

**The Effects of Active and Passive Recovery
on Blood Lactate Concentration and Performance
in a Simulated Ice Hockey Task**

by
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Abstract

The purpose was to examine the effects of active and passive recovery on blood lactate concentration and performance in a simulated ice hockey task. Eleven university, varsity and intramural level hockey players performed one continuous aerobic cycle ergometer test ($\dot{V}O_2\text{max}$) and three Repeat Sprint Skate (RSS) tests. The RSS test consisted of four repetitions of a 91.4 m skate with repetitions initiated on 30s intervals, repeated six times with six minutes of recovery between each RSS test. This protocol was performed using passive, skating, and cycling recovery. Results indicated: (1) The difference between pre and post test blood lactate concentration was similar in the passive and skating conditions but significantly lower ($p < 0.01$) in the cycling condition. (2) Speed index times were similar ($p > 0.05$) among all experimental conditions. (3) Anaerobic endurance index times were significantly faster ($p < 0.05$) in the skating and cycling recovery conditions. (4) There was significantly less ($p < 0.05$) drop-off in the skating and cycling recovery conditions.

Resume

Le but de cette étude était d'examiner les conséquences d'une période de répétition active ou passive sur la concentration plasmatique de lactates et la performance lors d'une épreuve simulée de hockey sur glace. Onze joueurs de hockey de niveau universitaire ou intramural ont été soumis à une épreuve continue maximale sur bicyclette ergométrique ($\dot{V}O_2\text{max}$) ainsi que trois Sprints Répétés de patinage sur glace (RSS). Le test RSS comprenait six sets de quatre répétitions de 91.4 m de patinage sur glace, chaque répétition étant espacée par 30 secondes. Une phase de récupération de six minutes était allouée entre les sets. Les participants étaient assignés soit à une récupération passive ou à une récupération active effectuée en patinage sur glace ou sur bicyclette ergométrique. Les résultats ont permis de démontrer (1) des concentrations plasmatiques de lactates similaires chez les groupes ayant récupéré façon passive ou en patinant, qui demeuraient toutefois inférieures aux valeurs observées chez le groupe ayant utilisé la bicyclette. (2) des indices de performance sur glace similaires pour toutes les conditions de récupération. (3) des indices d'endurance anaérobie significativement plus rapides chez les groupes ayant bénéficiés d'une récupération active. (4) un indice de fatigue significativement moins marqué chez les groupes ayant bénéficiés d'une récupération active.

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Chapter I

Introduction

Ice hockey is a game of Canadian origin which today is popular throughout Canada, the United States, and Europe. The game incorporates characteristics that make it one of the fastest and most exciting sports in the world.

The game demands from the player a balance of power and endurance, therefore both the aerobic and anaerobic energy systems are heavily taxed (Green and Houston, 1975; Houston and Green, 1976; Seliger et al., 1972). This presents the coach with a unique problem. He must use training techniques which will induce maximum development of both energy systems. Regardless though, of how well trained the athlete may be, due to the fast paced nature of hockey, there will always be an element of fatigue. Today many coaches turn to the scientist to analyse and help solve such problems. This is the case in many sports, not just hockey.

When a scientific approach is taken, athletes are usually evaluated using tests which have been proven to be valid, reliable, and objective. Through the use of tests which simulate game conditions, physiological parameters that influence performance can be measured and analyzed. Once this process is completed, problems can be identified and the appropriate solutions implemented. The merger of science and sport can thus be beneficial to the coach, athlete, and scientist.

1.1 Nature and Scope of the Problem

Some characteristics of ice hockey include high intensity intermittent bouts of skating, rapid changes in velocity and duration, puck handling skills, and frequent body contact (Montgomery, 1988). In order to keep the pace of the game at a high intensity, hockey players participate in shifts. The active on-ice shifts are

approximately 30 to 80 seconds in duration and the off-ice recovery periods are four to five minutes in length (Montgomery, 1988). Due to the nature of the game and the relatively short on-ice duration, the player is expected to put forth a maximal and sometimes supramaximal effort on every shift. In order to put forward such an effort, the anaerobic energy system must be heavily taxed (Green, 1979; Green et al., 1978b; Houston and Green, 1976).

Any sport which involves high intensity intermittent bouts of activity, that are longer than 10 seconds, will draw energy from anaerobic glycolysis (Green, 1979; Lehninger, 1982). Even though glycolysis has a high ATP yield per unit time (Green, 1979), one disadvantage of its use combined with short recovery periods is an accumulation of lactate. The rate of accumulation will depend on the intensity of the task. Higher work intensities will more quickly bring about a critical lactate level (Hermansen, 1971). If lactate concentration rises and stays above critical levels, acidosis will lead to muscular fatigue (Green, 1979; Jones and Green, 1984), which limits the player's ability to reproduce optimal performances.

Presently, ice hockey players recover by passively sitting four to five minutes between shifts. Lactate removal is relatively slow during passive recovery. If active recovery was employed between shifts to increase the rate of lactate removal the physiological potential for the players to play to their capacity would be enhanced (Jacobs, 1986).

Early studies by Newman et al. (1937) and Rammal and Strom (1949) indicated that active recovery decreases the time taken to lower blood lactate levels to near baseline values. A recent study that examined recovery using a simulated hockey task (Watson and Hanley, 1986), found that active recovery (bench-stepping and skating) decreased blood lactate levels to a greater degree than passive recovery. Skating, bench-stepping, and resting recovery lowered lactate levels by 45, 45, and 35%, respectively, after 15 minutes of recovery. Initial distances skated were statistically similar. Post recovery skating distances were similar across all conditions. Post

recovery skating performance levels were lower for all recovery conditions. Thus active recovery in this particular case increased lactate removal, but did not affect performance.

In most studies, when active recovery has been examined, the mode of recovery was identical to the initial type of exhaustive exercise (Belcastro and Bonen, 1975; Boileau et al., 1983; Bonen and Belcastro, 1976; Koutedakis and Sharp, 1985; Watson and Hanley, 1986). When different modes have been compared (Krukau et al., 1987; Siebers and McMurray, 1981), the sport-specific mode usually proved significantly more effective than the non-specific mode, although contrary findings do exist (Watson and Hanley, 1986). Recovery time between hockey shifts is inadequate in duration to permit blood lactate concentration to return to resting levels if recovery is of a passive nature. Since both skating and bench stepping are impractical recovery methods for hockey, then a form of active recovery that employs similar prime movers to skating, and is easily employed between shifts, should be investigated.

1.2 Significance of the Study

Through the use of time-motion analysis and the measurement of blood parameters such as lactate concentration, hockey games, periods, or shifts can be simulated. Simulations aid investigators to examine variables that may limit performance.

Green et al. (1976; 1978a) observed a decrease in blood lactate concentration from the first to the third periods. Lactate concentrations ranged from 80.3 mg% at the end of the first period, to 38.0 mg% at the end of the third period (Green et al., 1976). This could indicate a drop in energy production. Simulated ice hockey tasks, consisting of 10 one-minute bouts of skating at a velocity equal to 120% of $\dot{V}O_2\text{max}$ separated by five minutes of passive recovery, elicited blood lactate concentrations of 10.9 mmol/l after 30 minutes and 13.3 mmol/l after 60 minutes of intermittent skating

(Green, 1978). Montgomery et al. (1988) and Watson and Sargeant (1986) observed lactate values of 10.7 mmol/l and 11.5 mmol/l respectively, following six skating repetitions of 91.4 meters. Subjects performed the repeat sprint skate (RSS) hockey fitness test as described by (Reed et al., 1979) to simulate an intense shift. Blood lactate values of this magnitude reflect significant acidosis in the muscle causing metabolic and contractile disturbances, resulting in decreased work performance (Green, 1979).

Half times for lactate removal have been reported to be 20 minutes under passive recovery conditions (Bonen and Belcastro, 1977). Depending on the intensity of active recovery, half times of 9.5 minutes (Sahlin et al., 1976; Stamford et al., 1981) and 10 minutes (McLellan and Skinner, 1982) have been reported.

If active recovery was employed between shifts, there exists a possibility of improved performance on subsequent shifts. Since a secondary skating area is seldom available to the player, the opportunity to use skating as an active recovery mode during games to counteract some of the lactate accumulation in a shift, is not practical. If another form of active recovery that used the same prime movers as skating was shown to be as statistically effective as skating in eliciting lactate oxidation, the player should benefit by an increase in performance. It is feasible to perform active recovery by cycling which may serve as a substitute for skating. If cycling is proven statistically to be as expedient as skating in removing lactate, it would be possible to design portable cycle ergometers that the players could use between shifts in actual game situations.

1.3 Statement of the Problem

The aim of this study was to compare the effect of two modes of active recovery (skating, cycling) to passive recovery on blood lactate concentration and performance in a simulated ice hockey task. The simulated ice hockey task was a modified version of the repeat sprint skate test (Rhodes et al., 1985) that was repeated for six trials.

This study examines the following hypotheses:

1. Blood lactate concentration will be significantly lower following active recovery conditions than a passive recovery condition.
2. The speed index variable of the RSS test will be significantly faster in the active recovery conditions than a passive recovery condition.
3. The anaerobic endurance index variable of the RSS test will be significantly lower in the active recovery conditions than a passive recovery condition.
4. The drop-off index variable of the RSS test will be significantly lower in the active recovery conditions than a passive recovery condition.

1.4 Operational Definitions

1. Active Recovery: A form of recovery in which the subject exercises by either skating or cycling at a submaximal level following high intensity exertion (RSS test).
2. Passive Recovery: A form of recovery in which the subject sits on the bench.
3. Shift: An eight minute time segment during which the subject completes one RSS test (two minutes) and one recovery interval (six minutes).
4. Repetition: Each of the four segments within the RSS test during which the subject skates from goal line to goal line and back to the opposite blue line.
5. Speed Index: The time required to skate one length of the ice (54.9 m) on the first repetition of the modified repeat sprint skate (RSS) hockey fitness test (Gamble, 1986).
6. Anaerobic Endurance Index: The total time required to complete four repetitions (4 x 91.4 m) of the RSS hockey fitness test (Rhodes et al., 1985).
7. Drop-off Index: The difference between the fastest and slowest repetitions of the RSS hockey fitness test (Reed et al., 1979).

1.5 Limitations

Ice conditions may not be exactly the same for all subjects.

1.6 Delimitations

1. Subjects were male hockey players of varsity or intramural level.
2. Subjects were students at McGill University.
3. Subjects ranged between 20 and 25 years of age.
4. The ratio of on-ice shift length to off-ice recovery time was 1:3
(two minutes : six minutes).
5. Only forwards and defensemen were used.

Chapter II

Review of the Literature

The accumulation of lactic acid in the skeletal muscle, and its subsequent diffusion into the blood is one of the physiological aspects that is associated with both objective and subjective muscular fatigue. Short term, high intensity exercise performance is notably effected by lactate build-up (Jacobs, 1986). Hockey being a sport that involves high intensity intermittent skating, combined with rapid velocity changes and repeated body contact draws frequently on anaerobic energy sources (Montgomery, 1988). Due to the nature of hockey, there is an accumulation of lactate in the skeletal muscle. Recovery time between shifts is too brief to allow the dissipation of lactate back to levels that will not effect the performance of the player.

At this point in time, players recover passively between shifts. Studies focusing on active recovery have demonstrated that active recovery increases the rate of lactate removal (Belcastro and Bonen, 1975; Davies et al., 1970; Newman et al., 1937; Watson and Hanley 1986). Active recovery studies are infrequent and when applied to hockey are almost non-existent.

This section of the investigation will give a brief review of the scientific literature pertaining to the physiological and biochemical nature of active recovery. The chapter is divided into five sections:

2.1 Lactate Metabolism

2.1.1 Production

2.1.2 Removal

2.2 Exercise Intensity and Lactate Removal

2.3 Specificity of Exercise Mode

2.4 Performance and Lactate Level

2.5 Energetics of Ice Hockey

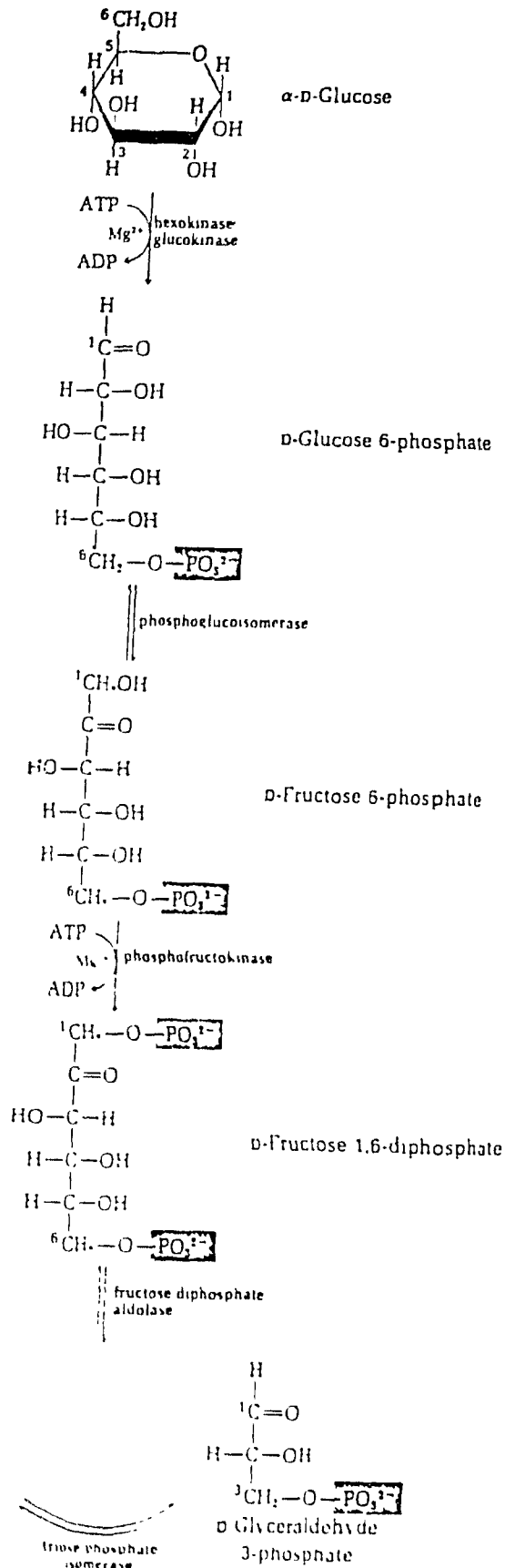
2.1 Lactate Metabolism

2.1.1 Production

Lactate is the terminal substrate of a linear biphasic biochemical pathway known as glycolysis. Glycolysis is a process by which glucose is enzymatically catabolized in a sequence of 10 reactions that yield pyruvate. Under anaerobic conditions such as high intensity contractions of the skeletal muscle, pyruvate is reduced to lactate. This process is commonly known as anaerobic glycolysis (Lehninger, 1982).

Reactions, substrates, and enzymatic catalysts involved in the conversion of glucose to pyruvate and then into lactate will be briefly summarized. The first priming reaction is the phosphorylation of glucose to glucose 6-phosphate catalyzed by hexokinase. Glucose 6-phosphate is then converted to fructose 6-phosphate catalyzed by phosphoglucisomerase. Fructose 6-phosphate the second priming reaction, catalyzed by phosphofructokinase yields fructose 1,6-diphosphate. Fructose diphosphate aldolase then catalyzes the cleavage of fructose 1,6-diphosphate to glyceraldehyde 3-phosphate. Glycolysis enters its second phase when glyceraldehyde 3-phosphate is oxidized to 3-phosphoglycerate catalyzed by glyceraldehyde phosphate dehydrogenase. Phosphoglycerate kinase then transfers a high energy phosphate group forming 3-phosphoglycerate. Phosphoglycerate mutase catalyzes the conversion of 3-phosphoglycerate to 2-phosphoglycerate. Enolase then promotes the dehydration of 2-phosphoglycerate to phosphoenolpyruvate. Pyruvate kinase is the catalyst in the transfer of phosphoenolpyruvate to pyruvate. Under aerobic conditions, pyruvate is oxidized to form acetyl-coenzyme A which is used in the Krebs cycle. When the tissue is functioning anaerobically, lactate is formed through the reduction of pyruvate catalyzed by lactate dehydrogenase (Lehninger, 1982). A schematic representation of glycolysis is illustrated in Figure 2.1.

First Phase of Glycolysis



Second Phase of Glycolysis

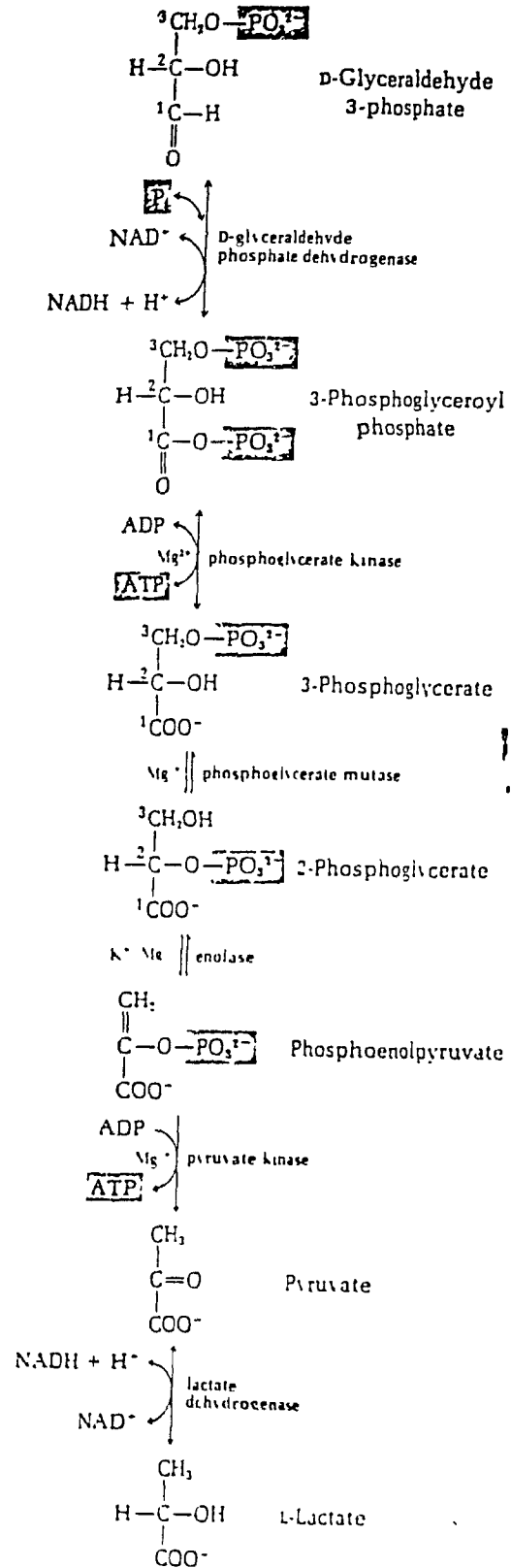


Figure 2.1 The Glycolytic Pathway (Lehninger, 1982).

Muscle fibre type, enzyme levels, and enzymatic activity within the muscle have a strong influence on lactate production during exercise. Sahlin and Henriksson (1984) observed trained subjects who possessed a higher percentage of slow twitch (ST) fibres than fast twitch (FT) fibres. Mitochondrial and glycolytic enzymatic activity were measured. The trained subjects had significantly higher citrate synthase (CS), succinate dehydrogenase (SDH), and 3-OH-acylCoA dehydrogenase (HAD) activity levels, than the sedentary subjects. The trained subjects were able to sustain an isometric contraction at 60% maximum voluntary contraction (MVC) for a longer period while producing less lactate. Essen and Haggmark (1975) measured muscle lactate levels in type I (ST) and type II (FT) fibres. After 80 seconds of dynamic work at 100% $\dot{V}O_{2max}$ and 65 seconds of static work at 50% MVC, muscle lactate levels were higher (5 and 10 mmol/kg wet weight) higher in the type II fibres. Tesch et al. (1978) studied lactate accumulation in muscles that were in a state of local fatigue caused by repeated isokinetic contractions. Lactate dehydrogenase(LDH) activity, LDH isozyme, and fibre type distribution were measured. Lactate concentration was found to be significantly higher in the fast twitch(FT) muscle fibres. Tesch, (1978) also found that lactate was in higher concentrations in FT fibres. Significant correlations were found between total LDH activity and lactate concentration, muscle LDH activity and lactate concentration, total LDH activity and muscle fibre type distribution, and muscle LDH activity and muscle fibre type distribution. These findings lead investigators to the conclusion that because of the greater total LDH activity and high proportion of muscle LDH, FT muscle fibres are capable of producing higher concentrations of lactate than ST fibres. Further support for this conclusion is found in studies which compare sprint trained to endurance trained subjects (Medbo and Sejersted, 1985; Sejersted et al., 1982; Sharp et al., 1986; Tesch and Karlsson, 1984). The sprint trained athletes had higher FT fibre area, greater glycolytic enzyme activity, and higher lactate levels following exhaustive exercise.

Through tracer experiments using [U- ^{14}C] lactate in rats (Brooks and Divine-Spurgeon, 1982; Brooks and Gaesser, 1980; Donovan and Brooks, 1983), sodium L(+)-[1- ^{14}C] lactate in dogs (Depocas et al., 1969; Eldridge, 1975) and Na^+ -D,L(+)-2-3-(^{13}C) lactate in humans (Hubbard, 1973; Mazzeo et al., 1982), researchers have found that lactate does not just accumulate in the body during exercise, nor does the body stop producing lactate below a certain work intensity. This indicates that lactate production levels are in a constant state of flux. Blood lactate concentration reflects the balance of a dynamic steady state (Brooks and Divine-Spurgeon, 1982).

2.1.2 Removal

Lactate produced in the muscle cell diffuses into the blood. Lactate is a relatively small and easily diffusible molecule (Hermansen, 1971) which permeates across the cell membrane in an ionized form (Hirche et al., 1973). Lactate is removed from the blood through a number of different sites. These removal sites include the heart, kidneys, spleen, brain, liver, and skeletal muscles (McGrail et al., 1977). The heart is responsible for about 10% of the lactate removed during exercise. The kidneys and brain are minor removal sites and contribute relatively little to the lactate removal process. The liver converts about 25% of blood lactate to glucose during rest and 12 - 20% during exercise. Rowell et al. (1966) studied subjects during treadmill exercise requiring 48% to 70% of $\dot{V}\text{O}_{2\text{max}}$. Through constant infusion of indocyanine green, splanchnic removal of lactate was calculated. Researchers concluded that up to 50% of lactate produced during moderate exercise is removed by hepatic-splanchnic tissues. Subsequent studies did not concur with Rowell's findings. Hermansen et al. (1975) observed that the major removal site for lactate during exercise is the skeletal muscle. As much as 75% of blood lactate produced during exercise is metabolized by the working (Minare and Forichon, 1975) and non-working skeletal muscle (Poortmans et al., 1978).

Tracer studies indicate that lactate turnover is directly related to metabolic rate (Brooks et al., 1973; Brooks and Divine-Spurgeon, 1982; Brooks and Gaesser, 1980; Depocas et al., 1969; Donovan and Brooks, 1983; Eldridge, 1975; Issekutz et al., 1976; Jorfeldt, 1970; Mazzeo et al., 1982). Therefore if the metabolic rate is increased, lactate production increases as well as lactate removal. Jorfeldt et al. (1978) found the maximal capacity for lactate release from the muscle to be approximately 5 mmol/min. This occurred under conditions of heavy exercise, at muscle lactate concentrations of 4 mmol/kg wet weight or higher. Concentration of lactate in the blood increases linearly until the lactate inflection point is reached, where lactate entry into the blood exceeds its removal (Brooks and Fahey, 1984). Concentration of lactate in the blood decreases if removal exceeds production. Issekutz (1984) illustrated this by pharmacologically lowering lactate production through the use of β -adrenergic blockers. Inderal was infused into exercising dogs. The inderal inhibited lactate production causing a rise in the metabolic clearance rate of lactate. Donovan and Brooks (1983) and Fremmet et al. (1975) used infusions of $[U-^{14}C]$ lactate to study the effects of endurance training on rats. They found that endurance training effected the oxidation and turnover rate of lactate, not its production. The increased turnover and oxidation rates combined to produce a high lactate clearance rate.

The lactic acid produced in the FT twitch muscle fibres is primarily oxidized by the ST muscle fibres which have a higher concentration of heart specific LDH isozymes (Bonen et al., 1978). This study found a significant positive correlation ($r=0.54$), between the lactate removal rate and the percentage of ST fibres. The above study had subjects exercise at high intensity (89.4% of $\dot{V}O_{2max}$), for six minutes. Twenty minutes of active recovery was employed at 39.1% of $\dot{V}O_{2max}$. The highest lactate removal rates were found in subjects with a high percentage of ST fibres.

McGrail et al. (1978) studied lactate removal rates in comparison to the relative muscle mass used in active recovery. Subjects performed six minutes of high intensity exercise at 90% of $\dot{V}O_{2max}$. Max $\dot{V}O_2$ was determined on a cycle ergometer for legs,

arms, and combined arm-leg exercise. Recovery rates were 26.8% of $\dot{V}O_2\text{max}$ for arm exercise, 26.8% of $\dot{V}O_2\text{max}$ for leg exercise, and 29% of $\dot{V}O_2\text{max}$ for combined arm-leg exercise. Lactate removal rates were significantly greater for the active recovery situations compared to rest. The leg condition was found to elicit a significantly faster lactate removal rate than the arm condition. The arm-leg condition produced the same results as the legs only condition. Due to the researchers lowering of the intensity at which the arms worked during the arm-leg recovery condition, lactate removal rates may have been decreased for this condition. Thus it was concluded that lactate removal rate is related to the muscle mass involved in the recovery.

2.2 Exercise Intensity and Lactate Removal

Early investigations by Margaria and Edwards (1934) and Margaria et al. (1933) which separated the oxygen debt into fast (alactacid) and slow (lactacid) components, lead to the belief that lactate was a "dead end metabolite" that was only formed and not removed during exercise (Brooks and Fahey, 1984). Subsequent studies by Newman et al. (1937) and Rammal and Strom (1949) dealing with recovery metabolism showed that this hypothesis was untrue.

Newman et al. (1937) and Rammal and Strom (1949) had subjects exercise during recovery periods subsequent to exhaustive exercise. Both investigations found that the lactate removal rate was augmented through the use of active recovery compared to resting recovery.

Gisolli et al. (1966) tested four subjects by having them run to exhaustion on a motor driven treadmill. The protocols were selected according to the subjects individual ability. Two of the subjects ran at 20.9 km/hr on a 2% grade while the other two ran at 19.3 km/hr on a 2.5% grade. Each subject ran to exhaustion. Recovery rates were set at 10.5 km/hr for the former two subjects while one of the latter subjects walked at 6.4 km/hr on a 5% grade while the other walked at 7.2 km/hr on a 2.5%

grade. The recovery exercise intensity represented 52 - 53% of the first two subjects aerobic capacity while the second two subjects worked at 38 - 42% of their aerobic capacity. All subjects recovered for 35 - 50 minutes on the treadmill. End lactate values were 19.0, 18.0, 15.5, and 57.5 mg% for subjects 1 to 4, respectively. Probably the high value for subject 4 compared to the others was due to the initial lactate value achieved, the amount of recovery time, or the subjects fitness level. Recovery time is the most probable explanation in this case since subject 4 was in the active recovery state for 35 minutes as opposed to the maximum recovery time of 50 minutes.

Hermansen and Stensvold (1972) studied lactate removal rate at recovery intensities of 30, 60, 70, and 80% of the subjects $\dot{V}O_{2max}$. An optimal lactate removal response of 8.0 mg%/min was predicted to occur at 63% of the subjects $\dot{V}O_{2max}$. Spath (1979) found lactate removal most expedient at 59.2% of $\dot{V}O_{2max}$. At this recovery intensity, lactate removal was 9.25 mg%/min. Timson (1976) compared rest, walking, and jogging recovery after 10 minutes of exhaustive exercise. After 15 minutes, lactate levels were significantly lower in the walking and jogging recovery conditions compared to the rest condition. Walking recovery intensity was 24% of $\dot{V}O_{2max}$ while jogging recovery was performed at 61% of $\dot{V}O_{2max}$. Similar optimal removal intensities were observed by Bonen and Belcastro (1976). Rest, self-selected continuous jogging, and free intermittent jogging were used in the recovery phase of the experiment. The optimal lactic acid removal rate in the above study was found to be 7.1 mg% per minute and occurred at 57.1 - 70.0% of the subjects $\dot{V}O_{2max}$.

Davies et al. (1970) exercised four subjects for six minutes at 80% of their $\dot{V}O_{2max}$. The subjects were then exercised at four different recovery intensities, 15, 30, 45, and 60% of $\dot{V}O_{2max}$. Lactate removal was better at 30% and 45% of the subjects maximum aerobic capacity than at the low (15%) and high (60%) recovery intensities.

Belcastro and Bonen (1975) and Dykstra et al. (1973) found similar results to Davies et al. (1970). In the former study, subjects were exercised at 89% of $\dot{V}O_{2max}$ for six minutes followed by recovery at rest, 30, 45, 60, or 80% of $\dot{V}O_{2max}$. The most

expedient removal rates occurred at 29.7% and 45.3% of $\dot{V}O_{2max}$. The latter study had subjects exercise for eight minutes at 90% of $\dot{V}O_{2max}$. Recovery was performed at rest, 25, 40, 55, and 70% of $\dot{V}O_{2max}$. Disappearance of lactic acid was most rapid between 25 and 47% of $\dot{V}O_{2max}$.

McLellan and Skinner (1982) used the aerobic threshold and fractions of the subjects $\dot{V}O_{2max}$ as markers for work intensity recovery levels. Expressing active recovery intensity as aerobic threshold $\pm\%$ $\dot{V}O_{2max}$ was found to decrease inter-individual variance. Subjects were exercised for 10 minutes at 90% of $\dot{V}O_{2max}$. Recovery intensity was expressed as the subjects aerobic threshold minus 30, 20, or 10% of $\dot{V}O_{2max}$. Rest, aerobic threshold and aerobic threshold plus 10% of $\dot{V}O_{2max}$ were also used as recovery intensities. Lactate removal was fastest when recovery exercise was performed at the condition described as the aerobic threshold minus 10% of $\dot{V}O_{2max}$. This intensity was equivalent to approximately 43% of $\dot{V}O_{2max}$. Compared to the resting condition, lactate removal was facilitated at recovery intensities between 27 - 58% of $\dot{V}O_{2max}$.

These figures concur with data collected by Koutedakis and Sharp (1985). They had rowers sprint 2000 meters then recover at 40% and 60% of the maximum stroke rate attained in the sprint. Both active recovery conditions produced significantly greater lactate turnover than the resting condition. The 40% condition was also significantly more effective than the 60% condition.

Stamford et al. (1978) experimented with different recovery rates when only one leg was exercised at supramaximal intensity. In this study alternating legs at different recovery rates were used. One recovery treatment also involved breathing 100% oxygen during the recovery period. The treatments in which recovery $\dot{V}O_2$ levels were at approximately 30% of the subjects maximum were significantly more effective than higher intensity recovery rates as well as the 100% oxygen condition.

A subsequent study by Stamford et al. (1981) investigated the effectiveness of active recovery above and below the anaerobic threshold. The recovery conditions

were rest, 40%, and 70% of $\dot{V}O_2\text{max}$. In this study, lactate levels at rest, 40% and 70% of $\dot{V}O_2\text{max}$ were used as baselines for the different recovery conditions. If the individual baselines were used as endpoints for lactate removal then the 70% condition was most effective. If return to resting baseline is used, then the 40% condition was more efficient. Since blood lactate levels peaked and started their decline sooner when the 70% condition was employed, the authors concluded that for active recovery it may be optimal to start at a higher intensity and progressively decrease the recovery work load. Along this line of thinking Dodd et al. (1984) experimented with a combination of high and low recovery rates. Following 50 seconds of maximal work on a cycle ergometer, subjects recovered for 40 minutes: 1) passively; 2) cycling at 35% $\dot{V}O_2\text{max}$; 3) cycling at 65% $\dot{V}O_2\text{max}$; 4) cycling at 65% $\dot{V}O_2\text{max}$ for 7 minutes followed by 33 minutes at 35% $\dot{V}O_2\text{max}$. Lactate disappearance was significantly greater in the 35% and combination 65% - 35% recovery conditions than the passive or 65% recovery conditions. No significant difference was observed between the 35% and combination recovery condition.

Bonen et al. (1979) using information from previous studies (Bonnen et al., 1978; Eldridge, 1975; Hermansen and Stensvold, 1972; McGrail et al., 1978) identified three factors in humans which may influence lactate removal rate. These factors were ST muscle fibre content, blood lactate concentration at the cessation of exercise, and the intensity of the recovery exercise. Physical condition is thought by some to be a factor but was found to have no significant effect on lactate disappearance (Evans and Cureton, 1983). The above factors were identified as statistically independent and therefore should contribute uniquely to the removal rate of lactate. From these statistically independent factors the researchers developed a regression equation to predict optimal recovery intensity.

To examine the validity of the equation, Bonnen et al. (1979) had their subjects perform high intensity exercise at 90% of $\dot{V}O_2\text{max}$ for six minutes. Recovery exercise was performed at approximately 40% of $\dot{V}O_2\text{max}$. The correlation between the

predicted lactate removal rate and the observed lactate removal rate was 0.91.

Bonen and Belcastro (1977) reported that active recovery could reduce lactate levels by as much as 88% in 20 minutes as opposed to a 50% reduction in lactate levels in a 20 minute period of passive recovery. This is important for the athlete who must perform repeated bouts of high intensity anaerobic exercise within one hour of each other.

From the previously mentioned studies the optimal recovery intensity for running would be from 55 - 70% of the subjects $\dot{V}O_{2\max}$ and 30 - 45% of $\dot{V}O_{2\max}$ for subjects performing a cycling task (Bonon and Belcastro, 1976). These recovery intensities seem to be the most effective, but differences in individual physiological make-up, such as the percentage of ST muscle fibres, LDH activity, LDH isozyme concentration and physical fitness (Bonon and Belcastro, 1977; Bonon et al., 1979; Bonon et al., 1978; Mann and Garrett, 1978; Tesch et al., 1978) make pinpointing an optimal intensity of recovery exercise difficult.

2.3 Specificity of Exercise Mode

Usually when studying active recovery, the mode of recovery is the same as the initial exhaustive exercise. If active recovery is used, it may be necessary and sometimes beneficial to use exercise modes that differ somewhat from the initial form of exertion. When using alternative modes of active recovery it is important to try and use the same or close to the same prime movers and muscle mass as was being used in the original activity.

McGrail et al. (1978) studied the effectiveness of using the arms, legs, and both in combination as a recovery mode after high intensity cycling. When the arms or the legs alone were used, the optimum recovery intensity was 26.8% of $\dot{V}O_{2\max}$.

Work intensity was 29% of $\dot{V}O_{2\max}$ when the arms and legs were used in combination. The leg recovery mode was found to be significantly more effective than

the arm mode of recovery. Arms and legs in combination were not significantly different from the legs alone condition. The reason for this is that even though the metabolic rate was higher in the combination mode, the muscle mass of the arms was not great enough to elicit a significantly greater effectiveness in lactate removal.

Boileau et al. (1983) found that when using a bicycle ergometer versus a treadmill, that the treadmill condition was slightly but not statistically more effective at lactate removal. Optimal recovery intensities were approximately 40% of $\dot{V}O_{2\max}$. Regression equations were derived based on the relationship between the rate of lactic acid removal and recovery exercise intensity. From these equations, it was calculated that optimal lactate removal occurs at 35.9% of $\dot{V}O_{2\max}$ on a bicycle ergometer and 32.5% of $\dot{V}O_{2\max}$ on a treadmill. This information is in agreement with the findings of Belcastro and Bonen (1975) with regards to the bicycle ergometer. The optimal recovery rate for running is however below that observed by Hermansen and Stensvold (1972) who reported the removal rate was highest at 63% of $\dot{V}O_{2\max}$.

Siebers and McMurray, (1981) studied swimming and walking as recovery modes after swimmers had exercised at 90% of $\dot{V}O_{2\max}$ for two minutes on a swimming ergometer. Lactate levels were reduced by 38.5% during the walking recovery and 53.3% during the swimming recovery. Swimming recovery was performed at 43% of the athletes aerobic capacity while the walking recovery was performed at 33% of aerobic capacity. The probable reason for the improved lactate turnover for the swimming condition was the higher work recovery intensity and the sport-specific nature of the recovery task. Krukau et al. (1987) also studied active recovery in swimmers. After a maximal 200m crawl, subjects recovered by swimming (complete movement and legs only) and on a cycle ergometer. The swimming recovery conditions were performed at a self selected pace while cycling was performed at 50% of the 4 mmol/l lactate threshold. Lactate half-life times were calculated to be 5.72, 8.25, and 12.83 min for the complete movement, legs only, and cycle ergometer recovery modes, respectively.

The results of Siebers and McMurray (1981) differ from those of Watson and Hanley (1986) who compared bench-stepping to skating as forms of active recovery from two high intensity skating bouts. Skating did not elicit a significantly greater lactate removal rate than bench-stepping. Both modes had greater lactate clearance than the resting mode. An explanation for this may be that there is a significant amount of glide while skating and even though the heart rates were kept the same (120 beats per minute) for both activities, inadequate muscle recruitment could be the reason for the sport-specific activity not having a more efficient lactate removal rate (Watson and Hanley, 1986).

2.4 Performance and Lactate Levels

Costill et al. (1984) and Spriet et al. (1985) studied performance after blood parameters had been manipulated through pharmacological means or changes in CO_2 tension. In the former study, subjects were given sodium bicarbonate to artificially lower resting p H . Endurance time was measured after five maximal cycling bouts. The low p H group recorded significantly better performance times. The latter study observed the isometric tension decay of rat hind quarters in three conditions: control, metabolic acidosis, and respiratory acidosis. Metabolic acidosis was induced by decreasing the perfusate $[\text{HCO}_3^-]$. Respiratory acidosis was induced by increasing CO_2 tension. Isometric tension decay was significantly greater in both acidosis conditions.

McCartney et al. (1983) studied the effects of placebo, metabolic acidosis, respiratory acidosis, and metabolic alkalosis on peak power and maximal work in a 30 second cycle ergometer test. Metabolic acidosis was induced by ingestion of ammonium chloride, respiratory acidosis was induced through 5% CO_2 inhalation, and metabolic alkalosis was induced by ingestion of sodium bicarbonate. In the acidosis conditions subjects produced lower peak power and did less total work than the alkalosis or placebo conditions.

Hogan and Welch (1984) studied performance on a bicycle ergometer after the subject's lactate concentrations had been manipulated by the inhalation of hypoxic, hyperoxic, and normoxic gas mixtures during the first exercise interval. The hypoxic condition produced higher lactate levels. Performance times were significantly lower even after a four minute rest period.

Weltman et al. (1977; 1979) conducted similar studies which compared different conditions of recovery and subsequent anaerobic performances after the recovery conditions. Weltman et al. (1977) compared active (1.0 Kg., 60 rpm) versus passive recovery, breathing 100% oxygen versus room air, and 10 versus 20 minutes of recovery. Significant differences were found between the passive and active recovery conditions and for the 10 minutes versus 20 minutes of rest. Performance was enhanced in both the 10 and 20 minute active recovery condition. Though the recovery intensity was low, lactate removal rates were far higher in the active recovery conditions. Recovery by breathing 100% oxygen produced no difference in lactate removal rates.

A subsequent study by Weltman et al. (1979) was similar in design and results except that the active recovery intensities were higher (40 and 60% of $\dot{V}O_{2max}$) and the recovery times were kept constant. The difference in results were that the 100% oxygen condition resulted in increased lactate turnover rates and unlike Weltman et al. (1977), total power output was not influenced by the experimental conditions.

Green et al. (1979a) caused endogenous increases in plasma lactate by having subjects perform four intermittent bouts of supramaximal arm work while they were simultaneously conducting submaximal leg work. Lactate values measured while the legs worked alone were used as control values. The arm work was performed for one minute at five minute intervals. Arm ergometry commenced after the subjects had cycled for 60 minutes. Lactate values increased significantly in the vastus lateralis in the arm-leg condition as compared to the control condition. The increased lactate levels in the legs caused by the arm work decreased, but did not return to control levels

even after the final 40 minutes of submaximal cycling. The immediate and sustained high lactate levels would be a probable cause for a decrease in performance.

Klausen et al. (1972) and Tesch and Wright (1983) both found that endogenous increases in lactate caused decrements in performance. Klausen et al. (1972) used five minutes of heavy arm exercise to increase lactate levels before having subjects cycle to exhaustion. Oxygen uptake was not affected but a reduction was observed in total work output. Tesch and Wright (1983) had subjects perform 50 consecutive maximum voluntary knee extensions. Following a 40 second rest period five additional maximal contractions were executed. Peak torque decreased 67% as a result of the first 50 contractions. Average post recovery torque was 70% of the initial value.

Both Karlsson et al. (1975) and Yates et al. (1983) observed that exhaustive exercise performed by one part of the body caused increased lactate levels in other parts of the body. In the former study, both blood and muscle lactate levels rose in the arms even though the legs were being exercised and vice versa. In the latter study, increases in blood lactate levels of the arms were caused by a one minute maximal effort on a cycle ergometer. Performance was decreased in the non-exercised limbs in both studies.

2.5 Energetics of Ice Hockey

Through the use of time-motion analysis and heart rate telemetry, intensities ranging from 70% to 90% of the maximal heart rate values measured during a $\dot{V}O_2$ max test were recorded during a hockey game (Green et al., 1976; Paterson et al., 1977). The above figures apply to forwards and defensemen. The high intensities during the on-ice shift of a player result in high concentrations of muscle lactate (Green, 1978). If the lactate accumulates at a rate that exceeds removal, the substrate reaches a level where it interferes with a player's performance (Hogan and Welch, 1984; Karlsson et al., 1975; Klausen et al., 1972; Tesch and Wright, 1983; Yates et al., 1983).

Green et al. (1976) observed that each on-ice shift of hockey lasted between 81 and 88 seconds. This period was broken up into 37.5 to 45.5 seconds of play and 25.7 to 28.7 seconds of stoppages in play. The experimental times are similar to those recorded by Green and Houston (1975). Shift length in this case was 75 to 85 seconds with continuous play lasting 35 to 40 seconds and stoppages lasting 25 to 30 seconds.

If the assumption is made that during the periods of continuous play, the athletes perform close to or above 100% intensity, then energy from glycolysis is needed to meet the player's energy demands. Adenosine triphosphate (ATP) and creatine phosphate (CP) stores are completely depleted in approximately 6 seconds (Bergstrom et al., 1971; McArdle et al., 1981). As a result of glycolysis and depending on the biochemical and physiological profiles of the energy systems, pyruvate will either be reduced to lactate or oxidized to form acetyl-CoA (Lehninger, 1984).

If the player obtains only 3.5 to 4 minutes rest between shifts (Green and Houston, 1975) and the half-time for lactate removal is 20 minutes (Bonen and Belcastro, 1977) in a passive condition, lactate will accumulate more quickly than it can be removed from the system. This causes a decrement in performance over time. If lactate levels can be used as a measure of work output (Jacobs, 1986) then a performance decrement is illustrated by the fact that lactate production values measured at the end of the third period are usually lower than those measured at the end of the first or second period (Green et al., 1976; 1978a).

With a trend towards shorter shifts and fewer play stoppages, higher intensity work output should produce higher lactate levels at the end of a shift. Bouts of six intermittent repetitions of all-out skating have elicited blood lactate values of 10.7 mmol/l (Montgomery et al., 1988) and 11.5 mmol/l (Watson and Sargeant, 1986). Watson and Hanley (1986) observed lactate levels of 12.1 mmol/l after subjects completed six 45 second maximal skating trials. The subjects rested passively on the bench between trials.

Daub et al. (1983) reported that ice hockey training did not significantly improve aerobic power. Green et al. (1979b) observed hypertrophy in the FT muscles of hockey players at post-season testing. This may lead to improved anaerobic endurance. Even if hockey training increases anaerobic endurance as observed by Green and Houston (1975), the player is not able to oxidize the lactate accumulated between shifts. The ever increasing build-up of lactate in the muscle and blood may become a limiting factor in the performance of the hockey player (Green, 1979).

Chapter III

Methods

This chapter is divided into the following sections:

- 3.1 Selection of Subjects
- 3.2 Treatment of Subjects
- 3.3 Continuous Cycle Ergometer $\dot{V}O_2$ max Test
- 3.4 Intermittent On-Ice Test
- 3.5 Active Recovery Conditions
- 3.6 Passive Recovery Condition
- 3.7 Collection of Data
- 3.8 Experimental Design and Statistical Analysis

3.1 Selection of Subjects

Subjects for this study were 11 male hockey players of varsity or intramural level. They were students at McGill University and ranged in age from 20 to 25 years.

3.2 Treatment of Subjects

All subjects were asked to participate in four testing sessions (one $\dot{V}O_2$ max test on a cycle ergometer, and three intermittent on-ice tests). The $\dot{V}O_2$ max test was performed in a laboratory setting prior to the on-ice tests, which were performed in a completely randomized order. During the on-ice tests, two modes of active recovery (skating and cycling) were employed along with a passive recovery session which was used as a control condition. All data and blood samples for the on-ice tests were collected in the McGill Arena. Subjects were given at least one day of recovery between each test. All testing was completed within two weeks.

Subjects were asked to refrain from eating and drinking (except water), for two hours prior to testing. For the laboratory test, the subjects arrived in proper gym wear. For the on-ice tests, subjects were assigned in groups of six to one of two testing times that were convenient for them on the testing day. Subjects were required to wear gloves and helmet, and carry a stick for the on-ice tests. Informed consent was obtained from each subject prior to the first testing session.

Subjects were encouraged to warm-up before each of the testing sessions. Verbal explanation as to the nature of the task was given by the investigators to the subjects at the beginning of each testing session. Subjects were encouraged verbally by investigators to put forth a maximal effort throughout all testing sessions. Prior to each of the on-ice segments of the test, subjects were informed that if any "holding back" or "pacing" was detected, the test would be considered unacceptable and a re-trial would have to be performed. Detection of pacing was accomplished by averaging the times of the first and second, second and third, and third and fourth trials in the on-ice portion of the test. The subject was considered to be pacing if the average time of the third and fourth trials was less than that of the average time for the second and third trials, or if the average time of the second and third trials was less than the average time of the first and second trials.

Between each on-ice portion of the test, subjects performed one of three recovery conditions. The recovery conditions were: cycling, skating, or resting in a sitting position on the bench.

Blood samples were drawn from each subject before their first on-ice trial and after the subjects last recovery bout. Heart rates were continuously monitored throughout all tests.

3.3 Continuous Cycle Ergometer $\dot{V}O_{2\max}$ Test

All subjects performed a cycling ergometer test to volitional exhaustion using the following protocol. The subject pedaled at a rate of 60 rpm for the duration of the test. The initial load was set at one kp and was increased by 0.25 kp every minute until the subject was exhausted. Exhaustion was determined when the pedal rate of 60 rpm could no longer be sustained. Verbal encouragement was offered by the investigator throughout the test. The subject's oxygen consumption was measured using a Roxon Metabolic Cart.

3.4 Intermittent On-Ice Test

A modified version (Rhodes et al., 1985) of the Repeat Sprint Skate (RSS) hockey fitness test (Reed et al., 1979), was used for the on-ice portion of the investigation. The test consists of four repetitions of maximal skating. Each subject was required to sprint 91.4 metres (from goal line to goal line and back to the blue line closest to the starting point) at 30 second intervals. Between repetitions, the subject glided slowly to the starting line (goal line) and waited for a whistle to initiate the next repetition. A five second warning was given before the start of each repetition. Since the subjects start each repetition every 30 seconds, the faster a repetition is completed the more time the subject has to rest before starting the next repetition. For example, subjects who completed a repetition (91.4 metres) in 14 seconds, had 16 seconds of recovery before having to start the next repetition.

Indices of performance on the RSS test include a speed index (measured on the first repetition by timing the subject from goal line to goal line, 54.9 metres), an anaerobic endurance index (total time to complete the four repetitions), and a drop-off index (the difference between the slowest and fastest repetitions). Therefore, on the first repetition, two times were obtained; one for the speed index (54.9 metres) and for

the complete distance (91.4 metres). Subjects performed four repetitions to constitute one skating shift. After four repetitions were completed, the subjects were randomly assigned to one of the three recovery conditions (skating, cycling, or resting on the bench) for six minutes. This procedure was repeated for a total of six shifts. Heart rate was monitored throughout the test. The indices to be computed from the on-ice test were:

Speed index: Time for first 54.9 metres of each shift.

Anaerobic endurance index: Sum of the times for the four repetitions of each shift.

Drop-off index: The difference between the fastest and the slowest repetitions of each shift.

3.5 Active Recovery Conditions

At the completion of each simulated shift (four repetitions of the RSS test), subjects participated in six minutes of active recovery. Skating was used as one form of active recovery. The subject skated at a self-selected pace around an oval course (120 metres), that was marked out on one side of the skating rink. The subject skated in the same direction for the duration of the recovery period. The course was marked every 10 metres by pylons in order to assist investigators in gauging accurately the distance that the subject covered in the six minute recovery period. Average skating speed was calculated in m/min for the six minutes of recovery. Finger tip blood samples were obtained five minutes after the last recovery period and analyzed for lactate concentration. Heart rate was monitored throughout the recovery period. The variable which was computed from the skating recovery condition was:

$$\text{Average Speed (m/min)} = \frac{\text{total distance covered in metres}}{\text{six minutes}}$$

Cycling was also used as an active recovery mode. Subjects pedaled a modified Monark cycle ergometer for six minutes at 60 rpm. The resistance was set so that the subject was cycling at 40% of $\dot{V}O_2\text{max}$. The ergometer's pedals were modified in order to permit the subject to cycle while wearing skates. Seat height was adjusted in order to allow for full leg extension with the ankle at 90 degrees. Subjects remained seated while cycling. Pedal cadence was achieved through the use of a metronome set at 120 beats per minute. In this manner if the subjects foot was at the bottom of a revolution each time the metronome sounded the required pedal cadence of 60 rpm was attained. Finger tip blood samples were obtained five minutes after the last recovery period and analyzed for lactate concentration. Heart rate was monitored throughout the recovery period.

3.6 Passive Recovery Condition

The passive recovery condition consisted of the subject coming off the ice after the RSS test and sitting quietly on the bench. Finger tip blood samples were obtained five minutes into each recovery period of this condition and analysed for lactate concentration. Heart rate was monitored throughout the recovery period. This condition was used as a control.

3.7 Collection of Data

Data collection were performed in a systematic manner. The administration of the laboratory test (continuous aerobic $\dot{V}O_2\text{max}$ test) was done on a modified Monark cycle ergometer. Expired gas volumes were analysed using a Roxon Metabolic Cart. The following variables were calculated from the expired gas volumes: $\dot{V}I$, $\dot{V}O_2$ Mets, $\dot{V}CO_2$, RQ, and ventilatory equivalent for oxygen.

Measurements were continuously recorded every 15 seconds throughout the duration of the test. Fifteen second values were displayed on-line with the use of an Apple IIe computer and Okidata micro-82A printer.

For the on-ice tests six research assistants aided in data collection. They were familiar with the experimental procedures and were practiced at taking finger tip blood samples.

Subjects were randomly assigned to a recovery condition. Investigators individually monitored one subject throughout each segment of the testing procedure. Subjects were tested in groups of six (in order to provide a competitive environment) at 60 minute intervals. Each subject was tested three times, (cycling recovery, skating recovery, and passive recovery).

In the active recovery conditions, two blood samples were drawn from each subject. The first sample was taken before the first on-ice segment commenced. This sample served as a baseline value for each subject. The second sample was taken following the recovery condition of the sixth shift. For the passive recovery condition, in addition to the pre test sample drawn, blood samples were drawn five minutes into the recovery period of each shift. Samples were drawn from the finger tip, which had been swabbed with alcohol in order to insure that there was no contamination from sweat and to minimize the possibility of infection. The blood was allowed to drip freely into an antiseptic receptacle. The first drop was discarded to minimize the chance of dilution by alcohol. Sample sizes were 100 ul in volume. The whole blood was immediately injected into a YSI (Yellow Springs Instrument) Model 27 lactate analyzer with a 25 ul syringe. The instrument was calibrated prior to each testing session using 5.1 mmol/l and 15.0 mmol/l standards. Duplicate lactate measurements were obtained for each test.

Subjects heart rates were monitored and stored using a Polar Electro PE 3000 Sport Tester. The unit consists of telemetry transmission device, which is strapped to the chest, and a receiving unit which is strapped to the wrist.

3.8 Experimental Design and Statistical Analysis

Descriptive statistics (means and standard deviations) were calculated for the following dependant variables: speed index, anaerobic endurance index, drop-off index, pre-test lactate level and post-test lactate level. The first hypothesis, which is concerned with the effect of different recovery modes on post test lactate levels, was examined using a one-way analysis of variance(ANOVA) with repeated measures on the subjects. The recovery conditions included passive, skating, and cycling. Lactate concentrations were measured pre and post-test. A diagram of the experimental design is presented in Table 3.1.

Table 3.1 Experimental Design for Hypothesis 1.

Tests	Passive	Skating	Cycling
Subjects			
1			
2			
3			
.			
.			
.			
11			

The second, third and fourth hypothesis are concerned with the effect of recovery modes on performance. These hypothesis use the speed index (hypothesis two), the anaerobic endurance index (hypothesis three), and the drop-off index (hypothesis four) as the dependant variables. The experimental design is a 3 x 6 factorial ANOVA with repeated measures on both factors. A diagram of the experimental design is presented in Table 3.2.

Table 3.2 Experimental Design for Hypothesis 2, 3, and 4.

Tests	Passive	Skating	Cycling
Shifts	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
Subjects			
1			
2			
3			
.			
.			
11			

Any significant differences ($p < .05$) observed were examined using Tukey's Honestly Significant Difference (HSD) post hoc procedure to determine the exact location of the performance differences.

The statistical procedures that were used to evaluate the four hypothesis are summarized in Table 3.3.

Table 3.3 Summary of Hypothesis and Statistical Analysis.

Comparison	Statistical Analysis
Hypothesis 1 - Blood Lactate	
Concentrations following recovery conditions	one-way ANOVA (repeated measures)
Hypothesis 2 - RSS test	
Speed index variable following recovery conditions	3 X 6 factorial ANOVA (repeated measures)
Hypothesis 3 - RSS test	
Anaerobic endurance index variable following recovery conditions	3 X 6 factorial ANOVA (repeated measures)
Hypothesis 4 - RSS test	
Drop-off index variable following recovery conditions	3 X 6 factorial ANOVA (repeated measures)

Chapter IV

Results

In this chapter, the results are summarized as follows:

4.1 Characteristics of the Subjects

4.2 Performance Indices for the RSS Test

4.3 Blood Lactate Measurements

4.4 Heart Rate Measurements

4.1 Characteristics of the Subjects

The subjects for this study were eleven male hockey players, ranging in ability from intramural to varsity level. Means, standard deviations, and ranges for the age, height, weight, and $\dot{V}O_2\text{max}$ of the subjects are presented in Table 4.1. The mean age was 21.8 years, height was 181.0 cm, weight was 79.3 kg, and $\dot{V}O_2\text{max}$ was 54.5 ml/kg•min.

Table 4.1 Characteristics of the Subjects (n=11).

Variable	Mean	S.D.	Range
Age (years)	21.8	1.7	20 - 25
Height (cm)	181.0	5.5	173.0 - 193.0
Weight (kg)	79.3	7.2	66.0 - 95.5
$\dot{V}O_2\text{max}$ (ml/kg•min)	54.5	5.4	48.1 - 64.9

4.2 Performance Indices for the RSS Test

The results for the speed index of the RSS test are summarized in Table 4.2 with the statistical analysis (factorial ANOVA) following in Table 4.3. There was no significant difference in the speed index values among the three experimental conditions. The significant F value of 5.32 ($p < 0.01$) for the "shift" variable was examined by post hoc analysis (Tukey test). Compared to shift 1, the hockey players were significantly slower ($p < 0.01$) on shifts 2, 3, 4, 5, and 6. There was no significant interaction between shifts and conditions.

The results for the anaerobic endurance index of the RSS test are summarized in Table 4.4 with the factorial ANOVA shown in Table 4.5. The F value (5.14) for the "conditions" variable was significant ($p < 0.02$). Post hoc analysis revealed that both skating and cycling recovery resulted in significantly faster times ($p < 0.05$) than the passive condition. There was a significant F value of 18.66, ($p < 0.01$) for the "shift" variable. Post hoc analysis revealed that compared to shift 1, the hockey players were significantly slower ($p < 0.01$) on shifts 2, 3, 4, 5, and 6.

There was a significant interaction for the "conditions X shifts" variable. This interaction is shown in Figure 4.1. Post hoc analysis revealed that the skating and cycling recovery conditions were significantly ($p < 0.05$) faster than the passive recovery condition in shifts 4, 5, and 6. The three recovery modes produced similar times during shifts 1, 2, and 3.

The results for the drop-off index of the RSS test are summarized in Table 4.6 with the factorial ANOVA shown in Table 4.7. A significant F value of 6.54, ($p < 0.01$) was found for the "conditions" variable. A post hoc Tukey test established that both the skating and cycling recovery conditions attributed to significantly ($p < 0.05$) less drop-off in both active modes of recovery compared to the passive mode of recovery. There was no significant difference in drop-off times among the six shifts. There was no significant interaction between conditions and shifts.

Table 4.2 Results ($n=11$, $\bar{x} \pm S.D.$) for the Speed Index(s).

Shift	Passive	Skating	Cycling
1	7.68 $\pm$ 0.37	7.82 $\pm$ 0.60	7.56 $\pm$ 0.42
2	7.68 $\pm$ 0.29	7.83 $\pm$ 0.50	7.80 $\pm$ 0.46
3	7.83 $\pm$ 0.43	7.96 $\pm$ 0.35	7.86 $\pm$ 0.56
4	7.90 $\pm$ 0.45	8.22 $\pm$ 0.46	7.79 $\pm$ 0.54
5	8.00 $\pm$ 0.49	8.14 $\pm$ 0.33	7.89 $\pm$ 0.50
6	7.85 $\pm$ 0.39	8.02 $\pm$ 0.38	7.78 $\pm$ 0.46

Table 4.3 Factorial ANOVA for the Speed Index.

Source	SS	df	MS	F	Prob.
Conditions	1.76	2	0.88	2.15	0.14
Within Subjects	18.48	10	1.88		
Error	8.21	20	0.41		
Shifts	2.48	5	0.50	5.32	0.01
Error	4.67	50	0.09		
Conditions X Shifts	0.62	10	0.06	1.24	0.27
Error	5.02	100	0.05		
Total	41.24	197			

Table 4.4 Results ($n=11$, $\bar{x} \pm S.D.$) for the Anaerobic Endurance Index(s)

Shift	Passive	Skating	Cycling
1	60.37 $\pm$ 2.42	60.28 $\pm$ 2.08	59.98 $\pm$ 1.64
2	62.06 $\pm$ 2.10	61.36 $\pm$ 2.18	60.87 $\pm$ 1.99
3	63.48 $\pm$ 2.79	61.94 $\pm$ 2.26	61.94 $\pm$ 2.22
4	64.07 $\pm$ 2.84	62.52 $\pm$ 2.03	61.76 $\pm$ 2.33
5	64.31 $\pm$ 2.62	62.33 $\pm$ 2.27	62.13 $\pm$ 2.25
6	64.63 $\pm$ 2.69	62.52 $\pm$ 2.21	62.02 $\pm$ 2.47

Table 4.5 Factorial ANOVA for the Anaerobic Endurance Index

Source	SS	df	MS	F	Prob.
Conditions	105.50	2	52.75	5.14	0.02
Within Subjects	552.03	10	55.20		
Error	205.47	20	10.27		
Shifts	204.73	5	40.95	18.66	0.01
Error	109.76	50	2.19		
Conditions X Shifts	24.99	10	2.50	2.50	0.01
Error	99.82	100	1.00		
Total	1327.30	197			

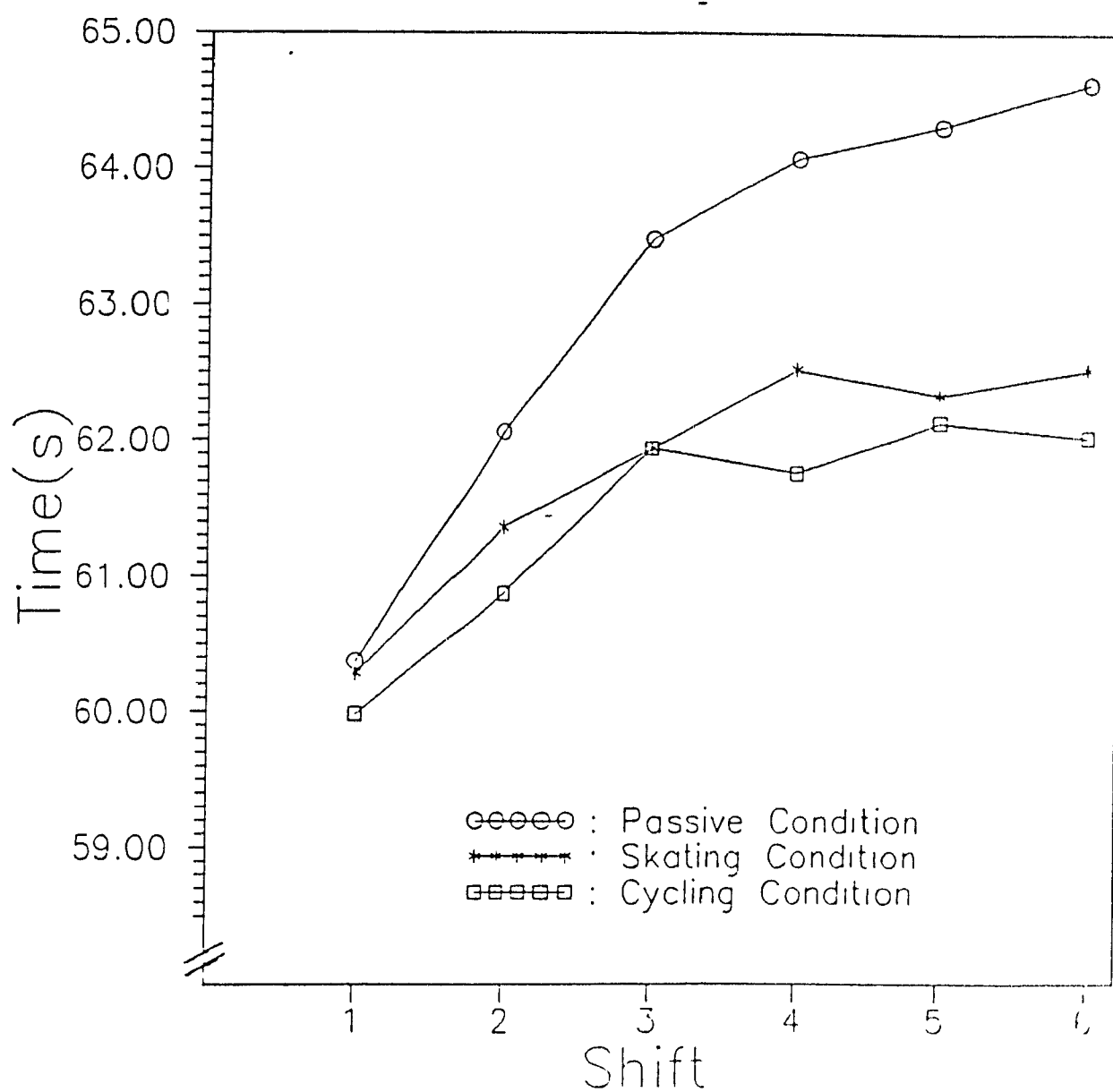


Figure 4.1 Anaerobic Endurance Index for Six Shifts of the RSS Test During Three Experimental Conditions.

Table 4.6 Results ($n=11$, $\bar{x} \pm S.D.$) for the Drop-off Index(s).

Shift	Passive	Skating	Cycling
1	1.80 $\pm$ 0.82	1.53 $\pm$ 0.57	1.63 $\pm$ 0.65
2	1.81 $\pm$ 0.77	1.68 $\pm$ 0.76	1.52 $\pm$ 0.47
3	1.94 $\pm$ 0.76	1.56 $\pm$ 0.63	1.55 $\pm$ 0.52
4	2.18 $\pm$ 0.79	1.48 $\pm$ 0.88	1.24 $\pm$ 0.62
5	2.13 $\pm$ 0.81	1.52 $\pm$ 0.76	1.60 $\pm$ 0.70
6	2.01 $\pm$ 0.70	1.65 $\pm$ 0.87	1.23 $\pm$ 0.44

Table 4.7 Factorial ANOVA for the Drop-off Index.

Source	SS	df	MS	F	Prob.
Conditions	9.78	2	4.89	6.54	0.01
Within Subjects	43.14	10	4.31		
Error	14.96	20	0.75		
Shifts	0.33	5	0.07	0.35	0.88
Error	9.38	50	0.19		
Conditions X Shifts	3.15	10	0.31	1.42	0.18
Error	22.15	100	0.22		
Total	102.88	197			

4.3 Blood Lactate Measurements

One of the purposes of this investigation was to examine if blood lactate concentration would be significantly lower after a period of active recovery compared to an equal period of passive recovery. For the statistical analysis of the blood lactate concentrations, a one-way analysis of variance (ANOVA) was applied in order to establish if there were significant differences among the three experimental conditions. The "gain scores" (pre-test values subtracted from post-test values) were analyzed because although similar, the pre-test lactate values were not identical for all experimental conditions. By using the above described procedure, the question as to whether the post-test results were influenced by the pre-test results is removed.

The results for the pre and post-test blood lactate concentrations are summarized in Table 4.8 with the statistical analysis (one-way ANOVA) following in Table 4.9. The analysis revealed a significant difference ($p < 0.01$) in lactate concentration among experimental conditions. A post hoc Tukey test indicated that the cycling mode of recovery produced significantly lower ($p < 0.01$) blood lactate levels than the passive mode of recovery. The skating condition produced similar results to that of the passive condition.

Table 4.8 Results ($n=11$, $\bar{x} \pm S.D.$) for Blood Lactate (mmol/l).

Condition	Pre Test	Post Test
Passive	1.7 $\pm$ 0.6	10.6 $\pm$ 2.0
Skating	2.0 $\pm$ 0.7	10.4 $\pm$ 2.2
Cycling	1.7 $\pm$ 0.5	8.5 $\pm$ 1.9

Table 4.9 ANOVA for Blood Lactate Results (Post-Pre Test).

Source	SS	df	MS	F	Prob.
Conditions	2144.69	2	1072.34	6.46	0.01
Within Subjects	8342.04	10	834.20		
Error	3319.52	20	165.98		
Total	13806.25	32			

Since the the subjects were in a sitting position on the bench during the passive mode of recovery, it was possible to obtain blood samples at the end of the recovery phase of each shift. This was unlike the skating and cycling conditions where blood samples were drawn only pre and post-test. The means and standard deviations of the highest and lowest heart rates for each shift of the passive condition were also calculated. The blood lactate concentrations, peak heart rates, and recovery heart rates are summarized in Table 4.10.

Table 4.10 Results ($n=11$, $\bar{x} \pm S.D.$) for Blood Lactate and Heart Rate in the Passive Condition.

Shift	Lactate(mmol/l)	Peak HR(bpm)	Recovery HR(bpm)
1	8.9 $\pm$ 1.9	178 $\pm$ 9	102 $\pm$ 12
2	10.2 $\pm$ 1.9	180 $\pm$ 7	108 $\pm$ 12
3	10.4 $\pm$ 2.0	176 $\pm$ 7	110 $\pm$ 10
4	11.2 $\pm$ 2.7	179 $\pm$ 7	110 $\pm$ 12
5	11.0 $\pm$ 2.3	177 $\pm$ 7	109 $\pm$ 10
6	10.8 $\pm$ 1.9	178 $\pm$ 7	106 $\pm$ 10

4.4 Heart Rate Measurements

Heart rates were measured and stored every 15 seconds during the six RSS test shifts in all experimental conditions. Peak heart rates during the RSS test were similar in all experimental conditions. The means were 172, 174, and 177 bpm for the passive, skating, and cycling conditions respectively. Means for the recovery heart rates varied greatly from passive to active recovery conditions. During the passive condition, the average heart rate during recovery was 123 bpm. During the skating and cycling conditions, the average recovery heart rates were 140 and 146 bpm, respectively. Heart rate results across the six shifts in the three experimental conditions are plotted in Figure 4.2 (Passive Condition), Figure 4.3 (Skating Condition), and Figure 4.4 (Cycling Condition).

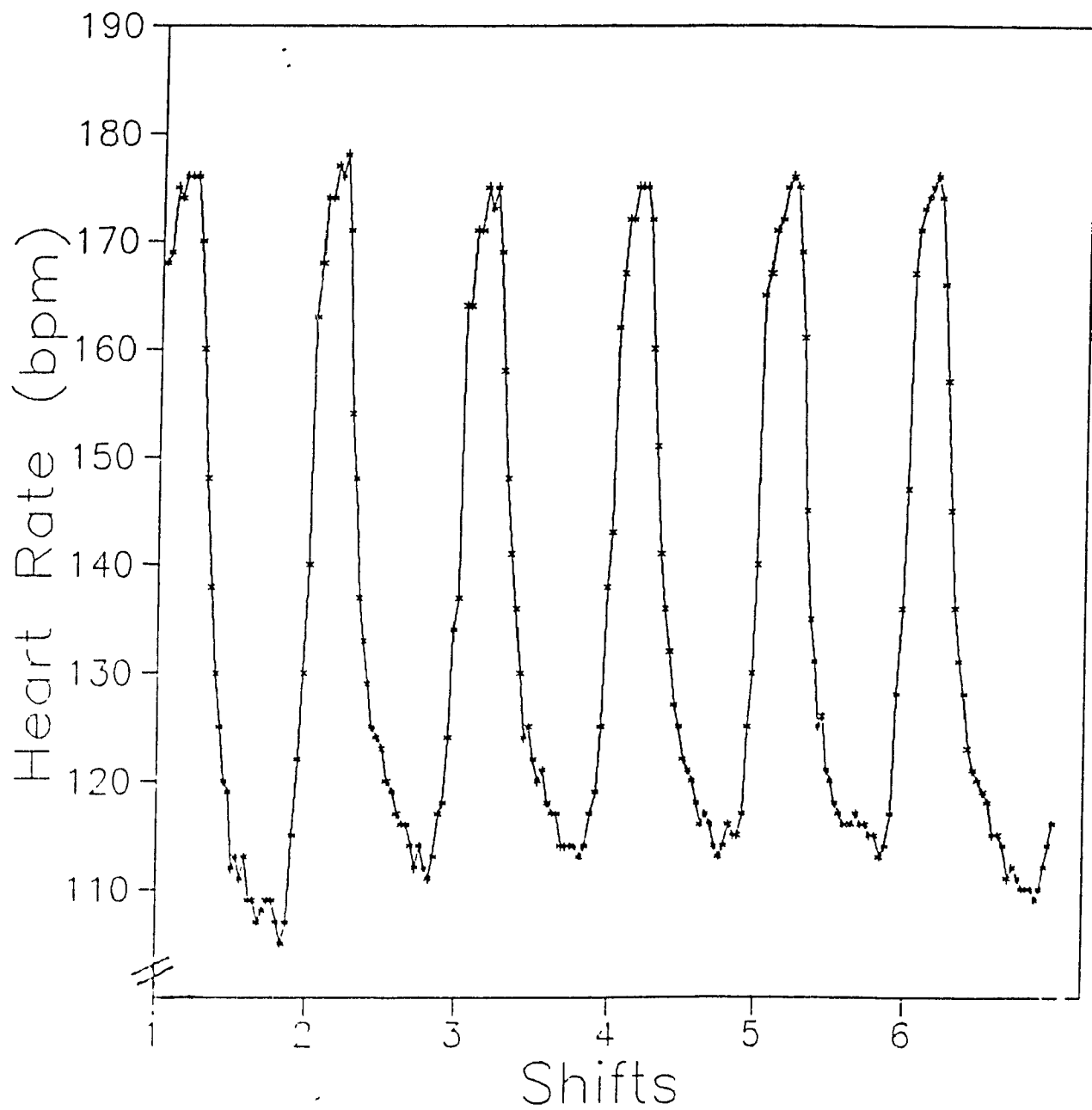


Figure 4 2 Heart Rate Response for Six Shifts of the RSS Test with Passive Recovery.

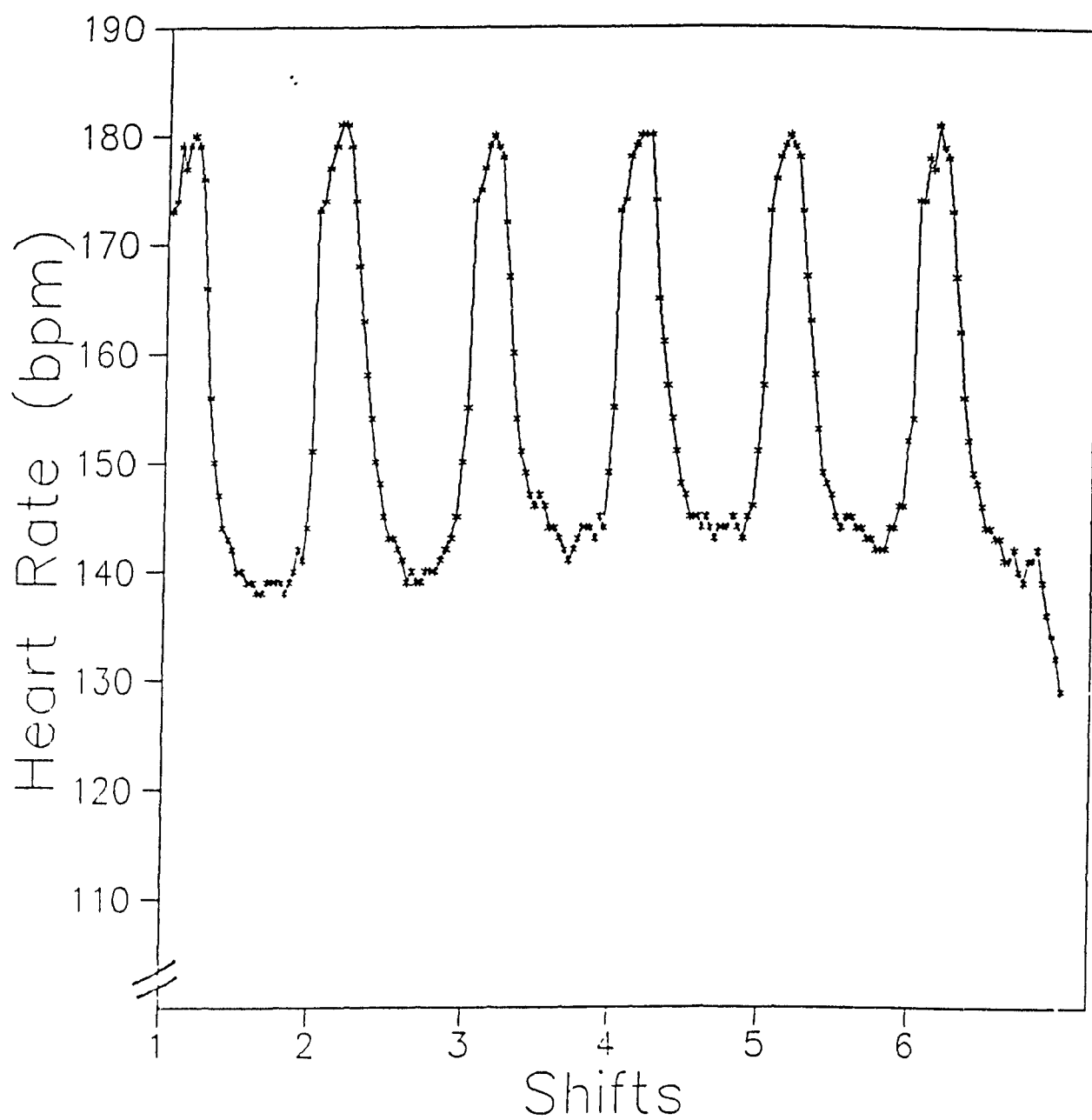


Figure 4.4 Heart Rate Response for Six Shifts of the Rss Test with Cycling Recovery.

Chapter V

Discussion

In this chapter, the results of this study are discussed in the following sections:

5.1 Performance Indices for the RSS Test

5.2 Blood Lactate

5.3 Heart Rate

5.1 Performance Indices for the RSS Test

In this study, the RSS test has been used to simulate a shift of hockey. The hockey players performed six "shifts" or trials of the RSS test. Previous studies (Montgomery et al., 1988; Rhodes et al., 1985; Watson and Sargeant, 1986) have reported the responses of hockey players to a single "shift" or trial of the RSS test. The RSS test has been shown (Montgomery et al., 1988; Watson and Sargeant, 1986) to be a good indicator of anaerobic power and anaerobic endurance when compared to a laboratory test measuring similar variables.

The speed index is measured on the first repetition of each shift of the RSS test. The times for the speed index ranged from 7.00 to 8.50 seconds depending on the skating ability of the hockey player. The primary fuel for this task is the high energy phosphagens in the muscle. Results for the speed index from this study are compared to previous studies in Table 5.1. Smith et al. (1982) reported the fastest times for the speed index variables. Their subjects were elite players from the 1980 Canadian Olympic hockey team. The forwards averaged 7.0 seconds and the defensemen averaged 7.3 seconds. A speed index time of 7.4 seconds has been reported for professional and junior A players (Reed as cited by Smith et al. 1982).

Table 5.1 Speed Index of the RSS Test ($\bar{x} \pm S.D.$) for Various Studies.

Level	n	Reference	Speed Index(s)
Canadian Olympic Team		Smith et al. (1982)	
forwards	15		7.0 ± 0.5
defense	6		7.3 ± 0.5
Professional and Jr.		Reed [cited by Smith et al. (1982)]	7.4
University and Jr.	24	Watson and Sargeant (1986)	7.6 ± 0.3
University		Brayne (1985)	
varsity	6		7.7 ± 0.2
jr. varsity	5		8.0 ± 0.2
University	11	Montgomery (1982)	8.0 ± 0.3
University		Montgomery et al. (1988)	
varsity	17		7.3 ± 0.2
varsity and jr. varsity	11		7.6 ± 0.3
jr. varsity	14		7.7 ± 0.3
Varsity and Intramural		Present Study	
Shift 1 Passive Cond.	11		7.7 ± 0.4
Shift 1 Skating Cond.	11		7.8 ± 0.6
Shift 1 Cycling Cond.	11		7.6 ± 0.4
Six Shifts Passive Cond.	11		7.8 ± 0.1
Six Shifts Skating Cond.	11		8.0 ± 0.2
Six Shifts Cycling Cond.	11		7.8 ± 0.1

The present study found speed index times of 7.7, 7.8, and 7.6 seconds on the first shift of the RSS test during the passive, skating, and cycling recovery conditions, respectively. These values are similar to the times reported by Brayne (1985); Montgomery et al. (1988); and Watson and Sargeant (1986) where the subjects were university varsity players, university junior varsity players or junior "A" players.

The speed index for the average of six shifts was 7.8 seconds in the passive condition, 8.0 seconds in the skating condition, and 7.8 seconds in the cycling condition. It is expected that the average time for six shifts will be slower than the times for a single shift because of the influence of fatigue.

Statistical analysis of the speed index variable indicated that there was no significant difference among the three recovery conditions (passive, skating, and cycling) however there was a significant difference across shifts.

The primary energy sources for all-out efforts of 10 seconds duration are the stores of adenosine triphosphate (ATP) and creatine phosphate (CP) in the muscle (Margaria et al., 1969; Saltin and Essen, 1971). The speed index of the RSS test is a measure of anaerobic power. The ATP and CP levels in the muscles will contribute to the speed index time.

The importance of the recovery periods in an intermittent activity, with relatively short work periods, has been associated with the process of phosphagen resynthesis. Fox and Mathews (1981) have related the duration of the relief interval to the percentage of ATP and CP resynthesized. When the recovery period was less than ten seconds, very little ATP and CP were restored. When the recovery interval was 30, 60, and 120 seconds, the resynthesis of ATP and CP was 50%, 75%, and 94%, respectively. In this study, the recovery time between shifts was six minutes which is adequate for complete resynthesis of the ATP and CP stores in the passive condition.

During recovery periods of less than 20 seconds the reloading of ATP-CP has an insignificant role in energy supply during intermittent exercise (Saltin and Essen, 1971). Within a shift, the recovery interval was approximately 15 seconds between the four

trials. Thus repetitions 2, 3, and 4 were performed with muscle levels of ATP and CP below the resting concentrations since 15 seconds of recovery was inadequate for complete replenishment of the ATP-CP stores.

Several studies have examined performance following repeated supramaximal tasks. McCartney et al. (1983) measured anaerobic power as the torque on a cycle ergometer test. Peak power comparisons following metabolic alkalosis, metabolic acidosis, and respiratory acidosis were similar to the control condition.

There was a significant difference across shifts for the speed index variable that was independent of the experimental condition. Accumulation of lactic acid or hydrogen ions has been postulated as a possible cause of fatigue during short-term, intense work (Dawson et al., 1978; Fitts and Holloszy, 1976; Hermansen and Osnes, 1972; Karlsson and Saltin, 1970; Tesch, 1980). Changes in intracellular hydrogen ion concentration may influence the activation of the contractile proteins by calcium (Donaldson and Hermansen, 1978; Fuchs et al., 1970; Nasser-Gentina et al., 1978), release and uptake of calcium by the sarcoplasmic reticulum (Fabiato and Fabiato, 1978; Nassar-Gentina et al., 1981; Sahlin et al., 1981)

Karlsson et al. (1975) used exercise by one muscle group (arms or opposite leg) to alter the performance of another muscle group. Prior arm exercise resulted in elevated leg muscle LA and a subsequent decrease in leg muscle performance. Thus it appears that lactate decreases performance even when the prior exercise has been performed by a different muscle group.

The decrease in the speed index across shifts may be attributed to a biochemical origin as well as a psychological origin. With only 15 seconds of recovery between repetitions in a shift, the players develop high levels of lactate. As a consequence of this fatigue, the players may unconsciously perform at a lower level on subsequent shifts.

The anaerobic endurance index was the sum of the times for the four repetitions of the RSS test within a shift. Times for the anaerobic endurance index ranged from

60 to 65 seconds. Within a shift, the exercise to recovery ratio was approximately 1:1 with each of the four repetitions being 15 seconds in duration and performed at maximum intensity. The primary energy source for a shift would be the lactate system.

Results for the anaerobic endurance index for this study are compared to previous studies in Table 5.2. All the studies reported in Table 5.2 used six repetitions to constitute a single shift of hockey. Table 5.2 was constructed from the sum of repetitions 1, 2, 3, and 4 of the investigators's data. Montgomery et al. (1988) reported the fastest times for the anaerobic endurance variable. Their subjects were university players on the varsity team. They averaged 57.6 seconds for four repetitions of the RSS test.

Brayne (1985) reported times of 60.2 seconds for varsity level players and 61.6 seconds for junior varsity players. When university and juniors were used as subjects, Watson and Sargeant (1986) observed an anaerobic endurance index time of 60.8 seconds. Montgomery (1982) recorded 62.1 seconds as an anaerobic endurance index for university level players.

In this study, the anaerobic endurance times for the first shift averaged 60.4, 60.3 and 60.0 seconds in the passive, skating, and cycling recovery conditions. There was no significant difference among conditions on the first repetition

The mean times for the six shifts in the passive, skating and cycling conditions were 63.2, 61.8, and 61.5 seconds, respectively. The average times were greater because of the fatigue that develops over the six shifts.

Both the skating and cycling recovery conditions resulted in significantly faster anaerobic endurance times than the passive recovery condition. The performance times did not deteriorate as fast during the skating and cycling conditions as the passive condition. This was illustrated in Figure 4.1.

Table 5.2 Anaerobic Endurance Index of the RSS Test ($\bar{x} \pm S.D.$)
for Various Studies.

Level	n	Reference	An. End. Index(s)
University and Jr.	24	Watson and Sargeant (1986)	60.8
University		Brayne (1985)	
varsity	6		60.2
jr. varsity	5		61.6
University	11	Montgomery (1982)	62.1
University		Montgomery et al. (1988)	
varsity	17		57.6
varsity and jr. varsity	11		58.5
jr. varsity	14		59.6
Varsity and Intramural		Present Study	
Shift 1 Passive Cond.	11		60.4 $\pm$ 2.4
Shift 1 Skating Cond.	11		60.3 $\pm$ 2.1
Shift 1 Cycling Cond.	11		60.0 $\pm$ 1.6
Six Shifts Passive Cond.	11		63.2 $\pm$ 1.6
Six Shifts Skating Cond.	11		61.8 $\pm$ 0.9
Six Shifts Cycling Cond.	11		61.5 $\pm$ 0.9

The accumulation of lactic acid or hydrogen ions is the probable cause of fatigue during repeated efforts of short term, intense exercise (Dawson et al., 1978; Fitts and Holloszy, 1976; Hermansen and Osnes, 1972; Karlsson and Saltin, 1970; Tesch, 1980). Changes in the intracellular hydrogen ion concentration appears to influence several of the rate-limiting steps of glycolysis (Danforth, 1965).

Several studies have compared the power output from pre and post test after the pre test, lactate levels were artificially raised by pharmacological means (Costill et al. 1984; Spriet et al., 1985), atmospheric manipulation of CO₂ levels (Hogan and Welch, 1984), and supra-maximal exercise (Karlsson et al., 1975; Jones and Green, 1984; Weltman et al., 1977; Yates et al., 1983). These studies reported a decrease in power in both dynamic and isometric exercise. The decrease in power is likely due to elevated lactate concentrations.

There is a strong correlation between increased lactate and decreased contractile force (Fitts and Holloszy, 1976). During high intensity intermittent exercise, Hermansen and Osnes (1972) observed a continual decrease in muscle and blood pH. Renaud and Mainwood (1985a; 1985b) found that muscles exposed to a low pH environment, fatigued more quickly. This was due to a modified ionic conductance of the sarcolemal membrane. Mucke and Jollner (1986) observed that increased lactic acid influenced the electrical membrane conductivity and the velocity of action potentials spreading along the muscle fibre. The increase in conduction velocity was accompanied by a decrease in contractile force. The decrease in pH that accompanies an increase in lactate can also effect the muscular force output. This is caused by the increased H⁺ ion concentration which interferes with calcium release from the sarcoplasmic reticulum and decreases Ca⁺⁺ affinity for binding with tropomyosin (Hermansen and Osnes, 1972; Hultman et al., 1986). The above sequence can decrease the substrate supply for myosin ATPase or reduce myosin ATPase activity and promote fatigue through a reduction in the cross-bridge turnover rate (Hultman et al., 1986).

Klausen et al., (1972) and Tesch and Wright (1983) both found that endogenous increases in lactate caused decrements in performance. Klausen et al (1972) used five minutes of heavy arm exercise to increase lactate levels before having subjects cycle to exhaustion. Oxygen uptake was not affected but a reduction was observed in total work output. Tesch and Wright (1983) had subjects perform 50 consecutive maximum voluntary knee exertions. Following a 40 second rest period, five additional maximal contractions were executed. Peak torque decreased 67% as a result of the first 50 contractions. Average post recovery torque was 70% of the initial value.

Hogan and Welch (1984) examined the effect of varied lactate levels on bicycle ergometer performance. Subjects performed five minutes of cycling, then had a recovery period of four minutes, followed by a performance task to exhaustion. By varying the fraction of inspired oxygen breathed during the initial work period, the response was a significantly different blood lactate concentration at the start of the performance task. When varied blood or muscle lactate levels were induced, the subsequent performance was significantly effected.

Active recovery has been shown to reduce lactate levels compared to passive recovery. Bonen and Belcastro (1977) reported that active recovery reduced lactate levels by 88% in 20 minutes as compared to a 50% reduction in lactate following 20 minutes of passive recovery.

Hermansen and Stensvold (1972) studied lactate removal rates at recovery intensities of 30, 60, 70, and 80% of the subjects' $\dot{V}O_2\text{max}$. An optimal lactate removal response of 8.0 mg%/min was predicted to occur at 63% of $\dot{V}O_2\text{max}$. Similar optimal removal intensities were found by Bonen and Belcastro (1976). Rest, self-selected continuous jogging, and free intermittent jogging were used in the recovery phase of the experiment. The optimal lactic acid removal rate in the above study was found to be 7.1 mg% per minute and occurred at 57.1 - 70.0% of $\dot{V}O_2\text{max}$.

Davies et al. (1970) exercised four subjects for six minutes at 80% of their $\dot{V}O_2\text{max}$. The subjects were then exercised at four different recovery intensities, 15,

30, 45, and 60% of $\dot{V}O_2\text{max}$. Lactate removal was better at 30% and 45% of the subjects' maximum aerobic capacity than at the low (15%) and high (60%) recovery intensities.

Belcastro and Bonen (1975) found similar results to Davies et al. (1970). Their subjects were exercised at 89% of $\dot{V}O_2\text{max}$ for six minutes followed by recovery at rest, 30, 45, 60, or 80% of $\dot{V}O_2\text{max}$. The most expedient removal rates occurred at 29.7% and 45.3% of $\dot{V}O_2\text{max}$.

McLellan and Skinner (1982) used the aerobic threshold and fractions of the subjects' $\dot{V}O_2\text{max}$ as markers for work intensity recovery levels. Lactate removal was fastest when recovery exercise was performed at the condition described as the aerobic threshold minus 10% of $\dot{V}O_2\text{max}$. This intensity was equivalent to approximately 43% of $\dot{V}O_2\text{max}$. Compared to the resting condition, lactate removal was facilitated at recovery intensities between 27 - 58% of $\dot{V}O_2\text{max}$.

These figures concur with data collected by Koutedakis and Sharp (1985). They had rowers sprint 2000 meters then recover at 40% and 60% of the maximum stroke rate attained in the sprint. Both active recovery conditions produced significantly greater lactate turnover than the resting condition. The 40% condition was also significantly more effective than the 60% condition.

It appears that the mode of active recovery is also an important variable. Siebers and McMurray (1981) studied swimming and walking as recovery modes after swimmers had exercised at 90% of $\dot{V}O_2\text{max}$ for two minutes on a swimming ergometer. Lactate levels were reduced by 38.5% during the walking recovery and 53.3% during the swimming recovery. Swimming recovery was performed at 43% of the athletes' aerobic capacity while the walking recovery was performed at 33% of aerobic capacity. The probable reason for the improved lactate turnover for the swimming condition was the higher work recovery intensity and the sport-specific nature of the recovery task.

The results of Siebers and McMurray (1981) differ from those of Watson and Hanley (1986) who compared bench-stepping to skating as forms of active recovery from two high intensity skating bouts. Skating did not elicit a significantly greater lactate removal rate than bench-stepping. Both modes had greater lactate clearance than the resting mode. An explanation for this may be that there is a significant amount of glide while skating and even though the heart rates were kept the same (120 beats per minute) for both activities, inadequate muscle recruitment could be the reason for the sport-specific activity not having a more efficient removal rate (Watson and Hanley, 1986).

In this study, active recovery by cycling or by skating produced better anaerobic endurance times than the passive condition. The cycling recovery was performed at 40% of $\dot{V}O_2\text{max}$. The lactate concentration in the cycling condition was 8.5 mmol/l after six shifts of the RSS test. In comparison, the lactate concentration in the passive condition was 10.6 mmol/l.

The drop-off index for the RSS test is the difference between the slowest and fastest repetitions in the shift. Results for the drop-off index from this study are compared to previous studies in Table 5.3. Since the other studies used six repetitions and this study used four repetitions, caution is necessary when comparisons are made.

Watson and Sargeant (1986) observed a drop-off index time of 2.7 seconds for university and junior players. It is interesting to note that the studies which found the slowest anaerobic endurance times recorded the best drop-off times.

In the present study the drop-off index for shift one averaged 1.8 seconds in the passive condition, 1.5 seconds in the skating condition, and 1.6 seconds in the cycling condition. The drop-off index for all six shifts averaged 2.0 seconds in the passive condition. Both the cycling and skating conditions resulted in significantly improved performances as measured by the drop-off score.

Table 5.3 Drop-off Index of the RSS Test ($\bar{x} \pm S.D.$) for Various Studies.

Level	n	Reference	Drop-off Index(s)
Canadian Olympic Team		Smith et al. (1982)	
forwards	15		3.2 ± 0.8
defense	6		2.8 ± 0.7
Professional and Jr.		Reed [cited by Smith et al. (1982)]	2.9
University and Jr.	24	Watson and Sargeant (1986)	2.7
University		Brayne (1985)	
varsity	6		2.9 ± 1.0
jr. varsity	5		3.4 ± 1.3
University	11	Montgomery (1982)	2.2 ± 0.9
University		Montgomery et al. (1988)	
varsity	17		2.6
varsity and jr. varsity	11		3.1
jr. varsity	14		3.6
Varsity and Intramural		Present Study	
Shift 1 Passive Cond.	11		1.8 ± 0.8
Shift 1 Skating Cond.	11		1.5 ± 0.6
Shift 1 Cycling Cond.	11		1.6 ± 0.7
Six Shifts Passive Cond.	11		2.0 ± 0.2
Six Shifts Skating Cond.	11		1.6 ± 0.1
Six Shifts Cycling Cond.	11		1.5 ± 0.2

5.2 Blood Lactate

One of the purposes of this investigation was to observe how different forms of recovery effect blood lactate concentration. The blood lactates were drawn pre and post test in all three conditions. The active recovery protocols were employed between shifts to determine if they would have any effect on skating performance.

The post-test lactate values were 10.6 mmol/l in the passive condition, 10.4 mmol/l in the skating condition, and 8.5 mmol/l in the cycling condition. These values are somewhat higher than earlier studies which have recorded blood lactate concentrations after one period of hockey in a game situation. Green (1976) obtained blood lactate values of 7.9, 8.9, and 8.9 mmol/l for centres, wings, and defensemen, respectively. Green et al. (1978a; 1978b) measured blood lactate levels in forwards and defensemen and obtained a mean of 4.9 mmol/l for two games. Lactate levels are lower in game situations because every shift is not a maximum effort as compared to the present study where players performed four repetitions totaling approximately 60 seconds of "all-out" skating. Wilson and Hedberg (1979) reported a value of 15.0 mmol/l for one subject at the conclusion of one period of hockey play. Watson and Hanley (1986) observed blood lactate levels as high as 12.1 mmol/l after a simulated period of hockey with a work to rest ratio of 1:2.

The cycling condition had a significantly lower ($p < 0.01$) post-test lactate level when compared to the passive recovery condition. These findings are contrary to those of Fox et al (1969), who observed elevated blood lactate levels during active recovery. Subjects performed 10 one minute treadmill runs at 21.6 km/h and 2% grade. Between exercise bouts, 2 5 minute relief intervals were performed at 9.6 km/h (60% $\dot{V}O_{2max}$). The present study used a six minute active recovery period (1:3 work to rest ratio), and is in agreement with previous studies (Boileau et al., 1983; Bonen and Belcastro, 1976; Hermansen et al., 1975; Hermansen and Stensvold, 1972; McGrail et al., 1978; Rammal and Strom, 1949; Stamford et al., 1978) which found lowered blood lactate levels after five minutes of active recovery.

In the skating condition, the subjects performed at a self-selected pace. The mean recovery velocity for shifts one to six was only 210, 206, 209, 200, 200, and 190 m/min. These speeds were probably too low to promote lactate oxidation. When substituted into the regression equation developed by Ferguson et al. (1969) to predict $\dot{V}O_2$ from skating speed, it is clear that the self-selected skating speed corresponded to low intensity exercise. This observation is appropriate if the assumption is made that one of the major factors in the rate of lactate removal is recovery intensity (Bonen et al., 1978; Bonen et al., 1979).

The lower lactate levels in the cycling recovery condition concur with the significantly better anaerobic endurance index and speed index times observed in that condition. Both indices were significantly better than the results obtained in the passive recovery condition.

Watson and Sargeant (1986) and Montgomery et al. (1988) have reported blood lactate concentrations of 11.5 mmol/l and 10.7 mmol/l, respectively for six repetitions of the RSS test. In this study, the blood lactate concentration was 8.9 mmol/l after the first shift in the passive condition. The lower value is attributed to less work since the shift consisted of four repetitions instead of the six repetitions used in previous studies. In the passive condition, the blood lactate reached a peak concentration of 11.2 mmol/l following the fourth shift and dropped to 11.0 mmol/l and 10.8 mmol/l after the fifth and sixth shifts, respectively.

5.3 Heart Rate

Heart rate is an indicator of the total stress on an individual. In this study the heart rate intensities for the six shifts were 93, 95, and 96% of the maximum heart rate, for the passive, skating, and cycling conditions, respectively. The mean heart rate was 174 bpm for all conditions. Telemetry monitoring of heart rate during hockey games has shown a peak heart rate of 173 bpm or 94% of maximum (Montgomery and Vartzbedian, 1977).

In the passive recovery condition the heart rate decreased to 102-110 bpm in this study. "Old timer" hockey players averaged 115 bpm at the end of recovery on the bench between shifts (Montgomery, 1979). Five-minute recovery heart rates averaged 113 bpm following performance of the RSS test (Montgomery, 1982).

Based on heart rate data, it appears that the protocol used in this study simulated the upper and lower intensities recorded in hockey games. Peak heart rates produced from four repetitions of RSS test corresponded to the peak heart rate during a hockey shift. The heart rates following six minutes of passive recovery matched the recovery heart rates between shifts.

Chapter VI

Summary, Conclusions, and Recommendations

6.1 Summary

The purpose of this investigation was to compare the effect of two modes of active recovery (skating and cycling) to passive recovery on blood lactate concentration and performance in a simulated ice hockey task. The simulated ice hockey task was a modified version of the repeat sprint skate (RSS) test. The modified RSS test consisted of four repetitions (Rhodes et al., 1985) of skating from goal line to goal line and back to the blue line closest to the starting point (91.4 meters), with repetitions initiated on 30 second intervals (Reed et al., 1979). The test was repeated six times with recovery intervals of six minutes between each test. The protocol for the task was based on prior studies which employed time motion analysis during game play. It was believed that the protocol created through the use of intermittent RSS tests would be more representative of a typical period of hockey, than previous protocols which have used "all-out" bursts of skating for a selected period of time around an oval course.

The subjects in this study were 11 males that participated in hockey at either the varsity or intramural level. All subjects performed a single continuous aerobic fitness test ($\dot{V}O_{2\max}$) on a cycle ergometer. All subjects completed six shifts of the modified RSS test on three occasions with random assignment of the mode of recovery, (cycling, skating, or passive). Cycling recovery was performed at 40% of $\dot{V}O_{2\max}$ while skating recovery was performed at a self-selected pace. For the passive recovery condition, subjects sat on the bench. Blood lactate levels in the passive condition were measured five minutes into each recovery period. Pre and post test lactate levels were measured in all recovery conditions. From the RSS test, three performance indices were measured: (1) speed index, (2) anaerobic endurance index, and (3) drop-off index.

Post-test lactate levels and skating performance indices were compared among treatment conditions in order to determine if the active recovery conditions produced lower lactate levels and better performances.

The first hypothesis of this study stated that blood lactate concentration would be significantly lower following active recovery conditions than the passive recovery condition. The one-way analysis of variance (ANOVA) for the three experimental conditions using the difference between pre and post test lactate values revealed an F-ratio of 6.46 which was significant at the 0.01 level. A Tukey post hoc test was used to determine the location of the significance. The results of the post hoc test showed that blood lactate levels measured in the cycling recovery condition were significantly lower ($p < 0.01$) than the passive recovery condition. These results suggest that the cycling recovery condition removed lactate faster than the passive recovery condition.

The second hypothesis predicted that the speed index variable of the RSS test would be significantly faster in the active recovery conditions than the passive recovery condition. A factorial ANOVA revealed an F-ratio of 2.15 for the "conditions" variable. This indicated that there was no significant difference ($p > 0.05$) among experimental groups for the speed index of the RSS test.

The third hypothesis stated that the anaerobic endurance index variable of the RSS test would be significantly lower in the active recovery conditions than the passive recovery condition. A factorial ANOVA revealed an F-ratio of 5.14 for the "conditions" variable which was significant at the 0.02 level. A Tukey post hoc test showed that both the skating and cycling recovery conditions had significantly ($p < 0.05$) faster anaerobic endurance times than the passive recovery condition. A significant interaction was found in the "conditions by shifts" variable. The F-ratio of 2.50 was significant at the 0.01 level. Tukey post hoc analysis indicated that both the skating and cycling recovery conditions produced significantly ($p < 0.05$) faster anaerobic endurance index times in shifts 4, 5, and 6 of the RSS test. These results indicate that

the active recovery conditions produced superior anaerobic endurance index times with less deterioration in performance in the latter shifts of the test.

The fourth hypothesis of this study predicted that the drop-off index variable of the RSS test would be significantly lower in the active recovery conditions than the passive recovery condition. A factorial ANOVA revealed a significant F-ratio of 6.54 for the "conditions" variable. These results indicate a significant difference among conditions at the 0.01 level. Further analysis using the Tukey post hoc test indicated that both the skating and cycling recovery conditions showed significantly less ($p < 0.05$) drop-off than the passive recovery condition.

6.2 Conclusions

Within the delimitations and limitations of this study, the following conclusions seem justified:

- 1) Cycling recovery at 40% of $\dot{V}O_{2\max}$, lowered blood lactate concentration significantly more than passive recovery. Skating recovery at a self-selected intensity did not lower blood lactate concentration compared to passive recovery.
- 2) The speed index times for the RSS test were statistically similar for the three experimental conditions (passive, skating, and cycling).
- 3) Anaerobic endurance index times for the RSS test were significantly faster in the skating and cycling recovery conditions than the passive recovery condition.
- 4) There was significantly less drop-off in the skating and cycling recovery conditions than the passive recovery condition.

6.3 Recommendations

The following recommendations are proposed for future investigations:

- 1) Follow-up studies should be conducted using different cycling recovery intensities in order to determine the most efficient intensity.
- 2) Follow-up studies should be conducted by using different work to recovery ratios in order to determine the effect of varying the duration of the recovery period.
- 3) Active recovery procedures should be observed during game situations in order to obtain more data on the effects of active recovery on blood and muscle parameters and their effect on performance.

References

- Belcastro, A. N. & Bonen, A. (1975). Lactic acid removal rates during controlled and uncontrolled recovery exercise. Journal of Applied Physiology, 39(6), 932-936.
- Bergstrom, J. E., Harris, R. C., Hultman, E., & Nordesjo, L. O. (1971). Energy rich phosphagens in dynamic and static work. In B. Pernow & B. Saltin (Ed.), Muscle Metabolism During Exercise (pp. 341-355). New York: Plenum Press.
- Boileau, R. A., Misner, J. E., Dykstra, G. L., & Spitzer, T. A. (1983). Blood lactic acid removal during treadmill and bicycle exercise at various intensities. Journal of Sports Medicine and Physical Fitness, 23(2), 159-167.
- Bonen, A. & Belcastro, A. N. (1976). Comparison of self-selected recovery methods on lactic acid removal rates. Medicine and Science in Sports, 8(3), 176-178.
- Bonen, A. & Belcastro, A. N. (1977). A physiological rationale for active recovery exercise. Canadian Journal of Applied Sport Sciences, 2, 63-65.
- Bonen, A., Campbell, C. J., Kirby, R. L., & Belcastro, A. N. (1978). Relationship between slow-twitch muscle fibres and lactic acid removal. Canadian Journal of Applied Sport Sciences, 3, 160-162.
- Bonen, A., Campbell, C. J., Kirby, R. L., & Belcastro, A. N. (1979). A multiple regression model for blood lactate removal in man. Pflugers Archives-European Journal of Physiology, 380, 205-216.

- Brayne, S. P. (1985) A comparison of on-ice and laboratory tests of ice hockey fitness. Unpublished masters thesis, McGill University, Montreal, Quebec.
- Brooks, G. A., Brauner, K. E., & Cassens, R. G. (1973). Glycogen synthesis and metabolism of lactic acid after exercise. American Journal of Physiology, 224(5), 1162-1166.
- Brooks, G. A. & Divine-Spurgeon, L. (1982). Effects of training on oxidation of injected [U-¹⁴C]-lactate in rats during exercise. In H. G. Knuttgen, J. Portmans, & J. A. Vogel (Ed.), Biochemistry of Exercise, Champaign, Ill.: Human Kinetics.
- Brooks, G. A. & Fahey, T. D. (1984). Exercise physiology: Human bioenergetics and its applications. New York: John Wiley and Sons.
- Brooks, G. A. & Gaesser, G. A. (1980). End points of lactate and glucose metabolism after exhausting exercise. Journal of Applied Physiology, 49(6), 1057-1069.
- Costill, D. L., Verstappen, F., Kuipers, H., Janssen, E., & Fink, W. (1984). Acid-base balance during repeated bouts of exercise: Influence of HCO- International Journal of Sports Medicine, 5, 228-231.
- Danforth, W. H. (1965). Activation of glycolytic pathway in muscle. In B. Chance & R. W. Estabrook (Ed.), Control of Energy Metabolism (pp.287-297), New York: Academic Press.
- Daub, W. B., Green, H. J., Houston, M. E., Thompson, J. A., Fraser, I. G., & Ranny, D. A. (1983). Specificity of physiologic adaptations resulting from ice-hockey training Medicine and Science in Sports and Exercise, 15(4), 290-294.

- Davies, C. T. M., Knibbs, A. V. & Musgrove, J. (1970). The rate of lactic acid removal in relation to different baselines of recovery exercise. Internationale Zeitschrift Fur Angewandte Physiologie, **28**, 155-161.
- Dawson, M. J., Gadian, D. G., & Wilke, D. R. (1978). Muscular fatigue investigated by phosphorus nuclear magnetic resonance. Nature London, **274**, 861-866.
- Depocas, F., Minaire, Y., & Chatonnet, J. (1969). Rates of formation and oxidation of lactic acid in dogs at rest and during moderate exercise. Canadian Journal of Physiology and Pharmacology, **47**, 603-610.
- Dodd, S., Powers, S. K., Callender, T., & Brooks, E. (1984). Blood lactate disappearance at various intensities of recovery exercise. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, **57**(5), 1462-1465.
- Donaldson, S. K. B. & Hermansen, L. (1978). Differential, direct effects of H^+ on Ca^{++} -activated force of skinned fibres from soleus, cardiac, and abductor magnus muscles of rabbits. Pflugers Archives-European Journal of Physiology, **376**, 55-65.
- Donovan, C. M. & Brooks, G.A. (1983). Endurance training affects lactate clearance, not lactate production. American Journal of Physiology, **244** (Endocrinology, Metabolism, **7**): 1:83-1:92.
- Dykstra, G. L., Boileau, R. A., & Misner, J. E. (1973). Effect of selected warm down work levels on blood lactate removal. AAPHER Abstract Research Papers, pp.49, (abstract).

- Eldridge, F. L. (1975). Relationship between turnover rate and blood concentration of lactate in exercising dogs. Journal of Applied Physiology, 39(2), 231-234.
- Essen, B. & Haggmark, T. (1975). Lactate concentration in type I and II muscle fibres during muscular contraction in man. Acta Physiologica Scandinavica, 95, 344-346.
- Evans, B. W. & Cureton, K. J. (1983). Effect of physical conditioning on lactate disappearance after supramaximal exercise. British Journal of Sports Medicine, 17(1), 40-45.
- Fabiato, A. & Fabiato, F. (1978). Effects of pH on the myofilaments and the sarcoplasmic reticulum of skinned cells from cardiac and skeletal muscle. Journal of Physiology London, 276, 233-255.
- Ferguson, R. J., Marcotte, G. G., & Montpetit, R. R. (1969). A maximal oxygen uptake test during ice skating. Medicine and Science in Sports, 1(4), 207-211.
- Fitts, R. H. & Holloszy, J. O. (1976). Lactate and Contractile force in frog muscle during development of fatigue and recovery. American Journal of Physiology, 231(2), 430-433.
- Fox, E. & Mathews, D. (1981). Interval training: Conditioning for sports and general fitness. Toronto, Ontario: W. B. Saunders Co.
- Fox, E. L., Robinson, S., & Wiegman, D. L. (1969). Metabolic energy sources during continuous and interval running. Journal of Applied Physiology, 27(2), 174-178.

- Freminet, A., Poyart, C., Bersaux, E., & Tablon, T. (1975). Effect of physical training on the rates of lactate turnover and oxidation in rats. In H. Howald & J. R. Poortmans (Ed.), Metabolic Adaptation to Prolonged Physical Exercise (pp. 113-118). Basel: Birkhauser.
- Fuchs, F., Reddy, V., & Briggs, F. N. (1970). The interaction of cations with the calcium-binding site of troponin. Biochimica Biophysica Acta, **221**, 407-409.
- Gamble, W. F. (1986). A laboratory test of anaerobic endurance for ice hockey players, Unpublished Master's Thesis, McGill University, Montreal, Quebec.
- Gisolfi, C., Robinson, S., & Turrell, E. S. (1966). Effects of aerobic work performed during recovery from exhausting work. Journal of Applied Physiology, **21**(6), 1767-1772.
- Green, H. J. (1978). Glycogen depletion patterns during continuous and intermittent skating. Medicine and Science in Sports, **10**(3), 183-187.
- Green, H. J. (1979). Metabolic aspects of intermittent work with specific regard to ice hockey. Canadian Journal of Applied Sport Sciences, **4**(1), 29-34.
- Green, H., Bishop, P., Houston, M., McKillop, R., Norman, R., & Stothart, P. (1976). Time-motion and physiological assessments of ice hockey performance. Journal of Applied Physiology, **40**(2), 159-163.
- Green, H. J., Daub, B. D., Painter, D. C., & Thomson, J. A. (1978a). Glycogen depletion patterns during ice hockey performance. Medicine and Science in Sports, **10**(4), 289-293.

- Green, H. J. & Houston, M. E. (1975). Effect of a season of ice hockey on energy capacities and associated functions. Medicine and Science and Sports, **7**(4), 299-303.
- Green, H. J., Houston, M. E., & Thomas, J. A. (1978b). Interand intragame alterations in selected blood parameters during ice hockey performance. In Landry & Orban (Ed.), Ice Hockey (pp. 37-46), Miami, Florida: Symposia Specialists Inc.
- Green, H. J., Houston, M. E., Thomson, J. A., Sutton, J. R., & Gollnick, P. D. (1979a). Metabolic consequences of supramaximal arm work performed during prolonged submaximal leg work. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, **46**(2), 249-255.
- Green H. J., Thompson, J. A., Daub, W. D., Houston, M. E., & Ranney, D. A. (1979b). Fibre composition, fibre size and enzyme activities in vastus lateralis of elite athletes involved in high intensity exercise. European Journal of Applied Physiology and Occupational Physiology, **41**, 109-117.
- Hermansen, L. (1971) Lactate production during exercise. In B. Pernow & B. Saltin (Ed.), Muscle Metabolism During Exercise (pp. 401-407). New York: Plenum Press.
- Hermansen, L., Maehlum, S., Pruett, E. D. R., Vaage, O., Waldum, H. & Wessel-Aas, T. (1975). Lactate removal at rest and during exercise. In H. Howald & J. R. Poortmans (Ed.), Metabolic Adaptation to Prolonged Physical Exercise (pp. 101-105). Basel: Birkhauser
- Hermansen, L. & Osnes, J. (1972). Blood and muscle pH after maximal exercise in man. Journal of Applied Physiology, **32**(3), 304-308.

- Hermansen, L. & Stensvold, I. (1972). Production and removal of lactate during exercise in man. Acta Physiologica Scandinavica, **86**, 191-201.
- Hirche, H., Bovencamp, U., Busse, J., Hombach, B., & Manthey, J. (1973). Factors influencing lactic acid production in working skeletal muscle. Scandinavian Journal of Clinical and Laboratory Investigation, **31**(Suppl. **290**), 11-15.
- Hogan, M. C. & Welch, H. G. (1984). Effect of varied lactate levels on bicycle ergometer performance. Journal of Applied Physiology: Respiratory, Environmental, & Exercise Physiology, **57**(2), 507-513.
- Houston, M. E. & Green, H. J. (1976). Physiological and anthropometric characteristics of elite Canadian ice hockey players. Journal of Sports Medicine and Physical Fitness, **16**(3), 123-128.
- Hubbard, J. L. (1973). The effect of exercise on lactate metabolism. Journal of Physiology, **231**, 1-18.
- Hultman, E., Spriet, L. L., & Soderland, K. (1986). Biochemistry of muscle fatigue. Biomedica Biochimica Acta, **1**(2), S97-S106.
- Issekutz, B. (1984). Effect of B-andrenergic blockage on lactate turnover in exercising dogs. Journal of Applied Physiology: Respiratory, Environmental, & Exercise Physiology, **57**(6), 1754-1759.
- Issekutz, B., Shaw, W. A. S., & Issekutz, A. C. (1976). Lactate metabolism in resting and exercising dogs. Journal of Applied Physiology, **40**(3), 312-319.
- Jacobs, I. (1986). Blood lactate: Implications for training and sports performance. Sport Medicine, **3**, 10-25.

- Jones, S. & Green, H. (1984). Human muscle fatigue during and following intermittent exercise. Canadian Journal of Applied Sport Sciences, 9, 9P (abstract).
- Jorfeldt, L. (1970). Metabolism of L(+)-lactate in human skeletal muscle during exercise. Acta Physiologica Scandinavia, (suppl. 338), 1-67.
- Jorfeldt, L., Juhlin-Dannfelt, A., & Karlsson, J. (1978). Lactate release in relation to tissue lactate in human skeletal muscle during exercise. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, 44(3), 350-352.
- Karlsson, J., Bonde-Peterson, F., Henriksson, J., & Knuttgen, G. (1975). Effects of previous exercise with arms or legs on metabolism and performance in exhaustive exercise. Journal of Applied Physiology, 38(5), 763-767.
- Karlsson, J. & Saltin, B. (1970). Lactate, ATP, and CP in working muscles during exhaustive exercise in man. Journal of Applied Physiology, 29, 598-602.
- Klausen, K., Knuttgen, H., G., & Forster, H. V. (1972). Effect of pre-existing high blood lactate concentration on maximal exercise performance. Scandinavian Journal of Clinical and Laboratory Investigation, 30, 415-419.
- Koutedakis, Y. & Sharp, N. C. C. (1985). Lactic acid removal and heart rate frequencies during recovery after strenuous rowing exercise. British Journal of Sports Medicine, 19(4), 199-202.

- Krukau, M., Volker, K., & Liesen, H. (1987). The influences of sport-specific and sport-unspecific recovery on lactate-behavior after anaerobic swimming. International Journal of Sports Medicine, **8**, 142, (abstract).
- Lehninger, A. L. (1982). Principles of Biochemistry. New York: Worth Pub. Inc.
- Mann, G. V. & Garrett, H. L. (1978). Lactate tolerance, diet, and physical fitness. In J. Parizkova & V. A. Rogozkin (Ed.), Nutrition, Physical Fitness, and Health (pp. 31-41). Baltimore, MD.: Park Press.
- Margaria, R. & Edwards, H. T. (1934). The removal of lactic acid from the body during recovery from muscular exercise. American Journal of Physiology, **107**, 681-686.
- Margaria, R., Edwards, H. T., & Dill D. B. (1933). The possible mechanisms of contracting and paying the oxygen debt and the role of lactic acid in muscular contraction. American Journal of Physiology, **106**, 689-715.
- Margaria, R., Oliva, R. D., Di Prampero, P. E., & Cerretelli, P. (1969). Energy utilization in intermittent exercise of supramaximal intensity. Journal of Applied Physiology, **26**(6), 752-756.
- Mazzeo, R. S., Brooks, G. A., Budinger, T. F., & Schoeller, D. A. (1982). Pulse injection ^{13}C tracer series of lactate metabolism in humans during rest and two levels of exercise. Biomedical Mass Spectrometry, **9**(7), 310-314.
- McArdle, W. D., Katch, F. I., & Katch, V. I. (1981). Exercise Physiology: Energy, Nutrition, and Human Performance (2nd ed.). Philadelphia: Lea and Febiger.

- McCartney, N., Heigenhauser, G. J. F., & Jones, N. L. (1983). Effects of pH on maximal power output and fatigue during short-term dynamic exercise. Journal of Applied Physiology: Environmental, Respiratory, and Exercise Physiology, 55(1), 225-229.
- McGrail, J. C., Bonen, A., & Belcastro, A. N. (1977). Lactic acid metabolism during exercise. Research Papers in Physical Education, 3(3), 4-9.
- McGrail, J. C., Bonen, A., & Belcastro, A. N. (1978). Dependence of lactate removal on muscle metabolism in man. European Journal of Applied Physiology, 39(2), 89-97.
- McLellan, T. M. & Skinner, J. S. (1982). Blood lactate removal during active recovery related to the aerobic threshold. International Journal of Sports Medicine, 3, 224-229.
- Medbo, J. I. & Sejersted, O. M. (1985). Acid-base and electrolyte balance after exhausting exercise in endurance-trained and sprint-trained subjects. Acta Physiologica Scandinavica, 125, 97-109.
- Minaire, Y. & Forichon, J. (1975). Lactate metabolism and Glucose lactate conversion in prolonged physical exercise. In H. Howald & J. R. Poortmans (Ed.), Metabolic Adaptation to Prolonged Physical Exercise (pp. 106-112). Basel: Birkhauser.
- Montgomery, D. L. (1979). Characteristics of "Old Timer" hockey play. Canadian Journal of Applied Sport Sciences, 4(1), 210-216.
- Montgomery, D. L. (1982). The effect of added weight on ice hockey performance. The Physician and Sports Medicine, 10(11), 162-168.

Montgomery, D. L. (1988). Physiology of ice hockey. Sports Medicine, 5, 99-126.

Montgomery, D. L., Turcotte, R., Gamble, F. W., & Ladouceur, G. (1988). Validation of a cycling test of anaerobic endurance for ice hockey players. Manuscript submitted for publication.

Montgomery, D. L., Varztbedian, B., & Beaudin, P. (1977). Telemetry monitoring of heart rate in recreational adult hockey games. Canadian Journal of Applied Sports Sciences, 2(4), 216 (abstract).

Mucke, R. & Zollner, I. (1986). Muscle fibre conduction velocity during fatiguing and non-fatiguing isometric arm contractions. Biomedica Biochimica Acta, 1(2), S77-S80.

Nasser-Gentina, V., Passonneau, J. V., & Rappaport, S. I. (1981). Fatigue and metabolism of frog muscle fibres during stimulation and in response to caffeine. American Journal of Physiology, 241(Cell Physiology 10): C160-C166.

Nasser-Gentina, V., Passonneau, J. V., Vergara, J. L., & Rappaport, S. I. (1978). Metabolic correlates of fatigue and of recovery from fatigue in single frog muscle fibres. Journal of General Physiology, 72, 593-606.

Newman E. V., Dill, D. B., Edwards, H. T., & Webser, F. A. (1937). The rate of lactic acid removal in exercise. American Journal of Physiology, 118, 457-462.

- Paterson, D. H., Cunningham, D. A., Penny, D. S., Lefcoe, M. & Sangal, S. (1977). Heart rate telemetry and estimated energy metabolism in minor league ice hockey. Canadian Journal of Applied Sport Sciences, **2**, 71-75.
- Poortmans, J. R., Bossche, J. D., & Leclercq, R. (1978). Lactate uptake by inactive forearm during progressive leg exercise. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, **45**(6), 835-839.
- Rammal, K. & Strom, G. (1949). The rate of lactate utilization in man during work and at rest. Acta Physiologica Scandinavia, **17**, 453-456.
- Reed, A., Hansen, H., Cotton, C., Gauthier, R., Jette, M., Thoden, J., & Wenger, H. (1979). Development and validation of an on-ice hockey fitness test. Canadian Journal of Applied Sport Sciences, **4**(4), 245 (abstract).
- Renaud, J. M. & Mainwood, G. W. (1985a). The effects of pH on the kinetics of fatigue and recovery in frog sartorius muscle. Canadian Journal of Physiology and Pharmacology, **63**, 1435-1443.
- Renaud, J. M. & Mainwood, G. W. (1985b). The interactive effects of fatigue and pH on the ionic conductance of frog sartorius muscle fibres. Canadian Journal of Physiology and Pharmacology, **63**, 1444-1453.
- Rhodes, E. C., Potts, J. E., & Benicky, D. E. (1985). Prediction of anaerobic capacity in eight year old ice hockey players. Canadian Journal of Applied Sport Sciences, **10**(4), 36P (abstract).

- Rowell, L. B., Kraning, K. K., Evans, T. O., Kennedy, J. W., Blackman, J. R., & Kusumi, F. (1966). Splanchnic removal of lactate and pyruvate during prolonged exercise in man. Journal of Applied Physiology, **21**(6), 1773-1783.
- Sahlin, K., Alvestrand, A., Brandt, R., & Hultman, E. (1978). Intracellular pH and bicarbonate concentration in human muscle during recovery from exercise. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, **45**, 474-480.
- Sahlin, K., Edsrom, L., Sjoholm, H., & Hultman, E. (1981). Effects of lactic acid accumulation and ATP decrease on muscle tension and relaxation. American Journal of Physiology, **240** (Cell Physiology, **9**): C121-C126.
- Sahlin, K., Harris, R. C., Nylin, B., & Hultman, E. (1976). Lactate content and pH in muscle samples obtained after dynamic exercise. Pflugers Archives-European Journal of Physiology, **367**, 143-149.
- Sahlin, K. & Henriksson, J. (1984). Buffer capacity and lactate accumulation in skeletal muscle of trained and untrained men. Acta Physiologica Scandinavica, **122**, 331-339.
- Saltin, B. & Essen, B. (1971). Muscle glycogen, lactate, ATP, and CP in intermittent exercise. In B. Pernow & B. Saltin (Eds.), Muscle Metabolism During Exercise (pp. 419-424). New York: Plenum Press.
- Sejersted, O. M., Medbo, J. I., & Hermansen, L. (1982). Metabolic acidosis and changes in water and electrolyte balance after maximal exercise. Ciba Foundation Symposium, **87**, 153-167.

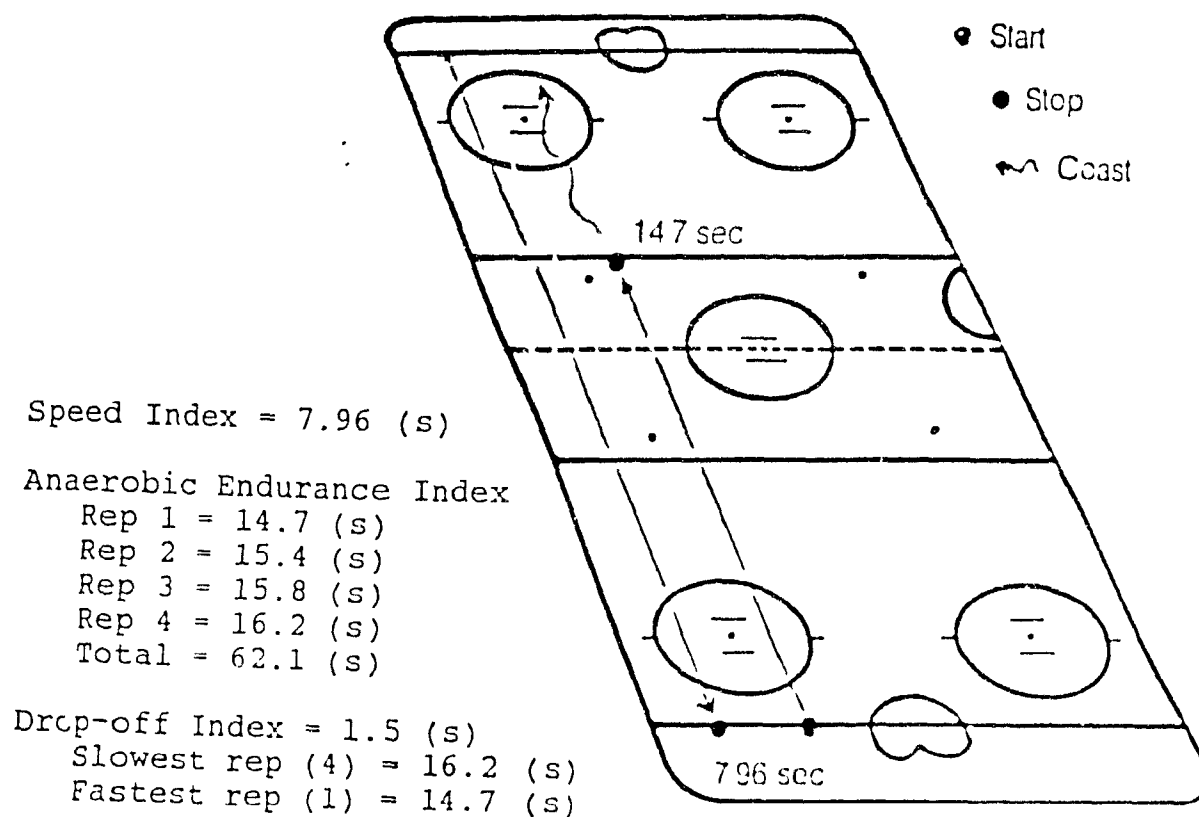
- Seliger, V., Kostka, V., Grusova, D., Kovac, J., Machovcova, J., Pauer, M., Pribylova, A., & Urbankova, R. (1972). Energy expenditure and physical fitness of ice hockey players. Internationale Zeitschrift für Angewandte Physiologie (Arbeitsphysiologie), **30**, 283-291.
- Sharp, R. L., Costill, D. L., Fink, W. J., & King, D. S. (1986). Effects of eight weeks of bicycle ergometer sprint training on human muscle buffer capacity. International Journal of Sports Medicine, **7**(1), 13-17.
- Siebers, L. S. & McMurray, R. G. (1981). Effects of swimming and walking on exercise recovery and subsequent swim performance. Research Quarterly for Exercise and Sport, **52**(1), 68-75.
- Smith, D. J., Quinney, H. A., & Steadward, R. D. (1982). Physiological profiles of the Canadian Olympic Hockey Team. Canadian Journal of Applied Sport Sciences, **7**(2), 142-146.
- Spath, W. K. (1979). The role of maximal oxygen consumption, conditioning, and maximal steady state in determining the lactate removal rate and optimal recovery work intensity following strenuous exercise. Unpublished doctoral dissertation, University of Missouri, Columbia, Missouri.
- Spriet, L. L., Matsos, C. G., Peters, S. J., Heigenhauser, G. J. F., Jones, N. L. (1985). Effects of acidosis on rat muscle metabolism and performance during heavy exercise. American Journal of Physiology, **248**, (Cell Physiology **17**), C337-C347.

- Stamford, B. A., Moffatt, R. J., Weltman, A., Maldonado, C., & Curtis, M. (1978). Blood lactate disappearance after supramaximal one-legged exercise. Journal of Applied Physiology: Respiratory, Environmental, & Exercise Physiology, 45(2), 244-248.
- Stamford B. A., Weltman, A., Moffatt, R., & Sady, S. (1981). Journal of Applied Physiology: Respiratory, Environmental, & Exercise Physiology, 51(4), 840-844.
- Tesch, P. (1978). Local lactate and exhaustion. Acta Physiologica Scandinavia, 104, 373-374.
- Tesch, P. (1980). Muscle fatigue in man with special reference to lactate accumulation during short term intense exercise. Acta Physiologica Scandinavia, (Suppl. 480), 1-40.
- Tesch, P. A. & Karlsson, J. (1984). Effects of exhaustive, isometric training on lactate accumulation in different muscle fibre types. International Journal of Sports Medicine, 5(2), 89-91.
- Tecsh, P., Sjodin, B., & Karlsson, J. (1978). Relationship between lactate accumulation, LDH activity, LDH isozyme and fibre type distribution in human skeletal muscle. Acta Physiologica Scandinavia, 103, 40-46.
- Tesch, P. A. & Wright, J. E. (1983). Recovery from short term intense exercise: Its relation to capillary supply and blood lactate concentration. European Journal of Applied Physiology, 52, 98-103.
- Timson, B. J. (1976). Lactate removal from the blood of trained distance runners following strenuous intermittent exercise. Unpublished masters thesis, Eastern Illinois University, Charleston

- Watson, R. C. & Hanley, R. D. (1986). Application of active recovery techniques for a simulated ice hockey task. Canadian Journal of Applied Sport Sciences, 11(2), 82-87.
- Watson, R. C. & Sargeant, T. L. C. (1986). Laboratory and on-ice test comparisons of anaerobic power of ice hockey players. Canadian Journal of Applied Sport Sciences, 11(4), 218-224.
- Weltman, A., Stamford, B. A., & Fulco, C. (1979). Recovery from maximal effort exercise: lactate disappearance and subsequent performance. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, 47(4), 667-682.
- Weltman, A., Stamford, B. A., Moffatt, R. J., & Katch V. L. (1977). Exercise recovery, lactate removal, and subsequent high intensity exercise performance. Research Quarterly for Exercise and Sport, 48(4), 786-796.
- Wilson, G. & Hedberg, A. (1979). Physiology of ice-hockey: a report. Ottawa, Ontario: Canadian Amateur Hockey Association.
- Yates, J. W., Gladden, L. B., & Cresanta, M. K. (1983). Effects of prior dynamic leg exercise on static effort of the elbow flexors. Journal of Applied Physiology: Respiratory, Environmental, Exercise Physiology, 55(3), 891-896.

Appendix A

Repeat Sprint Skate (RSS) Test



Speed Index: The time required to skate one length of the ice (54.9 m) on the first repetition of the RSS test.

Anaerobic Endurance Index: The total time required to complete four repetitions (4 X 91.4m) of the RSS test.

Drop-off Index: The difference between the fastest and slowest repetitions of the RSS test.

Appendix B

Data Collection Sheet (Passive Recovery Condition)

Subject _____ Date _____
 Tester _____

		Trials					
Shift	Speed Index	1	2	3	4	Total	Drop-off
1	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
2	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
3	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
4	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
5	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
6	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)

Pre-test Lactate Concentration _____ mg%

_____ mg%

Mean _____ mg%

Shift	Lactate Concentration (mg%)
1	_____
2	_____
3	_____
4	_____
5	_____
6	_____

Post-test Lactate Concentration _____ mg%

_____ mg%

Mean _____ mg%

Comments:

Appendix C

Data Collection Sheet (Skating Recovery Condition)

Subject _____
Tester _____

Date _____

		Trials					
Shift	Speed Index	1	2	3	4	Total	Drop-off
1	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
2	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
3	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
4	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
5	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
6	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)

		Shift					
Lap		1	2	3	4	5	6
1	Time (s)	_____	_____	_____	_____	_____	_____
2	Time (s)	_____	_____	_____	_____	_____	_____
3	Time (s)	_____	_____	_____	_____	_____	_____
4	Time (s)	_____	_____	_____	_____	_____	_____
5	Time (s)	_____	_____	_____	_____	_____	_____
6	Time (s)	_____	_____	_____	_____	_____	_____
7	Time (s)	_____	_____	_____	_____	_____	_____
8	Time (s)	_____	_____	_____	_____	_____	_____
9	Time (s)	_____	_____	_____	_____	_____	_____
10	Time (s)	_____	_____	_____	_____	_____	_____
11	Time (s)	_____	_____	_____	_____	_____	_____
12	Time (s)	_____	_____	_____	_____	_____	_____
13	Time (s)	_____	_____	_____	_____	_____	_____
14	Time (s)	_____	_____	_____	_____	_____	_____
15	Time (s)	_____	_____	_____	_____	_____	_____

Distance Skated (m)

Average Velocity (m/min)

Pre-test Lactate Con _____ mg% Post-test Lactate Con _____ mg%

_____ mg% _____ mg%

Mean _____ mg% Mean _____ mg%

Appendix D

Data Collection Sheet (Cycling Recovery Condition)

Subject _____ Date _____
 Tester _____

		Trials					
Shift	Speed Index	1	2	3	4	Total	Drop-off
1	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
2	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
3	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
4	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
5	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)
6	_____ (s)	_____	_____	_____	_____ (s)	_____ (s)	_____ (s)

Resistance at 40% of $\dot{V}O_{2\max}$ _____ kp

Pre-test Lactate Con _____ mg% Post-test Lactate Con _____ mg%
 _____ mg% _____ mg%
 Mean _____ mg% _____ mg%

Comments: