**Effect of Selected Recovery Conditions on Performance of
Repeated Bouts of Intermittent Cycling Separated by 24 Hours**

by

**Kirstin Nicole Lane
B.Sc., University of Victoria, 1997**

**A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of**

MASTER OF SCIENCE

In the Department of Physical Education

**We accept this thesis as conforming
to the required standard**

© Kirstin Nicole Lane, 1999

University of Victoria

**All rights reserved. This thesis may not be reproduced in whole or in part, by
photocopy or other means, without permission of the author.**

National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisitions et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-48202-2

Canada

Supervisor: Dr. H.A. Wenger

Abstract

The purpose of this study was to examine the effects of active recovery (AR), massage (MR), and cold water immersion (CR) on performance of repeated bouts of high intensity cycling separated by 24 hrs. For each recovery condition, subjects were asked to take part in two intermittent cycling sessions separated by 24 hours. The intermittent cycling session involved 22 repetitions of varying work intervals performed in succession at a resistance of 80 g per kg body weight (12 x 5 s work/25 s rest, 6 x 10 s work/50 s rest, 4 x 15 s work/75 s rest). One of four 15 min recovery conditions immediately followed the first intermittent cycling session and included: 1) AR – cycling at 30% $\dot{V}O_{2max}$, 2) CR – subjects immersed their legs in a 15°C water bath, 3) MR – massage of the quadriceps, hamstrings, and calf muscle groups, and 4) control – seated rest. Subjects were also asked to rate their readiness for each of the exercise sessions on a scale from 1 (“I am not able to give maximal effort”) to 5 (“I am able to give maximal effort”). A significant decline in the total work completed for the control condition was observed between the first and second exercise sessions (108.1 ± 5.4 kJ vs. 106.0 ± 5.0 kJ). As well, a significant decrease from session 1 to session 2 in the control condition for both the 10 s work bouts and 15 s work bouts (37.9 ± 1.9 kJ vs. 36.9 ± 1.8 kJ and 36.8 ± 1.8 kJ vs. 35.7 ± 1.7 kJ, respectively) was demonstrated. No difference was found between the two exercise sessions for any of the recovery conditions for the work completed in the first twelve 5 s work bouts. Subjects reported a significant decline in their readiness for the upcoming exercise protocol in both the AR and control trials. Thus, AR, MR, and CR

facilitated the recovery process between two high-intensity, intermittent exercise sessions separated by 24 hrs. In addition, AR and control resulted in the perception of a decreased ability to perform with the same maximal effort in the second exercise session.

Table of Contents

ABSTRACT	II
TABLE OF CONTENTS	IV
LIST OF TABLES	V
LIST OF FIGURES	VI
ACKNOWLEDGEMENTS	VII
DEDICATION.....	VIII
INTRODUCTION.....	1
METHODOLOGY	7
RESULTS	12
DISCUSSION	24
REFERENCES.....	36
APPENDIX A: DEFINITIONS, LIMITATIONS, AND ASSUMPTIONS	40
APPENDIX B: REVIEW OF THE LITERATURE.....	43
APPENDIX C: RATING OF READINESS	69
APPENDIX D: RAW DATA.....	71
APPENDIX E: PAIRED SAMPLE T-TESTS	76
APPENDIX F: INFORMED CONSENT.....	81

List of Tables

Table 1.	13
Table 2.	72
Table 3.	73
Table 4.	74
Table 5.	75
Table 6.	77
Table 7.	78
Table 8.	79
Table 9.	80

List of Figures

<u>Figure 1.</u> Time and event schedule for each recovery condition.....	8
<u>Figure 2.</u> Mean work (kJ) performed during 18 min intermittent exercise separated by 24 hrs under three different recovery conditions - AR, CR, MR - and a control condition ($n=10$).....	14
<u>Figure 3.</u> Mean work (kJ) performed in repetitions 1-12 (5 s work and 25 s rest) during 18 min intermittent exercise separated by 24 hrs under three different recovery conditions - AR, CR, MR - and a control condition ($n=10$).....	16
<u>Figure 4.</u> Mean work (kJ) performed in repetitions 13-18 (10 s work and 50 s rest) during 18 min intermittent exercise separated by 24 hrs under three different recovery conditions - AR, CR, MR - and a control condition ($n=10$).....	18
<u>Figure 5.</u> Mean work (kJ) performed in repetitions 19-22 (15 s work bouts and 75 s rest) during 18 min intermittent exercise separated by 24 hrs under three different recovery conditions - AR, CR, MR - and a control condition ($n=10$).....	20
<u>Figure 6.</u> Perception of readiness for the upcoming exercise protocol (18 min high-intensity, intermittent exercise) in 10 subjects for AR, CR, MR, and control conditions.	22

Acknowledgements

There are many people I would like to thank for either helping me with my thesis or being a supportive friend over the past few years. First, my supervisor and friend Dr. Howie Wenger. Thank you Howie for so many things - providing me with excellent direction in this research project, being a fantastic mentor, inspiring me (and challenging me) to always be a 'critical thinker', and for setting such a great example (along with Jan) on how to enjoy life! It has been so great to knock on your door and always see a smiling face and to get great advice on life as well as exercise physiology.

I would also like to thank my committee members, Dr. Lynne Wolski, Dr. Dave Docherty, and Dr. John Anderson for their help and assistance.

This thesis would not have been possible without the help of my close friend Sheri Piacente, R.M.T. When I was considering using massage as a recovery condition, Sheri did not hesitate to volunteer her services as a registered massage therapist even though she was in the midst of planning her own wedding. Thank you for rearranging your schedule and bringing your massage table up to the SFC!!

Although I was able to complete all the data collection on my own, there are many people I know would have been there to help had I needed it. So to Dona, Wendy, Holly, Dawn, Guy, Stef, Ben, and Shana – thanks! And thanks, too, for being great friends!!

Finally, I would like to thank two close friends – Renee and Kim – for always being there and keeping me busy with many social events.

And to the 'wine-tasting club' – I look forward to many more tasting events!

Dedication

I would like to dedicate this thesis to my mom and dad who are absolutely the greatest parents I could ever imagine having. I know my feet may be firmly entrenched in the trough but I promise one day I will try to take them out. I would also like to dedicate this to my Nana, Jessie Lane, who is very special to me and deserves to have her name in print!

Introduction

Intermittent type sports, such as ice hockey, soccer, and rugby, involve bursts of moderate to high intensity activity interspersed with periods of low intensity activity or complete rest. Due to the nature of these types of sports, demands are placed on each of the energy systems. The duration of work bouts is typically 5 to 15 s (Cox, Miles, Verde, & Rhodes, 1995; Ekblom, 1986; Nicholas, 1997) and falls within the range of the anaerobic alactic energy system (Greenhaff & Timmons, 1998). As anaerobic alactic energy stores - adenosine triphosphate (ATP) and creatine phosphate (CP) - become depleted, demands are placed on anaerobic lactic metabolism to provide energy (Greenhaff & Timmons). Blood lactate concentrations after the cessation of intermittent type sports have been shown to be 11 mmol L⁻¹ in hockey (Cox et al.) and 6 to 12 mmol L⁻¹ in rugby (Menchinelli, Morandini, & De Angelis, 1992). During rest periods from high-intensity work bouts, the aerobic energy system plays an important role. Several researchers (Sahlin, Harris, & Hultman, 1979; Harris et al., 1976) have demonstrated that depleted anaerobic alactic energy stores are resynthesized by aerobic regeneration of ATP. Lactate can be used as a metabolic fuel by slow-twitch muscle fibres and the liver and heart during aerobic energy production (Bonen & Belcastro, 1977).

A fast recovery may be important for athletes involved in a training program or who have a competition schedule that requires one or more high-intensity exercise sessions and/or games in a 24 hr period. After intense exercise the internal milieu of the body is disrupted. In addition to CP and ATP being depleted, intermittent exercise also

decreases muscle and blood pH, blood glucose concentration, and muscle glycogen levels (Gaitanos et al., 1993; Hargreaves et al., 1998; McCartney et al., 1986) and may cause inflammation (Kargotich, Goodman, Keast, & Morton, 1998) and fluid shifts from the vasculature to muscle (Gaitanos et al.). Consequently, any method that returns the disrupted internal environment back to homeostatic levels should lead to the ability to perform with maximal effort in subsequent exercise sessions. Anecdotal information from coaches, athletic trainers, and athletes suggests that active recovery, massage, and cold water immersion performed after the cessation of exercise to be such processes.

The rationale for performing active recovery after an intense competition or training session is to decrease the accumulation of lactate in muscle and blood. An active recovery increases blood perfusion to lactate oxidizing organs where it can be reconverted to pyruvate and utilized as an energy source (Bonen & Belcastro, 1977). Lactic acid may also be reconverted back to glucose via the Cori cycle or into glycogen via gluconeogenesis primarily in the liver but also, perhaps, in skeletal muscle (Pascoe & Gladden, 1996). An intensity of 30-40% VO_2max has been shown by Belcastro & Bonen (1975) to be the most effective in lactate clearance. There have not been any studies suggesting an optimal duration for active recovery. Although most studies have shown blood lactate clearance to be enhanced by active recovery (Bale & James, 1996; Gupta, Goswami, Sadhukhan, & Mathur, 1996; Taoutaou et al., 1996; Francaux, Jacqmin, deWelle, & Sturbois; 1995; Thiriet et al., 1993; Weltman & Regan, 1983; Watson & Hanley, 1986), only three studies (Thiriet et al; Welman & Regan; Watson & Hanley) have looked at subsequent performance. Thiriet et al. showed enhanced blood lactate clearance in the active recovery condition corresponded to the ability to maintain power

output on a cycle ergometer after a 20 min recovery period. This protocol included four, 2 min cycling bouts (130% VO_2max) with 20 min recovery (active arm, active leg, and seated rest) between each bout. Conversely, neither Watson and Hanley nor Weltman and Regan showed that subsequent work output was improved by enhanced blood lactate clearance. Watson and Hanley used a 15 min recovery period consisting of bench stepping, light skating, and seated rest separated two maximal effort, intermittent work bouts (six, 45 s skating trials interspersed with 90 s rest). This protocol was designed to simulate two periods of an ice hockey game. Weltman and Regan had subjects perform two maximal performance test (~ 4.8 min at 110% VO_2max) separated by 20 min recovery (40% VO_2max or seated rest). Thus, little is known about the effects of active recovery following intermittent exercise on performance 24 hours later.

Post-event sports massage has been proposed to help damaged skeletal muscles recover and regenerate after intense exercise (Tiidus & Shoemaker, 1995). Massage has been suggested to increase both blood flow (Wiktorsson-Möller, Oberg, Ekstrand, & Gillquist, 1983; Hovind, & Nielsen, 1974) and lymph drainage (Calder, 1990). Further, massage has been shown to have a positive psychological effect on both the mood and performance of the athlete (Weinberg, Jackson, & Kolodny, 1988). Post-event sports massage is typically performed for 15-20 min at the cessation of exercise and incorporates a variety of massage techniques (Callaghan, 1993).

Although many athletes and coaches believe post-event massage benefits subsequent performance, there is little research to support such a claim. Many of the studies using massage as an intervention have been done after a strength training session in order to determine the effects of massage on delayed onset muscle soreness (Tiidus &

Shoemaker, 1995; Cafarelli, Sim, Carolan, & Liebesman, 1990). For example, Tiidus and Shoemaker looked at the effect of massage on both muscle blood flow and long term post-exercise strength recovery. After completing eccentric contractions of the quadriceps muscle, effleurage massage was performed on only one of the exercised legs. Although the perceived level of delayed onset muscle soreness was reduced in the massaged leg 48-96 hours post-exercise, muscle blood flow and strength recovery was not significantly different. Cafarelli et al. also showed that short-term recovery from repeated submaximal quadriceps muscle contractions was not augmented by percussive vibratory massage.

The few studies that have been conducted using massage as an intervention after an aerobic and/or anaerobic exercise session have found that massage does not enhance blood lactate removal (Dolgener & Morien, 1993; Gupta et al., 1996). However, the effect of massage on subsequent performance was not determined. The positive psychological effect of massage on the mood of an athlete may be more pertinent to subsequent performance than a decline in blood lactate values.

Cold water immersion after intense exercise is proposed to cause vasoconstriction and reduce metabolism (Arnheim & Prentice, 1993). Further, it may also decrease the inflammatory response (Eston & Peters, 1999). Most research has concentrated on the effects of cold water immersion on both delayed onset muscle soreness and recovery from an acute injury (Denegar & Perrin, 1992). Temperatures and duration of the cold water bath have been recommended to be 10-15°C and 10-15 min, respectively (Arnheim & Prentice). No studies to date have investigated the effect of this therapeutic modality on performance after high-intensity, intermittent exercise.

Statement of the Problem

Research investigating the effects of active recovery, massage, and cold water immersion after intermittent exercise on subsequent performance has been few and inconclusive. Most studies have shown that active recovery enhances blood lactate clearance; however, few have expanded the protocol to include subsequent exercise performance. Studies that have been conducted have only looked at performance after a short period of recovery (15 – 20 min) whereas many training sessions or competitions are separated by at least 24 hrs. Further, massage and cold water immersion are commonly done after a training session or game yet the effects on performance 24 hours later are unknown. The majority of research investigating the efficacy of massage and cold water immersion has been done following strength training sessions and not intermittent exercise.

Statement of the Purpose

The purpose of this study was to investigate the effects of various recovery conditions (active recovery, massage, and cold water immersion) on repeated bouts of intermittent cycling separated by 24 hours. Three recovery and a control condition were performed: 1) active recovery (AR), 2) cold water immersion (CR), 3) massage (MR), and 4) passive rest (control).

Research Questions

- 1) Are there differences between the total work performed in two 18 min intermittent cycling sessions (separated by 24 hours) when 15 min of AR, CR, MR, or passive rest (control) is done after the first intermittent cycling session?
- 2) Are there differences in the total work performed in repetitions 1-12 (5 s work and 25 s rest) between two 18 min intermittent cycling session separated by 24 hours when the various recovery conditions are done after the first cycling session?
- 3) Are there differences in the work performed in repetitions 13-18 (10 s work and 50 s rest) between two 18 min intermittent cycling session separated by 24 hours when the various recovery conditions are done after the first cycling session? (Note: Repetitions 13-18 immediately follow repetitions 1-12).
- 4) Are there differences in the work performed in repetitions 19-22 (15 s work and 75 s rest) between two 18 min intermittent cycling session (separated by 24 hours) when the various recovery conditions are done after the first cycling session? (Note: Repetitions 19-22 immediately follow repetitions 1-18).
- 5) Are there differences in the rating of readiness on a 1 – 5 scale between two 18 min intermittent cycling sessions separated by 24 hours under each of the recovery conditions?

Methodology

Subjects

10 physically active males between the ages of 21-39 yrs were asked to participate in the study (Table 1). All procedures were approved by the University of Victoria Human Research Ethics Committee and written informed consent was obtained from each subject. Qualified individuals who had received proper instruction on testing protocols administered the tests.

Experimental Design

The dependent variables were total work (kJ), work performed during repetitions 1-12, work performed during repetitions 13-18, and work performed during repetitions 19-22, and the rating of readiness by subjects. The independent variable was the recovery condition: active recovery (AR), cold water immersion (CR), massage (MR), and passive rest (control). Control variables included the time of each intermittent cycling session, adequate sleep, and diet. The subjects were designated by random draw to test and treatment orders and at least 48 hrs separated each of the recovery conditions. Figure 1 graphically outlines the experimental design.

Experimental Procedures

Preliminary Tests

Subjects were familiarized with all procedures prior to testing. During the familiarization session, the sum of 5 skinfolds (triceps, biceps, subscapular, iliac crest, and medial calf) and a maximal oxygen consumption test ($\text{VO}_{2\text{max}}$) were performed

Figure 1. Time and event schedule for each recovery condition.

(Canadian Society for Exercise Physiology, 1993). The subjects also did several bouts of the 5 s intermittent cycling protocol to minimize any learning effect with performing the repeated sprints. The sum of 5 skinfolds and VO_2max tests were used as descriptive measures. In addition, the VO_2max test was used to determine the workload during the active recovery condition.

VO_2max was determined using a step-wise incremental protocol on a friction braked Monark cycle ergometer (model 818e). The test was terminated when one of the following criteria were attained: O_2 plateaus with an increase in power output or the subject stops due to exhaustion (Canadian Society for Exercise Physiology, 1993). Subjects expired air through a Rudolph valve into the mixing chamber of a Sensor Medics VMax 229 metabolic cart. Prior to and after each test, the VMax cart was calibrated against primary standard gases.

Exercise Protocol

Subjects reported to the laboratory for each of their tests at the same time of day, which was post-prandial. Subjects were requested to repeat their diet and refrain from any form of intense physical activity in the 48 hr prior to each test and between the first and second testing sessions.

For each recovery condition, subjects were asked to take part in 2 intermittent cycling sessions separated by 24 hours. The intermittent cycling sessions were identical and included a standardized warm-up and an 18 min intermittent cycling protocol. The standardized warm-up consisted of 5 min cycling followed by 5 min of stretching

(primarily the quadriceps, hamstrings, and calf muscle groups). Within the cycling portion of the workout, 4 min was spent cycling at 70 watts and the final minute included two 5 s maximal effort sprints at 2 kp separated by 50 s. These maximal effort sprints were done to remind the subjects of the importance of the explosive start. After completion of the warm-up, subjects began the intermittent cycling protocol. In total, 22 repetitions of cycling bouts of varying durations were performed with a work to rest ratio of 1:5. Repetitions 1-12 were 5 s each and were followed by 25 s rest, repetitions 13-18 were 10 s each (50 s rest), and repetitions 19-22 were 15 s each (75 s rest). Passive rest periods separated each work bout. Including each work and rest period, the total duration of the intermittent cycling protocol was 18 min.

A calibrated Monark 818e cycle ergometer connected to an electronic revolutions counter was used for the intermittent cycling protocol. Subjects began pedaling from a stationary start and were asked to cycle with maximal effort against a resistance of 80 g per kg body mass. The total number of pedal revolutions in each work bout was used to determine work (kJ) for all repetitions, and the amount of work done in repetitions 1-12, 13-18, and 19-22. Subjects were asked prior to the start of each intermittent cycling session to rate their level of “readiness” for the upcoming cycling session on a 5 point scale (Appendix C).

The first intermittent cycling session was followed by one of four recovery conditions assigned in a randomized, counterbalanced order. These recovery conditions included: AR – 15 min cycling at 30% VO_2max (Belcastro & Bonen, 1975), CR – 15 min immersion of the legs in a cold water bath of 15°C (Arnheim & Prentice, 1993), and MR – 15 min massage performed by a registered Massage Therapist on the quadriceps,

hamstrings, and calf muscle groups. The massage techniques included deep effleurage (2.5 min/leg), compressions (1 min/leg), deep muscle stripping (2 min/leg), jostling (1 min/leg), and cross-fibre frictions (1 min/leg). A control condition was also included during which subjects sat passively for 15 min at the cessation of the first cycling session. Exactly 24 hrs after the start of the first intermittent cycling session a second intermittent cycling session was performed (warm-up and intermittent cycling protocols were identical to that described above).

Statistical Analysis

Paired t-tests were performed on each of the recovery conditions between sessions one and two. As well, paired t-tests were performed on the rating of readiness by the subjects between session one and session 2. A probability error of ≤ 0.05 was considered significant. All results are presented as mean (SEM).

Results

10 subjects (table 1) performed two identical exercise sessions consisting of 18 min of high-intensity intermittent exercise separated by 24 hr. One of four recovery conditions – AR, CR, MR, and control - immediately followed the first exercise session. A significant drop in total work completed was observed between the two exercise sessions for the control condition (108.1 ± 5.4 kJ vs. 106.0 ± 5.0 kJ). AR, CR, and MR did not result in a decrease in total work over the two sessions (Fig. 2).

Repetitions 1-12 consisted of 5 s work bouts with 25 s rest (Fig. 3). Significant decreases were not found between the two exercise sessions for any of the recovery conditions. After the twelfth repetition of 5 s work and 25 s rest, the first of six 10 s work bouts with 50 s rest were performed. The work done during the six 10 s work bouts in the control condition significantly decreased from $37.9 (1.9)$ kJ to $36.9 (1.8)$ kJ after 24 hrs. The remaining recovery conditions did not result in a significant drop between the two exercise sessions.

The final four repetitions (18-22) consisted of 15 s work bouts with 75 s rest and began after the last 10 s work/50 s rest interval. Again, the control trial was the only recovery condition to result in a significant decrease between the two exercise sessions (36.8 ± 1.8 kJ vs. 35.7 ± 1.7 kJ) (Fig. 5).

Before performing each 18 min high-intensity, intermittent exercise session, subjects were asked to rate their readiness of a 5 point scale (Appendix C). Figure 6 shows a significant decline from session 1 to session 2 in the control and AR conditions only (4.4 vs. 4.0 and 4.8 vs. 3.8, respectively).

Table 1.

Physical Characteristics of Subjects (n=10).

	Mean	SEM	Range
Age (years)	26.3	2.0	21-39
Body Mass (kg)	74.3	2.8	61.0-74.3
Sum of 5 Skinfolds (mm)	41.5	4.3	27.0-59.4
VO ₂ max (L·min ⁻¹)	4.09	0.18	3.22-4.74
VO ₂ max (mL·kg ⁻¹ ·min ⁻¹)	55.4	2.2	40.3-64.2

Figure 2. Mean work (kJ) performed during 18 min intermittent exercise (including 12x5 s work and 25 s recovery, 6x10s work and 50 s recovery, 4x15 s work and 75 s recovery) separated by 24 hrs under three different recovery conditions - AR, CR, MR - and a control condition (n=10).

* $p \leq 0.05$

Figure 3. Mean work (kJ) performed in repetitions 1-12 (5 s work bouts each followed by 25 s rest) during 18 min intermittent exercise separated by 24 hrs under three different recovery conditions - AR, CR, MR – and a control condition (n=10).

$p \leq 0.05$

Figure 4. Mean work (kJ) performed in repetitions 13-18 (10 s work bouts each followed by 50 s rest) during 18 min intermittent exercise separated by 24 hrs under three different recovery conditions - AR, CR, MR - and a control condition (n=10).

* $p \leq 0.05$

Figure 5. Mean work (kJ) performed in repetitions 19-22 (15 s work bouts each followed by 75 s rest) during 18 min intermittent exercise separated by 24 hrs under three different recovery conditions - AR, CR, MR - and a control condition (n=10).

* $p \leq 0.05$

Figure 6. Perception of readiness for the upcoming exercise protocol (18 min high-intensity, intermittent exercise) in 10 subjects for AR, CR, MR, and control conditions.

* $p \leq 0.05$

Discussion

This study investigated the effects of active recovery, massage, and cold water immersion on repeated bouts of high-intensity, intermittent cycling separated by 24 hrs. The exercise protocol included twelve 5 s work bouts separated by 25 s rest, six 10 s work bouts (50 s rest), and four 15 s work bouts (75 s rest). As soon as the twelfth 5 s work/25 s rest interval was completed, the first of six 10 s work bouts followed by 50 s rest was performed. Again, after the sixth 10 s work/50 s rest interval was completed, the first of four 15 s work and 75 s rest began. The total work completed during the entire exercise protocol and the work done in the series of 5 s, 10 s, and 15 s work bouts was compared between the two exercise sessions for each of the recovery conditions.

According to Figure 2, a significant drop in the total work completed for the control condition was observed between the first and second exercise sessions (108.1 ± 5.4 kJ vs. 106.0 ± 5.0 kJ). As well, figures 4 and 5 show a significant decrease from session 1 to session 2 in the control condition for both the 10 s work bouts and 15 s work bouts (37.9 ± 1.9 kJ vs. 36.9 ± 1.8 kJ and 36.8 ± 1.8 kJ vs. 35.7 ± 1.7 kJ, respectively). There was not, however, a significant change found between the two exercise sessions for any of the recovery conditions for the 5 s work bouts (Fig.3). Thus, the ability to maintain power output during two high-intensity, intermittent cycling sessions separated by 24 hrs was maintained in the AR, MR, and CR trials.

High-intensity, intermittent exercise represents an acute disturbance in homeostasis. Gaitanos, Williams, Boobis, and Brooks (1993) demonstrated a significant decline in ATP, CP, glycogen, and plasma volume and a significant rise in both muscle

and blood lactate concentration after ten 6 s sprints with 30 s recovery. Other studies (Hargreaves et al., 1998; McCartney et al., 1986) have shown similar results despite longer work and recovery intervals (30 s work, 4 min rest). Further, Essen and Kaijser (1978) have demonstrated that fast twitch muscle fibers are primarily recruited during high-intensity, intermittent exercise (15 s work, 15 s rest at 100% VO_2max for 60 min). Because of the similarities in exercise protocols between the present study and that by Gaitanos et al., it can be assumed a decrease in muscle ATP, CP, and glycogen levels and a concomitant rise in muscle lactate levels occurred. Consequently, in the 24 hrs that separated the two identical high-intensity, intermittent cycling sessions, homeostasis needed to be regained if subjects were to perform again with maximal effort.

The ability to maintain power output between two identical high-intensity, intermittent sessions separated by 24 hrs was demonstrated in the AR condition (Fig. 2). Thus, AR appeared to facilitate the recovery process. This may be explained by the observation that blood lactate clearance is enhanced by active recovery (Gupta et al., 1996; Taoutaou et al., 1996; Francaux, Jacquin, deWelle, & Sturbois; 1995; Thiriet et al., 1993; Weltman & Regan, 1983; Watson & Hanley, 1986). Active recovery after high-intensity, intermittent exercise elevates muscle blood flow which increases oxygen delivery to the recovering muscle. Concomitantly, lactate and hydrogen ions (H^+) should be removed at a faster rate (Rowell, Kraning, Evans, Kennedy, Blackmon, & Kusumi, 1966). Lactate in the blood has several fates. It is primarily transported to slow-twitch muscle, and to a lesser extent heart, liver, and kidney, where it is reconverted to pyruvate and used as an energy source. Lactate can also be reconverted back to glucose via the Cori cycle or into glycogen via gluconeogenesis (Pascoe & Gladden, 1996).

Few have investigated the effect of AR on subsequent performance. Similar to the present study, Thiriet et al. (1993) also found that active recovery corresponded to the ability to maintain work output on a cycle ergometer. 15 min active or passive recovery periods separated four 2 min cycling bouts (Thiriet et al.) whereas 24 hrs separated two high-intensity, intermittent exercise sessions in the present study. Active leg recovery had the fastest blood lactate clearance kinetics while the slowest blood lactate clearance kinetics were found in the passive condition. Over the four work bouts, power output was significantly reduced as of the second bout in the passive recovery trial and did not significantly change in the active leg recovery trial. Thus, active recovery was related to maintenance of power output over succeeding bouts of this type.

Weltman and Regan (1983) and Watson and Hanley (1986), on the other hand, did not show subsequent performance to be improved by enhanced blood lactate clearance via active recovery. Shorter recovery periods of 20 min and 15 min, respectively, separated the 2 work bouts whereas 24 hrs separated exercise sessions in the present study. Weltman and Regan found that despite the significantly lower blood lactate concentrations in the active recovery condition (4.0 mM vs. 5.6 mM), differences in work output among the performance tests were not demonstrated (either between conditions or from pre- to post-recovery). However, it is only lactic acid in muscle, not blood, which interferes with enzyme activity and muscular contractions (Belcastro & Bonen, 1975). As long as the prior recovery condition led to sufficient removal of lactate from muscle, then there may not be considerable differences in power output between two work bouts. Further, blood lactate values of 4.0-5.6 mM may not be sufficient level to still have an effect on subsequent performance. Watson and Hanley (1986) designed a

study to simulate two periods of an ice hockey game separated by a 15 min intermission. At the end of the recovery period bench stepping resulted in significantly lower blood lactate values than rest recovery (6.1 mM vs. 8.1 mM); however, subsequent performance was significantly lower than initial performance in both treatment groups. The intermittent nature of the exercise protocol used by Watson and Hanley more closely mimicked that used in the present study. Perhaps, a 15 min recovery period is not of sufficient duration to remove sufficient lactate from the muscle after high-intensity exercise. Muscle lactate may have been at such a level that the concomitant rise in H^+ concentration was still inhibiting enzyme activity and interfering with muscular contractions in both trials (Belcastro & Bonen, 1975). Further, the replenishment of ATP and CP may have been compromised in the active recovery condition. Conceptually, active recovery may impede ATP and CP resynthesis. The aerobic regeneration of ATP would be used for muscular contractions if light exercise was performed rather than for the rephosphorylation of anaerobic alactic energy stores. In the present study, AR was only performed for the first 15 min of a 24 hr recovery period. Consequently, the beneficial effects of AR in terms of an increase in blood flow and oxygen delivery would still be achieved without compromising ATP and CP resynthesis. Further research is needed to address this issue.

There has been some disagreement in the literature as to whether performing an active recovery impedes the rate of muscle glycogen synthesis. However, this study would suggest that muscle glycogen in the AR, MR, and CR conditions had been replenished to such a level that it did not affect subsequent performance. Subjects were told to eat similar foods in the day prior to and between each exercise session.

Consequently, carbohydrate intake should have remained consistent for each recovery condition over the course of the study. Futre, Noakes, Raine, and Terblanche (1987) did not find a significant difference in the rate of muscle glycogen synthesis following intense intermittent exercise between active (30% VO_2max) and passive recovery trials ($24.0 \text{ mmol} \cdot \text{kg}^{-1} \text{ wet weight (w.w.)}$ and $25.0 \text{ mmol} \cdot \text{kg}^{-1} \text{ w.w.}$, respectively). Conversely, Choi, Cole, Goodpaster, Fink, and Costill (1994) found that active recovery (40-50% VO_2max) further depleted muscle glycogen stores during the recovery period. Mean muscle glycogen after 60 min of passive recovery and active recovery was demonstrated to be $+15.0 \text{ mmol} \cdot \text{kg}^{-1} \text{ w.w.}$ and $-6.3 \text{ mmol} \cdot \text{kg}^{-1} \text{ w.w.}$. No significant difference was found between muscle lactate disappearance following active recovery and passive recovery ($23.9 \text{ mmol} \cdot \text{kg}^{-1} \text{ w.w.} \cdot \text{hour}^{-1}$ and $23.3 \text{ mmol} \cdot \text{kg}^{-1} \text{ w.w.} \cdot \text{hour}^{-1}$, respectively). Thus, exercise performed during the recovery period may have continued to use muscle glycogen as a fuel source. This discrepancy in muscle glycogen resynthesis may be related to the intensity of the active recovery period. Although an intensity of 30-50% VO_2max has been shown (Belcastro & Bonen, 1975) to be optimal for blood lactate clearance, the intensity of the active recovery period chosen by Choi et al. may have been at such a high level that it impeded muscle glycogen synthesis. Intensities less than 30% VO_2max may be preferred if lactate rather than glycogen is to be used as an energy source. The intensity used in the present study for the AR condition was 30% VO_2max .

The present study found that MR appeared to facilitate performance of repeated bouts of high-intensity, intermittent exercise separated by 24 hrs (Fig. 2). Previous studies investigating the efficacy of massage after high-intensity exercise have not expanded the protocol to include subsequent performance. Rather the majority of this

research has focused on comparing massage to active recovery in terms of the rates of blood lactate clearance. The proposed effect of massage on blood flow (Wiktorsson-Möller, Oberg, Ekstrand, & Gillquist, 1983; Hovind & Nielsen, 1974) may explain why MR led to maintenance of power output over two high-intensity, intermittent exercise sessions. If massage does enhance blood flow, then the removal of lactic acid and other intermediates from muscle may be facilitated. McSwain (1990) reported the percent change in blood lactate clearance to be significantly greater from 30 to 50 min post-exercise in the massage trial when compared to both the active and rest recovery trials (34% vs. ~15% and ~17%). This suggests that the effects of massage in terms of blood lactate clearance may not be evident until later in the recovery period. Consequently, a longer period between exercise sessions (such as the 24 hrs used in the present study) may be more appropriate when massage is used after high-intensity, intermittent exercise. Conversely, Dolgener and Morien (1993) and Gupta et al. (1996) found active recovery resulted in a faster decline in blood lactate values compared to massage or passive recovery. Dolgener and Morien used an exhaustive run on the treadmill (average time to fatigue was 211 s) while Gupta et al. had subjects cycle for 1 min at 150% VO_2max with 15 s rest periods until exhaustion. Recovery periods were 20 min and 40 min, respectively. As mentioned earlier, the effect of massage may not be evident until later in the recovery period. Further, massage was only performed for the first 10 min of the 40 min recovery period whereas active recovery was performed for the entire 40 min (Gupta et al.). It is difficult to make comparisons between active recovery and massage when treatment times varied.

There are other reasons that could explain how MR facilitated the recovery process. Friden, Seger, and Ekbom (1988) reported abnormalities of the contractile material and the cytoplasmic organelles were evident after intensive sprint training. If high-intensity, intermittent exercise does cause mechanical disruption of the sarcomeres and sarcolemma, then the ability to perform again with maximal effort may be related to the time course of the subsequent repair of the contractile material. Again, if massage does lead to enhanced local microcirculatory blood and lymph flow because of the mechanical pressure on muscle blood tissue (Ernst, 1997), then oxygen delivery should also be increased. This may help to reduce edema and accumulation of harmful substances (Tiidus & Shoemaker, 1995). Massage has also been proposed to have an analgesic response which may help to lessen the discomfort that is often associated with intense muscular activity (Callaghan, 1993). More research is needed to elucidate the exact mechanisms of massage in the recovery process.

The ability to maintain power output during two identical high-intensity, intermittent exercise sessions separated by 24 hrs was demonstrated in the CR condition (Fig. 2). Thus, CR also appeared to facilitate the recovery process. This may be explained by the proposed effect of cold water immersion on vasoconstriction, muscle metabolism, and the inflammation process (Arnheim & Prentice, 1993). Immersion in cold water stimulates cutaneous cold receptors thereby causing constriction of peripheral blood vessels redirecting blood to the warmer core (Graham, 1988). Cold water immersion has also been suggested to reduce muscle blood flow and muscle metabolism (Arnheim & Prentice). Although a decrease in muscle blood flow would not appear to assist in removing metabolic intermediates from muscle, it may assist in reducing factors

related to an inflammatory response after exercise such as edema and increased lysosomal activity (Eston & Peters, 1999). The few studies that have been completed using cold water immersion as an intervention have concentrated on the effects of a cold water bath on both delayed onset muscle soreness and recovery from an acute injury (Denegar & Perrin, 1992). Denegar and Perrin found that cold resulted in significant decreases in perceived pain and significant increases in elbow extension range of motion. No studies have investigated the effect of this therapeutic modality on repeated performance of high-intensity, intermittent exercise.

The only recovery condition to result in a significant decline in power output during two identical high-intensity, intermittent exercise sessions separated by 24 hr was the control condition (Fig. 2). Thus, homeostasis may not have been regained when subjects were asked to sit for 15 min immediately after the 18 min high-intensity, intermittent cycling protocol. Because subjects were sitting passively, then there may be several factors that led to the decrement in performance observed during the second exercise session. First, muscle blood flow returns to resting levels at a faster rate during passive rest than it does during an exercise recovery. Consequently, metabolites such as lactic acid may remain in the muscle for a longer period causing a concurrent decrease in pH. This prolonged acidic environment may interfere with recovery processes such as inhibiting enzymes involved in glycogen synthesis. Because the majority of muscle glycogen synthesis occurs in the first two hours after exercise (Pascoe & Gladden, 1996), then a slow rate of synthesis during this period may prolong the return of muscle glycogen to resting levels. Second, the prolonged presence of lactate and other metabolites in muscle may also increase the osmotic gradient causing a fluid shift from

plasma to muscle. A decrease in plasma volume of ~15-20% has been shown after maximal exercise (Green, Thomson, Ball, Hughson, Houston, & Sharratt, 1984; Sjogaard & Saltin, 1982). Maximal exercise involved 24 repetitions of 1 min cycling with 4 min rest periods (Green et al.) and 3 repetitions of 3 min cycling with 3 min rest (Sjogaard & Saltin). An increase in leg water volume may increase the perfusion distance for substances to move from the circulatory system to muscle and vice versa. Further, if a decrease in plasma volume remains through to the second exercise session, then performance may be negatively affected. A decrease in plasma volume causes a decrease in stroke volume due to decreased diastolic filling rate (Krip, Gledhill, Jamnik, & Warburton, 1997). Because of this decrease in cardiac output and thus oxygen carrying capacity, then the aerobic regeneration in the brief rest periods that separated work bouts during the high-intensity, intermittent exercise protocol may be negatively affected. Third, passive rest may delay the time-course of the repair of any damage to contractile material. For example, sarcoplasmic reticulum damage and free O₂ radicals have been shown to interfere with power output (Gollnick, Korge, Karpalka, & Saltin, 1991). There may be something about performing AR, MR, or CR after high-intensity, intermittent exercise that reduces the amount of free O₂ radicals in muscle and helps reduce damage to contractile material. Finally, the positive psychological effects of performing some sort of recovery condition immediately after high-intensity, intermittent exercise may also be pertinent to the ability to perform maximally in subsequent sessions. In the present study, the readiness of the subject to perform the upcoming session of high-intensity, intermittent exercise was measured by way of a subjective rating on a 1-5 scale (Appendix C). A significant difference was not found between the two exercise sessions

for either MR or CR (Fig. 6). Thus, subjects felt they had the same degree of readiness for each session of high-intensity, intermittent exercise when both MR and CR were performed. Conversely, subjects did not feel they had the same degree of readiness for the second exercise session when either AR or the control condition was performed. Anecdotally subjects reported that their legs felt heavy and stiff during the control trial. The fact that there was a significant difference in the AR trial was an unexpected result. Massage has been shown to have a positive psychological effect on the mood and performance of the athlete. For example, Weinberg, Jackson, and Kolodny (1988) demonstrated that there was a greater relationship between massage and positive mood enhancement than between exercise (running) and positive mood enhancement.

In addition to the total work performed during each exercise session, the work performed in the 5 s, 10 s, and 15 s bouts were also compared between the two identical sessions of high-intensity intermittent exercise separated by 24 hrs. Repetitions 1-12 consisted of 5 s work bouts with 25 s rest (Fig. 3). Statistical analysis revealed no significant differences in the work completed during these repetitions between the two exercise sessions for any of the recovery conditions. This result was expected as 5 s as the full recovery time for the anaerobic alactic system has been shown to take 2 to 3 min (Harris et al., 1975). Consequently, sufficient time was available in the 24 hrs that separated the two high-intensity, intermittent exercise sessions to replenish muscle ATP and CP. Muscle ATP and CP were likely resynthesized immediately at the cessation of the exercise protocol and would not have been expected to impede performance in the second exercise session for any of the recovery conditions. Practical implications of this result indicate that the type of recovery performed after twelve or less repetitions of 5 s

work bouts is not related to maintenance of power output. Because both the six 10 s work/50 s rest intervals and four 15 s work/75 s rest resulted in a significant decrease in work performed from session 1 to session 2 (Fig. 4 and 5, respectively), then this contributed to the decline in total work seen in the control condition (Fig. 2). Consequently, when the training protocol is expanded to include 10 s or 15 s work bouts after a series of 5 s work bouts then AR, MR, or CR should be performed instead of passive rest.

The difference in total work performed between session 1 and session 2 in the control condition was 2133 J (Table 2). Since the average work done in a 5 s work bout was 2733 J, then a loss of 2133 J from session 1 to session 2 represented a difference of 3.9 s. The impact of losing 3.9 s of work output in a game situation may mean a goal in hockey or try in rugby being scored.

In summary, the purpose of this study was to examine the effects of 15 min of various recovery conditions (AR, MR, CR, and passive rest) on performance of repeated bouts of high intensity cycling separated by 24 hrs. The exercise protocol included twelve 5 s work bouts separated by 25 s rest, six 10 s work bouts (50 s rest), and four 15 s work bouts (75 s rest). Subjects were also asked to rate their readiness for each of the exercise sessions on a scale from 1 ("I am not able to give maximal effort") to 5 ("I am able to give maximal effort"). A significant decline in the total work completed for the control condition was observed between the first and second exercise sessions (Fig. 2). As well, a significant decrease from session 1 to session 2 in the control condition for both the 10 s work bouts and 15 s work bouts (Fig. 4 and 5, respectively) was demonstrated. No difference was found between the two exercise sessions for any of the

recovery conditions for the work completed in the first twelve 5 s work bouts. Subjects reported a significant decline in their readiness for the exercise protocol in both the AR and control trials. Thus it may be concluded that AR, MR, and CR appeared to facilitate the recovery process between two high-intensity, intermittent exercise sessions separated by 24 hrs. In addition, MR and CR resulted in the perception of an ability to perform again with the same maximal effort in the second exercise session. Further research is needed to determine if combinations of the various recovery conditions (i.e., AR followed by MR or CR) are more beneficial than performing a single recovery condition after high-intensity, intermittent exercise. Also, having muscle biopsies taken before and after the first and second exercise sessions may help to elucidate the physiological processes that may or may not have returned to resting levels.

References

- Arnheim, D.D., & Prentice, W.E. (1993). Principles of athletic training (9th ed.). Boston: McGraw Hill.
- Bale, P., & James, H. (1996). Massage, warmdown, and rest as recuperative measures after short term intense exercise. Physiotherapy in Sport, 12: 4-7.
- Belcastro, A.N., & Bonen, A. (1975). Lactic acid removal rates during controlled and uncontrolled exercise. Journal of Applied Physiology, 39(6): 932-936.
- Bonen, A., & Belcastro, A.N. (1977). A physiological rationale for active recovery exercise. Canadian Journal Applied Sport Sciences, 2: 634-665.
- Cafarelli, E., Sim, J., Carolan, B., & Liebesman, J. (1990). Vibratory massage and short-term recovery from muscular fatigue. International Journal of Sports Medicine, 11(6): 474-478.
- Calder, A. (1990). Recovery: restoration and regeneration as essential components within training programmes. EXCEL, 6(3): 15-19.
- Callaghan, M.J. (1993). The role of massage in the management of the athlete: a review. British Journal of Sports Medicine, 27(1): 28-33.
- Choi, D., Cole, K.J., Goodpaster, B.H., Fink, W.J., & Costill, D.L. (1994). Effect of passive and active recovery on the resynthesis of muscle glycogen. Medicine & Science in Sports and Exercise, 26(8): 992-996.
- Cox, M.H., Miles, D.S., Verde, T.J., & Rhodes, E.C. (1995). Applied physiology of ice hockey. Sports Medicine, 19(3): 184 - 201.
- Denegar, C.R., & Perrin, D.H. (1992). Effect of transcutaneous electrical nerve stimulation, cold, and a combination treatment on pain, decreased range of motion, and strength loss associated with delayed onset muscle soreness. Journal of Athletic Training, 27(3): 200-206.
- Dolgener, F.A., & Morien, A. (1993). The effect of massage on lactate disappearance. Journal of Strength and Conditioning Research, 7(3): 159-162.
- Ekblom, B. (1986). Applied physiology of soccer. Sports Medicine, 3: 50-60.
- Ernst, E. (1998). Does post-exercise massage treatment reduce delayed onset muscle soreness? A systematic review. British Journal of Sports Medicine, 32: 212-214.

- Essen, B., & Kaijser, L. (1978). Regulation of glycolysis in intermittent exercise in man. Journal of Physiology, 281: 499-511.
- Eston, R., & Peters, D. (1999). Effects of cold water immersion on the symptoms of exercise-induced muscle damage. Journal of Sport Sciences, 13(7): 231-238.
- Friden, J., Seger, J., & Ekblom, B. (1988). Sub lethal muscle injuries after high-tension anaerobic exercise. European Journal of Applied Physiology, 57: 360-368.
- Francaux, M., Jacqmin, P., deWelle, J.M., & Sturbois, X. (1995). A study of lactate metabolism without tracer during passive and active postexercise recovery in humans. European Journal of Applied Physiology, 71(1/2): 58-66.
- Gaitanos, G.C., Williams, C., Boobis, L.H., & Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise. Journal of Applied Physiology, 75(2): 712-719.
- Gollnick, P.D., Korge, P., Karpakka, J., & Saltin, B. (1991). Elongation of skeletal muscle relaxation during exercise is linked to reduced calcium uptake by the sarcoplasmic reticulum in man. Acta Physiologica Scandinavica, 142: 135-1367.
- Graham, T.E. (1988). Thermal, metabolic, and cardiovascular changes in men and women during cold stress. Medicine and science in sports and exercise, 20(5): S185-S192.
- Green, J.H., Thomson, J.A., Ball, M.E., Hughson, R.L., Houston, M.E., & Sharratt, M.T. (1984). Alterations in blood volume following short-term supramaximal exercise. Journal of Applied Physiology, 56: 145-149.
- Greenhaff, P.L., & Timmons, J.A. (1998). Interaction between aerobic and anaerobic metabolism during intense muscle contraction. In J. O. Holloszy (Ed.), Exercise and Sport Science Reviews (pp. 1- 30).
- Greenleaf, J.E., van Beaumont, W., Brock, P.J., Morse, J.T., & Mangseth, G.R. (1979). Plasma volume and electrolyte shifts with heavy exercise in sitting and supine positions. American Journal of Physiology, 236: R206-R214.
- Gupta, S., Goswami, A., Sadhukhan, A.K., & Mathur, D.N. (1996). Comparative study of lactate removal in short term massage of extremities, active recovery and a passive recovery period after supramaximal exercise sessions. International Journal of Sports Medicine, 17(2): 106-110.
- Hargreaves, M., McKenna, M.J., Jenkins, D.G., Warmington, S.A., Li, J.L., Snow, R.J., & Febbraio, M.A. (1998). Muscle metabolites and performance during high-intensity, intermittent exercise. Journal of Applied Physiology, 84(5): 1687-1691.

- Harris, R.C., Edwards, R.H.T., Hultamn, E., Nordesjo, L.O., Nyling, B., & Sahlin, K. (1975). The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. Pfluegers Archives, 367: 137-142.
- Hovind, H., & Nielsen, S.L. Effect of massage on blood flow in skeletal muscle. Scandinavian Journal of Rehabilitory Medicine, 6: 74-77.
- Kargotich, S., Goodman, C., Keast, D., & Morton, A.R. (1998). The influence of exercise-induced plasma volume changes on the interpretation of biochemical parameters used for monitoring exercise, training and sport. Sports Medicine, 26(2): 101-117.
- Krip, B., Gledhill, N., Jamnik, V., & Warburton, D. (1997). Effect of alterations in blood volume on cardiac founction during maximal exercise. Medicine and Science in Sports and Exercise, 29: 1469-1472.
- McCartney, N., Spriet, L.L., Heigenhauser, G.J., Kowalchuk, J.M., Sutton, J.R., & Jones, N.L. (1986). Muscle power and metabolism in maximal intermittent exercise. Journal of Applied Physiology 60(4): 1164-1169.
- McSwain, G. (1990). The effect of massage, exercise, and rest on the clearance rate of blood lactate after strenuous exercise. master's thesis, california state university, fullerton.
- Menchinelli, C., Morandini,k C., De Angelis, M. (1992). A functional model of rugby: determination of the characteristics of sports performance. Journal of Sports Sciences, 10, 196-197.
- Nicholas, C.W. (1997). Anthropometric and physiological characteristics of rugby union football players. Sports Medicine, 23(6): 377-396.
- Pascoe, D.D., & Gladden, L.B. (1996). Muscle glycogen resynthesis after short term, high intensity exercise and resistance exercise. Sports Medicine, 21(2): 96-118.
- Peters-Futre, E.M., Noakes, T.D., Raine, R.I., & Terblanche, S.E. (1987). Muscle glycogen repletion during active postexercise recovery. American Journal of Physiology, 253(3): E305-E311.
- Rowell, L.B., Kraning, K.K., Evans, T.O., Kennedy, J.W., Blackmon, J.R., & Kusumi, F. (1966). Splanchnic removal of lactate and pyruvate during prolonged exercise in man. Journal of Applied Physiology, 21: 1773-1783.
- Sahlin, K., Harris, R.C., & Hultman, E. (1979). Resynthesis of creatine phosphate in human muscle after exercise in relation to intramuscular pH and availability of

- oxygen. Scandinavian Journal of Clinical Laboratory Investigations, 39: 551-558.
- Sjogaard, G., & Saltin, B. Extra- and intracellular water spaces in muscles of man at rest and with dynamic exercise. American Journal of Physiology, 243: R271-R280.
- Taoutaou, Z., Granier, P., Mercier, B., Mercier, J., Ahmaidi, S., & Prefaut, C. (1996). Lactate kinetics during passive and partially active recovery in endurance and sprint athletes. European Journal of Applied Physiology, 73: 465 – 470.
- Thiriet, P., Gozal, D., Wouassi, D., Oumarou, T., Gelas, H., & Lacour, J.R. (1993). The effect of various recovery modalities on subsequent performance, in consecutive supramaximal exercise. Journal of Sports Medicine and Physical Fitness, 33(2): 118 – 129.
- Tiidus, P.M., & Shoemaker, J.K. (1995). Effleurage massage, muscle blood flow and long-term post-exercise strength recovery. International Journal of Sports Medicine, 16: 478-483.
- 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.
- Weinberg, R., Jackson, A., & Kolodny, K. (1988). The relationship of massage and exercise to mood enhancement. Sports Psychology, 2: 202-211.
- Weltman, A., Regan, J.D. (1983). Prior exhaustive exercise and subsequent, maximal constant load exercise performance. International Journal of Sports Medicine, 4, 184-189.
- Wiktorsson-Moller, M., Oberg, B., Eksrand, J., & Gillquist, J. (1983). Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. American Journal of Sports Medicine, 11: 249-252.

Appendix A: Definitions, Limitations, and Assumptions

Definitions:

- Active recovery (AR): cycling for 15 min at 30% VO_2max
- Massage recovery (MR): 15 min massage of the quadriceps, hamstrings, and calves
by a registered Massage Therapist
- Cold water immersion (CR): cold water immersion of the legs for 15 min at 15°C
- Control: seated rest for 15 minutes

Limitations:

1. The results will describe subsequent performance following various recovery conditions for active males between the ages of 21-40.
2. The results will compare intermittent cycling sessions of specific duration, intensity, and number of repetitions separated by 24 hrs.

Assumptions

1. Subjects will be given instructions for rest, diet, and hydration. It will be assumed that subjects will be adequately hydrated and rested for each testing session. It will also be assumed that the food intake prior to each exercise session will be similar in terms of the percent of calories coming from carbohydrate, fat, and protein.
2. It will be assumed that the all-out, intermittent cycling protocol simulates a typical training session for sports such as rugby, hockey and soccer, each of which involve bursts of high-intensity activity interspersed with periods of rest.

3. It will be assumed that any changes in the dependent variables will represent an effect of AR, CR, or MR versus an error in measurement or a change in the protocol.

Appendix B: Review of the Literature

Introduction

A fast recovery may be important for athletes involved in a training program or who have a competition schedule that requires one or more high-intensity exercise sessions and/or games in a 24 hr period. After intense exercise the internal milieu of the body is disrupted. Consequently, any method that returns the disrupted internal environment back to homeostatic levels should lead to the ability to perform with maximal effort in subsequent exercise sessions. Anecdotal information from coaches, athletic trainers, and athletes suggests that active recovery, massage, and cold water immersion performed after the cessation of exercise to be such processes. To date, scientific evidence regarding the efficacy these recovery conditions in facilitating the recovery process has not been conclusive. Thus, the purpose of this review of the literature will be to address research on the effect of active recovery, massage, and cold water immersion following intermittent exercise on subsequent high-intensity performance. Studies concerning the metabolic demands of intermittent work will be considered in order to understand the energy stores that must be replenished and the metabolic by-products that must be removed at the cessation of exercise. Further, the time course of the physiological processes that must occur during the recovery period to regain homeostasis will also be discussed.

Metabolic Effects of Intermittent Exercise

Characteristics of Intermittent Exercise

Sports, such as ice hockey, soccer, and rugby, involve bursts of moderate to high intensity activity interspersed with low intensity or inactive rest periods. Time-motion analysis of rugby indicate that mean work periods are 5 to 15 s while recovery between each bout of high intensity activity is less than 40 s (Docherty, Wenger, & Neary, 1988). Short sprints, tackles, and explosive accelerations are often performed during this 5 – 15 s of intensive effort (Nicholas, 1997). Green, Bishop, Houston, McKillop, Norman, and Stothart (1976) have shown an average shift in ice hockey to include 40 s of uninterrupted play and 2.3 play stoppages of 27 s each. Even within the 40 s of uninterrupted play large variations in tempo can occur as accelerating to top skating speed for a loose puck, driving up to body check an opponent, or shooting at the net is interspersed with periods of gliding (Twist & Rhodes, 1993). In order to sustain each high-intensity effort a rapid supply of energy is required. This energy is supplied predominantly by the anaerobic alactic system (Green, 1994; Cox, Miles, Verde, & Rhodes, 1995) which consists of creatine phosphate (CP) and adenosine triphosphate (ATP) - high-energy phosphagens stored directly at the muscle contractile site. Approximately 19-23 mmol·kg⁻¹ muscle of ATP and CP is available. Because CP and ATP represent the major and most immediate source of energy available to the contracting muscle, then the exercise can only be sustained for approximately 10 to 15 s before these energy stores are depleted (Karlsson, 1971).

High-intensity activities in intermittent sports are not always limited to 10-15 s in duration. For example, chasing kicks, covering in defence, or supporting the ball carrier during an intense rugby game (Nicholas, 1997) and fighting off a penalty in ice hockey

(Green, 1994) often involves continuous play of 25 or more seconds. As the work bout exceeds 10 to 15 s, the anaerobic lactic system becomes the predominant source of energy for contracting muscles (Greenhaff & Timmons, 1998). ATP production via anaerobic lactic metabolism is accomplished through the breakdown of muscle glycogen and blood glucose, generating lactic acid as a by-product. Lactic acid quickly dissociates into lactate and hydrogen ions (H^+) causing a decrease in pH. The rise in H^+ is thought to negatively affect work output in two major ways. First, H^+ compete with calcium ions for the calcium binding sites on troponin resulting in a reduction in the rate of muscular contractions. Second, H^+ are an allosteric inhibitor of phosphofructose kinase (PFK), the rate-limiting enzyme in anaerobic lactic metabolism (Bouchard, Taylor, Simoneau, & Dulac, 1993). So as more lactic acid is produced, H^+ concentration increases, leading to less available binding sites for calcium and inhibition of PFK. The overall result is a decline in ATP production via the anaerobic lactic energy system.

Blood lactate concentrations at the cessation of college hockey, amateur soccer, and first class rugby games have been reported to be 2.9 mM to 11 mM (Cox et al., 1995), 14 mM (Ekblom, 1986), and 6 – 12 mM (Menchinelli, Morandini, & De Angelis, 1992), respectively. Although high blood lactate levels may give an indication of the contribution of anaerobic lactic metabolism, it should be noted that the true contribution of this energy system might be misrepresented by blood lactate concentrations. Because the blood lactate concentration at any one time is the balance in the rates of production and removal (Fox, Bowers, & Foss, 1993), then a low value may be indicative of either low levels of lactate either being produced or being transported from the muscle to the blood. Further, any blood samples taken in a game situation are taken during a play

stoppage or at the end of a game. Consequently, this may not be a true reflection of blood lactate concentrations during actual play since several minutes may have separated the stop of play and the drawing of blood.

Greater demands may also be placed on the anaerobic lactic energy system during the later stages of intermittent exercise. The time required to replenish half of the anaerobic alactic energy stores is 30 s while full recovery has been shown to take approximately 2 to 3 min (Harris, Edwards, Hultman, Nordesjo, Nylinde, & Sahlin, 1976). Using rugby as an example, the mean rest period between each bout of high intensity exercise is approximately 40 s and so just over half of the anaerobic alactic energy stores would be resynthesized during this rest period. Because only partially resynthesized levels of ATP and CP would be available to contribute energy during subsequent work bouts, then increasing amounts of energy derived from other energy systems would be needed in order to maintain maximal effort.

Despite the fact that time-motion analysis studies from intermittent sports have indicated that the average work bout is brief, the aerobic system still plays a role in energy production. For example, Docherty et al. (1988) reported that props and centres spend 47% of their time walking and jogging during a rugby game compared to 6%, 9%, and 38% of the time spent in intense running, non-running intense activity (tackling and competing for the ball), and standing, respectively. The energy demand of walking and jogging can be met by aerobic metabolism. In addition, a greater demand is placed on aerobic metabolism to provide energy for muscular contractions during the later stages of a game when anaerobic alactic energy stores become depleted and lactic acid levels rise. Bogdanis, Nevill, Boobis, and Lakomy (1996) demonstrated that during 2 bouts of high

intensity cycling (bout 1 = 30 s, bout 2 = 10 s or 30 s) separated by 4 min recovery aerobic metabolism contributed approximately 49% of the energy produced. The high power output achieved during the initial 10 s of the second bout was primarily due to the anaerobic alactic system. Finally, as will be discussed later, the aerobic energy system plays an important role in the recovery process.

Metabolic Demands of Intermittent Exercise

The majority of studies investigating the metabolic demands of high-intensity, intermittent exercise have used exercise protocols consisting of two to four 30 s work bouts separated by 4 min recovery periods. Although these protocols do not simulate intermittent sports, insight can still be gained from this research. Hargreaves et al. (1998) investigated the effect of high-intensity intermittent exercise on CP, ATP, H^+ concentration, sarcoplasmic reticulum (SR) function, and muscle glycogen levels. Subjects performed 4 bouts of 30 s maximal intensity exercise on a cycle ergometer. The first three bouts were separated by 4 min recovery whereas 90 min of rest (including 30 min cycling at 30-35% VO_{2max}) separated the third and fourth exercise bout. Comparing values from bouts 1 and 3, muscle ATP, CP, and glycogen significantly decreased while H^+ concentration, lactate levels, and ATP degradation products significantly increased. Muscle ATP and glycogen levels were significantly lower prior to bout 4 than values obtained before bout 1 yet exercise performance was not significantly different between these two exercise bouts. McCartney, Spriet, Heigenhauser, Kowalchuk, Sutton, and Jones (1986) examined the associated metabolic changes that occur in muscle after four 30 s bouts of cycling with 4 min recovery

intervals. Again, muscle ATP and CP was demonstrated to be significantly reduced at the end of the four 30 s work bouts. In fact, a 40% reduction in muscle ATP from resting levels occurred after each exercise period while CP decreased successively to less than 5% of resting values.

In order to study the depletion of muscle glycogen stores during intermittent exercise, Green (1978), Green, Daub, Painter, and Thomson (1979) and Essen and Kaijser (1978) both used exercise protocols that more closely simulate intermittent sports. Green had subjects skating at 120% VO_2max for 1 min with 5 min recovery periods. After 10 min work, muscle glycogen valued decreased 70% and muscle lactate values increased significantly. Glycogen depletion was most pronounced in Type II fibres. In addition, Green et al. measured a 60% drop in muscle glycogen levels after a hockey game. Essen and Kaijser compared glycogen depletion (as well as a number of other variables) between intermittent exercise (15 s work, 15 s rest at 100% VO_2max for 60 min) and continuous exercise to exhaustion (140% VO_2max for 4 – 6 min). After 60 min of intermittent exercise and 4 – 6 min of continuous, exhaustive exercise glycogen content decreased by $192 \text{ mmol} \cdot \text{kg}^{-1}$ dry weight and $104 \text{ mmol} \cdot \text{kg}^{-1}$ dry weight, respectively. Thus, intermittent exercise results in large drops in muscle glycogen levels and must be replenished if an athlete is to perform with maximal effort in subsequent exercise sessions.

In summary, intermittent exercise involves bursts of moderate to high intensity activity interspersed with low-intensity or complete rest periods. The duration of the work bouts typically falls within the range of the anaerobic alactic energy system; however, significant demands are also placed on both anaerobic lactic and aerobic

metabolism. Depleted muscle ATP and CP are thought to contribute to the decline in exercise performance; however, other factors such as increased lactate, impairment in SR function, and/or reduced glycogen levels may also play a role in fatigue from high-intensity intermittent exercise. Finally, most studies investigating the metabolic demands of intermittent exercise have used an exercise protocol of two to four 30 s work bouts separated by 4 min rest. Time-motion analyses from intermittent sports indicate the average work and rest times are much shorter but repeated over a longer duration of time. Thus, more research is needed into the metabolic demands of intermittent exercise using protocols that more closely simulate intermittent sports.

Time-Course of the Processes Involved in the Return to Homeostasis

Exercise represents an acute disturbance in homeostasis. For example, catecholamines are released into the blood stream, blood is redistributed from areas of low activity to areas of high activity, energy stores such as ATP, CP, and glycogen are depleted, metabolites such as lactic acid rise in muscle and in blood, body temperature increases, and shifts in plasma volume occur. In order to return the body to the resting state a number of physiological processes must occur. Some of these processes, such as the replenishment of CP and ATP, may take only a few minutes while others, such as the resynthesis of muscle and liver glycogen stores may take as long as 24 hours. The focus of this section will be on the time course of both the replenishment of energy stores (CP, ATP, and glycogen) and removal of lactic acid from the muscle and blood.

Restoration of Anaerobic Alactic Energy Stores

The aerobic energy system plays an important role during the low intensity periods of intermittent exercise. Sahlin, Harris, and Hultman (1979) and Harris et al. (1976) have both demonstrated that depleted anaerobic alactic energy stores are resynthesized by aerobic regeneration of ATP. The time required to replenish half of the anaerobic alactic energy stores is ~30 s (Sargeant & Dolan, 1987) while full recovery has been shown to take 2 to 3 min (Harris et al., 1976). Because aerobic metabolism is essential to the recovery process, then it has been thought that an increase in the maximal aerobic power may facilitate ATP and CP resynthesis (Cooke, Peterson, & Quinney, 1997). Associated with increased maximal aerobic power are biochemical changes in cellular function including an increase in capillary density (Tesch & Wright, 1983); an increase in the number and size of mitochondria (Gollnick, Riedy, Quintinskie, & Bertocci, 1985; Green, 1994; Hickson, Bomze, & Holloszy, 1978); an increase in mitochondrial enzymes (Gollnick et al.); and an increase in myoglobin (Hickson et al.). These cellular adaptations may improve the ability of muscle to deliver and extract oxygen allowing for more efficient resynthesis of ATP and CP during recovery periods from high-intensity intermittent exercise.

Glycogen Resynthesis

Muscle glycogen may take 24 hrs to replenish after high intensity, intermittent exercise as demonstrated by MacDougall, Ward, and Sutton (1977). Following intermittent exercise (1 min at 140% $\text{VO}_{2\text{max}}$ interspersed with 3 min rest periods until the exercise could no longer be maintained), muscle glycogen was measured repeatedly

over a 24 hour period. At 2, 5, 12, and 24 hrs, muscle glycogen concentration had recovered to 39%, 53%, 67%, and 102%, respectively, of the pre-exercise value. They also found that the rate of muscle glycogen resynthesis was not accelerated by a higher than normal carbohydrate diet.

Reduction of Lactic Acid

The aerobic energy system also plays an important role in the reduction of lactic acid. Lactic acid can be oxidized and used as a metabolic fuel by slow-twitch muscle, heart, liver, and kidney (Belcastro & Bonen, 1975). Specifically, lactic acid is reconverted to pyruvic acid, which can then be aerobically metabolized to produce further ATP. Although the oxidation of lactic acid represents the major method of lactic acid removal from blood, lactic acid may also be reconverted to glucose, and thus, glycogen (Pascoe & Gladden, 1996). The half-time for lactic acid removal is 25 min while full recovery time may take up to 1 hr (Hermansen & Stensvold, 1972). As will be discussed in subsequent sections, the speed of lactic acid removal is dependent on whether active or passive recovery is performed (Bonen & Belcastro, 1977).

In summary, during the low-intensity periods that follow high-intensity work bouts, the aerobic energy system plays an important role in restoring anaerobic alactic energy stores and oxidizing lactic acid. The full recovery time for ATP and CP replenishment, lactic acid removal, and glycogen resynthesis is 3 min, 60 min, and 24 hr, respectively. Therefore, appropriate methods of hastening ATP, CP, and muscle glycogen resynthesis and muscle lactate clearance are needed if the athlete is to return to

competition and continue performing with maximal intensity. Anecdotal information from athletes, coaches, and trainers suggests that active recovery, massage, and/or cold water immersion may be such processes.

Active Recovery Following Intermittent Exercise and Subsequent Performance

The rationale for performing an active recovery subsequent to a high-intensity exercise session is to keep muscle blood flow elevated. Adequate muscle blood flow increases oxygen delivery to the recovering muscle and concomitantly, should remove lactate and hydrogen ions (H^+) at a faster rate (Rowell, Kraning, Evans, Kennedy, Blackmon, & Kusumi, 1966). Lactate is then transported primarily to slow-twitch muscle but also may be taken to the heart, liver, and/or kidney to be oxidized to pyruvate and used as an energy source (Pascoe & Gladden, 1996). Little is known about the effects of active recovery following high intensity, intermittent exercise on subsequent performance. This is due to the fact that studies investigating the effects of active recovery following intermittent exercise are difficult to compare due to the number of different protocols that have been used. For example, the protocols used may include 6 s work followed by 30 s recovery repeated 10 times (Gaitanos, Williams, Boobis, & Brooks, 1993); 30 s work/4 min recovery repeated 2 times (Bogdanis, Nevill, Lakomy, Graham, & Louis, 1996); or, 2 min work/20 min recovery repeated 4 times (Thiriet, Gozal, Wouassi, Oumarou, Gleas, & Lacour, 1993). In the aforementioned studies the work to rest ratio varied from 1:5, 1:8, and 1:10, respectively. Because the duration of the

exercise and recovery periods and the number of repetitions differ, then the predominant energy systems used and the extent of recovery that may have occurred between work bouts varies among the research. The cycle ergometer is the common mode of exercise since power output can be easily quantified, although the treadmill has also been used (Bale & James, 1986). The intensity of active recovery periods following an intermittent exercise protocol is generally between 30 to 40% VO_2max as this has been shown by Belcastro and Bonen (1977) to be the most effective in lactate clearance. The duration of active recovery varies from 4 min (Bogdanis et al.), 15 min (Watson & Hanley, 1986) to 40 min (Gupta, Goswami, Sadhukhan, & Mathur, 1986). There has not been any studies suggesting an optimal duration for active recovery after intermittent exercise.

Active Recovery and Resynthesis of Anaerobic Alactic Energy Stores

Conceptually, active recovery may impede ATP and CP resynthesis; however, research has not been conducted to address this issue. If light exercise were to be performed during the recovery period then aerobic regeneration of ATP would be used for muscular contractions rather than for the rephosphorylation of anaerobic alactic energy stores. In many sporting situations, however, the time between the end of the game and the start of an active recovery period is of sufficient duration to allow for full resynthesis of anaerobic alactic energy stores.

Active Recovery and Glycogen Resynthesis

Studies investigating glycogen resynthesis during active and passive recovery conditions following intermittent exercise have not been conclusive. Specifically, Choi,

Cole, Goodpaster, Fink, and Costill (1994) and Bonen, Ness, Belcastro, and Kirby (1985) demonstrated that active recovery might, in fact, further deplete muscle glycogen stores during the recovery period. Choi et al. had subjects perform three 1 min cycling bouts at 130% VO_2max with 4 min rest between each bout. An active recovery period (30 min cycling with both legs and 30 min of seated rest) or passive recovery period (60 min seated rest) then followed. Mean muscle glycogen after 60 min of passive recovery was shown to increase $15.0 \text{ mmol} \cdot \text{kg}^{-1}$ wet weight (w.w.) whereas mean muscle glycogen decreased $6.3 \text{ mmol} \cdot \text{kg}^{-1}$ w.w. following the 60 min active recovery protocol. Thus, exercise performed during the recovery period may have continued to use muscle glycogen as a fuel source. Peters-Futre, Noakes, Raine, and Terblanche (1987), on the other hand, did not find a significant difference in the rate of muscle glycogen resynthesis following intense intermittent exercise between active and passive recovery trials. Subjects in this study cycled 45 min with one leg only followed by 45 min of seated rest in the active recovery trial. The difference in active recovery duration and the mode of exercise (one-legged cycling vs. two legged cycling) may account for the differences in glycogen resynthesis between the two studies. Further, the intensity of the active recovery period differed between the study conducted by Choi et al. (40-50% VO_2max) and Peters-Futre et al. (30% VO_2max). Although an intensity of 30 to 50% VO_2max is recommended to be optimal in lactate clearance (Belcastro & Bonen, 1977), it may be that an intensity greater than 40% VO_2max may in fact impede glycogen resynthesis.

Active Recovery and Lactate Clearance

Few studies have examined changes in muscle lactate concentration after an active recovery period since muscle lactate concentrations can only be determined by a muscle biopsy. Rather blood lactate values, an easier measurement to obtain, are often used to reflect anaerobic lactic metabolism in the active muscle. As mentioned earlier, however, blood lactate measurements may not be a true indication of muscle lactate concentrations.

Choi and colleagues (1994) measured both muscle and blood lactate concentrations in subjects who performed three, 1 min cycling bouts at 130% VO_2max with a 4 min rest period between each bout. A 60 min recovery period consisting of either 30 min active recovery (40-50% VO_2max) and 30 min seated rest or 60 min seated rest then followed. No significant difference was found between muscle lactate disappearance following active recovery ($23.85 \text{ mmol} \cdot \text{kg w.w.}^{-1} \cdot \text{hour}^{-1}$) and passive recovery ($23.33 \text{ mmol} \cdot \text{kg w.w.}^{-1} \cdot \text{hour}^{-1}$). However, muscle biopsies were only taken prior to exercise, immediately post-exercise, and after 60 minutes of recovery. Because active recovery was only performed for the first 30 min of the total 60 min recovery period, then there may have been apparent differences in the rate of muscle lactate clearance earlier in the recovery period.

Most studies have shown blood lactate clearance to be enhanced by active recovery (Bale & James, 1996; Gupta et al., 1996; Taoutaou, Granier, Mercier, Mercier, Ahmaidi, & Prefaut, 1996; Francaux, Jacqmin, deWelle, & Sturbois, 1995; Thiriet et al., 1993; Weltman & Regan, 1983; Watson & Hanley, 1986). An active recovery increases blood perfusion to the liver, heart and slow twitch muscle where lactate is reconverted to

pyruvate and utilized as an energy source (Lehninger, Nelson, & Cox, 1993). Lactic acid may also be reconverted back to glucose via the Cori cycle or gluconeogenesis (Pascoe & Gladden, 1996). While most studies have shown active recovery to enhance blood lactate clearance, Bogdanis et al. (1996) and Choi et al. (1994) have both shown otherwise. Bogdanis et al. did not find a significant difference in blood lactate concentrations after two, 30 s cycle sprints separated by either 4 min of active recovery at 40% VO_2max or 4 min of seated rest. Power output, however, during the second sprint was significantly greater in the active recovery trial. It was hypothesized by the authors that a 4 min active recovery period may be too brief for lactate to be transported out of the muscle and oxidized by other tissues. Although Choi et al. demonstrated that the active recovery trial had significantly lower blood lactate concentrations at 10 min and 30 min post exercise, a significant difference was not shown at the cessation of the recovery period. Again, this discrepancy may be because active recovery was only performed for the first 30 min of the 60 min recovery period. Perhaps, a longer active recovery period may have led to a lower blood lactate value compared to the passive recovery trial at 60 min post-exercise.

Only three studies (Thiriet et al., 1993; Welman & Regan, 1983; and Watson & Hanley, 1986) have looked at subsequent performance after a period of active recovery. Thiriet et al. revealed that enhanced blood lactate clearance in the active recovery condition corresponded to improved work output on a cycle ergometer. This protocol included four, 2 min cycling bouts (130% VO_2max) with 20 min recovery (active arm, active leg, and seated rest) between each bout. Active leg recovery had the fastest blood lactate kinetics, while intermediate values were found in the active arm and the slowest values were found in the passive condition. Over the four work bouts, power output was

significantly reduced as of the second bout in the passive recovery trial and the last bout in the active arm recovery trial and did not significantly change in the active leg recovery trial. These results indicate that active recovery may not only be related to maintenance of power output over succeeding bouts, but should also involve the musculature used in the exercise to achieve the best results.

Conversely, Watson and Hanley (1986) and Weltman and Regan (1983) did not show that subsequent performance was improved by enhanced blood lactate clearance via active recovery. Watson and Hanley designed a study in which a 15 min recovery period consisting of bench stepping, light skating, and seated rest separated two maximal effort, intermittent work bouts (six, 45 s skating trials interspersed with 90 s rest). This protocol was specifically designed to simulate two periods of an ice hockey game. Although bench stepping resulted in significantly lower lactate values (6.1 mM) than rest recovery (8.1 mM), subsequent performance was unaffected by any treatment. Weltman and Regan had subjects perform two maximal performance test (~4.8 min at 110% VO_2max) separated by 20 min recovery (40% VO_2max or seated rest). Despite the active recovery condition resulting in significantly lower blood lactate concentration, there were no differences in work output among the performance tests (either between conditions or from pre- to post-recovery). Blood lactate levels in both studies were about 4 to 6 mM immediately prior to the second exercise bout. Perhaps, blood lactate concentrations in this range are not at a sufficient level to either interfere with calcium ions binding to troponin or to inhibit enzyme activity, and thus, affect subsequent performance.

In summary, the effects of active recovery in terms of resynthesis of both anaerobic alactic energy stores and muscle glycogen have not been conclusive.

Theoretically, active recovery would not appear to enhance the replenishment of ATP and CP; however, this energy system has been shown to completely recover within 3 to 5 min and is most likely replenished during the transition from competition to the recovery period. Additional research is needed to determine the effects of active recovery on muscle glycogen resynthesis, as prior studies have not used protocols that simulate intermittent-type sports. Finally, most studies have shown that active recovery enhances blood lactate clearance; however, few researchers have looked at subsequent exercise performance. Even if active recovery enhances blood lactate clearance, the concentration in the passive recovery trial may have also lowered to such a level that the lactic acid no longer interferes with muscular contractions or enzyme activity.

Massage Following Intermittent Exercise and Subsequent Performance

There are a variety of techniques that are described as “massage” in the literature such as classical massage, sports massage, underwater massage, shiatsu, and acupressure. Consequently, it can be difficult to compare studies because of the differences in techniques used and the time each technique is performed. This review will focus on post-event sports massage.

Post-event sports massage is employed with the thought that it helps damaged skeletal muscles recover and regenerate after intense exercise (Tiidus & Shoemaker,

1995). Massage has been suggested to increase both blood flow (Wiktorsson-Möller, Oberg, Ekstrand, & Gillquist, 1983; Hovind & Nielsen, 1974), and lymph drainage (Calder, 1990). Increased blood flow during massage is thought to occur because massage increases intramuscular pressure, which in turn assists in local venous emptying (Wiktorsson-Möller et al.). Massage may also have a psychological effect on the athlete's mood and performance. For example, Weinberg, Jackson, and Kolodny (1988) demonstrated that there was a greater relationship between massage and positive mood enhancement than between exercise (running) and positive mood enhancement.

Although many athletes and coaches believe post-event massage benefits subsequent performance, there is little research to support such a claim. Most studies using massage as an intervention have been done after a strength training session in order to determine the effects of massage on delayed onset muscle soreness (Tiidus & Shoemaker, 1995; Cafarelli, Sim, Carolan, & Liebesman, 1990). For example, Tiidus and Shoemaker looked at the effect of massage on both muscle blood flow and long term post-exercise strength recovery. After completing eccentric contractions of the quadriceps muscle, effleurage massage was performed on only one of the exercised legs. Although the perceived level of delayed onset muscle soreness was reduced in the massaged leg 48-96 hours post-exercise, muscle blood flow and strength recovery was not significantly different. Cafarelli et al. also showed that short-term recovery from repeated submaximal quadriceps muscle contractions was not augmented by percussive vibratory massage.

Few studies have been conducted using massage as an intervention after an aerobic and/or anaerobic exercise session. Dolgener and Morien (1993) investigated the

effect of massage and active recovery after a short-term exhaustive run on the treadmill (average time to exhaustion was 211 s). Blood lactate values were monitored during the 20 min recovery period. At 15 and 20 min post-exercise, the active recovery group (40% VO_2max) had a significantly greater percent change in blood lactate values than massage or passive recovery (55% vs. 26.4% and 22.3%, respectively). Gupta et al. (1996) also studied the effect of massage and active recovery on lactate removal. Subjects cycled for 1 min at 150% VO_2max with 15 s rest periods until exhaustion. Following exercise, subjects either had a 40 min active recovery (30% VO_2max), 10 min massage/30 min seated rest, or 40 min passive recovery period. Again, active recovery resulted in a faster decrease in blood lactate values compared to massage or passive recovery. Researchers did not determine the effect of the various recovery conditions on subsequent performance. Perhaps, the positive psychological effect of massage on the mood of an athlete may be more pertinent to subsequent performance than a decline in blood lactate values. Drews et al. (1990) had six elite cyclists perform a four-day stage race (161 km per day) with either 30 min of massage therapy or 30 min microwave diathermy treatment (blind placebo) following each race. 18 days later an identical four-day stage race was repeated. Recovery from ultraendurance cycling and subsequent performance was not improved when post-event muscle massage therapy was employed. Although an 18-day rest period between these types of ultraendurance cycling stage races may be typical of the sport, the effects of massage may be lost after such a long delay. Comparing variables after each day of the four day stage race may have shown differences between the massage and blind placebo conditions.

Cold Water Immersion Following Intermittent Exercise and Subsequent Performance

Cold water immersion is proposed to cause vasoconstriction and reduce metabolism thereby causing a decrease in the release of waste products (Arnheim & Prentice, 1993). The few studies that have been completed using cold water immersion as an intervention have concentrated on the effects of a cold water bath on both delayed onset muscle soreness and recovery from an acute injury (Denegar & Perrin, 1992). Denegar and Perrin found that cold resulted in significant decreases in perceived pain and significant increases in elbow extension range of motion. No studies have investigated the effect of this therapeutic modality on performance after high-intensity, intermittent exercise. Temperatures of the cold water bath are typically 10-15°C and the time spent in the bath has been recommended to be 10-15 min (Arnheim & Prentice).

Summary

Due to the nature of intermittent exercise, significant demands are placed on each of the three energy systems. Thus, a number of processes such as replenishment of ATP and CP stores, resynthesis of muscle glycogen, and removal of lactic acid need to occur during the recovery period to return the body to the resting state. If active recovery, massage, or cold water immersion can be shown to facilitate these processes, then the athlete who has to return to competition within 24 hrs will benefit.

The effects of active recovery, massage, and cold water immersion after intermittent exercise on subsequent performance have not been conclusive. Most research has shown that active recovery enhances blood lactate clearance; however, few have demonstrated the critical link with subsequent exercise performance. Studies that have been conducted have only looked at performance after a short period of recovery (15 – 20 min) whereas many training sessions or competitions are separated by at least 24 hrs. Further research is needed to address the effects of active recovery following intermittent exercise on subsequent performance. Few studies have investigated glycogen depletion and lactate accumulation after intermittent exercise and how these variables may effect subsequent performance. Although most investigations support the prescription of active recovery to accelerate blood lactate clearance, the performance of light aerobic activity during the recovery period may impede glycogen resynthesis. Massage and cold water immersion are commonly done after a training session or game yet the effects on performance 24 hours later are unknown. The majority of research investigating the efficacy of massage and cold water immersion has been done following strength training sessions and not intermittent exercise.

References

- Arnheim, D.D., & Prentice, W.E. (1993). Principles of athletic training (9th ed.). Boston: McGraw Hill.
- Bale, P., & James, H. (1996). Massage, warmdown, and rest as recuperative measures after short term intense exercise. Physiotherapy in Sport, 12: 4-7.
- Belcastro, A.N., & Bonen, A. (1975). Lactic acid removal rates during controlled and uncontrolled exercise. Journal of Applied Physiology, 39(6): 932-936.
- Bogdanis, G.C., Nevill, M.E., Boobis, L.H., & Lakomy, H.K. (1996). Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. Journal of Applied Physiology, 80(3): 876-884.
- Bogdanis, G.C., Nevill, M.E., Lakomy, H.K.A., Graham, C.M., & Louis, G. (1996). Effects of active recovery on power output during repeated maximal sprint cycling. European Journal of Applied Physiology, 74: 461-469.
- Bonen, A., Ness, G.W., Belcastro, A.N., & Kirby, R.L. (1985). Mild exercise impedes glycogen repletion in muscle. Journal of Applied Physiology, 58(5): 1622-1629.
- Bonen, A., & Belcastro, A.N. (1977). A physiological rationale for active recovery exercise. Canadian Journal Applied Sport Sciences, 2: 634-665.
- Bouchard, C., Taylor, A., Simoneau, J-A., & Dulac, S. (1991). The purpose of physiological testing. In J.D. MacDougall, H.A. Wenger, & H.J. Green (Eds.), Physiological Testing of the High Performance Athlete (pp. 1 - 5). Champaign, Ill.: Human Kinetics.
- Cafarelli, E., Sim, J., Carolan, B., & Liebesman, J. (1990). Vibratory massage and short-term recovery from muscular fatigue. International Journal of Sports Medicine, 11(6): 474-478.
- Calder, A. (1990). Recovery: restoration and regeneration as essential components within training programmes. EXCEL, 6(3): 15-19.
- Choi, D., Cole, K.J., Goodpaster, B.H., Fink, W.J., & Costill, D.L. (1994). Effect of passive and active recovery on the resynthesis of muscle glycogen. Medicine & Science in Sports and Exercise, 26(8): 992-996.
- Cooke, S.R., Petersen, S.R., & Quinney, H.A. (1997). The influence of maximal aerobic power on recovery of skeletal muscle following anaerobic exercise. European Journal of Applied Physiology, 75: 512-519.

- Cox, M.H., Miles, D.S., Verde, T.J., & Rhodes, E.C. (1995). Applied physiology of ice hockey. Sports Medicine, 19(3): 184 - 201.
- Denegar, C.R., & Perrin, D.H. (1992). Effect of transcutaneous electrical nerve stimulation, cold, and a combination treatment on pain, decreased range of motion, and strength loss associated with delayed onset muscle soreness. Journal of Athletic Training, 27(3): 200-206.
- Docherty, D., Wenger, H.A., & Neary, P. Time-motion analysis related to the physiological demands of rugby. Journal of Human Movement Studies, 14: 269-277.
- Dolgener, F.A., & Morien, A. (1993). The effect of massage on lactate disappearance. Journal of Strength and Conditioning Research, 7(3): 159-162.
- Drews, T., et al. (1990). Effects of post-event massage therapy on repeated ultraendurance cycling (abstract). International Journal of Sports Medicine, 11: 407.
- Eklom, B. (1986). Applied physiology of soccer. Sports Medicine, 3: 50-60.
- Essen, B., & Kaijser, L. (1978). Regulation of glycolysis in intermittent exercise in man. Journal of Physiology, 281: 499-511.
- Fox, E.L., Bowers, R.W., & Foss, M.L. (1988). The physiological basis of physical education and athletics (4th ed.). Philadelphia: Saunders College.
- Francaux, M., Jacqmin, P., deWelle, J.M., & Sturbois, X. (1995). A study of lactate metabolism without tracer during passive and active postexercise recovery in humans. European Journal of Applied Physiology, 71(1/2): 58-66.
- Gaitanos, G.C., Williams, C., Boobis, L.H., & Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise. Journal of Applied Physiology, 75(2): 712-719.
- Gollnick, P.D., Riedy, M., Quintinskie, J.J., & Bertocci, L.A. (1985). Differences in metabolic potential of skeletal muscle fibres and their significance for metabolic control. Journal of Experimental Biology, 115: 191-199.
- Green, H.J. (1994). Physiologic challenges induced by participation in ice hockey – implications for training. Journal of Testing and Evaluation, 22(1): 48 – 51.
- Green, H.J. (1978). Glycogen depletion patterns during continuous and intermittent ice skating. Medicine and Science in Sports and Exercise, 10: 183-187.

- Green, H., Bishop, P., Houston, B., 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, W.D., Painter, D.C., & Thomson, J. Glycogen depletion patterns during ice hockey performance. Medicine and Science in Sports and Exercise, 10: 289-293.
- Greenhaff, P.L., & Timmons, J.A. (1998). Interaction between aerobic and anaerobic metabolism during intense muscle contraction. In J. O. Holloszy (Ed.), Exercise and Sport Science Reviews (pp. 1- 30).
- Gupta, S., Goswami, A., Sadhukhan, A.K., & Mathur, D.N. (1996). Comparative study of lactate removal in short term massage of extremities, active recovery and a passive recovery period after supramaximal exercise sessions. International Journal of Sports Medicine, 17(2): 106-110.
- Hargreaves, M., McKenna, M.J., Jenkins, D.G., Warmington, S.A., Li, J.L., Snow, R.J., & Febbraio, M.A. (1998). Muscle metabolites and performance during high-intensity, intermittent exercise. Journal of Applied Physiology, 84(5): 1687-1691.
- Hickson, R.C., Bomze, H.A., & Holloszy, J.O. (1978). Faster adjustment of O₂ uptake to the energy requirement of exercise in the trained state. Journal of Applied Physiology, 44(6): 877-881.
- Harris, R.C., Edwards, R.H.T., Hultamn, E., Nordesjo, L.O., Nylinde, B., & Sahlin, K. (1975). The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. Pfluegers Archives, 367: 137-142.
- Hermansen, L., & Stensvold, I. (1972). Production and removal of lactate during exercise in man. Acta Physiologica Scandinavica, 86: 191-201.
- Hovind, H., & Nielsen, S.L. Effect of massage on blood flow in skeletal muscle. Scandinavian Journal of Rehabilitory Medicine, 6: 74-77.
- Karlsson, J. (1971). Lactate and phosphagen concentrations in working muscle of man. Acta Physiologica Scandinavica, 358: 1-72.
- Lehninger, A.L., Nelson, D.L., & Cox, M.M. (1993). The principles of biochemistry (2nd ed.). New York: Worth Publishers.
- MacDougall, J.D., Ward, G.R., & Sutton, J.R. (1977). Muscle glycogen repletion after high-intensity intermittent exercise. Journal of Applied Physiology, 42(2): 129-132.

- McCartney, N., Spriet, L.L., Heigenhauser, G.J., Kowalchuk, J.M., Sutton, J.R., & Jones, N.L. (1986). Muscle power and metabolism in maximal intermittent exercise. Journal of Applied Physiology 60(4): 1164-1169.
- Menchinelli, C., Morandini, C., De Angelis, M. (1992). A functional model of rugby: determination of the characteristics of sports performance. Journal of Sports Sciences, 10, 196-197.
- Nicholas, C.W. (1997). Anthropometric and physiological characteristics of rugby union football players. Sports Medicine, 23(6): 377-396.
- Pascoe, D.D., & Gladden, L.B. (1996). Muscle glycogen resynthesis after short term, high intensity exercise and resistance exercise. Sports Medicine, 21(2): 96-118.
- Peters-Futre, E.M., Noakes, T.D., Raine, R.I., & Terblanche, S.E. (1987). Muscle glycogen repletion during active postexercise recovery. American Journal of Physiology, 253(3): E305-E311.
- Rowell, L.B., Kraning, K.K., Evans, T.O., Kennedy, J.W., Blackmon, J.R., & Kusumi, F. (1966). Splanchnic removal of lactate and pyruvate during prolonged exercise in man. Journal of Applied Physiology, 21: 1773-1783.
- Sahlin, K., Harris, R.C., & Hultman, E. (1979). Resynthesis of creatine phosphate in human muscle after exercise in relation to intramuscular pH and availability of oxygen. Scandinavian Journal of Clinical Laboratory Investigations, 39: 551-558.
- Sargeant, A.J., & Dolan, P. (1987). Effect of prior exercise on maximal short-term power output in humans. Journal of Applied Physiology, 63(4): 1475-1480.
- Taoutaou, Z., Granier, P., Mercier, B., Mercier, J., Ahmaidi, S., & Prefaut, C. (1996). Lactate kinetics during passive and partially active recovery in endurance and sprint athletes. European Journal of Applied Physiology, 73: 465 – 470.
- 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.
- Thiriet, P., Gozal, D., Wouassi, D., Oumarou, T., Gelas, H., & Lacour, J.R. (1993). The effect of various recovery modalities on subsequent performance, in consecutive supramaximal exercise. Journal of Sports Medicine and Physical Fitness, 33(2): 118 – 129.
- Tiidus, P.M., & Shoemaker, J.K. (1995). Effleurage massage, muscle blood flow and long-term post-exercise strength recovery. International Journal of Sports Medicine, 16: 478-483.

- Twist, P., & Rhodes, T. (1993). The bioenergetics and physiological demands of ice hockey. National Strength and Conditioning Association Journal, 15(5): 68-70.
- 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.
- Weinberg, R., Jackson, A., & Kolodny, K. (1988). The relationship of massage and exercise to mood enhancement. Sports Psychology, 2: 202-211.
- Weltman, A., Regan, J.D. (1983). Prior exhaustive exercise and subsequent, maximal constant load exercise performance. International Journal of Sports Medicine, 4, 184-189.
- Wiktorsson-Moller, M., Oberg, B., Eksrand, J., & Gillquist, J. (1983). Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. American Journal of Sports Medicine, 11: 249-252.

Appendix C: Rating of Readiness

Please rate your “readiness” for the upcoming intermittent exercise protocol:

1

I am NOT able
to give maximal
effort (i.e., I do
NOT feel recovered).

2

3

I am able to
give MARGINAL
effort (i.e., I feel
SEMI-recovered).

4

5

I am able to give
MAXIMAL effort
(i.e., I feel FULLY
recovered).

Appendix D: Raw Data

Table 2

Total Work (kJ) Performed During 18 Min Intermittent Exercise (Including 12x5 s Work and 25 s Recovery, 6x10s Work and 50 s Recovery, 4x15 s Work and 75 s Recovery) Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a Control Condition (n=10).

	AR	CR	MR	CONTROL
	(kJ)	(kJ)	(kJ)	(kJ)
Session 1				
<u>M</u>	105.0	104.6	105.8	108.1
<u>SEM</u>	(5.4)	(4.8)	(5.3)	(5.4)
Session 2				
<u>M</u>	104.7	104.9	104.8	106.0*
<u>SEM</u>	(5.3)	(4.6)	(5.1)	(5.0)

* significant decrease from Session 1 ($p < 0.05$)

Table 3

Total Work (kJ) Performed During Repetitions 1-12 (5 s Work Bouts and 25 s Rest)
Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a
Control Condition (n=10).

	AR	CR	MR	CONTROL
	(kJ)	(kJ)	(kJ)	(kJ)
Session 1				
<u>M</u>	33.1	32.3	32.8	33.4
<u>SEM</u>	(1.6)	(1.5)	(1.6)	(1.7)
Session 2				
<u>M</u>	32.2	32.8	32.4	33.4
<u>SEM</u>	(1.5)	(1.4)	(1.5)	(1.6)

Table 4

Total Work (kJ) Performed During Repetitions 13-18 (10 s Work Bouts and 50 s Rest)
Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a
Control Condition (n=10).

	AR	CR	MR	CONTROL
	(kJ)	(kJ)	(kJ)	(kJ)
Session 1				
<u>M</u>	36.8	36.6	37.2	37.9
<u>SEM</u>	(2.1)	(1.7)	(1.9)	(1.9)
Session 2				
<u>M</u>	36.7	36.5	36.7	36.9*
<u>SEM</u>	(1.8)	(1.7)	(1.8)	(1.8)

* significant decrease from Session 1 ($p < 0.05$)

Table 5.

Total Work (kJ) Performed During Repetitions 19-22 (15 s Work Bouts and 75 s Rest)
Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a
Control Condition (n=10).

	AR	CR	MR	CONTROL
	(kJ)	(kJ)	(kJ)	(kJ)
Session 1				
<u>M</u>	35.2	35.8	35.8	36.8
<u>SEM</u>	(1.9)	(1.7)	(1.9)	(1.8)
Session 2				
<u>M</u>	35.7	35.8	35.6	35.7*
<u>SEM</u>	(1.7)	(2.1)	(1.6)	(1.9)
* significant decrease from Session 1 ($p < 0.05$)				

Appendix E: Paired Sample T-Tests

Table 6.

Paired Samples T-Test Results for the Total Work Performed During 18 Min Intermittent Exercise (Including 12x5 s Work and 25 s Recovery, 6x10s Work and 50 s Recovery, 4x15 s Work and 75 s Recovery) Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a Control Condition (n=10).

Pair	Df	Significance (2 tailed)
AR – Session 1 & Session 2	9	.77
CR– Session 1 & Session 2	9	.70
MR– Session 1 & Session 2	8	.07
Control– Session 1 & Session 2	9	.01*

* $p \leq 0.05$

Table 7.

Paired Samples T-Test for the Total Work Performed During Repetitions 1-12 (5 s Work Bouts and 25 s Rest) Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a Control Condition (n=10).

Pair	Df	Significance (2 tailed)
AR– Session 1 & Session 2	9	.09
CR– Session 1 & Session 2	9	.13
MR– Session 1 & Session 2	8	.32
Control– Session 1 & Session 2	9	.97

Table 8.

Paired Samples T-Test for the Total Work Performed During Repetitions 13-18 (10 s Work Bouts and 50 s Rest) Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a Control Condition (n=10).

Pair	df	Significance (2 tailed)
AR– Session 1 & Session 2	9	.86
CR– Session 1 & Session 2	9	.84
MR– Session 1 & Session 2	8	.21
Control– Session 1 & Session 2	9	.01*

* $p \leq 0.05$

Table 9.

Paired Samples T-Test for the Total Work Performed During Repetitions 19-22 (15 s Work Bouts and 75 s Rest) Separated by 24 hrs Under Three Different Recovery Conditions - AR, CR, MR - and a Control Condition (n=10).

Pair	df	Significance (2 tailed)
AR– Session 1 & Session 2	9	.11
CR– Session 1 & Session 2	9	.66
MR– Session 1 & Session 2	8	.73
Control– Session 1 & Session 2	9	.05*

* $p \leq 0.05$

Appendix F: Informed Consent

CONSENT FORM FOR PARTICIPATION IN THE STUDY

“THE EFFECT OF SELECTED RECOVERY CONDITIONS ON PERFORMANCE OF INTERMITTENT EXERCISE SEPARATED BY 24 HOURS”

This research project is studying the effects of various recovery conditions on repeated performance of intermittent exercise on the cycle ergometer. In total, four recovery conditions will be performed which include:

- 1) **active recovery** – cycling at a light resistance for 15 minutes,
- 2) **cold water immersion** of the legs for 15 minutes at 14°C,
- 3) **massage** of the quadriceps, hamstrings, calves, and lower back by a registered Massage Therapist,
- 4) **seated rest** for 15 minutes.

For each recovery condition, you will be asked to take part in 2 intermittent cycling sessions separated by 24 hours. The intermittent cycling sessions will be identical. Each consist of a 10 minute standardized warm-up (stretching and cycling at a light resistance) followed by a maximal-effort, intermittent cycling protocol. This cycling protocol will consist of alternating periods of cycling at a resistance of 80 grams per kilogram of body weight (similar to riding up a fairly steep hill) and seated rest. Specifically, 10 repetitions of 5 seconds work/25 seconds rest, 8 repetitions of 10 seconds work/50 seconds rest, and 2 repetitions of 20 seconds work/100 seconds rest will be completed. These 20 repetitions of work and rest intervals will take 17 minutes for each session.

Immediately following the first intermittent cycling session, one of the four recovery conditions will be performed (as described above). Then you will be asked to

return 24 hours after the start of the first intermittent cycling session in order to complete the second intermittent cycling session. A minimum of 72 hours will separate each recovery condition. So depending on your schedule you may decide to come in 1 or 2 times per week until all 4 recovery conditions are completed.

Your participation should require about 45 minutes for the first intermittent cycling session and 30 minutes for the second intermittent cycling session (performed 24 hours later) for each recovery condition. Therefore, approximately 5 hours of your time in total will be taken up with this study if you decide to participate. Once the data has been collected and analyzed you will be invited to a debriefing session where you will be given an information sheet detailing the purpose of the study, preliminary conclusions, and your individual results compared with the mean of the group.

Your participation is completely voluntary and you can withdraw from the study at any time (even in the midst of a testing session), **without explanation**. If you decide to withdraw midstream, you have the right to decide whether your data that has been collected up to that point can be used as part of the analysis. Any data collected in the study will remain confidential; all data sheets and diskettes will be kept in a locked filing cabinet in a locked office. Your name will not be attached to any published results, and your anonymity will be protected by using code numbers to identify results instead of your name and only I will have access to the code numbers. As well, signed consent forms will be stored separately from any data. 5 years after the study is complete, all forms of records and documentation will be destroyed in a paper shredder and all diskettes with data will be reformatted, and thus, erased. If you are a student of the

- Lane, K.N. (1999). Effect of various recovery conditions on intermittent cycling performance separated by 24 hrs: A proposal. Pacific Northwest Exercise Group Conference, Sechelt, B.C.
- Lane, K.N. (1997). Nutrition for elite field hockey players. Presented at the Junior National Field Hockey Selection Camp, Vancouver B.C.
- Lane, K.N. (1997). Relationship of maximal aerobic power to repeated skating sprints. Pacific Northwest Exercise Group Conference, Vancouver, B.C.

RESEARCH EXPERIENCE

1999-present

Research assistant for Lynne Wolski Consulting. Projects include establishing pre-employment fitness tests for MacMillan Bloedel - Soan Division and reviewing the validity of the *Bona Fide Occupational Fitness Requirements* in place for the British Columbia Forest Service Protection Branch.

1997, 1999

Coordinator, University of Victoria Sport and Fitness Centre. Responsible for the organization and co-ordination for the use of the centre and equipment in addition to conducting physiological assessments and assisting with faculty research. Also involved in the development of occupational fitness standards and research with various interest groups such as the British Columbia Forest Service Fire Protection Branch and ongoing fitness testing with the Royal Canadian Mounted Police and the Canadian Coast Guard.

1995-97, 1998

University of Victoria Sport and Fitness Centre. Assisted with ongoing lab research projects including: a strength and power study, children's interval training study, the BC Forest Service, an aerobic power training study for pre- and post-menarcheal girls.

OTHER RELATED EXPERIENCE

1996-present

Exercise Consultant

Responsibilities include the organization and conducting of physiological testing as well as the preparation and presentation of training programs for various sport groups.

- e.g. Island Breaststrokes Dragon Boat Team (Breast cancer survivors)
- Junior National Field Hockey Team
- Cowichan Capitals Junior 'A' Ice Hockey Team

1995-98

Exercise technician at the University of Victoria Sport and Fitness Centre

Duties include physiological testing along with exercise and wellness prescriptions for various occupational and sports groups.

- e.g. New York Rangers and Los Angeles Kings Hockey Teams
- Canadian National Alpine and Freestyle Ski Teams
- Canadian National Rugby, Mountain Biking, and Cycling Teams
- Canadian Coast Guard, RCMP, and BC Forest Service