skates for performing turns and jumps, others use in-line skates as a mode of transportation or as a means of exercise. Athletes such as hockey players, speed skaters, and cross country skiers use in-line skates for dryland training during the off-season. It is estimated that 400,000 people in the United States alone own in-line skates (Strauss, 1990).

For training purposes, in-line skates are used to improve aerobic and anaerobic fitness. In-line skates are very popular among hockey players due to the specificity of training. Using in-line skates during the off-season allows hockey players to maintain their fitness level and at the same time keep their training specific to the sport of hockey.

Since in-line skating is a relatively new activity, there are few studies that have examined its physiological response. Heart rate and oxygen uptake are the traditional markers that have been used by exercise physiologists to measure the response to exercise and training. These variables are the proposed markers for this study. There are many conditions that could affect the physiological response of in-line skating. Some of the variables include type of surface, wheel, and bearing.

1.1 Nature and Scope of the Problem

Hockey is a game characterized by a series of short high intensity bursts of activity requiring rapid changes in velocity and frequent body contact (Seliger et al., 1972). The activities of ice hockey, in particular ice skating, require utilization of all the major muscle groups of the body.

Ice hockey is a compromise between two extremes: on one hand high intensity effort is involved, and on the other hand the characteristic of endurance is important. Ice hockey, therefore, depends on a maximal involvement of the aerobic systems for ATP resynthesis while minimizing the glycolytic involvement (Green, 1979). During the off-season, specificity of training implies that the energy systems should be challenged to simulate the game of hockey. Various literature exists concerning the training and testing of athletes. Wilmore (1984), for example, concluded that the testing mode should be identical with the athlete's specific sport activity. Daub et al. (1983) reported similar conclusions for the specificity of training.

de Boer et al. (1987b) listed the following variables as being important for the specificity of training for speed skating:

- maximal aerobic power (Pechar et al., 1974; Stromme et al., 1977; Verstappen et al., 1982).
- muscle fibre recruitment (Gollnick et al, 1974; Green, 1978)
- force, velocity, and mechanical power of muscle fibre recruitment (Caiozzo, et al. 1981; Duchateau & Hainaut, 1984; Kaneko et al., 1983).
- speed of movement (Kanehisa & Miyashita, 1983; Lesmes et al., 1978).

Dryland training programs for hockey should also be designed to include the above variables.

Pollock et al. (1982) described the dryland training program of the 1980 US Olympic team. Thirty to thirty-five hours a week (14 times a week) were spent on training: 40% of the time was spent on general aerobic training (cycling and running), 20% on general anaerobic high intensity interval training, 15% on general weight training and only 25% of the time was used for specific training (slide-board, roller skating, and dry skating movements) (de Boer, 1987b).

The amount of time that can justifiably be spent in a particular "specific" form of training depends on the similarity that it has with the actual performance (de Boer, 1987b). In-line skating is very similar to hockey in terms of both technique and performance.

1.2 Significance of the study

Skating is the primary skill in ice hockey. In dryland training, the more closely the exercise approximates ice hockey, the more likely it is to improve the skill, quickness, and endurance of a player.

When training with in-line skates, a player uses similar muscles that are used in hockey skating. Thus, in-line skating is an excellent method for staying in shape during the off-season. Training with in-line skates makes it possible to practice the majority of manoeuvres and skills necessary for good ice hockey skating including forward and backward skating, crossovers, turns, agility, and quickness (Blatherwick, 1985). It allows players to improve both anaerobic and aerobic conditioning and to strengthen their skating muscles making the player a more powerful skater. At the same time, the player may improve skating technique.

A good player must also be adept at skills other than skating, including passing, shooting, and stickhandling. There are two advantages to practising these skills on in-line skates as opposed to practising in running shoes: timing and speed. A player's timing may not be accurate if practising stick and puck work in running shoes due to the 6 cm difference in height. In-line skates place a player at the same distance off the ground as ice skating thus enabling a player to practice and perfect timing under conditions that closely resemble skating on ice (Buetow, 1985). While using in-line skates, players can also practice their puck and stick handling skills at all speeds including all-out.

The development of in-line skates has made it possible for players to train during the off-season with a high degree of specificity for the sport of hockey. Few studies, however, have examined the physiological response of training with in-line skates. It is expected that changes in surface, wheel type, and bearing type will alter the physiological response and have implications for training. One could speculate that a combination of these variables may reduce rolling resistance so that the athlete does not obtain physiological training benefits. A study comparing the physiological responses to in-line skating is warranted.

1.3 Statement of Problem

The aim of this study was to determine the physiological response of in-line skating on two surfaces using two wheel types and two bearing types. The variables measured were VO_2 and HR. The physiological responses during in-line skating were compared to the physiological response during on-ice skating.

1.4 Hypotheses

The hypotheses are presented in the declarative format and the null format. It is implicitly understood that a statistically significant difference in the declarative format infers a failure to accept the null hypothesis there upon reaffirming the declaratory hypothesis.

1. There will be no significant difference between wheels of 78 Shore A durometer and wheels of 82 Shore A durometer in the physiological response (VO_2 and HR).
2. There will be a significant difference between semi-precision bearings and precision bearings in the physiological response (VO_2 and HR).
3. There will be a significant difference among the five experimental conditions in the physiological response (VO_2 and HR).
4. There will be a significant "condition X velocity" interaction for the physiological variables (VO_2 and HR).
5. There will be no significant difference in the rolling resistance (N) between (1) bearing type, (2) wheel type, (3) and surface type.

1.5 Operational Definitions

Skating Conditions: There were five skating conditions used in this study:

- skating on asphalt with precision bearings,
- skating on asphalt with semi-precision bearings,
- skating on concrete with precision bearings,
- skating on concrete with semi-precision bearings,
- skating on ice.

1.6 Abbreviations

VO_2 - oxygen uptake

HR - heart rate

1.7 Delimitations

Random sampling from the general population was not carried out thus limiting generalizations to be made to individuals of the same gender, age, and ability. Inferences are confined to male varsity hockey players between the ages of 18 and 23. Generalizations are also confined to in-line skating on asphalt and concrete using the particular wheel and bearing types that were used in this study.

1.8 Limitations

Limitations of this study include the possibility that the players' fitness levels were not constant throughout all the experimental sessions because the test sessions were not carried out at the same time of season. Also, the circumferences of the courses (on-ice, asphalt, and concrete) were not the same dimensions.

Chapter 2

Review of Literature

2.1 Analysis of Hockey

Many studies have examined the sport of hockey. Sports vary widely in their ranges of work intensity, duration, and in recovery duration. As a result, the stresses imposed on the anaerobic and aerobic energy supply systems also vary widely between sports.

2.1.1 Time Motion Analysis

Hockey is essentially a sport characterized by a series of short, high intensity bursts of activity requiring rapid changes in velocity and frequent body contact. These bursts are normally followed by periods of moderate activity, such as coasting, face-offs, regrouping, etc. When players can not maintain an adequate pace they return to the bench for recovery (Seliger et al., 1972).

Three major junior level hockey games and a professional game were monitored by Thoden and Jette (1975) in order to determine the proportion of time spent in anaerobic or bursting activity, coasting or recovery, and time spent on the bench. They reported that the average player was on the ice for 75 to 90 seconds per shift. Each shift consisted of 5 to

7 bursts with each burst lasting 2 to 3.5 seconds for a total of 15 to 20 seconds of bursting per shift. Each player was on the ice for 5 to 6 shifts per period for a total time of 5 to 7 minutes. The time between shifts was 3 to 4 minutes, the total playing time per game was 15 to 21 minutes with 4 to 6 minutes of that being anaerobic bursting.

Similar results were reported by Green et al. (1976) in a time motion study using varsity ice hockey players. Players were on-ice for 42 percent of the total game time, playing 5 or 6 shifts per 20 minute period. Each shift averaged 85 seconds of actual playing time. Continuous play within a shift averaged 40 seconds with a 27 second break for each 2 or 3 whistle stops. Thus the 85 second stop-time play required 160 seconds (2.7 minutes) on the ice. The average time spent on the bench between shifts was 225 seconds. The average velocity per shift was 227 meters per minute and the heart rate during a shift averaged 173 beats per minute (87 to 92 percent of maximum). Based on the time stoppages per shift and playing time per shift, the ratio of work to recovery was approximately 1 to 3.

The differences between positions (centre, wing, defense, and goalie) were quantified by Green et al. (1976). By position, the greatest contrast was provided between the forwards and the defensemen. The defensemen played much longer than the forwards (+21.2%) due to a greater number of shifts (+26.1%) and a much shorter recovery period (-37.1%).

On the other hand, each shift was shorter in duration (-7.4%), shorter in continuous play time (-10.1%), and longer in the time taken to resume play (+12.9%). A large difference was noticed in the average velocity of each shift with the defensemen only averaging 61 percent of the value obtained by the forwards. The defensemen also had heart rates that averaged 10 to 15 beats per minute lower during a shift.

In a later study by Green et al. (1978), slightly different results were reported concerning the time motion characteristics of different positions. This study, when compared to the study in 1976, indicated that the average player skated 7 percent less (228 minutes), had 25 percent more shifts (21.7), but 26 percent less playing time (63.6 seconds) per shift. The playing time between stoppages decreased 27 percent (29.1 seconds), the time of each play stoppage increased by 10 percent (29.8 seconds), and the recovery time between shifts increased 13 percent (254 seconds) (Brayne, 1985).

Leger (1980) performed time motion analyses of 80 junior and 170 midget players. For the junior players, the forwards and defensemen had similar playing times (88.5 versus 84.9 seconds) per shift. Since the defensemen spent less time on the bench between shifts, the ratio of bench time to on-ice time was higher for forwards (2.3 ratio) than the defensemen (2.1 ratio) (Montgomery, 1988).

2.1.2 Physiology of Ice Hockey

The character of the work that is being performed, including the muscle mass involved, the intensity and duration of the work periods, the length and nature of the recovery of rest intervals, and the number of repetitions are all significant determinants of the metabolic pathway that is used by the body to generate and regenerate the energy required to perform the task at hand (Green, 1979).

The activities of ice hockey, in particular skating, require utilization of all the major muscle groups of the body. They are characterized by intermittent work bouts of high intensity that produce near maximal cardiac frequency measurements (Green, 1978). During high intensity exercise of this nature, there is a rapid depletion of phosphocreatine (PC) which occurs during the first several seconds of effort (Green, 1979). As high intensity work continues, there is a progressive contribution of glycolysis with a rapid increase in muscle lactate and a decrease in muscle pH. Following this type of effort, the removal of lactate and the recovery of the pH characteristics of the muscle are relatively slow processes. For PC recovery, the synthesis is oxygen dependent. Approximately 90 percent is resynthesized in the first minute of recovery (Harris et al., 1976), but full PC resynthesis is not completed for 20 minutes. If another work shift is attempted within a minute or two, the muscle lactate will still be substantially elevated. This would elevate muscle lactate and depress the pH to an even greater degree. Since hydrogen ion concentration can inhibit certain key regulatory enzymes in glycogenolysis and glycolysis, and disturb contractile activity, work performance will be reduced (Green, 1979).

In a study performed by Green et al. (1978), four hockey games were monitored in order to investigate the alterations in blood substrates and the depletion pattern of glycogen in the vastus lateralis muscle. The peak playing heart rates averaged in excess of 90 percent of maximal values. The total glycogen depleted amounted to 60 percent, and was similar for forwards and defensemen. Given the nature of the game, a much greater glycogen loss was expected. The low glycogen depletion suggested that aerobic mechanisms were dominant in ATP resynthesis. This was supported, in part, by low blood lactate values. The reason for the low lactate levels appeared to be that in a shift, there was an average of two to three play stoppages. This would provide sufficient time for 60 to 65 percent of the PC to be resynthesized and available for the next phase of the shift (Green, 1979).

Green (1978) studied the glycogen depletion patterns from the vastus lateralis muscle during continuous and intermittent exercise. The continuous skating was performed at 55 percent of maximal VO_2 for 60 minutes, and the intermittent skating was performed at 120 percent of maximal VO_2 and consisted of ten 1-minute bouts followed by a five minute recovery period.

With continuous skating, average depletion following 60 minutes of skating amounted to 29 percent with the depletion being most pronounced in the type I (slow twitch oxidative) fibres. For the intermittent skate, depletion following the fifth work bout was 45 percent followed by a progressive depletion in the remaining bouts. The final glycogen concentration was 70 percent reduced from the pre-exercise concentration with the greatest depletion observed in the type II (fast twitch glycolytic) fibres. Of the two types of fast twitch fibres (type IIA - fast twitch oxidative glycolytic, type IIB - fast twitch glycolytic), the greatest depletion was in the type IIB fibres. It was concluded from the continuous skate that ice skating appears to be similar to cycling and running where prolonged efforts result in a selective and marked glycogen depletion in type I fibres before a progressive glycogen depletion in type II fibres is observed. Green also stated that this study implicates the extreme importance of the vastus lateralis muscle in supramaximal bouts of ice skating as evidenced by the rapid depletion that occurs.

Luetsolo (1976) indicated that the hockey player is capable of having high muscle glycogen stores before a game. From this study it was reported that during a very hard game, hockey players can lose almost their entire muscle glycogen stores (as much as 40 grams per kilogram of wet muscle).

Muscle glycogen is utilized first from slow twitch fibres and only during strenuous games is it used from the fast twitch fibres (Gamble, 1986).

2.1.3 Energy Expenditure

The maximum oxygen uptake of athletes of several sports has been determined in the laboratory and has been measured during actual performance of certain sports which demand maximal or near maximal oxygen uptakes (Ferguson et al., 1969). Aerobic capacity is essential to optimal performance in many sports, and certain physiological parameters vary directly with the work intensity expressed as a percentage of maximum VO_2 (Rowell, 1969). Oxygen consumption of hockey players has been estimated by many researchers (Ferguson et al., 1969; Green et al., 1976; Green & Houston, 1975; Houston & Green, 1976; Leger et al., 1979; Paterson, 1979; Smith et al., 1982; Hutchison et al., 1979). Hockey players have an average maximum oxygen uptake between 50 to 60 ml/kg*min (Brayne, 1985). Values range as low as 42.3 ml/kg*min for NHL players tested in pre-season to as high as 62.4 ml/kg*min for Eastern European Countries tested during mid season (Enos et al., 1976). Hockey players have similar VO_2 max (Cunningham et al., 1976), which does not seem to change significantly during the hockey season (Green & Houston, 1975).

Seliger et al. (1972) estimated the oxygen consumption during a hockey game by studying players of the Czechoslovakian national team performing one shift averaging 1.17 minutes followed by 2.1 minutes of recovery. Seliger reported that 69 percent of the oxygen consumption was in the recovery period, and the oxygen consumption during the shift averaged 32 ml/kg*min or 66 percent of VO_2 max. During the simulated play, the on-ice heart rates averaged 152 beats per minute. Montgomery (1988) stated that Seliger's protocol to simulate a model game underestimated aerobic intensity based on other methods to estimate aerobic intensity. This could possibly be explained by the fact that the on-ice gas collection apparatus may have restricted the player's movement.

Seliger et al. (1972) stated that ice hockey is characterized by partly submaximal metabolic rate with 31 percent participation of aerobic metabolism and 69 percent participation of anaerobic metabolism. Green et al. (1976) monitored eight varsity ice hockey team members during a game. Telemetered recordings of heart rates revealed rates between 170 and 174 beats per minute over three periods of the game. Green et al. (1976) estimated the on-ice energy requirements to be 70 to 80 percent of VO_2 max, a value substantially higher than previously reported by Seliger (1972). Paterson et al. (1979) also estimated on-ice aerobic involvement. Values in excess of 80 percent of VO_2 max were reported.

Ice hockey, therefore, is a compromise between two extremes; on one hand high intensity effort is involved, and on the other hand the characteristic of endurance is important since the effort must be repeated for upwards of 20 minutes over a typical contest. Thus ice hockey depends on a maximal involvement of the aerobic system for ATP resynthesis while minimizing the glycolytic involvement (Green, 1979).

2.2 Skating Mechanics

The type of skating employed in hockey is power skating; the movement pattern is different than that used in either speed skating or figure skating (Marino & Weese, 1979).

Ice skating, as performed by hockey players, has been characterized as being biphasic with each forward stride consisting of alternate periods of single support and double support (Marino, 1977). Marino and Weese (1979) have further broken down ice skating into three functional phases: glide during single support, propulsion during single support, and propulsion during double support. The glide phase of skating begins during the initial stages of single support and lasts for approximately one half of the single support time. Following this the propulsive phase begins and lasts until the end of the double support period. Marino and Weese (1979) suggested that technique modifications could minimize the duration of the glide phase and maximize propulsion, thereby maintaining a more uniform and possibly higher maximum skating velocity.

Concerning the factors that contribute to elite skating performance, studies have reported varying results. Lariviere (1968) studied the mechanical aspects of the first four strides during a period of acceleration from a standing start. He reported a significant positive correlation between the length of the first stride and velocity after four strides. Marino (1979) studied the mechanical aspects of the starting task of hockey. He concluded that in a starting task, hockey players generate propulsion forces during both phases of the stride but that most of the propulsion occurs during single support, since up to four strides take place during each start and in some cases no double support period exists during the first two or three strides.

In a follow-up study by Marino (1983) the skating start was reported to show a strong pattern associated with a high rate of acceleration that included a high stride rate, significant forward lean at the point of touchdown of the recovery skate, short single support periods, and replacement of the recovery foot below the hip of the recovery leg at the end of the single support period (Montgomery, 1988).

Marino (1977) analyzed skating at different velocities. The following conclusions were drawn: (a) significant increases in skating velocity are accompanied by increases in stride rate and decreases in both single and double support times; (b) stride length does not change significantly as skating velocity changes from low through medium to high levels; (c) as skating velocity increases, both single and double support times decrease but double support time undergoes proportionately greater changes; and (d) skating velocity is more dependent on the number of times a person strides than on the length of each stride. McCaw (1984) added to Marino's findings in that he observed that better performance in hockey players was dependent upon stride rate, shorter duration of double support, and an increased range of motion of the hips and knees due to greater joint flexion.

In contrast to reports on performance of skating in hockey players, literature on stroke mechanics in speed skating (van Ingen Schenau & Bakker, 1980; van Ingen Schenau et al., 1983; van Ingen Schenau et al., 1985; de Boer et al., 1986a) show that among groups of elite skaters, performance is related to (a) a large amount of work per stroke, (b) large gliding time followed by a horizontal (and thus effective) push off, and (c) knee extension velocity.

There are, however, fundamental differences in push-off mechanics between skating the straight segments and skating the curves. de Boer et al. (1987a) performed a study that involved measuring the characteristics of stroke mechanics during speed skating of curves. The subjects were elite and trained male speed skaters. The results indicated that the left stroke showed a more powerful push-off in the curve, caused by a greater push-off angle compared to the right leg. de Boer et al. (1987a) stated that the high speed and power output of the better skaters is a result of a high amount of work per stroke, caused by a short and effective directed push-off. These results strongly support the previous finding that speed skaters of different performance levels can be distinguished by differences in amount of work per stroke and not by differences in stroke frequency (de Boer et al., 1987a).

In a study performed by de Boer et al. (1987b), in-line skating and on-ice skating were compared using eight well trained marathon skaters. Each subject performed four maximal exercise tests: two with in-line skating and two with ice skating. de Boer et al. (1987b) reported that the parameters concerning skating technique demonstrated a great similarity between ice and in-line skating. The differences that were reported include a smaller knee angle in the gliding phase of ice skating, and consequently the push-off trajectory was greater. Knee extension velocity was also greater in ice skating (de Boer et al., 1987b). Results also indicated a shorter bipedal phase which resulted in a shorter contact phase during in-line skating. The placement of the opposite leg occurred later in in-line skating, sometimes after the onset of push-off. In on-ice skating the gliding phase was 50 milliseconds shorter and the push-off phase was 31 milliseconds longer. However, the total stroke time (gliding phase plus push-off phase) during both skating activities were similar.

2.3 Economy of Running

Running economy is defined as the amount of oxygen consumed (VO_2) for a given submaximal running velocity. Being able to measure the VO_2 related to a particular velocity of running provides a useful way of comparing individuals, or any individual with her/himself, under various conditions.

2.3.1 Running Economy and Performance

It has been demonstrated that running economy can account for a substantial proportion of the variation in endurance running performance among individuals with similar VO_2 max values (Bransford & Howley, 1977; Conley & Krahenbuhl, 1980; Krahenbuhl et al., 1989; Morgan et al., 1989a; Morgan et al., 1989b)

The importance of economy in distance running performance was examined by Conley et al. (1981). In this short term longitudinal study, the subject was tested weekly during 18 weeks of training. During this time, the subject's VO_2 max increased from 70.2 to 75.1 ml/kg*min, and his economy at 295 m/min improved from 58.7 to 53.5 ml/kg*min. It was concluded that at the race pace intensity (93 percent of VO_2 max), this individual would have covered an additional 960 meters in a 30-minute run, thus lending credence to the importance of economy in distance running performance. Daniels et al. (1978) performed a long term longitudinal study which involved 20 boys aged 10 to 13 years in a two to five year middle and long distance training program. There were no significant changes in relative VO_2 max reported but the 1- and 2-mile run times were significantly lower. This was accounted for by lower oxygen demands for a given velocity. Similar results were reported by Krahenbuhl et al (1989). Non-run trained boys aged ten years were studied for seven years. Over this time period, there was no significant change in relative VO_2 max, but the nine-minute run distance increased by 29 percent. The improvements in running performance were explained by a 13 percent reduction in submaximal VO_2 expressed relative to distance travelled.

Svendenhag & Sjodin (1985) performed a long term longitudinal study using elite adult male distance runners. Over a period of nearly two years, the runners underwent slow distance, uphill, and interval training. While running at 15 and 20 km/h, significant reductions in aerobic demands were reported. Also 5000 meter run times were significantly reduced. It was concluded that the enhancement of running performance which occurred after VO_2 max plateaued may have been associated with a slow steady improvement in economy.

2.3.2 Intra-Individual Variability

There have been a wide range of reports concerning intra-individual variability of running economy. It is crucial to determine the stability of running economy in order to validate and make use of running economy as a measure of performance. Often reports of large variability in studies have been due to small sample sizes, limited number of test sessions, or lack of control of possible extraneous variables.

Even with control over most of the extraneous variables, differences in the degree of variability between studies have been reported. Morgan et al. (1987) performed a study which involved ten elite male runners who were tested on four 6-minute treadmill tests at 230, 248, 268, and 293 m/min on three separate days. They found that daily variation in running economy ranged from 3 percent to 5 percent of the mean VO_2 at each speed. Also, the largest within subject variation in economy represented 9 percent of the mean VO_2 values. Daniels et al. (1984) also performed tests of ten male runners. They were tested on 15 treadmill tests which consisted of four equally spaced testing periods composed of three or six runs each at 268 m/min during a seven month period. For all tests, footwear, running speed, learning, and test equipment were controlled, yet still they reported an 11 percent variability in individual stability in running economy within a particular test period.

In an attempt to improve upon the earlier study Morgan et al. (1988) did a follow up investigation. This time there was an attempt at controlling for the extraneous variables including circadian variation, training activity, and length of treadmill accommodation along with the variables in the previous study. The subjects were runners with similar fitness and 10 km performance backgrounds. The test involved two 10-minute economy tests at 200 m/min in the same pair of shoes and at the same time of day within a four day period. Intra-individual economy variation was found to be only 1.6 percent which was expressed as a percentage of the initial test value. These results allude to the fact that with a tightly controlled experiment with control for time of day, footwear, treadmill running experience, and training activity, stable economy values can be obtained.

2.3.3 Treadmill versus Overground Running

Most studies indicate that the aerobic demand of overground running exceeds the VO_2 of indoor treadmill running. This is because air and wind resistance are not factors during indoor testing.

Early work done by Pugh (1970) estimated that 8 percent of the total energy cost of middle distance (5000 m) track running would be expended in overcoming air resistance. He was able to conclude that the extra VO_2 associated with treadmill running at 4.42 m/s increased as a function of the square of opposing wind velocity. Other studies (Davies, 1980a) following Pugh's work found the cost of overcoming air resistance during outdoor running was somewhat lower; the total energy cost of overcoming air resistance for middle-distance running was found to be 4 percent and marathon running was 2 percent.

Daniels et al. (1986) studyied six elite male runners running at speeds of 268 m/min (4.47 m/s) and 322 m/min (5.37m/s). They found that the cost of overground running in calm air was 7.1 percent greater than treadmill running. It was also found that when the tailwind velocity was equal to the running velocity, the oxygen cost was the same as treadmill running.

Conflicting reports were, however, stated in an investigation by Basset et al. (1985). They found that there was no significant difference in the mean VO_2 values for level treadmill running versus level overground running, and for graded treadmill running versus graded overground running.

2.3.4 Training

The effects of training on the economy of running and the differences in economy of highly trained athletes have been widely investigated.

The majority of reports indicate that trained subjects are more economical than their untrained or less trained counterparts (Bransford & Howely, 1977; Mayers & Gutin, 1979; Pollock et al., 1980).

Various training modes have been associated with better running economy. Patton and Vogel (1977) used 60 untrained and trained military personnel. They were trained for six months using a program that consisted of long distance running at moderate intensities (2- and 4-mile runs at 8- and 9-minute per mile paces). Running economy significantly improved. Since VO_2 was increased only in the untrained groups, it was suggested that a combination of training, improved mechanical efficiency, and treadmill habituation may have been associated with the observed reduction in submaximal VO_2. Svendenhag and Sjodin (1985) used training programs that consisted of long distance, uphill and interval running over a period of 22 months for 16 elite male distance runners. Significant improvements in running economy were observed. Sjodin et al. (1982) also demonstrated an improvement in the economy of middle and long distance male runners using a regular training program with one weekly 20-minute run performed at the velocity eliciting a 4 mmol/L blood lactate concentration. The authors suggested that alterations in running style and intracellular oxidative capacity may have been responsible for the lower oxygen demand.

It has been speculated that untrained subjects are less economical due to a lack of training, a reduced predisposition for success in distance running, admonished efficiency of mechanical movement or a decreased efficiency of oxidated energy supply (Bransford & Howley, 1977). Few studies, however, have been conducted to confirm or refute these hypotheses.

It has also been demonstrated that long distance and elite marathon runners are more economical than middle distance runners (Daniels, 1985; Pollock, 1977; Pollock et al., 1980). This difference in economy may be due to a lower vertical displacement of the body or to other metabolic and neuromuscular factors linked to slow distance training (Svendenhag & Sjodin, 1984). An alternative, but equally plausible hypothesis is that long distance runners gravitate naturally towards endurance events due to a certain genetic predisposition. This, however, is difficult to prove.

2.3.5 Biomechanical Factors

2.3.5a Body mass

Since running economy is usually expressed relative to body mass (ml/kg*min), body mass should not account for inter-subject variability in economy. Davies & Thompson (1979) reported that lightweight men were no more or less economical than their heavier counterparts. Likewise, Skinner et al. (1973) reported nearly identical economy values during treadmill walking for lean, obese, and weighted lean subjects.

Other studies have, however, given conflicting reports. Davies (1980b) reported that body mass can influence economy even when economy is expressed relative to body mass. Children (11 to 13 years) ran on a treadmill under unloaded and loaded conditions (either 5 or 10 percent of body weight was carried on the trunk). The results indicated that at lower running velocities (9 km/h), the added weight had no effect on economy, but at higher velocities (14 to 16 km/h), the added weight resulted in lower aerobic demand. In a study using elite male runners (Williams & Cavanagh, 1986), higher correlations were reported for running economy with anthropometric variables rather than those describing running mechanics. In particular, the anthropometric measures reflecting linear dimensions of the body (leg length, pelvic width, and foot length) showed the strongest links to VO_2.

Body and segment mass distribution studies have been performed to provide insight into the inter-individual differences in economy. Morgan et al. (1989a) reported that carrying a given load on the distal aspect of the lower extremity increases the aerobic demand of running by approximately 1 percent per 100 g of load, while the rise in VO_2 associated with carrying the same load on the trunk is only 0.1 percent per 100 g of load. A plausible conclusion from this is that a runner whose body mass is concentrated in the extremities (especially in the legs) may perform more work moving body segments (therefore consume more oxygen) versus an individual with a lower proportion of body mass concentrated in the extremities.

2.3.5b Kinematics

Research since 1950 generally supports the concept of a linear relationship between running speed and VO_2 as noted by Daniels (1985). The energy cost of running expressed relative to distance travelled (kcal/kg*km) is essentially constant (Margaria, 1963).

Stride length is one of the few variables that has been shown to effect economy through direct experimental evidence. Studies (Cavanagh & Williams, 1982; Hogberg, 1952; Kaneko et al., 1987; Knuttgen, 1961; Powers et al., 1982) have shown that at a given running speed, the aerobic demand increases curvilinearly as stride length is shortened or lengthened from a self-selected stride length. In general, most athletes select stride lengths which minimize VO_2 demand of locomotion (Cavanagh & Williams, 1982). In this study by Cavanagh & Williams (1982), seven stride length conditions were evaluated at a single running speed (13.8 km/h) for ten well-trained recreational runners. They found that VO_2 was lowest at stride lengths close to the self-selected condition. The increases in VO_2 were nearly identical for similar increases or decreases in stride length from the self-selected value.

2.3.5c Mechanical Power

An alternative approach was taken to determine the inter-individual differences in economy that involved a more complete and comprehensive outlook than focusing on the discrete instances or events of the gait pattern. This approach looked at the mechanical power or work that is derived from muscle contraction. It was thought that it might better integrate the weighted influences of numerous biomechanical inputs and demonstrate a stronger relationship with economy (Morgan et al., 1989b).

Many studies have reported that as the speed of locomotion increases, the mechanical work done per step and the average mechanical power increases (Burdett et al., 1983; Heglund et al., 1982; Shorten et al., 1981; Taylor, 1986). The validity of this approach as a means of determining whether inter-individual differences in economy are related to variations in mechanical power is questionable, since changes in VO_2 and mechanical power are related to speed (Morgan et al., 1989b). However, Williams & Cavanagh (1987) reported that with control of speed, one of three significant predictors of economy was net positive power. They also noted that the least economical runners showed significantly less mechanical energy transfer between the legs and the trunk than their more economical counterparts.

2.4 Energetics of Skating

Ice skating is a highly skilled activity that takes many years to develop to a high level of skill. The experimental data concerning the energetics of skating are limited.

Ferguson et al. (1969) performed a study using 17 varsity hockey players. The players skated around a 140m oval course for three minute intervals with five minutes of rest between each interval. The velocities were 350, 382, 401, 421, and 443 m/min which corresponded to lap times of 24, 22, 21, 20 and 19 s/lap respectively. Expired gas was collected during the third minute of skating at each workload. The results indicated a mean maximal oxygen uptake of 54.8 ml/kg*min with a range from 44.9 to 68.5 ml/kg*min. A linear relationship between VO_2 and submaximal skating velocity was reported. However, the VO_2 for a given submaximal velocity varied considerably among subjects. At a velocity of 382 m/min the mean VO_2 was 46.7 ml/kg*min with a range from 40.1 to 54.7 (+ or - 15 percent). The inter-individual variability in VO_2 of 15 percent is considerably larger than the 5 to 7 percent difference between trained and untrained runners reported by Margaria et al. (1963a). Considerable differences must have existed in the skill of skating, therefore suggesting that some players were more economical than others.

Efficiency of skating has been shown to influence the energy requirements at a given velocity of skating. It is measured using the following equation:

$$\text{Efficiency} = \frac{\text{Velocity(m/min)}}{VO_2\ \text{(ml/kg*min)}} * 100$$

Green (1979) found a substantial inter-individual difference in skating efficiency using elite hockey players as subjects. Three individuals were tested. The skater with the lowest VO_2 max expended the least energy in skating at velocities of 350, 382, and 401 m/min. Green concluded that the ability to maintain skating intensity at the high velocities was far superior to the other two subjects, in spite of their superiority in VO_2 max.

Results from Leger et al. (1979) agree with the above mentioned study. Leger reported that the coefficients of variation of maximal skating speeds that were reached by ten high level hockey players indicated a relatively homogeneous group of subjects. However, a large coefficient of variation for skating VO_2 max indicated a much wider distribution of the subjects around the mean. It was concluded that this was due to a wide range in mechanical efficiency of skating. Thus a functional skating capacity test or a performance test appears more informative than the VO_2 max score to establish the ability of the player to perform aerobic skating (Leger et al., 1979).

When comparing efficiency of skating between hockey players and speed skaters, the VO_2 of hockey skaters (Ferguson et al., 1969) and speed skaters (Ekblom et al., 1967), skating at a velocity of 350 m/min, were calculated to be 40 and 34 ml/kg*min respectively. Ferguson et al. (1969) found the cost of increasing the skating velocity to be approximately 1 kcal/kg*km whereas Ekblom et al. (1967) reported a cost of 0.06 ml/kg*m (equivalent to approximately 0.3 kcal/kg*m) for speed skating. Therefore, the rate of increase of VO_2 with skating velocity was approximately three times as great for the hockey players (Ferguson, 1969). This difference between hockey players and speed skaters suggests that speed skaters are more efficient.

Hockey players have also been compared to runners. Leger et al. (1979) concluded that hockey players, as compared to runners, required 15 percent less energy to skate at the same speed but also needed 7 percent more energy to run on the treadmill, thus proving hockey players to be more mechanically efficient on-ice and less efficient on a treadmill than runners.

2.4.1. Energetics of In-Line Skating

There are only a few studies that have examined the physiological demands of in-line skating. Snyder et al. (1993) examined the relationships among oxygen uptake and heart rate, ventilation, respiratory exchange ratio, and blood lactate for in-line skating compared to running and cycling (n = 7). The subjects performed three to five individualized submaximal exercise bouts for each test condition. The authors reported that across the spectrum of VO_2's studied, HR was higher with in-line skating than cycling or running, and at a 4 mM lactate concentration, VO_2 for in-line skating was lower than for running and the same for cycling. They concluded that while in-line skating may be an effective mode of aerobic exercise, the training adaptations for in-line skating at 4 mM lactate may be less than for running, and at a given HR may be less than for running or cycling.

Martinez et al. (1993) conducted a similar study by comparing the physiological response of roller skating, treadmill running, and ergometer cycling. Each subject (n = 9) participated in three maximal exercise tests. The authors reported no differences in HR during submaximal workloads between the three test conditions, however, HR values which elicited 4 mmol/l lactate were significantly higher for running than for cycling and roller skating. No differences were observed in blood lactate responses between cycling and roller skating. It was concluded that the heart rate-blood lactate relationships during submaximal and maximal exercise were similar in cycling and roller skating.

Three different in-line skating techniques were examined by Hoffman et al. (1992). The physiological responses of the commonly used in-line skating technique, and two cross-country ski skating techniques (double poling and V1 skating) were compared. Ten male cross-country skiers skated three continuous velocities (14.6, 16.4, and 18.0 km/h) for a duration of four minutes for each skating technique on a rubberized track. Their findings indicated that at these velocities the VO_2 requirements were similar for the V1 and conventional skating techniques. The double pole technique produced a lower VO_2 for all three velocities. The double pole technique was concluded to be the most economical of the three in-line skating techniques.

The metabolic cost of in-line skating was compared to on-ice skating in a study by Carroll et al. (1993). Twelve Division I collegiate ice hockey players skated at velocities of 12.5, 16.5, and 20 km/h on ice and on concrete. In-line skating produced significantly greater relative VO_2 values than ice skating for 16.5, and 20 km/h, and produced significantly greater HR values for all three velocities. The authors concluded that in terms of cardiovascular training and leg strength development, in-line skating appears to be a beneficial training method for collegiate ice hockey players.

Chapter 3

Methods

3.1 Treatment of Subjects

Ten male varsity hockey players from the McGill University team served as volunteers for this study. The age of the subjects ranged from 18 to 23.

Prior to the testing session, each subject was informed of the procedure of each test and of the possible risks that were involved. Each subject was asked to sign an individual informed consent document (Appendix A) attesting to an understanding of the expectations and a willingness to participate.

Each subject participated in four test sessions. The first test session was in the laboratory, the second was on-ice, the third was performed outdoors using in-line skates on asphalt, and the fourth was performed in an arena using in-line skates on a smooth concrete surface. The laboratory and on-ice tests were performed during the hockey season and were approximately three weeks apart. The two in-line skating tests were performed approximately one month post-season.

The subjects were informed not to ingest any food or drink (with the exception of water) for two hours prior to the testing times. A five minute warm-up consisting of stretching and light skating/jogging preceded each test session. During the skating test the subjects carried a stick and wore hockey gloves and warm-up suits. The testing sessions are presented in Table 1.

Table 1 Testing Sessions Performed By Each Subject

1. Treadmill VO_2 max test - Laboratory
2. Submaximal skating test - Skating on-ice
3. Submaximal skating test - In-line skating on concrete using two types of bearings
4. Submaximal skating test - In-line skating on asphalt using two types of bearings

3.2 VO_2 max Test

Prior to the VO_2 max test, physical characteristics including height, weight, and age were recorded. The VO_2 max test was performed in the laboratory using a treadmill, and the oxygen consumption was measured using a Roxon Metabolic Cart.

The protocol was characterized by a gradual increase in speed then inclination using two minute intervals until volitional exhaustion. Peak VO_2 was established as the highest minute value attained for VO_2 during the maximal exercise. Prior to the start of the test, subjects were fitted with a Polar Electro 3000 Sport Tester in order to measure maximal heart rate. After a five minute warm-up, the subjects began running at a speed of 4 mph and 0 degrees of inclination. After two minutes, the speed was increased to 6 mph then to 8 mph with no increase in inclination. For the remaining two minute intervals, the speed remained constant but the inclination increased by 2 degrees. Maximal oxygen uptakes were reached between minutes 12 and 16. The protocol is listed in Table 2.

Verbal encouragement was offered by the investigators throughout the test.

Table 2 VO_2 max Test Protocol

Time (min)	Speed (m/min)	Inclination (degrees)
0 - 2	4	0
2 - 4	6	0
4 - 6	8	0
6 - 8	8	2
8 -10	8	4
10 -12	8	6
12 -14	8	8
14 -16	8	10

3.3 Submaximal Skating Tests

The submaximal skating tests were performed under three different conditions; on-ice, on concrete, and on asphalt. For the in-line skating tests, subjects were assigned one of two wheel types with varying durometers. Each subject performed the test twice for each surface using a different type of bearing each time.

3.3.1 On-Ice Skating Test

An oval course of 140 m in length was set up on the ice. Ten cones were placed around the course at distances of 14 m apart. Subjects skated at velocities of 336, 357, 381, 409, and 442 m/min which corresponded to lap times of 25, 23.5, 22, 20.5 and 19 s/lap, respectively. The velocities were monitored using an audio system. Skating velocities were maintained by following a taped audio signal which sounded five times per lap. The subjects were required to skate at a velocity that would synchronize the audio signals with every second cone. Subjects were expected to be within one meter of the cone. If the subject was not, one warning was issued. If the subject was still behind the pace at the next audio signal, the test was terminated with gas collection at this time.

At the commencement of the test, a blood sample was drawn in order to determine resting lactate levels. The player was then prepared for the skating test (heart rate monitor, respiratory valve with mouth piece, nose clip, and Douglas bag). After a five minute warm-up, instructions for test procedures were reviewed. The audiotape was started. The subject skated around the course until the required velocity was achieved. This took between one and two laps of the course. Each velocity was skated for a duration of four minutes. At this time, the subject was signalled to turn the respiratory valve which directed the expired air into the Douglas bag. During gas collection, the subject maintained the skating velocity. After 30 seconds of gas collection, the subject was again signalled to turn the respiratory valve. The subject then rested for five minutes in the dressing room. After two minutes, fingertip blood samples were drawn for velocities 1 and 3. The subject was then prepared for the next skating velocity.

For the higher velocities, the subjects were instructed to signal the researchers if they were fatigued and no longer able to maintain the pace. At that point, the respiratory valve was opened for the thirty second collection of expired air.

The heart rate was monitored throughout the test with a Polar Electronics Sport Tester (model PE 3000). An average value for each minute was recorded.

3.3.2 In-Line Skating Tests

Two surfaces were used for the in-line skating test sessions; polished concrete and asphalt. The testing was performed on a car racing circuit for the asphalt surface and on an indoor skating rink (with the ice removed) for the concrete surface. Five subjects were assigned wheel type A (78 Shore A durometer), and five subjects were assigned wheel type B (82 Shore A durometer) for the in-line skating tests. The subjects performed the protocol twice on each surface using two types of bearings (NMB singapore precision and semi-precision). The subjects skated at velocities of 336, 357, and 381 m/min. The velocities were controlled via an audio system using cones set at distances of 14 m around the 400 m oval courses on asphalt and 14 m apart around the 140 m oval course on concrete.

The protocols were carried out in the same manner as the on-ice test session with the exception that blood samples were taken at rest and after each velocity. The blood samples were again taken at two minutes following each skating velocity. Data were collected using the same method as the on-ice testing using a respiratory valve with mouthpiece, Douglas bag, and a heart rate monitor.

3.4 Collection of Data

3.4.1 VO_2

In order to measure the oxygen consumption during the skating test sessions, an open circuit gas collection apparatus was used. It consisted of a respiratory valve connected to a 100 litre Douglas bag. While the subject was skating, expired air was returned to the atmosphere until the valve was opened. At that point, the expired air was directed into the Douglas bag until the valve was closed. Depending upon skating velocity, the gas collection period was either a 30 or 60 second sample.

The respiratory valve was secured in place with attachments to an adjustable headpiece. The subjects, while wearing a nose clip, breathed into the respiratory valve via a rubber mouthpiece. Depending on the position of the 3-way valve, the subjects either expired directly to the atmosphere or directly into the Douglas bag. The bag was secured to the back of the subject via velcro straps attached to the bag and to a belt worn around the subject's waist. This design held the bag behind the subject's back thereby reducing wind resistance and did not restrict gas collection.

During the VO_2 max test and following the submaximal skating tests, the expired air was analyzed using a Roxon Metabolic Cart. Volume was analyzed using a Morgan ventilometer. Oxygen and carbon dioxide concentrations were determined with Applied Electrochemisty analyzers. The gas analyzers were calibrated before each test with standard gases. Measurements of expired air were analyzed every 30 seconds and were displayed on-line with an Apple IIe computer and an Okidata micro-82A printer. This computerized system calculated VE, VO_2, VCO_2, and RQ.

For all submaximal skating tests, the expired air was collected in Douglas Bags which were kept at room temperature for ten minutes prior to gas analysis. The gas volume was measured with a Parkinson-Cowan Gasometer and then directed into the Roxon Metabolic Cart for analysis. Prior to testing, the Gasometer was calibrated using a Tissot tank.

3.4.2 Heart Rate

The heart rates were monitored continuously using a Polar Electro Sport Tester (model PE 3000). The device consists of a receiving unit which is worn on the wrist, and a telemetry transmission unit which straps around the chest. Heart rates were stored in the memory of the receiving unit. Following each test, the values were recorded in beats/minute. For the VO_2 max test, the peak value was recorded. For the submaximal skating tests, the heart rate was recorded during the final minute at each skating velocity.

3.4.3 Lactate

The blood samples were taken while the subjects were seated. The samples were obtained from a peripheral finger using an Ames Glucolet with Monolet sterile lancets. Blood sample sizes of 50-100 ul were collected in heparinized capillary tubes. No storage or erythrocyte lysing agents were used. Whole blood was injected with a 25 ul syringepet into a YSI (Yellow Springs Instrument) Model 27 lactate analyzer. The apparatus employed an enzyme electrode method for lactate analysis (Clark et al., 1984). The instrument was calibrated prior to each testing session using 5.0 mmol and 15.0 mmol standards. Duplicate analyses were made from each blood sample.

3.4.4 Stride Rate and Stride Length

During the submaximal skating tests, kinematic data were collected on-ice at velocities of 336, 357, 381, 409 and 442 m/min and on concrete and asphalt at 336, 357, and 381 m/min. At each skating velocity, stride rate was measured on three occasions. The number of skating strides were counted for one lap of the course and converted into number of strides/min. Stride length was calculated as:

Stride length = Velocity (m/min)/Stride Rate (#/min)

3.5 Rolling Resistance of In-Line Skates

The rolling resistance was determined for the asphalt and concrete using both wheel types and both bearing types. Resistance was measured using a cart with four wheels positioned in a rectangular formation. The cart weighed 7.25 kg and had 31.8 kg mounted on it.

Lines were marked on the surface to indicate 0 m, 3 m, 9 m and 12 m. With the cart positioned behind the 0 m mark, it was given an initial velocity. The cart travelled past each line at which point the time was taken using the 0 m mark as the starting time. This was repeated nine times for each wheel and bearing type. From the times and distances for each trial, an initial velocity and a final velocity was calculated using the formula:

Velocity (m/s) = Distance (m)/ Time (s).

Knowing the time between the initial and final velocity, the deceleration was calculated using the formula:

Deceleration (m/s^2)= (Final Velocity - Initial Velocity)/Time

From this number a final calculation using the following formula was used to determine the rolling resistance:

Rolling Resistance (N)= Mass (kg) * Deceleration (m/s^2)

This was performed on asphalt and concrete.

3.6 Experimental Design and Statistical Analysis

Means and standard deviations were calculated for age, height, weight, VO_2 max, and heart rate.

Hypotheses 1 and 2 examined the effects that different wheel types and bearing types have on the physiological response (VO_2 and HR) of in-line skating. A 2 X 2 X 2 X 3 repeated measures factorial design (wheel by surface by bearing by velocity) with subjects nested within wheel type was employed for hypothesis 1 and hypothesis 2. A MANOVA was used for statistical analysis. The experimentsl design for hypotheses 1 and 2 are presented in Table 3.

The effects of skating at varying velocities with different conditions (surface, bearing) on the physiological responses of the body (VO_2 and HR) were examined in hypotheses 3 and 4. Five different conditions were tested:

skating on asphalt with type A bearings,
skating on asphalt with type B bearings,
skating on concrete with type A bearings,
skating on concrete with type B bearings,
skating on ice.

For the analyses, a 5 X 3 repeated measures factorial design (condition by velocity) using MANOVA was employed. A diagram of the design is presented in Table 4.

Table 3 Experimental Design for Hypotheses 1 and 2

Surface		A						B					
Bearing		A			B			A			B		
Velocity		1	2	3	1	2	3	1	2	3	1	2	3
Subjects	Wheel												
1	A												
2													
3													
4													
5													
6	B												
7													
8													
9													
10													

Dependent Variables - VO_2 and HR

Table 4 Experimental Design for Hypotheses 3 and 4

Condition	1			2			3			4			5		
Velocity	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Subjects															
1															
2															
3															
.															
.															
10															

Dependent Variables - VO_2 and HR

For the fifth hypothesis, the effect of rolling resistance on bearing type, wheel type, and surface type was examined. A 2 X 2 X 2 factorial design was employed. An ANOVA program was used for statistical analysis. The experimental design is presented in Table 5.

For all comparisons, an apriori probability level of .05 was administered. The statistical procedures for the five hypotheses are summarized in Table 6.

Table 5 Experimental Design for Hypothesis 5

Surface	A				B			
Wheel	A		B		A		B	
Bearing	A	B	A	B	A	B	A	B
Trial								
1								
2								
.								
.								
.								
9								

Dependent Variables - Rolling Resistance (N).

Table 6 Summary of Hypotheses and Statistical Analyses.

Comparison	Statistical Analysis
<u>Hypothesis 1</u> - Effect of wheel type on the physiological response of skating	MANOVA (2 X 2 X 2 X 3 factorial design with subjects nested within wheel type)
<u>Hypothesis 2</u> - Effect of bearing type on the physiological response of skating	MANOVA (2 X 2 X 2 X 3 factorial design with subjects nested within wheel type)
<u>Hypothesis 3</u> - Effect of conditions and velocities on the physiological response of skating	MANOVA (5 X 3 repeated measures factorial design)
<u>Hypothesis 4</u> - Effect of the interaction of conditions and velocity on the physiological response of skating	MANOVA (5 X 3 repeated measures factorial design)
<u>Hypothesis 5</u> - Effect of bearings, wheels, and surfaces on rolling resistance	ANOVA (2 X 2 X 2 factorial design)

Chapter 4

Results

The purpose of this study was to investigate the physiological responses obtained during in-line submaximal skating tests on two surfaces using two wheel types and two bearing types, and to compare these results to the physiological response obtained during an on-ice submaximal skating test. The dependent variables were oxygen uptake (VO_2) and heart rate (HR).

It was hypothesized that a significant difference would not be found between wheel types, but would be found between bearing type. In addition, it was hypothesized that there would be a significant difference between the five experimental conditions, and there would be a significant condition by velocity interaction for the physiological variables (VO_2 and HR). Finally, with rolling resistance as a measure, it was hypothesized that a significant difference would be found between bearing, surface, and wheel type.

4.1 Descriptive Data

The subjects in this study included 10 male varsity hockey players. Means and standard deviations (S.D.) for age, height, weight, and sum of five skinfolds are presented in Table 7.

Table 7 Physical characteristics of the subjects

Subject	Age (yrs)	Height (cm)	Weight (kg)	Sum of five skinfolds (mm)
1	21	175.0	75	38.7
2	23	194.0	97	48.9
3	20	178.0	83	47.8
4	18	180.0	78	40.1
5	22	185.0	81	41.2
6	21	178.0	80	31.1
7	22	180.0	87	53.0
8	20	170.0	70	27.0
9	20	189.0	93	40.7
10	22	175.0	83	48.2
Mean	20.9	180.4	82.7	41.7
S.D.	1.4	6.7	9.2	7.7

4.2 VO_2 max Treadmill Test

Results of the treadmill VO_2 max test are presented in Table 8. The mean VO_2 and HR were 59.5 (ml/kg*min) and 192 (bpm), respectively.

Table 8 Treadmill VO_2 max Test

Subject	VO_2 max (l/min)	VO_2 max (ml/kg*min)	HR max (bpm)	VE max (l/min)	Time (min)
1	5.02	66.9	193	147.7	15.0
2	5.60	57.9	185	145.6	12.5
3	4.84	58.3	205	146.9	14.0
4	4.44	56.9	200	134.8	14.0
5	4.71	57.4	186	139.9	12.5
6	4.14	51.8	191	118.8	13.0
7	5.05	60.4	186	134.7	13.0
8	4.93	70.3	190	137.8	17.0
9	5.34	57.4	191	166.0	12.5
10	4.81	58.0	192	143.2	13.0
Mean	4.89	59.5	192	141.5	13.7
S.D.	0.42	5.3	6	12.1	1.4

4.3 Submaximal Skating Tests

The results of the submaximal skating tests are presented in Tables 9 through 29.

Tables 9 through 23 list the results separately for each variable measured on asphalt, concrete, and ice. The variables measured for each surface were VO_2 (ml/kg*min), HR (bpm), stride length (m/stride), stride rate (stride/min), and lactate (mmol/l). Each submaximal skating test was performed at three velocities (336, 357, and 381 m/min). For the in-line skating tests on asphalt and concrete, each subject was assigned one of two wheel durometers (wheel 1 = 78 Shore A and wheel 2 = 82 Shore A), and skated on each surface twice, with semi-precision bearings and precision bearings. Means and S.D. are presented in each table.

Table 9 VO_2 (ml/kg*min) for Submaximal Skating Test on Asphalt

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1 Subject						
1	45.1	56.1	65.3	33.4	51.2	56.3
2	42.5	41.3	55.9	36.6	50.4	59.0
3	39.2	45.9	52.4	37.1	43.6	58.0
4	36.1	48.6	57.1	44.7	47.9	50.5
5	44.6	53.1	59.2	48.7	55.5	61.9
Mean	41.5	49.0	58.0	40.1	49.7	57.1
S.D.	3.8	5.8	4.8	6.3	4.4	4.2
WHEEL 2 Subject						
6	29.1	52.7	53.5	45.7	52.7	66.9
7	45.8	52.1	56.0	44.1	49.7	58.8
8	42.2	50.4	57.0	42.4	50.8	69.6
9	33.7	43.8	59.8	47.7	48.0	52.0
10	53.1	55.2	57.7	50.1	56.3	58.1
Mean	40.8	50.8	56.8	46.0	51.5	61.1
S.D.	9.6	4.3	2.3	3.0	3.2	7.1

Table 10 VO_2 (ml/kg*min) for Submaximal Skating Test on Concrete

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1 Subject						
1	35.3	41.1	57.8	38.4	48.0	55.4
2	39.2	47.0	47.4	40.1	45.3	49.9
3	38.9	44.9	55.5	36.4	50.4	58.3
4	46.5	51.4	60.7	47.0	52.1	61.7
5	41.6	44.1	58.7	43.3	51.2	55.2
Mean	40.3	45.7	56.0	41.0	49.4	56.1
S.D.	4.1	3.8	5.2	4.2	2.8	4.4
WHEEL 2 Subject						
6	54.3	54.3	60.0	54.4	54.4	61.9
7	46.0	56.5	54.6	49.9	52.2	55.1
8	42.1	48.8	58.0	47.6	51.9	54.6
9	40.8	44.8	53.3	47.6	51.5	52.2
10	48.4	53.0	55.9	56.4	55.9	56.9
Mean	46.3	51.5	56.4	51.2	53.2	56.1
S.D.	5.4	4.7	2.7	4.0	1.9	3.6

Table 11 VO$_2$ (ml/kg*min) for Submaximal Skating Test on Ice

Velocity (m/min)	336	357	381
Subject			
1	40.8	52.0	56.2
2	37.1	41.5	48.4
3	36.1	40.2	54.7
4	45.6	51.1	56.0
5	37.4	43.7	47.8
6	32.5	41.1	54.6
7	38.5	44.5	58.4
8	40.9	41.9	52.6
9	38.9	44.9	49.1
10	36.9	43.2	52.2
Mean	38.5	44.4	53.0
S.D.	3.5	4.1	3.6

Table 12 HR (bpm) for Submaximal Skating Test on Asphalt

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1						
Subject						
1	156	175	182	156	166	181
2	175	186	192	181	184	193
3	187	191	196	186	191	199
4	185	184	187	187	189	186
5	174	184	185	177	186	188
Mean	175	184	188	177	183	189
S.D.	12	6	6	13	10	7
WHEEL 2						
Subject						
6	153	170	187	159	169	179
7	186	185	186	180	186	187
8	173	185	188	180	190	192
9	172	176	189	176	185	188
10	179	188	189	180	195	199
Mean	173	181	188	175	185	189
S.D.	12	8	1	9	10	7

Table 13 HR (bpm) for Submaximal Skating Test on Concrete

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1						
Subject						
1	152	159	171	149	163	174
2	174	180	193	174	188	195
3	184	184	197	172	184	188
4	168	181	182	175	182	186
5	157	169	182	156	170	179
Mean	167	175	185	165	177	184
S.D.	13	10	10	12	11	8
WHEEL 2						
Subject						
6	181	187	193	179	189	187
7	174	184	185	177	188	184
8	175	180	191	168	180	191
9	166	174	185	169	177	181
10	174	188	191	173	189	192
Mean	174	183	189	173	184	187
S.D.	5	6	4	5	5	5

Table 14 HR (bpm) for Submaximal Skating Test on Ice

Velocity (m/min)	336	357	381
Subject			
1	145	161	174
2	169	181	187
3	162	174	183
4	174	185	189
5	155	168	177
6	160	173	181
7	161	171	184
8	160	165	172
9	162	168	179
10	159	170	179
Mean	161	172	181
S.D.	8	7	5

Table 15 Stride Length (m/stride) for Submaximal Skating Test on Asphalt

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1						
Subject						
1	4.3	4.4	4.3	4.1	4.2	4.2
2	5.0	5.0	4.4	5.1	5.7	4.8
3	4.4	4.5	4.1	3.9	4.3	4.0
4	3.7	3.5	3.5	3.6	3.5	3.5
5	3.9	3.8	3.7	3.4	3.7	3.6
Mean	4.3	4.2	4.0	4.0	4.3	4.0
S.D.	0.5	0.6	0.4	0.7	0.9	0.5
WHEEL 2						
Subject						
6	4.6	4.0	4.1	4.0	3.9	4.0
7	5.2	4.6	4.1	5.0	4.5	4.4
8	3.7	3.5	3.7	3.7	3.6	3.6
9	4.0	4.1	4.1	4.0	3.9	3.9
10	4.2	3.6	3.5	3.8	3.7	4.0
Mean	4.3	4.0	3.9	4.1	3.9	4.0
S.D.	0.6	0.4	0.3	0.5	0.4	0.3

Table 16 Stride length (m/stride) for Submaximal Skating Test on Concrete

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1						
Subject						
1	4.1	4.2	4.2	4.0	4.2	4.0
2	4.9	4.7	4.7	4.6	4.4	4.4
3	4.5	4.3	4.1	4.2	4.0	3.8
4	3.7	3.4	3.6	3.8	3.4	3.3
5	3.9	3.5	3.8	3.5	3.5	3.5
Mean	4.2	4.0	4.1	4.0	3.9	3.8
S.D.	0.5	0.6	0.4	0.4	0.4	0.4
WHEEL 2						
Subject						
6	4.8	4.9	4.9	4.4	4.2	4.1
7	4.6	5.3	4.9	4.6	4.9	4.8
8	3.6	3.2	3.5	3.8	3.9	3.8
9	4.9	5.1	4.9	4.7	5.2	4.7
10	4.1	4.9	4.9	5.0	5.2	4.6
Mean	4.4	4.7	4.6	4.5	4.7	4.4
S.D.	0.5	0.8	0.6	0.4	0.6	0.4

Table 17 Stride Length (m/stride) for Submaximal Skating Test on Ice

Velocity (m/min)	336	357	381
Subject			
1	4.1	4.1	3.9
2	4.7	4.4	4.1
3	3.9	4.1	4.1
4	3.7	3.7	3.5
5	4.0	3.9	3.7
6	3.9	4.7	3.9
7	4.7	4.7	4.7
8	4.1	3.7	3.5
9	4.2	3.5	3.5
10	4.1	4.0	3.8
Mean	4.1	4.1	3.9
S.D.	0.3	0.4	0.4

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Table 18 Stride Rate (stride/min) for Submaximal Skating Test on Asphalt

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1						
Subject						
1	78	81	89	82	85	91
2	67	71	87	66	63	79
3	76	79	93	86	83	95
4	91	102	109	93	102	109
5	86	94	103	99	97	106
Mean	75	85	96	85	86	96
S.D.	9	12	10	13	15	12
WHEEL 2						
Subject						
6	73	89	93	84	92	95
7	65	78	93	67	79	87
8	91	102	103	91	99	106
9	84	87	93	84	92	97
10	80	99	109	88	97	95
Mean	79	91	98	83	92	96
S.D.	10	10	7	9	8	7

Table 19 Stride Rate (stride/min) for Submaximal Skating Test on Concrete

Bearing	Precision			Semi-Precision		
Velocity (m/min)	336	357	381	336	357	381
WHEEL 1						
Subject						
1	82	85	91	84	85	95
2	69	76	81	73	81	87
3	75	83	93	80	89	100
4	91	105	106	88	105	116
5	86	102	100	96	102	109
Mean	81	90	94	84	92	101
S.D.	9	13	10	9	11	11
WHEEL 2						
Subject						
6	70	73	78	76	85	93
7	73	67	78	73	73	79
8	93	112	109	89	92	100
9	69	70	78	71	69	81
10	82	73	78	67	69	83
Mean	77	79	84	75	78	87
S.D.	10	19	14	8	10	9

Table 20 Stride Rate (stride/min) for Submaximal Skating Test on Ice

Velocity (m/min)	336	357	381
Subject			
1	82	87	98
2	72	82	93
3	86	87	93
4	91	97	109
5	84	92	103
6	86	77	98
7	72	77	82
8	82	97	109
9	79	102	109
10	82	89	99
Mean	82	89	99
S.D.	6	9	9

Table 21 Lactate (mmol/l) for Submaximal Skating Test on Asphalt

Bearing		Precision			Semi-Precision		
Velocity (m/min)	Resting	336	357	381	336	357	381
WHEEL 1 Subject							
1	1.2	-	-	-	-	-	-
2	1.8	-	3.7	4.2	2.9	3.8	-
3	1.6	-	-	-	-	-	-
4	4.9	-	-	-	6.9	4.9	5.6
5	1.8	3.9	5.4	7.8	3.8	5.8	8.0
Mean	2.3	3.9	4.6	6.0	4.5	4.8	6.8
S.D.	1.5	-	1.2	2.5	2.1	1.0	1.7
WHEEL 2 Subject							
6	3.0	4.3	5.4	7.8	6.4	6.5	10.8
7	1.8	5.8	4.3	-	4.3	6.2	8.3
8	1.3	3.7	-	-	2.4	3.5	6.9
9	2.3	3.9	3.9	6.2	4.1	-	-
10	-	-	-	-	-	-	-
Mean	2.1	4.4	4.5	7.0	4.3	5.4	8.7
S.D.	0.7	1.0	0.8	1.1	1.6	1.7	2.0

Table 22 Lactate (mmol/l) for Submaximal Skating Test on Concrete

Bearing		Precision			Semi-Precision		
Velocity (m/min)	Resting	336	357	381	336	357	381
WHEEL 1 Subject							
1	1.2	2.0	2.9	7.0	1.6	4.2	-
2	1.8	-	3.2	6.5	4.2	3.6	7.1
3	1.6	3.3	4.4	7.4	2.6	4.6	6.2
4	4.9	5.2	5.7	6.6	5.3	5.9	7.2
5	1.8	2.5	2.3	4.7	3.8	3.2	4.9
Mean	2.3	3.3	3.7	6.4	3.5	4.3	6.4
S.D.	1.5	1.4	1.4	1.0	1.4	1.0	1.1
WHEEL 2 Subject							
6	3.0	5.5	6.6	11.4	6.0	7.4	8.9
7	1.8	3.3	4.2	8.0	5.2	6.5	12.3
8	1.3	4.0	4.4	5.8	4.3	4.4	6.7
9	2.3	3.9	3.0	6.0	4.1	4.5	5.1
10	-	-	-	-	-	-	-
Mean	2.1	4.2	4.6	7.8	4.9	5.7	8.3
S.D.	0.7	0.9	1.5	2.6	0.9	1.5	3.1

Table 23 Lactate (mmol/l) for Submaximal Skating Test on Ice

Velocity (m/min)	Resting	336	381
Subject			
1	1.2	2.0	4.8
2	1.8	2.0	3.2
3	1.6	2.1	4.2
4	4.9	4.3	6.2
5	1.8	1.8	3.3
6	3.0	1.2	4.5
7	1.8	2.2	4.7
8	1.3	2.4	5.1
9	2.3	2.4	3.9
10	-	-	-
Mean	2.2	2.3	4.4
S.D.	1.2	0.8	0.9

To examine hypotheses 3 and 4, the HR and VO_2 data from the submaximal skating tests were grouped into five separate conditions based upon surface and bearing type:

- condition 1 = asphalt and precision bearing
- condition 2 = asphalt and semi-precision bearing
- condition 3 = concrete and precision bearing
- condition 4 = concrete and semi-precision bearing
- condition 5 = ice

The data are presented in Tables 24 through 29 according to the skating velocity and the variable. With VO_2 (ml/kg*min) as a marker, the means for conditions 1 through 5 at 336 m/min were 41.2, 43.1, 43.3, 46.1, and 38.5 (ml/kg*min), respectively. At 357 m/min, the means were 49.9, 50.6, 48.6, 51.3, and 44.4 (ml/kg*min), respectively. For the final velocity (381 m/min), the mean VO_2 were 57.4, 59.1, 56.2, 56.1, 53.0 (ml/kg*min) respectively. With HR as the physiological marker, the means for conditions 1 through 5 at 336 m/min were 174, 176, 170, 169, and 160 (bpm). At 357 m/min the means were 182, 184, 178, 181, 172 (bpm) respectively. The means for the highest velocity (381 m/min) were 188, 189, 187, 186, and 181 (bpm). Means of the experimental conditions for VO_2 and HR are presented in Figures 1 and 2.

Table 24 VO_2 (ml/kg*min) for Five Submaximal Skating Conditions at a Velocity of 336 m/min

Condition	1	2	3	4	5
Subject					
1	45.1	56.1	35.3	38.4	40.8
2	42.5	41.3	39.2	40.1	37.1
3	39.2	45.9	38.9	36.4	36.1
4	36.1	48.6	46.5	47.0	45.6
5	44.6	53.1	41.6	43.3	37.4
6	29.1	52.7	54.3	54.4	32.5
7	45.8	52.1	46.0	49.9	38.5
8	42.2	50.4	42.1	47.6	40.9
9	33.7	43.8	40.8	47.6	38.9
10	53.1	55.2	48.4	56.4	36.9
Mean	41.2	43.1	43.3	46.1	38.5
S.D.	6.9	5.6	5.5	6.6	3.5

Table 25 VO_2 (ml/kg*min) for Five Submaximal Skating Conditions at a Velocity of 357 m/min

Condition	1	2	3	4	5
Subject					
1	56.1	51.2	41.1	48.0	52.0
2	41.3	50.4	47.0	45.3	41.5
3	45.9	43.6	44.9	50.4	40.2
4	48.6	47.9	51.4	52.1	51.1
5	53.1	55.5	44.1	51.2	43.7
6	52.7	52.7	54.3	54.4	41.1
7	52.1	49.7	56.5	52.2	44.5
8	50.4	50.8	48.0	51.9	41.9
9	43.8	48.0	44.8	51.5	44.9
10	55.2	56.3	53.0	55.9	43.2
Mean	49.9	50.6	48.6	51.3	44.4
S.D.	4.9	3.7	5.0	3.0	4.1

Table 26 VO_2 (ml/kg*min) for Five Submaximal Skating Conditions at a Velocity of 381 m/min

Condition	1	2	3	4	5
Subject					
1	65.3	56.3	57.8	55.4	56.2
2	55.9	59.0	47.4	49.9	48.4
3	52.4	58.0	55.5	58.3	54.7
4	57.1	50.5	60.7	61.7	56.0
5	59.2	61.9	58.7	55.2	47.8
6	53.5	66.9	60.0	61.9	54.6
7	56.0	58.8	54.6	55.1	58.4
8	57.0	69.6	58.0	54.6	52.6
9	59.8	52.0	53.3	52.2	49.1
10	57.7	58.1	55.9	56.9	52.2
Mean	57.4	59.1	56.2	56.1	53.0
S.D.	3.6	5.9	3.9	3.8	3.6

Table 27 HR (bpm) for Five Submaximal Skating Conditions at a Velocity of 336 m/min

Condition	1	2	3	4	5
Subject					
1	156	156	152	149	145
2	175	181	174	174	169
3	187	186	184	172	162
4	185	187	168	175	174
5	174	177	157	156	155
6	153	159	181	179	160
7	186	180	174	177	161
8	173	180	175	168	160
9	172	178	166	169	162
10	179	180	174	173	159
Mean	174	176	171	169	161
S.D.	12	11	10	10	8

Table 28 HR (bpm) for Five Submaximal Skating Conditions at a Velocity of 357 m/min

Condition	1	2	3	4	5
Subject					
1	175	166	159	163	161
2	186	184	180	188	181
3	191	191	184	184	174
4	184	189	181	182	185
5	184	186	169	170	168
6	170	169	187	189	173
7	185	186	184	185	171
8	185	190	180	180	165
9	176	185	174	177	168
10	188	195	188	189	170
Mean	182	184	179	181	172
S.D.	7	9	9	9	7

Table 29 HR (bpm) for Five Submaximal Skating Conditions at a Velocity of 381 m/min

Condition	1	2	3	4	5
Subject					
1	182	181	171	174	174
2	192	193	193	195	187
3	196	199	197	188	183
4	187	186	182	186	189
5	185	188	182	178	177
6	187	179	193	187	181
7	186	187	185	184	184
8	188	192	191	191	172
9	189	188	185	181	179
10	189	199	191	192	179
Mean	188	189	187	186	181
S.D.	4	7	8	6	5

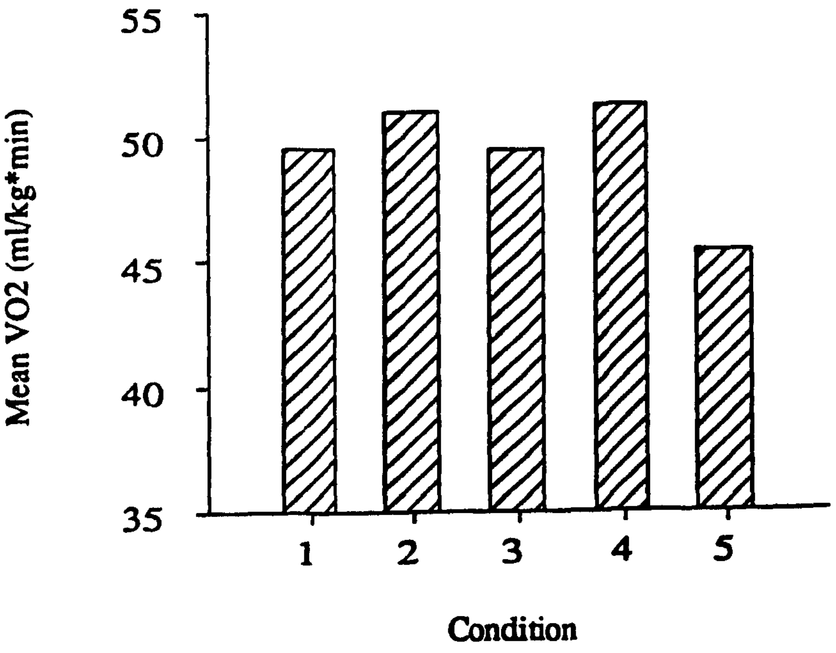

Figure 1 Mean VO2 for Five Conditions

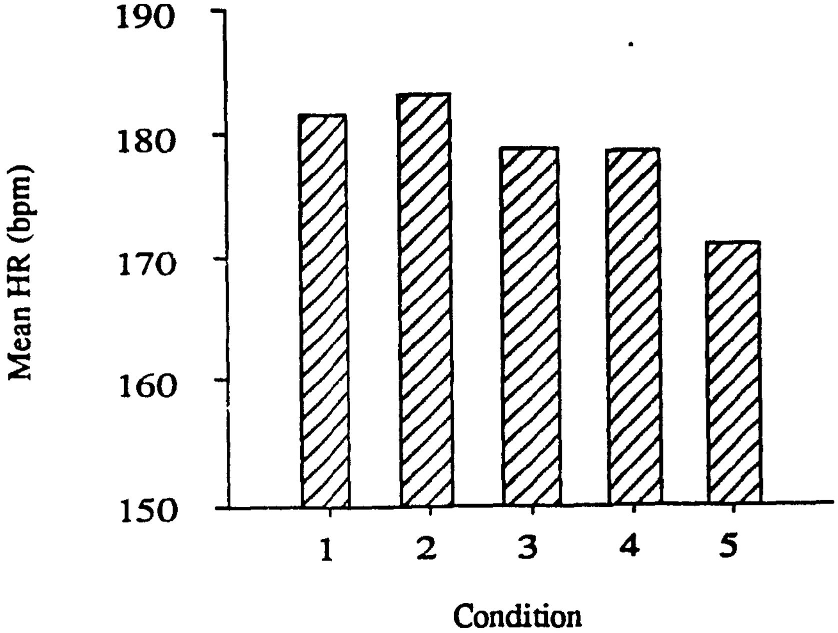

Figure 2 Mean HR for Five Conditions

4.4 Rolling Resistance

Rolling resistances (N) presented in Tables 30 and 31, include measures for both bearing and wheel types. The mean resistances for the wheel of 78 Shore A durometer on asphalt were 3.07 and 3.98 (N) for precision and semi-precision bearings, respectively. The means on concrete for the precision and semi-precision bearings were 2.38 and 3.71 (N), respectively. For the wheel of 82 Shore A durometer, the means for the precision and semi-precision bearings on asphalt were 4.63 and 5.14 (N), respectively. On concrete, the means for the precision and semi-precision bearings were 4.17 and 5.08 (N), respectively.

Table 30 Rolling Resistance (N) on Asphalt

Wheel Durometer	78		82	
Bearing	P.	S.P.	P.	S.P.
Trial				
1	3.37	4.76	5.29	5.05
2	2.87	4.29	4.91	5.48
3	3.57	4.01	4.39	4.45
4	2.71	4.10	4.87	5.05
5	3.40	3.70	4.16	4.70
6	3.07	3.37	4.36	5.24
7	2.94	3.40	3.90	5.13
8	3.02	3.94	5.02	6.02
9	2.65	4.26	4.77	5.10
Mean	3.07	3.98	4.63	5.14
S.D.	0.32	0.44	0.45	0.45

P.= precision bearings
S.P.= semi-precision bearings

Table 31 Rolling Resistance (N) on Concrete

Wheel Durometer	78		82	
Bearing	P.	S.P.	P.	S.P.
Trial				
1	2.22	2.90	4.27	5.10
2	2.16	3.31	3.89	5.11
3	2.89	4.66	4.08	5.21
4	2.19	3.15	3.99	4.83
5	2.14	3.52	4.33	4.84
6	2.98	3.25	4.97	4.95
7	2.35	4.11	3.90	5.25
8	2.39	4.58	3.93	5.68
9	2.18	3.93	4.17	4.79
Mean	2.38	3.71	4.17	5.08
S.D.	0.32	0.64	0.34	0.28

4.5 Testing of Hypotheses 1 and 2

Hypotheses 1 and 2 were examined using a MANOVA. These analyses are summarized in Tables 32 and 33.

Hypothesis 1 tested for significant differences between the physiological response of in-line skating with wheels of 78 and 82 Shore A durometers. Hypothesis 2 tested for a significant difference between the physiological response of in-line skating with precision and semi-precision bearings. The effects of the two surfaces and three velocities are included in the analyses.

Table 32 presents the results in terms of VO_2 (ml/kg*min). It was found that there was no significant difference between the wheel types (F = 4.23, p = 0.07). A significant difference was found, however, between bearing types (F = 6.08, p<.05) and velocity (F = 121.10, p<.01). A significant interaction was found between surface and velocity (F = 4.72, p<.05).

Table 33 presents the physiological response of in-line skating in terms of HR (bpm). The results also indicate no significant difference between the wheels of durometer 78 and 82 (F = 0.31, p = 0.60). Contrary to the results with VO_2 as the physiological measure, no significant difference was found between in-line skating with precision and semi-precision bearings (F = 1.19, p = 0.31) and no interactions were observed. Again, a significant difference was found between the physiological response of in-line skating at different velocities (F = 62.35, p<.01).

The results of the lactate collection were incomplete and therefore not used in the statistical analyses. However, the trends observed in Tables 21, 22, and 23 indicate an increase in lactate levels with increasing velocity. For both concrete and asphalt surfaces, lower lactate values were reported for precision bearings versus semi-precision bearings. These trends are in accordance with the results of the HR and VO_2 analyses. In contrast with these results are the lower lactate levels reported for wheels of 78 versus 82 Shore A durometers.

Table 32 MANOVA for Hypotheses 1 and 2 for VO_2 (ml/kg*min)

Source	df	MS	F	p
<u>Between</u>				
Wheel (W)	1	295.47	4.23	0.07
Error	8	69.79		
<u>Within</u>				
Surface (S)	1	0.18	0.00	0.96
Bearing (B)	1	79.22	6.08	0.04
Velocity (V)	2	1904.93	121.10	0.01
(B)*(W)	1	37.97	2.92	0.13
Error	8	13.04		
(S)*(W)	1	44.04	0.94	0.36
Error	8	47.10		
(V)*(W)	2	51.94	3.30	0.06
Error	16	15.73		
(S)*(B)	1	1.03	0.05	0.83
(S)*(V)	2	56.60	4.72	0.02
(V)*(B)	2	5.90	0.42	0.66
(S)*(V)*(W)	2	28.45	2.37	0.13
Error	16	11.99		
(V)*(B)*(W)	2	25.65	1.83	0.19
Error	16	14.03		
(S)*(B)*(W)	1	20.25	1.01	0.35
Error	8	20.14		
(S)*(V)*(B)	2	9.53	0.63	0.55
(S)*(V)*(B)*(W)	2	2.18	0.15	0.87
Error	16	15.10		

Table 33 MANOVA for Hypotheses 1 and 2 for HR (bpm)

Source	df	MS	F	p
<u>Between</u>				
Wheel (W)	1	175.21	0.31	0.60
Error	8	57.38		
<u>Within</u>				
Surface (S)	1	471.88	2.64	0.14
Bearing (B)	1	18.41	1.19	0.31
Velocity (V)	2	2270.06	62.35	0.01
(B)*(W)	1	3.68	0.24	0.64
Error	8	15.48		
(S)*(W)	1	392.41	2.45	0.16
Error	8	159.95		
(V)*(W)	2	9.58	0.25	0.78
Error	16	36.41		
(S)*(B)	1	27.08	1.79	0.22
(S)*(V)	2	23.43	1.14	0.35
(V)*(B)	2	10.41	1.42	0.27
(S)*(V)*(W)	2	24.36	1.18	0.33
Error	16	20.61		
(V)*(B)*(W)	2	3.38	0.50	0.62
Error	16	7.32		
(S)*(B)*(W)	1	12.68	0.84	0.39
Error	8	15.10		
(S)*(V)*(B)	2	10.98	1.40	0.28
(S)*(V)*(B)*(W)	2	7.28	0.93	0.41
Error	16	7.82		

Therefore, the null hypothesis which states that there is no significant difference in the physiological response of in-line skating using different wheel durometers is accepted. The declarative hypothesis, which states that there is a significant difference between in-line skating with precision bearings and semi-precision bearings on two surfaces is accepted for the variable VO_2. However, for the physiological marker HR, no significant difference was found between bearing types.

4.6 Testing of Hypotheses 3 and 4

Hypothesis 3 examined the physiological variables VO_2 (ml/kg*min) and HR (bpm) for significant differences among five experimental skating conditions. Hypothesis 4 examined the interaction between skating conditions and skating velocity. The results of the Manova are presented in Tables 34 and 35. A significant difference among experimental conditions with both VO_2 and HR as physiological markers was found ($F = 5.42$, $p<.01$, and $F = 9.15$, $p<.01$, respectively). A significant condition by velocity interaction resulted with HR as a measure ($F = 2.09$, $p<.05$), however, no significant difference resulted when analysed with VO_2 ($F = 1.45$, $p=0.19$). The observed interaction suggests that the response to the three velocities was different for the five experimental conditions. It may be explained by the smaller increase in

VO_2 for condition 4 from the velocity of 357 m/min to 381 m/min as compared to the increases observed in the other four conditions.

Table 34 MANOVA for Hypotheses 3 and 4 for VO_2 (ml/kg*min)

Source	df	MS	F	p
<u>Within</u>				
Condition	4	166.66	5.42	0.01
Error	36	30.73		
Velocity (V)	2	2434.15	139.20	0.01
Error	18	17.49		
(C)*(V)	8	19.12	1.45	0.19
Error	76	13.16		

Table 35 MANOVA for Hypotheses 3 and 4 for HR (bpm)

Source	df	MS	F	p
<u>Within</u>				
Condition	4	665.01	9.15	0.01
Error	36	72.67		
Velocity (V)	2	3206.42	100.23	0.01
Error	18	31.99		
(C)*(V)	8	22.97	2.09	0.05
Error	76	10.99		

In order to determine which experimental conditions were significantly different from one another, a planned contrast analysis was carried out. The results are presented in Tables 36 and 37.

The results for VO_2 (ml/kg*min) conclude that there are significant physiological differences between skating on asphalt and ice ($F = 12.51$, $p<.05$), between skating on concrete and ice ($F = 11.23$, $p<.05$), but there is no significant difference between in-line skating on concrete and asphalt ($F = 0.01$, $p = 0.96$).

The results for HR (bpm) conclude that there is a significant physiological difference between skating on asphalt and ice ($F = 25.82$, $p<.05$), between skating on concrete and ice ($F = 13.55$, $p<.05$), but no significant difference was found between skating on asphalt and concrete ($F = 2.27$, $p = 0.17$).

The trend in lactate levels is also in agreement with the results of the VO_2 and HR analyses.

Table 36 Planned Contrast Analysis for Hypotheses 3 and 4 for VO_2 (ml/kg*min)

Source	df	MS	F	p
Condition	4	166.66	5.42	0.01
Ashpalt vs Ice	1	2169.73	12.51	*
Error	9	173.46		
Concrete vs Ice	1	222.56	11.23	*
Error	9	198.33		
Concrete vs Asphalt	1	0.38	0.01	
Error	9	140.26		

* (p<.05)

Table 37 Planned Contrast Analysis for Hypotheses 3 and 4 for HR (bpm)

Source	df	MS	F	p
Condition	4	665.01	9.15	0.01
Ashpalt vs Ice	1	47059.60	25.81	*
Error	9	1822.93		
Concrete vs Ice	1	21252.10	13.55	*
Error	9	1568.54		
Concrete vs Asphalt	1	5062.50	2.27	
Error	9	2229.39		

* (p<.05)

Therefore, the declaratory hypothesis suggesting that skating under the five experimental conditions is significantly different was accepted for both VO_2 and HR as physiological markers. The means were found to differ significantly for skating on ice versus concrete and skating on ice versus asphalt for both pysiological markers.

The declaratory hypothesis stating there is a significant velocity by condition interaction was accepted with HR as the physiological marker but not with VO_2.

4.7 Testing of Hypothesis 5

Hypothesis 5 tested for significant differences between wheel durometer, bearing precision, and surface type with rolling resistance (N) as the dependent variable. Table 38 presents the results of the ANOVA. The analysis showed that the effect of wheel ($F = 204.09$, $p<.01$), bearing ($F = 68.89$, $p<.01$), and surface type ($F = 7.94$, $p<.05$) were all significant. A significant interaction also occurred between surface and bearing ($F = 5.89$, $p<.05$), and wheel and bearing ($F = 7.63$, $p<.05$).

Therefore, the declarative hypothesis stating that there is a significant difference in rolling resistance (N) between wheel, bearing, and surface was accepted.

Table 38 ANOVA for Hypothesis 5

Source	df	MS	F	p
Wheel (W)	1	38.79	204.09	0.01
Error	8	0.02		
Surface (S)	1	2.38	7.94	0.02
Error	8	0.03		
Bearing (B)	1	15.06	68.88	0.01
Error	8	0.22		
(W)*(S)	1	0.23	1.74	0.22
Error	8	0.13		
(W)*(B)	1	0.74	7.63	0.03
Error	8	0.10		
(S)*(B)	1	0.77	5.89	0.04
Error	8	0.13		
(W)*(S)*(B)	1	0.00	0.00	0.99
Error	8	0.14		

Chapter 5

Discussion

In-line skating is a highly specific form of dryland training used by hockey players during the off-season. The purpose of this study was to examine the physiological response during in-line submaximal skating using high and low durometer wheels, semi-precision and precision bearings, and asphalt and concrete surfaces. These results were then compared to a similar on-ice test.

5.1 Comparison to On-Ice Skating

Although in-line skating is believed by many hockey coaches to simulate on-ice skating, few studies have compared the physiological responses of in-line skating and on-ice skating.

Carroll et al. (1993) compared the metabolic cost of on-ice skating to in-line skating on a concrete surface. Division I collegiate ice hockey players (n = 12) were monitored when skating at velocities of 12.5 km/h (208 m/min), 16.5 km/h (275 m/min), and 20 km/h (333 m/min). The dependent variables were HR and VO_2. The results indicated that mean HR and absolute VO_2 were greater for in-line skating compared to on-ice skating at all three velocities. Relative VO_2 was greater for in-line skating than for on-ice skating at 16.5 km/h and 20 km/h. The authors concluded that increases in VO_2

and HR values observed with in-line skating may have resulted from a heavier (120 grams) in-line skate and an apparent greater frictional force. No measures of frictional force were taken in Carroll et al.'s study.

Ferguson et al. (1969) measured the metabolic cost of on-ice skating (n = 17) at velocities of 350, 382, 401, 421, and 443 m/min. Higher velocities were used since the purpose of the study was to measure maximum VO_2. The mean maximum oxygen uptake for the test-retest were 54.8 and 55.3 ml/kg*min respectively.

Three different in-line skating techniques were examined by Hoffman et al. (1992). The physiological responses of the commonly used in-line skating technique, and two cross-country ski skating techniques (double poling and V1 skating) were compared. Ten male cross-country skiers skated three continuous velocities (14.6, 16.4, and 18.0 km/h) for a duration of four minutes for each skating technique on a rubberized asphalt track. Their findings indicated that the VO_2 requirements were similar for the V1 and conventional skating techniques. The double pole technique produced a lower VO_2 for all three velocities. The double pole technique was the most economical of the three in-line skating techniques.

A comparison of the VO_2 (ml/kg*min) in Carroll et al.'s study, Ferguson et al.'s study, Hoffman et al.'s study, and this study is shown in Table 39 and graphically depicted in Figures 3 and 4.

Table 39 VO_2 (ml/kg/min) Comparison During On-ice and In-Line Skating

Surface	Ice	Concrete		Asphalt	
Bearing		S.P	P.	S.P.	P.
Velocity (m/min)					
This study					
336	38.5	46.1	43.3	43.1	41.2
357	44.4	51.3	48.6	50.6	49.9
381	53.0	56.1	56.2	59.1	57.4
*Carroll et al.(1993)					
208	17.0	18.0			
275	23.0	32.0			
333	35.0	42.0			
Ferguson et al.(1969)					
382	47.4				
401	50.9				
421	54.5				
*Hoffman et al.(1992)					
243				27.0	
273				32.0	
300				35.8	

S.P.= Semi-Precision Bearings, P.= Precision Bearings
* did not specify bearing type.

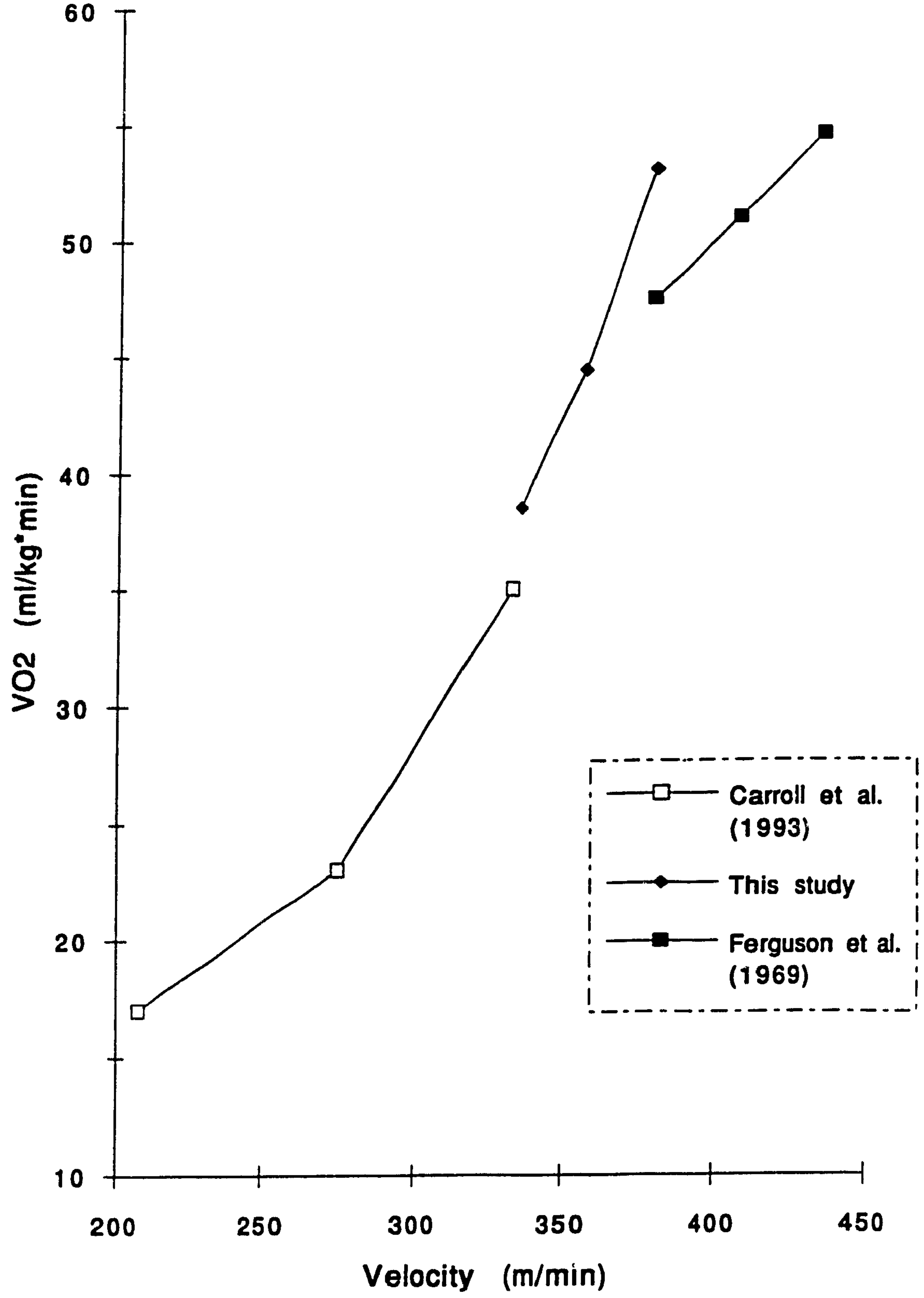

Figure 3 Comparison of On-Ice Skating Studies

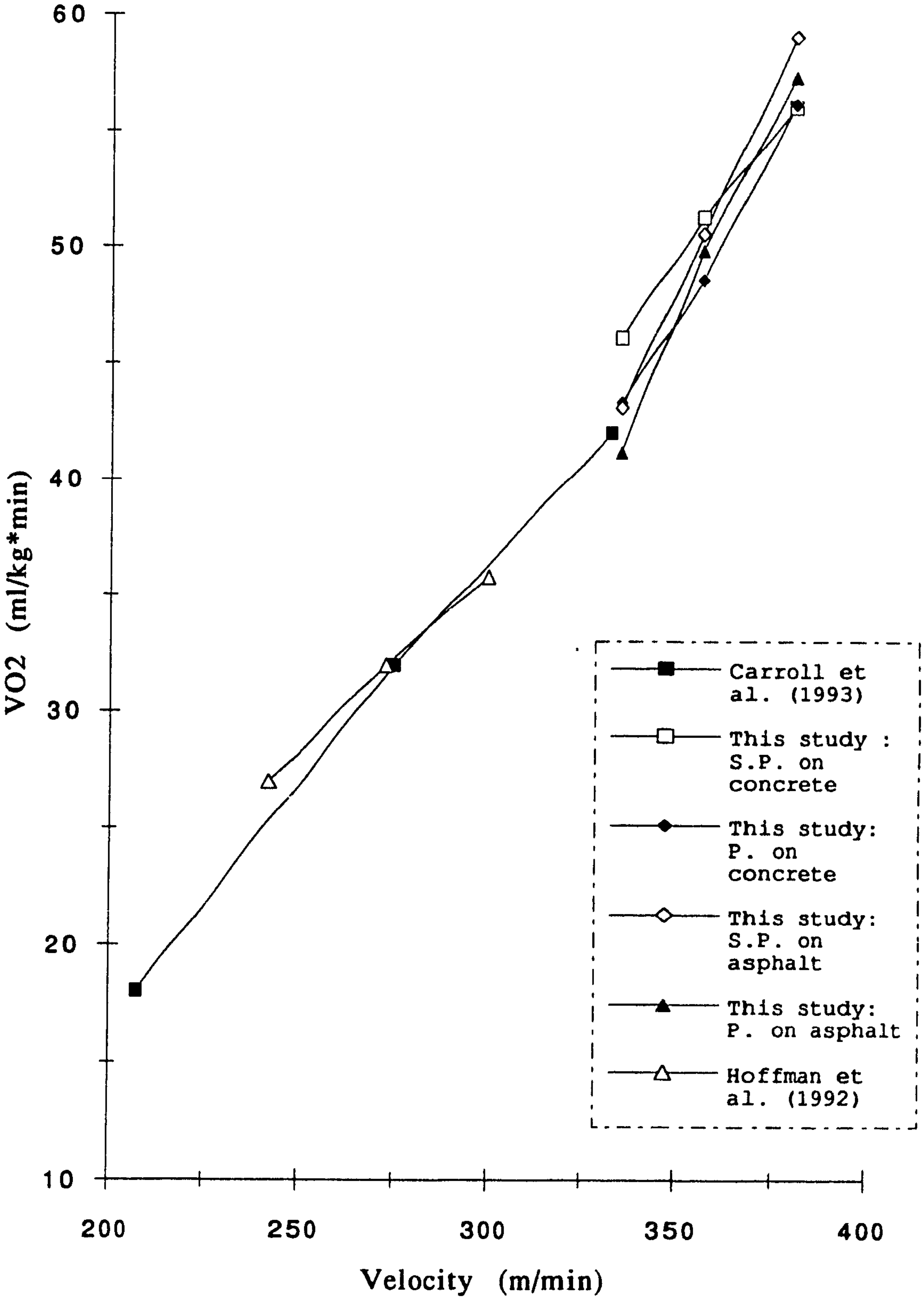

Figure 4 Comparison of In-Line Skating Studies

The on-ice comparison shown in Figure 3 indicates that the oxygen cost of on-ice skating was similar for the three studies. Carroll et al. reported the oxygen cost of skating at 333 m/min to be 35.0 ml/kg*min which is a little lower than the oxygen cost reported in this study of 38.5 ml/kg*min at a similar velocity of 336 m/min. Ferguson et al. reported a lower oxygen cost (47.4 ml/kg*min at 382 m/min) than the oxygen cost (53 ml/kg*min at 381 m/min) in this study. The higher values for oxygen cost in this study compared to the other two studies may be due to a difference in skating economy between groups. The higher VO_2 for a given velocity would suggest a lower efficiency of skating.

Green (1979) found a substantial inter-individual difference in skating efficiency using elite hockey players as subjects. Three individuals were tested at velocities of 350, 382, and 401 m/min. The skater with the lowest VO_2 max was superior to the other two subjects, in spite of their superiority in VO_2 max. Results from Leger et al. (1979) agree with the above mentioned study. Leger et al. reported that the coefficients of variation for maximal skating speed indicated a relatively homogeneous group of high level hockey players (n=10). However, a large coefficient of variation in VO_2 max while skating indicated a much wider distribution of the subjects around the mean. They attributed their findings to the mechanical efficiency of skating.

The in-line skating results from the studies by Carroll et al. (1993) and Hoffman et al. (1992) are compared with this study in Figure 4. The oxygen cost of 42.0 ml/kg*min at 20 km (333 m/min) reported by Carroll et al. is similar to the oxygen cost of 43.1, 41.2, 46.1, and 43.3 at 336 m/min reported in this study. The oxygen cost of 32.0 ml/kg*min at 16.4 km/h (273 m/min) reported by Hoffman et al. is the same as the oxygen cost at 16.5 km/h (275 m/min) reported by Carroll et al. Even though the surfaces skated in the three studies were different, a similar physiological response is observed. This is in accordance with the findings that the physiological response during in-line skating for this study was not found to differ significantly when skating on concrete and asphalt surfaces. Bearing types were not specified in either Carroll et al.'s or Hoffman et al.'s study thus limiting the comparisons to surface only.

5.2 Effect of Added Mass

Studies of the body segment mass distribution provide insight into the inter-individual differences in running economy. Morgan et al. (1989a) reported that carrying a given load on the distal aspect of the lower extremity increases the aerobic demand of running by approximately 1 percent per 100 g of load, while the rise in VO_2 associated with carrying the same load on the trunk is only 0.1 percent per 100 g of load. Frederick et al (1984) studied the effects of added weight of running shoes on aerobic demands of running. The findings indicated that 75 grams added to each foot resulted in a significant aerobic effect on running at certain velocities.

The biomechanics of running are different than for skating. Ice skating can be broken down into three functional phases according to Marino and Weese (1979): glide during single support, propulsion during single support, and propulsion during double support. The glide phase of skating begins during the initial stages of single support and lasts for approximately half of the single support time. Following this the propulsive phase begins and lasts until the end of the double support period. The mode of recovery during the glide phase of a skating stride suggests that the aerobic demand would be lower when the same mass is attached to the skate compared to the mass of the running shoe (Carroll et al., 1993). The in-line skate in this study was approximately 300 grams heavier than the equivalent skate size. This added weight may have been enough to produce a significant difference in aerobic demand of in-line skating and on-ice skating.

Only a few studies have examined the effects of added mass on skating performance. Montgomery (1982) examined the effects of added mass to the torso. Speed index (sec), anaerobic endurance (sec), drop-off index (sec), and three and five-minute recovery HR (bpm) were measured and calculated for 0%, 5%, 10%, and 15% added body mass. Added mass caused a significantly slower performance on both speed and anaerobic endurance components of a hockey fitness test. When carrying 5% added mass, anaerobic endurance time increased by 4%. The drop-off index was relative to the times produced for that specific condition, and there were no significant changes in either the three-minute or five-minute HR recovery patterns because the players exercised to maximum performance in each condition.

Added mass attached to the extremities has a greater effect than the same mass added to the torso. Chomay et al. (1982) examined the effect of added mass (0, 227, and 555 grams) attached to the skate (n = 11 hockey players). The variables speed (180 ft skate), anaerobic endurance, drop-off index, and HR recovery index at 2- and 4-minutes were measured and calculated for repeat sprints. During the added skate weight conditions, there was a significant ($p < .05$) increase in performance time resulting in a slower performance in both the speed and anaerobic components of the ice hockey fitness test. It was concluded that a heavier skate resulting from adding mass to the skate produces slower times in an ice hockey fitness test.

5.3 Biomechanics of Skating

The type of skating employed in hockey is power skating; it is different from both figure skating and speed skating (Marino and Weese, 1979).

Marino (1977) analysed skating at different velocities and concluded the following: (a) significant increases in skating velocity are accompanied by increases in stride rate and decreases in both single and double support times; (b) stride length does not change significantly as skating velocity changes from low through medium to high levels; (c) as skating velocity increases, both single and double support times decrease but double support time undergoes proportionately greater changes; and (d) skating velocity is more dependent on the number of times a person strides than on the length of each stride. McCaw (1984) extended Marino's findings in a study that compared the biomechanics of novice, intermediate, and elite skaters. He observed that better performance in hockey players was dependent upon stride rate, shorter duration of double support, and an increased range of motion of the hips and knees due to greater joint flexion.

Stride rate and stride length were recorded for in-line skating on asphalt and concrete in this study. The findings were in agreement with Marino (1977) in that there was little change in stride length when velocities increased from 336 to 381 m/min on both surfaces. The increase in skating velocity was accompanied by an increase in stride rate.

Comparisons between skating on-ice and on concrete revealed a longer stride length and slower stride rate on concrete than on-ice. The circumference of the course (140 m) was identical for the on-ice and concrete testing, however, the testing on asphalt was performed on a 400 m course. As a result, the curve angle and straight segment lengths were different on asphalt which may influence the stride length and rate. The push-off mechanics between skating the straight segments and skating the curves are fundamentally different (de Boer et al., 1987a). The kinematic results on asphalt were therefore not analysed for comparison to other surfaces.

The differences in metabolic cost between in-line and on-ice skating may partly be due to differences in skating style. Knee angle and stride phase were not measured in this study. de Boer et al (1987b) have compared the biomechanics of in-line skating and on-ice skating. Eight trained marathon skaters performed four maximal exercise tests: two with in-line skating and two with on-ice skating. de Boer et al. reported that in speed skating and in-line skating the work per stroke, stroke frequency, and the power losses were equal. The parameters concerning skating technique demonstrated a great similarity between on-ice and in-line skating. However, the knee angle was smaller in the gliding phase of on-ice skating, and consequently the push-off trajectory was greater. Knee extension velocity was also greater for on-ice skating, In on-ice skating the gliding phase was 50 milliseconds shorter and the push-off phase was 31 milliseconds longer. The total stroke time (gliding phase plus push-off phase) during both skating activities was similar.

Chapter 6

Summary, Conclusions, and Recommendations

6.1 Summary

This study examined the physiological response of an in-line submaximal skate using two bearing and two wheel types on two surfaces. These results were then compared to an on-ice submaximal skate. The physiological markers were HR and VO_2. Ten male varsity hockey players ranging in age from 18 to 23 years served as volunteers for this study. Prior to the in-line submaximal skating tests, each subject performed a VO_2max test on a treadmill followed by an on-ice submaximal skate. Physical characteristics were measured for each subject.

The in-line skating tests were performed on concrete and asphalt. Each subject was randomly assigned one of two wheel types (78 and 82 Shore A durometers), and performed the test twice on each surface using a different type of bearing (NMB Singapore precision and semi-precision). Subjects skated at velocities of 336, 357, 381 m/min on an oval shaped course. Each velocity was skated for a duration of four minutes separated by five minutes of rest.

Following the in-line skating tests, a rolling resistance measure was taken to determine if there was a significant difference between surface, wheel and bearing type. A cart mounted with different combinations of wheel and bearing types was used to determine the rolling resistance measure (N) on each surface.

The first hypothesis predicted no significant difference while in-line skating with wheels of 78 and 82 Shore A durometers. The second hypothesis predicted a significant difference while in-line skating with semi-precision and precision bearings. A 2 (wheel type) X 2 (bearing type) X 2 (surface) X 3 (velocity) repeated measures factorial design with subjects nested within wheel type was used to analyse HR and VO_2

For the first hypothesis the F-test of the MANOVA revealed an F-ratio of 4.23 ($p = 0.07$) with VO_2 as the physiological marker, and an F-ratio of 0.31 ($p = 0.60$) with HR as the physiological marker. No significant difference was observed between in-line skating with two different wheel durometers.

For the second hypothesis the F-test of the MANOVA revealed an F-ratio of 6.08 ($p < .05$) with VO_2 as the physiological marker and an F-ratio of 1.19 ($p = 0.31$) with HR as the physiological marker. A significant difference between in-line skating with two different bearing types was observed using VO_2 as the marker ($p < .05$), however, no significant difference was observed using HR as the marker ($p=0.31$).

The third hypothesis stated that there would be a significant difference among the five experimental conditions.

The conditions were as follows:

condition 1=skating on asphalt with precision bearings
condition 2=skating on asphalt with semi-precision bearings
condition 3=skating on concrete with precision bearings
condition 4=skating on concrete with semi-precision bearings
condition 5=skating on-ice.

Hypothesis 4 predicted that a significant "condition by velocity" interaction would occur.

A 5 X 3 repeated measures factorial design was used to analyse HR and VO_2 for the five conditions and three velocities. A significant difference among the five experimental conditions with both VO_2 and HR as physiological markers was found ($F = 5.42$, $p <.01$, and $F = 9.15$, $p <.01$, respectively). A significant condition by velocity interaction resulted with HR as a measure ($F = 2.09$, $p <.05$), however, no significant difference resulted when analysed with VO_2 ($F = 1.45$, $p = 0.19$).

In order to determine which experimental conditions were significantly different from one another, a planned contrast analysis was carried out. The results for VO_2 and HR concluded that there were significant physiological differences between skating on asphalt and ice ($F = 12.51$, $p<.05$; and $F = 25.82$, $p <.05$, respectively), between skating on concrete and ice ($F = 11.23$, $p < .05$; and $F = 13.55$, $p<.05$, respectively), but there was no significant difference between skating on concrete and asphalt ($F = 0.01$, $p = 0.96$, and $F = 2.27$, p = 0.17, respectively).

The fifth hypothesis predicted a significant difference in rolling resistance between wheel, bearing, and surface type. A 2 X 2 X 2 ANOVA factorial design was used to test for significant differences. The F-test of ANOVA revealed an F-ratio of 204.09 (p = 0.01) for the wheel variable, an F-ratio of 68.88 (p = 0.01) for the bearing variable, and an F-ratio of 7.94 (p = 0.02) for the surface variable. A significant difference in rolling resistance (N) was observed between wheel, bearing, and surface types.

6.2 Conclusions

The following conclusions were made within the limitations and delimitations of this study:

1. The physiological response (VO_2 and HR) is similar when skating at submaximal velocities using in-line skates fitted with wheels of 78 and 82 Shore A durometers.

2. In-line skating with semi-precision and precision bearings produces a different physiological response using VO_2 as the marker, however, there is no change with HR as the marker.

3. The physiological response of skating on-ice is significantly different than in-line skating on asphalt and concrete. In-line skating on asphalt and concrete produces similar physiological responses.

4. The rolling resistance (N) differs between concrete and asphalt; between semi-precision and precision bearings; and between wheels of 78 and 82 Shore A durometers.

6.3 Recommendations

It is recommended that future research examine the physiological response of in-line skating with a wider range of bearing and wheel types. A study examining the variability of wheels and bearings of the same type is warranted. It is also recommended that further research examine the effects of added skate weight on the aerobic demands of in-line skating.

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Appendix A Consent Form for In-Line Skating Study

Required Task

You will be required to participate in two test sessions which will consist of the following experimental design:

1. Submaximal skating test on asphalt
2. Submaximal skating test on concrete

For each skating session, three submaximal velocities will be skated for a duration of four minutes. Between each velocity you will rest for five minutes during which time a blood sample will be drawn form a peripheral finger by a qualified tester. Following a 30 minute rest, the three velocities will be repeated using a different bearing type.

Physical Risks

Just as with any performance test, there is a possibility of discomfort and risk as a result of exercise. However, because the exercise involved is submaximal, the discomforts will be minimal. There is a risk of falling while in-line skating. This possibility has been minimised by creating a course on asphalt that has a large circumference. Every effort has been made to minimise these discomforts and risks.

Rights and Inquiries .

Information given by you will remain confidential. Confidentiality is assured since the data will all be coded, eliminating the need for names. Group data is necessary for valid research since individual scores offer little experimental or statistical value.

Freedom of Consent

Participation in this research study is entirely voluntary. You are free to deny consent and withdraw from the study at any time should you do desire.

I have read this form and I understand the procedures and the extent of my involvement in the study. I understand that I am free to withdraw from this research at any time without repercussions. I freely consent to participate in this research.

Date: ____________ Signature: ____________________

Witness: ____________________