

THE EFFECT OF AN AEROBIC INTERVAL TRAINING  
PROGRAM ON INTERMITTENT ANAEROBIC PERFORMANCE

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DEAN

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## ABSTRACT

The purpose of this study was to investigate the effect of a nine week aerobic interval training program on high intensity, short duration work. Twenty- four recreationally active males were separated into a training group and a control group. The training group (TG) participated in a nine week aerobic interval training program which consisted of 3 minute intervals in a work to rest ratio of 1:1, repeated 5-10 times at a heart rate intensity corresponding to  $\dot{V}O_{2max}$ . The control group (CG) continued with their regular activity program. Measurements of aerobic power ( $\dot{V}O_{2max}$ ) and intermittent anaerobic performance were recorded prior to the study and at completion of the training program. The anaerobic performance test (APT) involved four 30 second Wingate tests with by 3 minutes of recovery. Short-term peak power (SPP), short-term anaerobic capacity (SAC), intermediate-term peak power (IPP) and total work (TW) were measured during the four Wingate tests.

Relative and absolute values of aerobic power significantly increased from  $51.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $3.7 \text{ L} \cdot \text{min}^{-1}$  to  $55.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.0 \text{ L} \cdot \text{min}^{-1}$  for the TG. No significant change was observed for the CG with values of  $51.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.2 \text{ L} \cdot \text{min}^{-1}$  for the pre-test and  $50.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.0 \text{ L} \cdot \text{min}^{-1}$  in the post-test. There was no significant difference in body mass (kg) between the two groups from pre to post-test. There were significant increases in all the four variables (SPP, SAC, IPP and TW) and across the four repeats for anaerobic performance (T1-T4) in the TG whereas

the CG demonstrated a significant increase only in SPP for Repeat 3. These data suggest that the type of interval training program used in the study increases aerobic power and also enhances performance in repeated high intensity, short duration work.

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## DEDICATION

This thesis is dedicated to my family and friends. To my mother and father for their continued love, support and for being the greatest teachers I have ever had; I love you always. To my sister and brother and their families, thank you for always being there for me. And to my friends, the greatest people I have ever met, thanks for never forgetting me and believing in me. But most importantly I would like to thank them all for creating the most positive, happy environment that has made my love of life overwhelming.

## INTRODUCTION

Many intermittent sports demand anaerobic energy production, but it has been suggested that the aerobic system also plays an important role in the success of an athlete in this type of activity (Montgomery, 1988; Paterson, 1979; Watson & Hanley, 1986). The development of aerobic power has been suggested to aid in the replenishment of energy stores and in the removal of lactic acid between the high intensity efforts (Hermansen, 1969; Malomsoki, 1986; Montgomery, 1988; Rhodes & Twist, 1990; Smith, Quinney, Steadward, Wenger & Sexsmith, 1982; Viitasalo, Rusko, Pajala, Rahkila, Ahila & Montonen, 1987; Watson & Hanley, 1986). Depletion of creatine phosphate (CP) and accumulation of lactic acid due to a decrease in muscle pH are limiting factors in muscular work. Creatine phosphate, which is a high energy store for adenosine triphosphate (ATP) regeneration, is considered to be almost completely replenished within minutes of recovery (Green, 1979; Karlsson, Bonde-Petersen, Henrikson & Knuttgen, 1975b; McCartney et al., 1986; Montgomery, 1988; Watson & Hanley, 1986). Lactic acid, the by-product of anaerobic glycolysis, takes longer to be removed from the muscle and blood. To minimize the inhibiting effect of lactic acid on performance, a recovery period is essential to remove it and reduce its effect on muscular fatigue.

During submaximal periods of recovery the aerobic system plays an important role in the recovery process. The transport of oxygen to muscle tissue is necessary for the resynthesis of CP and ATP. In addition an efficient aerobic system facilitates the removal of

lactic acid via aerobic oxidation. The increased blood flow also helps transport the waste products from the muscle to the blood where it can be more effectively buffered (Belcastro & Bonen, 1975; Berry & Montani, 1985; Evans & Cureton, 1983; Green, 1979; Hermansen, 1969; Montgomery, 1988; Watson & Hanley, 1986; Weltman, Stamford, Moffatt & Katch, 1977).

A high level of aerobic power should facilitate recovery and allow the athlete to maintain a high level of intensity in subsequent efforts (Rhodes & Twist, 1990). However, the direct effect of aerobic training on anaerobic performance has not been well documented. McCartney et al. (1986) investigated the metabolic changes of ATP and CP concentrations during four repeated 30 second maximal tests with recovery periods of 4 minutes between each effort. No reference was made to the contribution of the aerobic energy system to the performance of high intensity, repeated efforts. Schreiner (1988) and Sleivert (1991) investigated the metabolic changes within skeletal muscle that occurred in athletes with high and low  $\dot{V}O_{2\max}$  after intense intermittent exercise. They observed no difference between the groups in lactate removal, (Schreiner, 1988) pH, or Pi/CP ratio (Sleivert, 1991) during recovery from the high intensity efforts. However, they did not train the aerobic power of the athletes so the role of aerobic power in recovery from high intensity, intermittent work can only be inferred. Therefore, the purpose of this study was to investigate whether an interval training program designed to enhance aerobic power would also improve performance in repeated high intensity, short duration work.

## **METHODS**

### **Subjects**

Twenty-four recreationally active males volunteered for the study and signed Informed Consent forms and a pre-screening form. The subjects were placed in either a control (N=11) or training group (N=13). Control group subjects took part in only the pre and post testing procedures and were asked not to change their current recreational activities. The training group participated three times per week in an interval training program for nine weeks.

## **TESTING PROCEDURES**

### **Anthropometry**

Anthropometric measures included height, weight and the sum of eight skinfolds: triceps, biceps, subscapular, suprailiac, supraspinale, abdominal, thigh and medial calf. These measures were taken pre and post study and used for descriptive purposes as well as to monitor any change in weight which may affect relative maximal aerobic power ( $\text{VO}_2\text{max}$ ).

### **$\text{VO}_2\text{max}$ Protocol**

$\text{VO}_2\text{max}$  was measured on a Monark cycle ergometer (model 868). The test protocol involved a continuous test starting at a predetermined resistance of 2 kiloponds (kp) and increased according to the subject's aerobic fitness. The resistance was increased every 2 minutes for three different loads. Thereafter, the

resistance was increased every minute until  $\text{VO}_2\text{max}$  had been reached.  $\text{VO}_2\text{max}$  was considered to be achieved when two or more of the following criteria were met: a plateau or decline in oxygen consumption despite an increase in power output; a respiratory exchange ratio which exceeded 1.10; the achievement of predicted maximum heart rate; or the test participant stopped due to exhaustion.  $\text{VO}_2\text{max}$  was expressed as  $\text{L} \cdot \text{min}^{-1}$  and  $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ .

A two-way Rudolph valve was used to collect expired air which was analyzed every 30 seconds using a Beckman Metabolic Measurement Cart (MMC). Prior to and following each test the MMC was calibrated using primary standard gases. Heart rate was recorded each minute using a PE3000 Sportester.

The control and training groups performed a  $\text{VO}_2\text{max}$  test prior to and following the 9 week training program. A mid-training  $\text{VO}_2\text{max}$  test was also completed by the training group to monitor training effectiveness and correct training intensity.

### **Anaerobic Performance Test (APT)**

Subjects performed four 30 second high intensity efforts on a Monark friction-braked cycle ergometer (model 868) set at  $90\text{g} \cdot \text{kg}^{-1}$  of body weight. Between intervals there was a 3 minute recovery period. To ensure the subject was working at an all-out intensity the resistance was set within 2 seconds of the subjects sprint start. The cue "pick it up, ready and go" was used to standardize the start procedure. Revolutions were recorded by an electronic revolution counter which measured pedal revolutions for the four 30 second

APT. During the 3 minute recovery period the subjects pedalled easily at 0 load for two minutes, thereafter the subjects sat passively for one minute.

The four APT were performed pre and post training for the training group and the control group. Four dependent variables were measured within each APT. Short-term peak power (SPP) was measured as the highest average power output (Watts) in a 5 second period during the first 10 seconds of the 30 second tests. Short-term anaerobic capacity (SAC) consisted of the total work completed in the first 10 seconds. Intermediate-term peak power (IPP) was calculated as the highest average power output in a 5 second period of the last 10 seconds and total work (TW) was the total work completed during each 30 second test.

### **Training Procedures**

Subjects in the training group reported to the University of Victoria Sport and Fitness Centre three times a week for nine weeks. The first week consisted of continuous aerobic training at 60-80%  $\dot{V}O_2\text{max}$  for 30-40 minutes. Weeks two to nine involved interval training. Interval work periods were 3 minutes in length followed by a 3 minute recovery period. The training program began with five 3 minute intervals. The number of intervals increased progressively depending on the subjects adaptation to the previous training workouts. The subjects remained at each training level for at least one week to ensure they could complete the increase in training intensity.

Intensity of the intervals was based on the heart rate for each subject at  $VO_2\text{max}$ . Heart rate was monitored by the use of a PE3000 Sportester attached to the subject. The investigator was able to monitor the intensity of the work and adjust either the resistance of the cycle ergometer or the pedal velocity, depending on which the subject chose, to ensure training heart rate was achieved.

During recovery between each aerobic interval the subjects continued to pedal at an intensity that did not allow the heart rate to drop lower than 140 bpm, which was in the range of 25-45%  $VO_2\text{max}$ . This intensity has been found to be most effective in returning the muscle energy stores and lactic acid levels closer to resting values, as well to ensure the subject will reach maximum heart rate within the 3 minute work interval (Belcastro & Bonen, 1975; Boileau et al., 1983; Davies et al., 1970; Dodd et al., 1984; Weltman et al., 1979).

### **Statistical Analysis**

A 2x2 ANOVA was used to compare the training and control groups on the pre and post-test measures for  $VO_2\text{max}$ . Changes in anaerobic performance were initially determined by a 3 way ANOVA with repeated measures on the two factors of Time (pre and post) and Repeats (T1-T4). This analysis was also used to test for differences between the training and control groups. When a significant interaction between the two groups was indicated a series of paired T-tests were employed to locate where the differences existed. Percentage change was also conducted to observe the change between each anaerobic variable over the four APT for each group from pre to

post-test. The level of significance for all comparisons was set at  $p < .05$ .

## RESULTS

The relative and absolute  $\dot{V}O_{2\max}$  values significantly increased ( $p < .05$ ) for the TG from pre to post-test (Table 1) whereas the CG showed no significant difference. The pre-test mean values for relative and absolute  $\dot{V}O_{2\max}$  were  $51.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $3.7 \text{ L} \cdot \text{min}^{-1}$  for the TG and  $51.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.2 \text{ L} \cdot \text{min}^{-1}$  for the CG which were not significantly different between the groups. The mean relative and absolute  $\dot{V}O_{2\max}$  values for the post-test were  $55.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.0 \text{ L} \cdot \text{min}^{-1}$  for the TG and  $50.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.0 \text{ L} \cdot \text{min}^{-1}$  for the CG.

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 Insert Table 1 here  
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There was no significant difference in body mass (kg) between the two groups from pre to post-test. Mean values for pre and post-tests were 72.8 kg and 73.0 kg for the TG and 81.3 kg for the CG (Table 1).

There were significant differences between the TG and the CG in all four anaerobic variables: short-term peak power (SPP), short-term anaerobic capacity (SAC), intermediate-term peak power (IPP) and total work (TW) (Tables 2 to 5). Significant differences were found between the first two repeats of the APT in SPP and SAC and between all the repeats for IPP and TW ( $p < .01$ ). The CG significantly increased anaerobic performance from pre to post-test only in Repeat 3 of SPP. The TG demonstrated significant improvement from pre to post-test in the mean relative values in all the Repeats across the four

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Insert Table 2 to 5 here  
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APT variables (Table 2 to 5, Figures 1 to 4) whereas the CG showed decreases in performance in most of the APT across the four conditions (Table 2 to 5, Figures 1 to 4). The percentage change results also reflect the significant improvement in APT for the TG from pre to post-tests (Table 6).

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Insert Figures 1 through 4 here  
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Insert Table 6 here  
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## DISCUSSION

A nine week aerobic interval training program was effective in eliciting significant increases in  $\dot{V}O_2\text{max}$  ( $p < .01$ ). The  $\dot{V}O_2\text{max}$  for the training group (TG) increased from  $51.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $3.7 \text{ L} \cdot \text{min}^{-1}$  to  $55.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.0 \text{ L} \cdot \text{min}^{-1}$  after nine weeks of cycle ergometer interval training. The  $\dot{V}O_2\text{max}$  scores for the control group (CG) showed no significant changes with values decreasing slightly from  $51.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.2 \text{ L} \cdot \text{min}^{-1}$  to  $50.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and  $4.0 \text{ L} \cdot \text{min}^{-1}$ . The training intervals consisted of 3 minutes of high intensity work followed by 3 minutes of low intensity recovery. These findings support the conclusion of previous studies (Astrand, Christensen & Hedman, 1960; Knuttgen, Nordesjo, Ollander & Saltin, 1973) that a 3 min : 3min work to rest ratio is effective in overloading the cardiovascular system and the rate of aerobic metabolic flux in muscle and thus quickly developing aerobic power. The 3 minute work period allowed the individual to train at an intensity close to or at  $\dot{V}O_2\text{max}$  followed by a low intensity "active rest" period. The results of the present study support past research which concluded that interval training is effective in increasing aerobic power (Davis, 1976; Fox, Robinson & Wiegman, 1969; Fox, Bartels, Billings, O'Brien, Bason & Mathews, 1975; Knuttgen et al., 1973).

Values for each of the four variables measured during the APT demonstrated a decline over the four repeats which is characteristic of high intensity intermittent anaerobic performance (Balson, Seger, Sjodin & Ekblom, 1992; Jacobs, Bar-Or, Dotan, Karlsson & Tesch, 1983; McCartney et al., 1986; Schreiner, 1988). The purpose of this

study was to measure the effects of an aerobic interval training program on anaerobic performance. The nine week interval training program significantly increased the aerobic power of the TG. In addition, the TG demonstrated an increase in SPP and SAC across all four anaerobic repeats from pre to post-test.

Significant differences were found between the two groups in Repeats 1 and 2. The percentage changes for the TG were 13.3 (Repeat1) and 9.8 (Repeat2) in SPP and 13.7 and 11.0 for SAC. The CG demonstrated no significant change for SPP (-2.3 and -1.0) and SAC (-3.0 and -1.0) in Repeats 1 and 2. Less of a difference between the two groups in the first two repeats was expected because it has been demonstrated that less lactic acid accumulates in the early stages of the anaerobic work (Balson et al., 1992; McCartney et al., 1986; Roberts et al., 1982). However, the specificity of training on a cycle ergometer may have contributed to the significant difference between the two groups in Repeats 1 and 2 of SPP and SAC. The TG could have become accustomed to the increases in load or were able to condition the muscles fibers to be recruited at a faster rate. There was no significant difference between Repeats 3 and 4 for the two groups in SPP and SAC. Both the TG and CG showed an increase in performance from pre to post-test. The TG had percentage changes of 10.7 and 11.6 in Repeats 3 and 4 for SPP and the CG increased similarly with values of 9.1 and 10.8. Significant increases were demonstrated by the TG in both Repeats 3 and 4 but only in Repeat 3 for the CG. The SAC percent changes were 14.1 and 14.7 for the TG and 6.1 and 7.7 for the CG in Repeats 3 and 4. However, the CG values were not significant. It has been hypothesized that aerobic

interval training stimulates physiological adaptations that will assist in performance in repeated high intensity work. Consequently, the increase in aerobic power for the TG should have had a greater impact on the Repeats 3 and 4. The increase in power output by both groups resulted in no significant differences between the TG and CG in Repeats 3 and 4.

The overall increase in anaerobic performance demonstrated by the TG in all the four anaerobic variables in each of the repeats may have been due to a combined contribution from aerobic and anaerobic adaptations. A 3 minute interval would involve energy supplied by both the anaerobic and aerobic energy systems. Medbo and Tabata (1989) concluded that the energy contribution for a maximal 2 minute effort was 65% from the aerobic system and 35% from the anaerobic energy system. During a 90 second maximal effort Serresse et al. (1988) showed the energy release to be 12%, 42% and 46% from ATP-CP, anaerobic glycolysis and aerobic energy sources. In comparison Bouchard et al. (1991) concluded that there are equal contributions from aerobic and anaerobic pathways. These studies suggest that a 3 minute maximal effort could benefit both aerobic and anaerobic performance. Analysis of IPP and TW showed significant differences between groups from pre to post-test in each of the four APT measures (Tables 2 to 5). The energy system associated with these time periods involves the breakdown of glycogen to form ATP (Hermansen, 1969; Medbo & Tabata, 1989) and the formation of lactic acid (Katch and Weltman, 1979; Shephard, 1978). The TG improved in performance over all four repeated APT and IPP demonstrating the greatest percentage change in Repeat 2 and 3

(21.3, 25.9) (Table 6). These values seem to support the assumption that an interval training program can assist in improving performance in intermittent high intensity work.

The improvements in Repeats 1 through 4 in IPP and TW for the TG may have been due to the development of the anaerobic system through interval training. High intensity interval training tends to enhance the peripheral adaptations (Berg et al., 1989; Fardy, 1981). These peripheral changes may enhance the muscles capability to remove and tolerate lactic acid (Bloomfield, Fricker and Fitch, 1992; Fox et al., 1969; Holloszy, 1982; Sjodin et al., 1975) and as a result explain the greater power output over the repeated high intensity efforts for the TG over the CG. As well, Cunningham, McCrimmon and Vlach (1979) stated that cycle ergometer training may place more emphasis on extraction of oxygen from the muscle and less adaptation on the heart as a pump. Improved performance and the ability to sustain the increase in power output in the later tests (Repeats 3 and 4) for the TG could have been caused by the increase in aerobic power.

The conclusion that the aerobic system plays an essential role in enhancing recovery is based on time-motion analyses and/or physiological profile studies performed on numerous intermittent sporting activities (Ekblom, 1986; Green, 1979; Malomsoki, 1986; Montgomery, 1988; Rhodes & Twist, 1990; Smith, Quinney, Steadward, Wenger & Sexsmith, 1982; Watson & Hanley, 1986). Coaches and exercise physiologists involved in intermittent sports attempt to maintain or reduce the “drop off” in anaerobic performance of the athletes by developing the aerobic system. This

should enhance resynthesis of energy stores and/or removal of lactic acid between repeated intervals. If the resynthesis of energy stores and removal of lactic acid are inhibited they will become critical contributors to muscular fatigue and decreased performance. No reduced “drop off” was observed in the present study but there were substantial improvements in performance. The TG post-test mean value for Repeat 4 of IPP is similar to the pre-test mean score of the TG for Repeat 2. This suggests that although performance may not have been maintained or there was no reduction in the amount of the “drop off” between repeats for IPP; improvement in power output was evident. TW also showed a similar increase from pre to post-test for the TG. Interval training would be beneficial for athletes involved in repeated high intensity activities.

No study has actually trained the aerobic power of subjects and monitored the effects on repeated short-term high intensity efforts. Schreiner (1988) investigated differences in total work during four repeat 30 second tests with 4 minutes recovery between each bout in high ( $57.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) versus low ( $47.9 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )  $\text{V}_{\text{O}_2\text{max}}$  groups. She found that there were no differences between the groups in concentration of lactate, the removal of lactate from the muscle and the concentration in blood lactate after the four minutes of recovery over the four 30 second tests. Schreiner (1988) did find a significant difference in total work in the last APT, the low  $\text{V}_{\text{O}_2\text{max}}$  group demonstrating a greater decrease. In general these results were not supported in the present study which showed significant differences in TW in all the four APT. Sleivert (1991) conducted a pilot study to investigate the relationship of  $\text{V}_{\text{O}_2\text{max}}$  and phosphagen and

pH during recovery after intense intermittent exercise. He observed no difference in response to intracellular pH or the Pi/CP ratio during recovery in low ( $52.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) and high ( $58.5 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )  $\text{VO}_2\text{max}$  groups. Neither of these studies incorporated an aerobic training program.  $\text{VO}_2\text{max}$  values were already established in the groups they investigated and different anaerobic performance results may have been seen if the groups had been specifically trained. The present study trained the subjects to improve aerobic power.

The increase in anaerobic performance for the TG was probably due to the combined adaptations in the aerobic and anaerobic energy systems which were developed through the 3 minute interval training program. The results support the position often stated by exercise physiologists that an interval training program may create the physiological adaptations within the muscle and the cardiovascular system which will assist in improving high intensity, intermittent, short-duration performance (Hermansen, 1969; Malomsoki, 1986; Montgomery, 1988; Rhodes & Twist, 1990; Smith et al., 1982; Viitasalo et al., 1987; Watson & Hanley).

**Table 1. Means ( $\bar{x}$ ) and Standard Deviations (sd) of  $\text{VO}_2\text{max}$  Scores and Body Mass (kg) for the Training and Control Groups in Pre and Post-Tests**

Variables							
Group	VO <sub>2</sub> max						
	ml · kg <sup>-1</sup> · min <sup>-1</sup>		L · min <sup>-1</sup>		Body Mass (kg)		
	Pre x (sd)	Post x (sd)	Pre x (sd)	Post x (sd)	Pre x (sd)	Post x (sd)	
<b>Training</b>							
n = 13							
	51.7 (5.2) <sup>a</sup>	55.0 (4.8) <sup>a</sup>	3.7 (.44) <sup>a</sup>	4.0 (.37) <sup>a</sup>	72.8 (8.6)	73.0 (8.0)	
<b>Control</b>							
n = 11							
	51.7 (7.1)	50.1 (6.5)	4.2 (.52)	4.0 (.47)	81.3 (11.3)	81.3 (11.4)	

\* paired letters are significantly different at the  $p < .05$  level i.e. aa bb etc.

**Table 2. Means (x) and Standard Deviations (sd) for Short-Term Peak Power Measured During the Four Repeated Anaerobic Performance Tests (APT) for the Training and Control Groups on Pre and Post-Tests**

APT	Groups			
	Training n = 13		Control n = 11	
	Pre x (sd)	Post x (sd)	Pre x (sd)	Post x (sd)
1.	11.7 (1.3) <sup>a</sup>	13.2 (1.5) <sup>ab</sup>	12.0 (1.0)	11.7 (.70) <sup>b</sup>
2.	11.3 (1.0) <sup>a</sup>	12.4 (1.4) <sup>ab</sup>	11.3 (1.3)	11.1 (.90) <sup>b</sup>
3.	10.0 (1.6) <sup>a</sup>	10.9 (1.3) <sup>a</sup>	9.4 (1.6) <sup>b</sup>	10.1 (1.0) <sup>b</sup>
4.	8.9 (1.7) <sup>a</sup>	9.8 (1.5) <sup>a</sup>	8.5 (2.2)	9.0 (1.2)

\* paired letters show significant differences at the p<.05 level, i.e. aa bb etc. within rows.

**Table 3. Means (x) and Standard Deviations (sd) for Short-Term Anaerobic Capacity Measured During the Four Repeated Anaerobic Performances Test (APT) for the Training and Control Groups on Pre and Post-Tests**

APT	Groups			
	Training n = 13		Control n = 11	
	Pre x (sd)	Post x (sd)	Pre x (sd)	Post x (sd)
1.	111.2 (11.5) <sup>a</sup>	127.2 (14.5) <sup>ab</sup>	113.5 (10.1)	109.8 (6.8) <sup>b</sup>
2.	105.8 (8.9) <sup>a</sup>	117.1 (11.9) <sup>ab</sup>	104.5 (12.7)	102.6 (9.1) <sup>b</sup>
3.	92.1 (13.6) <sup>a</sup>	104.2 (11.6) <sup>a</sup>	88.2 (14.3)	92.7 (11.2)
4.	84.2 (15.9) <sup>a</sup>	95.3 (14.3) <sup>a</sup>	82.2 (19.8)	85.5 (12.1)

\* paired letters show significant differences at the p<.05 level, i.e. aa bb etc. within rows.

**Table 4. Means (x) and Standard Deviations (sd) for Intermediate-Term Peak Power Measured During the Four Repeated Anaerobic Performance Tests (APT) for the Trained and Control Groups on Pre and Post-Tests**

APT	Groups			
	Training n = 13		Control n = 11	
	Pre x (sd)	Post x (sd)	Pre x (sd)	Post x (sd)
1.	8.2 (.90) <sup>a</sup>	8.9 (1.0) <sup>ab</sup>	7.7 (.90)	7.5 (.80) <sup>b</sup>
2.	6.5 (.80) <sup>a</sup>	7.9 (1.0) <sup>ab</sup>	6.5 (1.1)	6.3 (.90) <sup>b</sup>
3.	5.4 (.80) <sup>a</sup>	6.7 (1.1) <sup>ab</sup>	5.8 (1.1)	5.6 (1.0) <sup>b</sup>
4.	5.2 (1.0) <sup>a</sup>	6.3 (1.0) <sup>ab</sup>	5.6 (1.1)	5.3 (.90) <sup>b</sup>

\* paired letters show significant differences at the p<.05 level, i.e. aa bb etc. within rows.

**Table 5. Means ( $\bar{x}$ ) and Standard Deviations (sd) for Total Work Measured During the Four Repeated Anaerobic Performance Tests (APT) for the Training and Control Groups on Pre and Post-Tests**

APT	Groups			
	Training n = 13		Control n = 11	
	Pre x (sd)	Post x (sd)	Pre x (sd)	Post x (sd)
1.	283.9 (28.5) <sup>a</sup>	318.9 (33.7) <sup>ab</sup>	277.8 (26.2)	267.7 (19.9) <sup>b</sup>
2.	249.7 (23.7) <sup>a</sup>	281.6 (25.9) <sup>ab</sup>	242.7 (32.1)	239.1 (27.3) <sup>b</sup>
3.	209.3 (29.0) <sup>a</sup>	247.5 (31.2) <sup>ab</sup>	211.6 (36.6)	213.5 (31.9) <sup>b</sup>
4.	195.1 (33.5) <sup>a</sup>	231.7 (33.5) <sup>ab</sup>	199.3 (41.8)	201.8 (28.9) <sup>b</sup>

\* paired letters show significant differences at the  $p < .05$  level, i.e. aa bb etc. within rows.

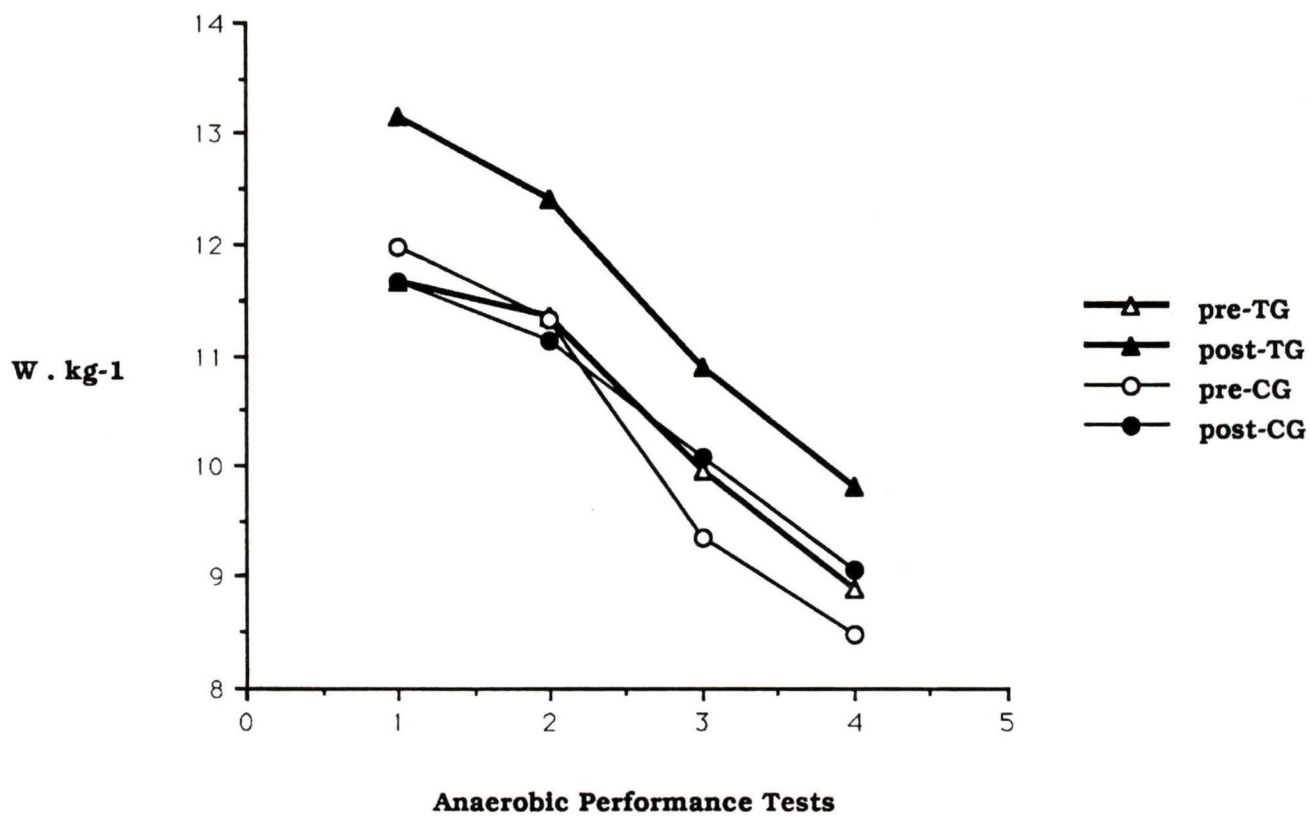
**Table 6. Means (x) and Standard Deviations (sd) for Percentage Change for Short-Term Peak Power (SPP), Short-Term Anaerobic Capacity (SAC), Intermediate-Term Peak Power (IPP) and Total Work (TW) of the Four Repeated Anaerobic Performance Tests for the Training (TG) and Control Groups (CG) from Pre to Post-Test**

Variables		Anaerobic Performance Test				
		1	2	3	4	
Multivariate F		x (sd)	x (sd)	x (sd)	x (sd)	
SPP	TG	13.3 (11.6)	9.8 (11.6)	10.7(10.8)	11.6 (13.2)	
	CG	-2.3 (6.2)	-1.0 (9.7)	9.1 (11.1)	10.8 (21.8)	
SAC	TG	13.7 (10.5)	11.0 (10.5)	14.1 (10.1)	14.7 (12.0)	
	CG	-3.0 (5.1)	-1.0 (9.2)	6.1 (9.3)	7.7 (20.2)	
IPP	TG	9.6 (9.9)	21.3 (11.2)	25.9 (19.6)	21.4 (12.6)	
	CG	-2.1 (9.0)	-1.8 (10.3)	-2.4 (8.0)	-4.3 (9.2)	
TW	TG	12.7 (10.7)	13.1 (9.0)	19.1 (12.2)	19.4 (7.1)	
	CG	-3.4 (3.9)	-1.0 (7.5)	1.6 (8.3)	3.2 (13.7)	

\* p<.05

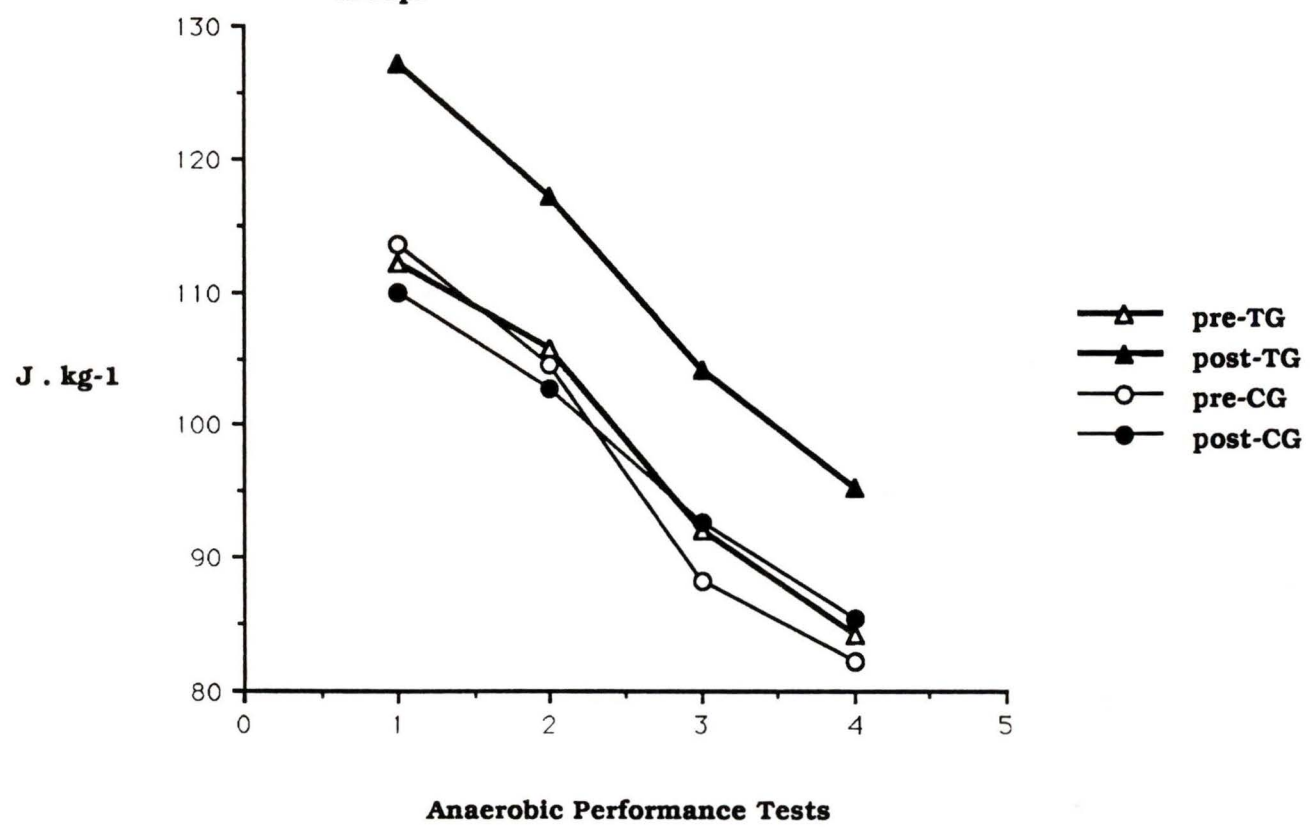
**Figure 1. Short-Term Peak Power in Four Anaerobic Performance Tests from Pre to Post-Test for the Training and Control Groups**

**Short-Term Peak Power in Four Anaerobic Performance Tests from Pre to Post-Test Between the Training and Control Groups**



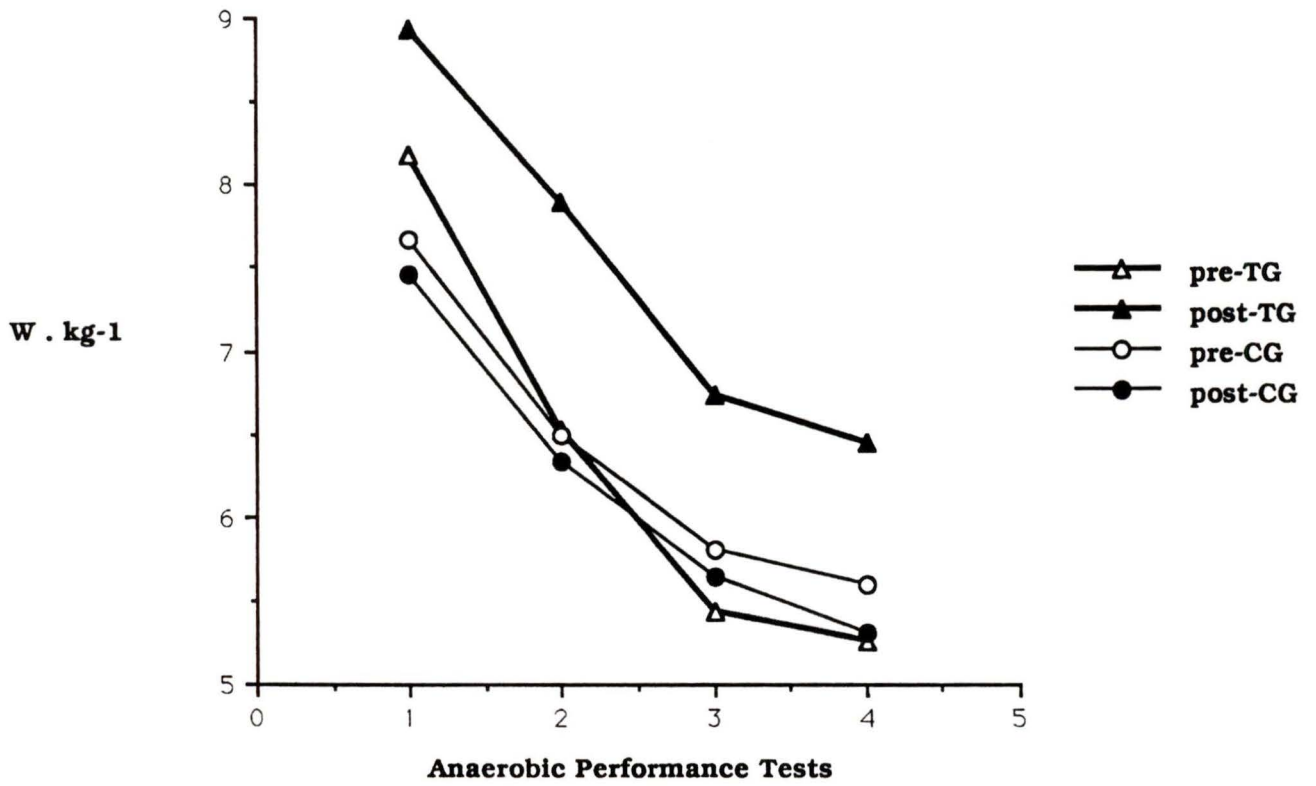
**Figure 2. Short-Term Anaerobic Capacity  
on Four Anaerobic Performance Tests  
from Pre to Post-Test for the Training  
and Control Groups**

**Short-Term Anaerobic Capacity in Four Anaerobic Performance Tests from Pre to Post-Test Between the Training and Control Groups**



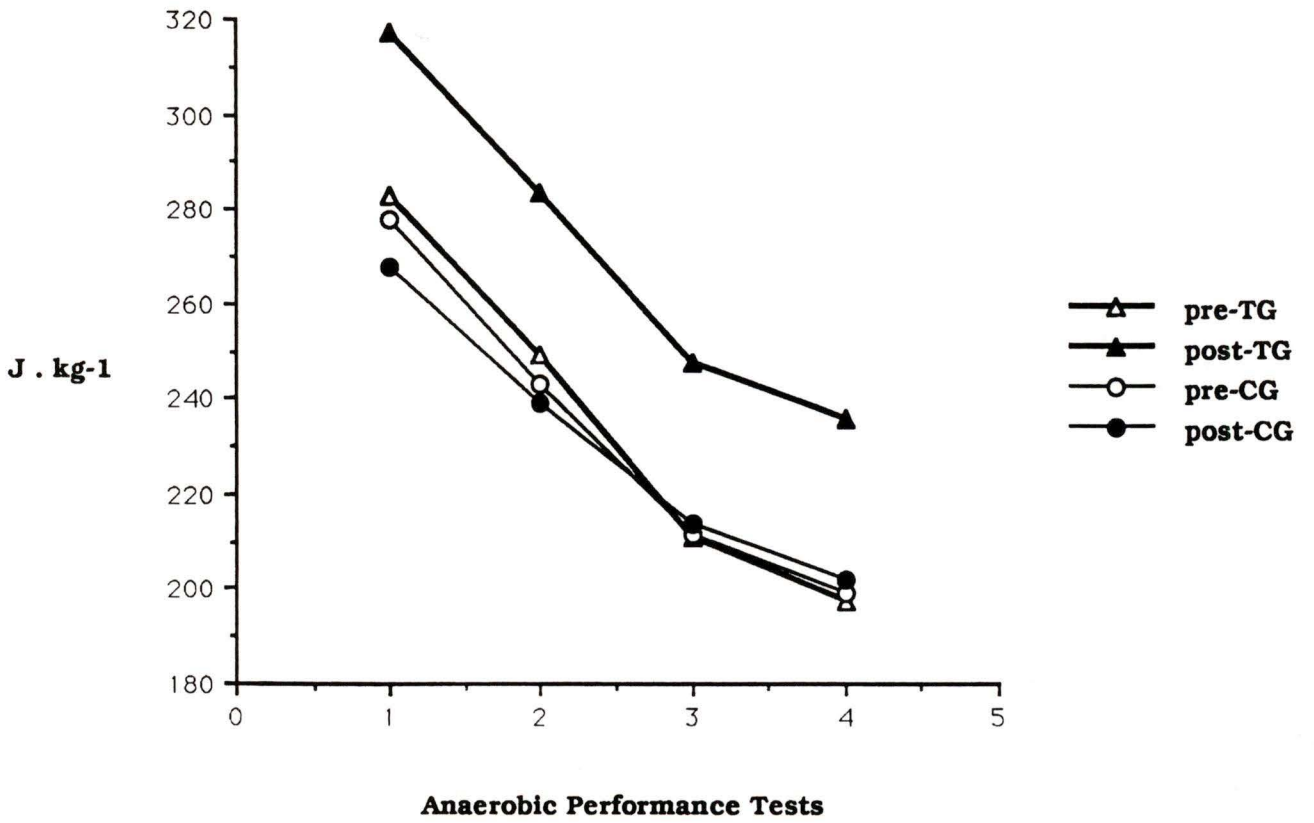
**Figure 3. Intermediate-Term Peak Power on Four Anaerobic Performance Tests from Pre to Post-Test for the Training and Control Groups**

**Intermediate-Term Peak Power in Four Anaerobic Performance Tests from Pre to Post-Test Between the Training and Control Groups**



**Figure 4. Total Work on Four Anaerobic Performance Tests from Pre to Post-Test for the Training and Control Groups**

**Total Work in Four Anaerobic Performance Tests from Pre to Post-Test Between the Training and Control Groups**



## REFERENCES

- Astrand, I, Astrand, P.O., Christensen, E.H. & Hedman, R. (1960). Intermittent muscular work. Acta Physiologica Scandinavica, 48, 448-453.
- Balsom, P.D., Seger, J.Y., Sjodin, B. & Ekblom, B. (1992). Maximal-intensity intermittent exercise: Effect of recovery duration. International Journal of Sports Medicine, 13(7), 528-533.
- Bloomfield, J., Fricker, P.A. & Fitch, K.D. (1992). The Textbook of Science and Medicine in Sport. Champaign IL.: Human Kinetics Books.
- Cunningham, D.A., McCrimmon, D. & Vlach, L.F. (1979). Cardiovascular response to interval and continuous training in women. European Journal of Applied Physiology and Occupational Physiology, 41, 187-197.
- Dodd, S., Powers, S.K., Callendar, T. & Brooks, E. (1984). Blood lactate disappearance at various intensities of recovery exercise. Journal of Applied Physiology, 57(5), 1462-1465.
- Ekblom, B. (1986). Applied physiology of soccer. Sports Medicine, 3, 50-60.
- Froese, E.A. & Houton, M.E. (1987). Performance during the Wingate Anaerobic Test and muscle morphology in males and females. International Journal of Sports Medicine, 8, 35-39.
- Gibson, H. & Edwards, R.H.T. (1985). Muscular exercise and fatigue. Sports Medicine, 2, 120-132.
- Green, H.J. (1979). Metabolic aspects of intermittent work with specific regard to ice hockey. Canadian Journal of Applied Sport Sciences, 4(1), 29-34.
- Hermansen, L. (1969). Anaerobic energy release. Medicine and Science in Sports, 1(1), 32-38.
- Houston, M. (1982). Exercise Biochemistry. In JJ. Jackson & H.A. Wenger (Eds.), Physical Education Series: 4. The Sport Sciences. University of Victoria, Victoria, B.C.

Jacobs, I. Bar-Or, O., Dotan, R., Karlsson, J. & Tesch, P. (1983). Changes in muscle ATP, CP, glycogen, and lactate after performance of the Wingate Anaerobic Test. In, Knuttgen, H.G. (ed.) et al., Biochemistry of Exercise: Vol 13, Champaign IL: Human Kinetics Publishers, Ltd.

Katch, V.L. & Weltman, A. (1979). Interrelationship between anaerobic power output, anaerobic capacity and aerobic power. Ergonomics, 22(3), 325-332.

Knuttgen, H.G., Nordesjo, L.O., Ollander, B. & Saltin, B. (1973). Physical conditioning through interval training with young male adults. Medicine and Science in Sports and Exercise, 5(4), 220-226.

MacDougall, J.D. (1974). Limitations to anaerobic performance. Symposium at McMaster University, Ontario, Oct 18-20, 22-30.

Malomsoki, J. (1986). The aerobic power and the parameters of the anaerobic metabolism of boxers. Hungarian Review of Sports Medicine, 27(3), 214-219.

McCartney, N., Spriet, L.L., Heigenhauser, G.J.F., Kowalchuk, J.M., Sutton, J.R. & Jones, N.L. (1986). Journal of Applied Physiology, 60(4), 1164-1169.

Medbo, J.I. & Tabata, I. (1989). Relative importance of aerobic and anaerobic energy release during short lasting exhausting bicycle exercise. Journal of Applied Physiology, 67(5), 1881-1886.

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

Rhodes, T. & Twist, P. (1990). The Physiology of Ice Hockey: A Testing and Training Manual. University of British Columbia.

Schreiner, A.B. (1988). Differences in the rate of lactate removal from skeletal muscle following intense exercise in groups with different aerobic power. Unpublished master's thesis, University of Victoria, Victoria, B.C.

Shephard, R.J. (1978). Aerobic versus anaerobic training for success in various athletic events. Canadian Journal of Applied Sport Sciences, 3, 9-14.

Sleivert, G.G. (1991). The relationship of  $V\dot{O}_2$ max to skeletal muscle phosphagen and pH recovery from repeated bouts of high intensity exercise. Unpublished research, University of Alberta, Edmonton, Alberta.

Smith, D.J., Quinney, H.A., Steadward, R.D., Wenger, H.A. & Sexsmith, J.R. (1982). Physiological profiles of the Canadian Olympic hockey team. Canadian Journal of Applied Sport Sciences, 7(2), 142-146.

Tesch, P.A., Wright, J.E., Vogel, J.A., Daniels, W.L., Sharp, D.S. & Sjodin, B. (1985). The influence of muscle metabolic characteristics on physical performance. European Journal of Applied Physiology, 54, 237-243.

Watson, R.C. & Hanley, R.D. (1986). Application of active recovery techniques for a simulated ice hockey task. Canadian Journal of Sports Science, 11(2), 82-87.

Weltman, A., Stamford, B.A. & Fulco, C. (1979). Recovery from maximal effort exercise: Lactate disappearance and subsequent performance. Journal of Applied Physiology, 47(4), 677-682.

**APPENDIX A**

**INFORMED CONSENT**

**INFORMED CONSENT**

I \_\_\_\_\_ have volunteered to participate in the research project investigating the effectiveness of an aerobic interval training program on four measures of anaerobic recovery periods.

I understand that participation as a subject is entirely voluntary. No coercion of any kind has been used to obtain my cooperation.

I understand that I may withdraw and terminate my participation at any time during the study.

I understand that all results will remain completely confidential, and that if requested the data will be destroyed after analysis.

I understand that I shall be given the opportunity to ask questions prior to the start, during and after my participation in the study.

Date \_\_\_\_\_ Signature \_\_\_\_\_

Phone Number \_\_\_\_\_

**APPENDIX B****TABLE 1  
A NINE WEEK AEROBIC INTERVAL TRAINING  
SCHEDULE**

**Table 1 An 9 week aerobic interval training schedule**

<b>Weeks</b>	<b>Type of Training</b>	<b>Duration workrest</b>	<b>Repetitions</b>	<b>Intensity (% HR max)</b>	<b>Frequency per week</b>
<b>1</b>	<b>Continuous</b>	<b>30-40min</b>	<b>1</b>	<b>60-80%</b>	<b>3</b>
<b>2</b>	<b>Interval</b>	<b>3:3</b>	<b>5</b>	<b>100%</b>	
<b>3</b>			<b>6</b>		
<b>4</b>			<b>7</b>		
<b>5</b>			<b>8</b>		
<b>6-9</b>			<b>8-10</b>		

**APPENDIX C**

**INTRODUCTION**

## INTRODUCTION

Certain sports are dependent on energy stores supplied by the aerobic energy system. Such activities include long distance running, rowing, swimming and cross-country skiing. These events require an athlete to maintain a high submaximal intensity for a prolonged period of time. The power of the aerobic energy system ( $\text{VO}_2\text{max}$ ) has been demonstrated to correlate highly with performance (Foster, Daniels & Yarbrough, 1977; Hagan, Smith & Gettman, 1981; Pollock, Jackson & Pate, 1980; Secher, 1983). High intensity events such as sprinting, that perform a single, short duration effort, are dependent upon energy derived from anaerobic metabolism. Within this high intensity bout the energy systems activated are the ATP-PC system (Houston, 1982; McCartney, Spriet, Heigenhauser, Kowalchuk, Sutton & Jones, 1986; Rhodes & Twist, 1990) and/or anaerobic glycolysis (Hermansen, 1969; Medbo & Tabata, 1989).

Some sports are characterized by short burst, high intensity repeated efforts lasting between 5 and 30 seconds. Examples of such intermittent activities are ice hockey, soccer, basketball and volleyball. The high intensity efforts that last from 1-10 seconds obtain the energy required from stored ATP-CP (Astrand & Rodahl, 1986; Houston, 1982; MacDougall, 1974; Shephard, 1978). Continued work at maximal intensity beyond 10 seconds and up to approximately 2 minutes, stresses the ability of an athlete to produce energy by anaerobic glycolysis (Hermansen, 1969; Medbo & Tabata, 1989; Shephard, 1978).

Many intermittent sports demand anaerobic energy production, but it has been suggested that the aerobic system also plays an important role in the success of this type of athlete (Montgomery, 1988; Paterson, 1979; Watson & Hanley, 1986). The development of aerobic power has been suggested to aid in the replenishment of energy stores and in the removal of lactic acid between the high intensity efforts (Hermansen, 1969; Malomsoki, 1986; Montgomery, 1988; Rhodes & Twist, 1990; Smith, Quinney, Steadward, Wenger & Sexsmith, 1982; Viitasalo, Rusko, Pajala, Rahkila, Ahila & Montonen, 1987; Watson & Hanley, 1986). Depletion of creatine phosphate (CP) and accumulation of lactic acid due to a decrease in muscle pH are limiting factors in muscular work. Creatine phosphate, which is a high energy store for adenosine triphosphate (ATP) regeneration, is considered to be almost completely replenished within minutes of recovery (Green, 1979; Karlsson, Bonde-Petersen, Henrikson & Knuttgen, 1975b; McCartney et al., 1986; Montgomery, 1988; Watson & Hanley, 1986). Lactic acid, the by-product of the anaerobic glycolysis, takes longer to be removed from the muscle and blood. To minimize the inhibiting effect of lactic acid on performance, a recovery period is essential to remove it and reduce its effect on muscular fatigue.

During submaximal periods of recovery the aerobic system plays an role in the recovery process. The transport of oxygen to muscle tissue is necessary for the resynthesis of CP and ATP. In addition an efficient aerobic system facilitates the removal of lactic acid via aerobic oxidation. The increased blood flow also helps transport the waste products from the muscle to the blood where it

can be more effectively buffered (Belcastro & Bonen, 1975; Berry & Montani, 1985; Evans & Cureton, 1983; Green, 1979; Hermansen, 1969; Montgomery, 1988; Watson & Hanley, 1986; Weltman, Stamford, Moffatt & Katch, 1977).

A high level of aerobic power should facilitate recovery and allow the athlete to maintain a high level of intensity in subsequent efforts (Rhodes & Twist, 1990). However, the direct effect of aerobic training on anaerobic performance has not been well documented. McCartney et al. (1986) investigated the metabolic changes of ATP and CP concentrations during four repeated 30 second maximal tests with recovery periods of 4 minutes. No reference was made to the contribution of the aerobic energy system to the performance of high intensity, repeated efforts. Schreiner (1988) and Sleivert (1991) investigated the metabolic changes within skeletal muscle that occurred in athletes with high and low  $\dot{V}O_{2\max}$  after intense intermittent exercise. They observed no difference between the groups in lactate removal, (Schreiner, 1988) pH, or Pi/CP ratio (Sleivert, 1991) during recovery from the high intensity efforts. However, they did not train the aerobic power of the athletes. So the role of aerobic power in recovery from high intensity, intermittent work can only be inferred. Therefore, the purpose of this study was to investigate whether an interval training program designed to enhance aerobic power would also improve performance in repeated high intensity, short duration work.

**APPENDIX D**

**STATEMENT OF THE PROBLEM**

**AND**

**RESEARCH QUESTIONS**

## STATEMENT OF THE PROBLEM

The purpose of this study was to investigate the effect of an aerobic interval training program on intermittent, high intensity, short duration work.

## RESEARCH QUESTIONS

1. Is there an increase in  $V_{O_2\max}$  after a nine week interval training program?
2. Is there a change in the peak power of each 30 second interval of the four repeated 30 second periods of high intensity work following a nine week aerobic interval training program?
3. Is there a change in work performed during the first 10 second period in each of the four repeated 30 second aerobic interval training program?
4. Is there a change in the peak power in the last 10 seconds in each of the four repeated 30 second periods of high intensity work following a nine week aerobic interval training program?
5. Is there a change in the total work performed in four repeated 30 second periods of high intensity work following a nine week aerobic interval training program?

**APPENDIX E****OPERATIONAL DEFINITIONS**

## OPERATIONAL DEFINITIONS

**Anaerobic Performance Test (APT):** four repeated 30 second high intensity efforts with 3 minutes active/passive recovery between each work period. The load is set at .09 kp/kg.

**Short-Term Peak Power (SPP) :** the highest power output (watts) in a 5 second period during the first 10 seconds of the APT (Armstrong et al., 1983; Bouchard, et al., 1991; Maud & Schultz, 1989; Simoneau et al., 1986).

**Short-Term Anaerobic Capacity (SAP) :** the total work (Kjoules) completed in the first 10 seconds of the APT (Bouchard et al., 1991; Boulay et al., 1985; MacDougall et al., 1982; Simoneau et al., 1986).

**Intermediate-Term Peak Power (IPP) :** the highest power output (watts) in a 5 second period during the last 10 seconds during the APT (Bouchard et al., 1991; Boulay et al., 1985; MacDougall et al., 1982).

**Total Work (TW):** the total work (Kjoules) completed during the 30 second APT (McCartney et al., 1986; Serresse et al., 1988; Smith & Hill, 1991).

**Aerobic interval training (AIT):** high intensity work for three minutes followed by three minutes of low intensity activity repeated 5-10 times (Astrand et al., 1960; Fox et al., 1973; Knuttgen et al., 1973).

## **APPENDIX F**

### **DELIMITATIONS AND LIMITATIONS**

## **DELIMITATIONS**

1. The APT consisted of four repeated 30 second high intensity efforts.
2. The intensity of the aerobic intervals will be based on heart rate maximum measures.
3. The programme length of the training study is nine weeks.

## **LIMITATIONS**

1. The subjects may be limited in their training response due to physiological or motivational factors.
2. Subjects may be unaccustomed and/or uncomfortable training and testing on a cycle ergometer.
3. The subjects may not be motivated or have the physical ability to perform the required training program.
4. SAP and IPP are not instantaneous but averaged over a 5 second period.

**APPENDIX G****REVIEW OF LITERATURE**

## REVIEW OF LITERATURE

### Continuous vs Interval Training

The aerobic system can be developed either by continuous or interval training. Continuous training consists of non-interrupted work for a varied length of time. Interval training involves intermittent running over short distances with intervening rest periods. It has been concluded by various authors (Davis, 1976; Fox et al., 1969; Fox et al., 1973; Fox et al., 1975; Knuttgen et al., 1973) that interval training is more effective in improving maximal aerobic power. Other authors suggest that both methods of training are equally effective in developing aerobic fitness (Bhambhani & Singh, 1985; Cunningham et al., 1979; Eddy, Sparks & Adelizi, 1977; Gregory, 1979). Cunningham et al. (1979) studied cardiorespiratory responses to interval training at 90%  $VO_2$ max and continuous training at 70%  $VO_2$ max in women. They concluded that these training regimes yielded similar improvements in aerobic power but believed that if the training intensity is a critical factor, interval training may produce greater improvements than continuous training. A similar study which was conducted by Eddy et al. (1977) demonstrated that continuous 70%  $VO_2$ max training and 100%  $VO_2$ max interval training produced identical changes in aerobic power when the total work load was equal. As well, Overend et al. (1992) demonstrated that continuous training at 80%  $VO_2$ max and interval training at 100% and 120%  $VO_2$ max with total work held constant did not show any differences in aerobic power at the end of a 10 week training program. Bhambhani & Singh (1985) also concluded

that the two training methods were equal when total amount of work was the same for both. In a review by Wenger & Bell (1986), it was concluded interval training allows for greater physiological adaptations to occur for increases in  $VO_2\text{max}$  but continuous training brings about quicker initial improvements in maximal aerobic power.

Physiologically both types of training cause different adaptations within the body that are involved in the function and enhancement of the aerobic energy system. Continuous training has been recommended to be the method of exercise in pre-season and off-season (Davis, 1976; Fardy, 1981; Fox et al., 1989). During continuous training high intensity work levels cannot be maintained for a long period of time so the intensity must be lower. Astrand et al. (1960) showed that continuous training at 100%  $VO_2\text{max}$  intensity can only be maintained for approximately 9 minutes before fatigue forces the activity to cease. At the onset of training the athlete's body needs to slowly adapt to allow for the physiological changes to occur without injury or discomfort to the athlete so continuous training is favoured. As well, continuous training is said to be the best method for improving resting heart rate due to the decreased sympathetic drive by an increased stroke volume (Burke & Franks, 1975; Fox et al., 1975; Paabo & Karpman, 1981). Fardy (1981) concluded in an aerobic power training review that one of the main physiological adaptations of continuous training is conditioning the heart to enhance oxygen delivery. Changes within skeletal muscle are less prominent than those that occur with interval training (Berg, Olsen, McKinney, Hofschire, Latin & Bell, 1989).

Interval training is not recommended at the beginning of an exercise program but is identified as being the most effective means by which to increase maximal aerobic power. A main reason for the popularity of interval training with coaches and athletes is that more intense physical work can be executed in a training session (Cunningham et al., 1979; Fox et al., 1969). Training criteria involve the components of intensity, frequency, duration and length of training.

### **Intensity of Training**

The intensity of the workout is concluded to be the most important component for improving cardiorespiratory fitness (Atomi & Miyashita, 1980; Burke & Franks, 1975; Fox et al., 1973; Fox et al., 1975; Knuttgen et al., 1973; Paabo & Karpman, 1981). The higher the rate of intensity, the greater the hypoxic state of the muscle tissues and the more likely the chance of improvement (Fox et al., 1973; MacDougall & Sale, 1980). Hypoxia is the point at which an inadequate amount of oxygen is available to supply the energy demands of the muscle. When the muscle is exposed to a continually depleted oxygen supply brought about by training, there will be adaptations taking place in the oxygen transport system. Wenger & Bell (1986) concluded in their review of cardiorespiratory fitness, that the hypoxic state which is believed to enhance aerobic power is best achieved at an intensity of 90-100%  $VO_2$ max. Davies & Knibbs (1971) and Gaesser & Wilson (1988) supported the conclusion that the exercise intensity must be close to  $VO_2$ max for improvements in aerobic power to occur. Gaesser & Wilson (1988) reported that the

interval training group in their study worked at 100%  $\text{VO}_2\text{max}$  intensity and demonstrated significant improvements over the continuous group at 50%  $\text{VO}_2\text{max}$ . Total work was kept constant at 40 minutes which suggests the intensity of the workout is a factor in improving aerobic power.

Intensity of less than 90%  $\text{VO}_2\text{max}$  also elicits improvements in aerobic power but not as rapidly. Continuous training within 70-90%  $\text{VO}_2\text{max}$  has continually been supported to be a sufficient work intensity in eliciting improvements in aerobic power (Atomi & Miyashita, 1980; Burkes & Franks, 1975; Cunningham et al., 1979; Davies & Knibbs, 1971; Deitrick & Ruhling, 1978; Eddy et al., 1977; Gregory, 1979). Wenger & Bell's (1986) review supports this statement in that during continuous training effective gains in  $\text{VO}_2\text{max}$  were also achieved when athletes trained at 70-90%  $\text{VO}_2\text{max}$  intensity. Gregory (1979) demonstrated that an interval training program consisting of three 4 minute work bouts at 174 bpm (below  $\text{VO}_2\text{max}$ ) was also effective in improving  $\text{VO}_2\text{max}$  ( $p < .01$ ). Most of the studies involving interval training are usually performed close to 100%  $\text{VO}_2\text{max}$  (Astrand et al., 1960; Cunningham et al., 1979; Eddy et al., 1977; Hickson, Bomze & Holloszy, 1977; Knuttgen et al., 1973). In a study by Fox et al. (1973) investigating the effect different interval training intensities have on aerobic power, they found that the lower intensity intervals did not elicit a significant change in  $\text{VO}_2\text{max}$  ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ). It can be concluded from the mentioned authors, the closer the training program is to 100%  $\text{VO}_2\text{max}$  intensity, the greater the increase in maximal aerobic power in continuous and most importantly in interval training. Davies & Knibbs (1971) reported

subjects who exercised at or below 50%  $\text{VO}_2\text{max}$  showed no improvements in aerobic power. Insignificant changes in aerobic power due to low intensity training was also supported by Faria (1970) who found no difference between a group training at a heart rate of 120-130 beats per minute and the control group.

### **Heart Rate and Training**

Heart rate is used quite frequently as an indicator of work effort because it is a practical method for monitoring exercise intensity. The athlete is able to increase or decrease the work output during the exercise depending on his/her heart rate to ensure the training intensity is appropriate for improving the desired energy system. Heart rate reflects the overload placed on the body and becomes an indirect way of estimating oxygen consumption (Paabo & Karpman, 1981). The estimation of oxygen consumption from heart rate is based on the notion that there is a linear relationship between the two but at very low and high workloads this relationship decreases (Franklin, Hodgson & Buskirk, 1980). The more elevated the heart rate the higher the level of exercise intensity.

Karvonen & Vuorimaa (1988) presented a review on the use of heart rate as a measurement of exercise intensity in sport. Heart rate can be measured as percentage of heart rate maximum (%HRmax) and calculated to specify a percentage of  $\text{VO}_2\text{max}$  (% $\text{VO}_2\text{max}$ ). There is some scepticism over %HRmax and its accuracy in predicting % $\text{VO}_2\text{max}$ . Burke & Franks (1975) showed that an intensity of 75% HRmax corresponded to approximately 70%  $\text{VO}_2\text{max}$ . The relationship between %HRmax and % $\text{VO}_2\text{max}$  seem to be similar but

not equal. It was found by Londeree & Ames (1976) that 74% HRmax was equivalent to 60% VO<sub>2</sub>max. Franklin et al. (1980) reported that %VO<sub>2</sub>max values were slightly lower (p<.05) at a given %HRmax. Karvonen & Vuorimaa (1988) concluded when exercising below VO<sub>2</sub>max there is a greater difference between %HRmax and %VO<sub>2</sub>max because the heart rate may not increase relative to the maximum work load. The prediction of %VO<sub>2</sub>max from measurement of %HRmax is not 100% accurate. However, for the coach and/or the athlete estimation of exercise intensity by heart rate monitoring is a practical and the only common method available (Davis & Convertino, 1975; Franklin et al., 1980; Karvonen & Vuorimaa, 1975).

### **Duration and Interval Training**

For interval training to be effective in improving the power of the aerobic system, not only does the intensity need to be close to 100% VO<sub>2</sub>max but the duration must be of an adequate length (Davies & Knibbs, 1971; Fox et al., 1975; Gregory, 1979; MacDougall & Sale, 1980; Wenger & Bell, 1986). The length of an interval needs to be long enough so the athlete is able to reach an intensity that will challenge the aerobic system. Work intervals lasting 2 to 5 minutes seem to be the most supported length of high intensity exercise. This duration has been shown to be the most effective in enhancing aerobic power (Astrand et al., 1960; Gregory, 1979; Knuttgen et al., 1973). Within this 2 to 5 minute period, maximal heart rate is reached indicating the intensity is high enough for physiological adaptations to occur (Knuttgen et al., 1973). Astrand et al. (1960) and Knuttgen et al. (1973)

concluded that intervals of 3 minutes produce the most hypoxia and as a result provide the optimal stress on the aerobic energy system to elicit improvement.

Hickson et al. (1977) investigated the effect six 5 minute intervals had on aerobic power and found the improvement in  $VO_2\text{max}$  over 10 weeks with recreational athletes to be 44%. Three 4 minute intervals were studied over a 6 week period and resulted in a significant increase in  $VO_2\text{max}$  (24.6%) at  $p < .01$  (Gregory, 1979). Intervals below 2 minutes also improve aerobic power but to a lesser extent. To emphasize the aerobic systems contribution to short high intensity intervals Withers et al. (1991) performed a study which investigated the aerobic contribution during a 60 and 90 second all out bicycle test. Their results showed the aerobic contribution in a 60 second all out test was 49% and 61% for the 90 second test. In a similar study, Serresse et al. (1988) concluded that the aerobic contribution to a 90 second maximal bicycle test was 46%. These findings support the conclusion that the aerobic system is challenged in short duration interval workouts which may contribute to an increase in aerobic power. In the even shorter duration intervals, maximal oxygen consumption cannot be reached so the stress placed on the power of the respiratory system will be less (Fox et al., 1969; Katch & Weltman, 1979; Knuttgen et al., 1973; Medbo & Tabata, 1989; Smith & Wenger, 1981).

The optimal duration of a workout has been suggested by Wenger & Bell's (1986) review to be in excess of 35 minutes. However, Astrand et al. (1960) and Pruett (1970) stated that during continuous training there would be difficulty in sustaining an intensity of 90% or

above  $VO_2\max$  for 35 minutes due to the high degree of glycogen depletion and lactate accumulation which causes the onset of fatigue. With interval training the length of the total effort does not present a problem because the recovery periods between the high intensity intervals allows for replenishment of energy stores and the removal of lactic acid (Fox et al., 1969; Wootton & Williams, 1983) This process allows for continued maximal efforts to be executed. When training continuously the intensity must drop to accommodate the extended duration. Fox et al. (1973) performed a study looking at intensity and duration and found the group who performed longer workouts working at a lower intensity demonstrated lower levels of aerobic power than the more intensely active groups. As concluded from the literature it seems that the duration of interval training workouts should be in the range of 2 to 5 minutes (Astrand et al., 1960; Gregory, 1979; Knuttgen et al., 1973) with a substantial total work period to tax the aerobic system. Knuttgen et al. (1973) reported a significant increase in  $VO_2\max$  by 20% in interval training with a total work period of 30 minutes.

### **Frequency and Training**

In addition to intensity and duration, frequency and the length of the training program also play a significant role in improving the power of the aerobic system. Improvements have been demonstrated to occur between 3 and 7 days per week of training (Fox et al., 1973; Gregory, 1979; Paabo & Karpman, 1981; Witten & Witten, 1973). Pollock et al. (1969) reported a significant difference in the improvement of  $VO_2\max$  between a frequency of 2 and 4 days per

week. The 4 day frequency gave greater improvements in aerobic power. Wenger & Bell's (1986) review supported these findings that 4 days a week invoked the greatest improvements in  $VO_2\text{max}$ .

Fox et al. (1975) performed a study investigating the effect of exercising 2 and 4 days a week over a training period of 7 and 13 weeks. No significant difference was found between any training program on  $VO_2\text{max}$ . They concluded that frequency of 2 and 4 days a week was not a factor in distinguishing the difference between these programs, even when intensity and length of the workouts were kept constant. A study which looked at 3 versus 5 days a week interval training (Witten & Witten, 1973) found no difference between the frequency of the training program. Witten & Witten (1973) suggested that a 3 day a week schedule for an interval training program would be best for optimal aerobic improvements because 5 days a week seemed to stress the body causing an increased chance of injury.

### **Program Length and Training**

The length of a program must also be considered when preparing a training program for the athlete. Smith & Wenger (1981) conducted a study looking at the effects of a 10 day aerobic interval and continuous training program. The results suggested even when comparing low and high intensity workouts, there was no improvement in  $VO_2\text{max}$ . Knuttgen et al. (1973) concluded training adaptations can occur within one month with interval training. Within one month  $VO_2\text{max}$  increased 22% for a 3 minute interval group and 8% for the 15 second interval group. Further increases in

VO<sub>2</sub>max were recorded for the remainder of the eight week training program in both interval groups. Wenger and Bell's (1986) review identified a 10 to 11 week training program to be the ideal length for improvements in aerobic power. This review was based on continuous training whereas Knuttgen et al. (1973) found are based on interval training. From these findings and the literature already cited, it can be concluded that interval training may elicit a more rapid improvement in aerobic power.

### **Energy System Utilization in Intermittent Activities**

Intermittent activities are represented by high intensity exercise interspersed with rest phases or low intensity periods. Examples of intermittent activities include sports such as, ice hockey, soccer, basketball and volleyball. Many intermittent activities are not purely dependent on just one energy system; combined contributions from a pair or even all three energy systems may take place. The high intensity efforts of the activity require energy via the ATP-CP energy system or anaerobic glycolysis. During high intensity work bouts that range from 1-10 seconds the energy is supplied by the anaerobic alactic system (ATP-CP system) (Houston 1982; McCartney et al., 1986; Rhodes & Twist, 1990) The energy is provided from direct sources of adenosine triphosphate (ATP) within the muscle. Once ATP is used, it is reduced to ADP + Pi (inorganic phosphate) and is resynthesized by the breakdown of creatine phosphate (CP). Examples of sports that require energy from the anaerobic alactic system include ice hockey, soccer, volleyball, basketball and wrestling. Ice hockey depends on the ATP-CP system to execute

explosive bursts on the ice (Montgomery, 1988). Green et al. (1979) performed a time motion analysis on ice hockey and identified goalkeepers as being the most dependent on this energy system. In making a save or clearing the puck the direct, rapid source of ATP is utilized (Montgomery, 1988). Mayhew and Wenger's (1985) analysis of the game of soccer showed that the mean time of the maximal efforts was 4.4 seconds, which is definitely characteristic of the ATP-CP energy system. The spikes and blocking exercises in the game of volleyball are explosive and demand use of the immediate energy stores (Viitasalo et al., 1987). As well, basketball utilizes this energy system to perform the continual fast starts and stops whereas the sport of wrestling utilizes the ATP-CP system during takedowns (Houston, Sharratt & Bruce, 1983).

Continued work at a high intensity beyond 10 seconds stresses the capacity of the anaerobic system and is known as anaerobic glycolysis (Hermansen, 1969; Medbo & Tabata, 1989). The main energy source for this system is glucose, which is broken down to form ATP. The capacity of the anaerobic lactic system is said to last from 20 seconds to approximately 2 minutes (Medbo & Tabata, 1989). Forwards and defensemen in ice hockey utilize this energy system to a great extent. Green et al. (1976) identified each shift to be 85 seconds in length with two stoppages, resulting in a continuous playing time of 35-40 seconds. This time period of high intensity work will depend on the glycolytic supply of the anaerobic lactic system. Forwards are continually attacking and backchecking while the defensemen are fighting off penalties and chasing pucks in their own end (Rhodes & Twist, 1990). Other intermittent sports such as wrestling and

basketball have the potential to place considerable demand on the lactic system. During a game of basketball, the intensity of the game, the number of play stoppages and the level of competition all are indicators of the frequency and length of each anaerobic bout (Cabrera, Smith & Byrd, 1977) Wrestling's utilization of this energy system is to sustain the high muscular performance during the two 3 minute exhausting rounds (Sharratt et al, 1986). Beyond 2 minutes, the aerobic energy system begins to contribute more substantially to the fuel supply.

### **Aerobic Energy Systems Role in Intermittent Activities**

The periods of low intensity during intermittent activities require energy supplied by oxidative pathways. The aerobic energy systems most important contribution to intermittent activities has been reported to be in assisting in a more rapid recovery between high intensity efforts (Montgomery, 1988; Rhodes & Twist, 1990; Smith et al., 1982; Watson & Hanley, 1986). For recovery to be successful it must involve two primary processes; the replenishment of high energy phosphates and removal of lactic acid. The replenishment of high energy stores (ATP/CP) can occur within a few minutes in an oxygen rich environment (Hermansen, 1969; Wootton & Williams, 1983). In the game of ice hockey recovery between shifts is approximately 2 to 4 minutes and has been shown to be an adequate time period for the majority of CP to be resynthesized (Green, 1979; Montgomery, 1988; Watson & Hanley, 1986). The removal of lactic acid from muscle takes much longer so only partial reduction of lactic acid can take place within the off-ice shift (Green, 1979;

Montgomery, 1988; Watson and Hanley, 1986). In the game of soccer the depletion of stores from the bursts of speed on attack or when running back to play defense are replenished during the submaximal work periods (Hermansen, 1969; Rhodes et al., 1986). A well developed aerobic system will also allow the athlete to train and compete at a high intensity for an extended period of time without a reduction in muscular contractions which may hinder performance.

The length of the intermittent activity ranges from less than 10 minutes (wrestling) to a couple of hours (ice hockey). Mayhew & Wenger (1985) and Ekblom (1986) reported distances of up to or greater than 10km covered by a soccer player in a 90 minute game. The 10km distance would indicate that there is a large contribution by the aerobic system. The more developed the aerobic system the more likely the athlete is able to endure the 90 minute game (Ekblom, 1986). Similarly, an ice hockey game may take three hours to complete (Green & Houston, 1975). Montgomery (1988) concluded that the length of the game and the need to recover quickly between each shift demands a good aerobic system.

A good aerobic system is most commonly represented by maximal aerobic power ( $VO_2\text{max}$ ) (Drinkwater, Horvath & Wells, 1975; Saltin & Astrand, 1967; Wenger & Bell, 1986). Maximal aerobic power identifies the maximum amount of oxygen the body is able to take up, transport and utilize (Wenger & Bell, 1986). Elite athletes in sports that require a large contribution from anaerobic energy sources, have demonstrated high  $VO_2\text{max}$  values. Ice hockey players have  $VO_2\text{max}$  values that range from 55 to 60  $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  (Green, 1979; Montgomery, 1988; Wilmore, 1979). Soccer players have

been identified as having some of the highest  $\text{VO}_{2\text{max}}$  values of the intermittent activities.  $\text{VO}_{2\text{max}}$  values on average have been reported to be above  $60 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  (Ekblom, 1986; Houston et al., 1983; Wilmore, 1979). The higher the level of competition the more frequent and lengthy the periods of high intensity exercise (Ekblom, 1986) and the more critical the aerobic systems role becomes in enhancing a more rapid recovery.

### **Recovery from High Intensity Work**

Recovery during high intensity, repeated work is essential if the activity is to be performed for an extended period of time and/or to ensure the quality of performance in each successive bout does not drop dramatically from the initial effort. Depending on the duration of the high intensity effort and the type of energy system utilized will dictate the estimated optimal recovery time. Maximal repeated intervals that predominantly rely on the energy supplied by the ATP-CP system, requires less recovery time for the energy stores to be replenished (Hermansen, 1969). High intensity exercise which depends on anaerobic glycolysis will need much more time to recover to near resting values (Roberts et al, 1982)

McCartney et al. (1986) performed a study which looked at the metabolic changes in muscle during four 30 second maximal bouts each followed by 4 minutes of recovery. They found that as each interval progressed there was a decrease in anaerobic power and total work performed. There was no change noted between the third and the fourth interval. Muscle ATP concentration decreased 40% and the CP concentration declined 70% after the first bout. After the

first bout these energy store concentrations decreased another 60% in the second and third interval and leveled off in the fourth high intensity effort. McCartney et al. (1986) also concluded that CP is almost completely depleted in the first 10 seconds and glycolytic energy stores take over and as a result lactic acid accumulates. A similar study was also performed by Roberts et al. (1982) with eight repeated 30 second high intensity bouts each followed by a 2 minute recovery period. The 30 second intervals resulted in high levels of lactic acid that was only partially removed during the 2 minute rest periods. Roberts and associates (1982) also concluded that once all high intensity intervals were completed blood lactate after 10 minutes recovery remained at a level above resting values. Wootton & Williams (1983) investigated shorter, high intensity work bouts of 6 seconds repeated five times with a rest phase of either 30 or 60 seconds. The shorter recovery period of 30 seconds resulted in declined power output. On completion of the fifth bout, peak power decreased 17.9% and the end power output declined 29.1%. The 60 second recovery period seemed to be substantial to ensure consistent peak power output values over the five efforts, but total power output decreased 12.7% by the fifth bout. Even within this short maximal period of exercise blood lactate increased in the 60 second recovery group from 1.16 to 10.29mM. With longer, high intensity intervals high levels of blood lactate are also reported. Keul & Doll (1973) demonstrated high blood lactate levels in both 2 ( $12.5\text{mM L}^{-1}$ ) and 4 ( $14.7\text{mM L}^{-1}$ ) minutes of intermittent intervals. The more dominant the anaerobic glycolytic system the higher the venous blood lactate concentration (Keul & Doll, 1973).

### **Active versus Passive Recovery**

High intensity efforts cause a decrease in phosphate stores or an accumulation of lactic acid. Two forms of recovery have been studied extensively; active and passive. The literature has continually supported active recovery as the most effective method of returning lactic acid levels back to resting values (Boileau et al., 1983; Dodd et al., 1984; Weltman et al., 1979; Wootton & Williams, 1983). Active recovery provides a continued blood flow to the muscle encouraging the oxidation or removal of lactic acid from the muscle during the submaximal periods (Dodd et al., 1984; Weltman et al., 1979). Boileau et al. (1983) concluded that a possible critical factor for influencing the rate of blood lactate removal is blood flow to the removal sites. Lactic acid is not a limiting factor in single supramaximal efforts that depend on the ATP-CP system. In the case of repeated work bouts, as is the case in intermittent activities, the time course for complete replenishment of ATP-CP stores may not be adequate (McCartney et al, 1986; Roberts, Billeter & Howald,1982). As a result, anaerobic glycolysis will contribute the needed energy to sustain the high intensities and lactic acid will begin to accumulate.

Active recovery during extended interval durations is important. Dodd et al. (1984) studied blood lactate disappearance during 10 minute recovery periods after each of the three 6 minute workouts. Four recovery treatments were considered; passive, 35%, 65%, and a combination of 35% and 65%  $VO_2$ max intensity. The 35%  $VO_2$ max recovery treatment demonstrated a significantly faster disappearance rate than the others. Weltman et al. (1979) looked at two 5 minute intervals with a 20 minute recovery period between

them consisting of passive, 40% or 65% active exercise. The 40%  $\text{VO}_2\text{max}$  active recovery period proved to be more effective in assisting lactic acid removal. The 65%  $\text{VO}_2\text{max}$  recovery may have been close to or above the anaerobic threshold and if so lactic acid production may be continually increasing (Weltman et al., 1979). The general consensus is that active recovery is effective in increasing the disappearance of lactic acid. With a decrease in work output and an increase in intensity similar disappearance rates were found. One minute intervals were investigated by three authors with varying recovery periods. Boileau et al. (1983) researched 1:1 work to rest ratio of repeated 1 minute intervals to exhaustion. They observed a 20 minute recovery period with five recovery treatments; passive, 25%, 45%, 65% and 75%  $\text{VO}_2\text{max}$  intensity. All four active recovery treatments removed lactic acid more readily than the passive treatment. The optimal active recovery was concluded to be between 25% and 45%  $\text{VO}_2\text{max}$ . Weltman et al. (1979) performed an earlier study reporting on two repeated 1 minute intervals with 10 and 20 minutes recovery, either passive or active at 60rpm at 1.0 kp. Once again active recovery proved to be the key activity method in lactic acid removal. Weltman et al. (1979) found that the pre and post revolution scores were not significantly different when 20 minutes of recovery was performed. From the literature active recovery between high intensity, repeated intervals is essential for the reduction in lactic acid and optimal continued performance. The intensity that enhances the removal of lactic acid is between 25%-45%  $\text{VO}_2\text{max}$  (Belcastro & Bonen, 1975; Boileau et al., 1983; Davies, Knibbs & Musgrove, 1970; Dodd et al., 1984; Weltman et al., 1979).

## **Physiological Adaptations To Interval Training**

The hypoxic conditions that interval training provides is believed to be an important stimulus for improvements in maximal aerobic power (Fox et al., 1973; MacDougall & Sale, 1980). The lack of oxygen available to the working muscles under high intensity exercise creates the opportunity for muscular change. The adaptations that take place within the muscle as a result of training consist of increased capillarization, increased mitochondrial activity, increased muscle myoglobin and an increased ability to remove lactic acid. An increase in the number and fiber ratio of capillaries around each muscle fiber enhances the oxygen availability of the muscle by the elevated blood volume (Holloszy, 1982; Tesch & Wright, 1983). The oxidative capacity of the muscle is correlated with the capillary supply and recovery from high intensity exercise (Tesch & Wright, 1983). The increased blood supply to the muscle due to an elevated capillarization encourages the rate of lactic acid release from the muscle into the blood (Tesch & Wright, 1983). Recovery is dependent on lactic acid removal so an increased blood flow due to an enhanced capillary network (Boileau et al., 1983; Dodd et al., 1984; Holloszy, 1982; Tesch & Wright, 1983) which is developed through aerobic training is a beneficial adaptation in intermittent high intensity exercise.

Aerobic training causes an increase in the number and size of mitochondria (Galun et al., 1988; Holloszy, 1982; Ivy et al., 1980; Skinnner & Mcllellan, 1980; Thiart, 1982) as well as increasing the mitochondrial enzyme activity that assists in the generation of ATP (Holloszy, 1982; Thiart, 1982). As the number and size of the

mitochondria increases so does the oxidative metabolism of the muscle (Holloszy, 1982). An important mitochondrial enzyme that triggers aerobic metabolism is succinate dehydrogenase (SDH). Succinate dehydrogenase functions by oxidizing pyruvate and NADH (Holloszy, 1975; Holloszy, 1982). Pyruvate is then reduced to lactate (Holloszy, 1982). Training significantly increases the level of enzyme activity (Holloszy, 1975). Short periods of detraining cause significant drops in the SDH enzyme. Houston et al. (1979) performed a fifteen week detraining study which showed SDH activity declined 24% resulting in a 3-7% decrease in  $VO_2\text{max}$ . This study demonstrated that changes in aerobic power are enhanced by increases in muscle enzymes. As a result of endurance exercise mitochondrial content and its capacity to generate ATP increases (Holloszy, 1980).

The myoglobin content of skeletal muscle also increases with training (Fox et al., 1969; Jansson et al., 1983; Thiart, 1982). Myoglobin is a protein stored within the muscle that functions to store oxygen and to facilitate a greater oxygen diffusion within skeletal muscle (Astrand & Rodahl, 1986; Holloszy, 1982; Jansson et al., 1983). If myoglobin stores in the muscle are depleted there will be a delayed return of oxygen to the muscle (Hermansen, 1969); a recovery period allows for the replenishment of these stores (Fox et al., 1969).

The skeletal muscle, where many of the physiological adaptations take place is comprised of slow twitch and fast twitch fibers which have their role in aerobic and anaerobic metabolism. Several authors have stated that there is a high correlation between  $VO_2\text{max}$  and percent slow twitch fibers (Armstrong et al., 1983;

Bonen, Campbell, Kirby & Belcastro, 1978; Ivy et al., 1980; Thiart, 1982). Slow twitch fibers have a higher respiratory capacity due to the increased number of mitochondria, the increased myoglobin content and a more developed capillary network around the muscle fibers (Tesch & Wright, 1983). These capillary muscular changes provide an increased blood supply that creates an enhanced delivery of oxygen (Holloszy, 1982; Tesch & Wright, 1983). The high oxygen availability allows slow twitch fibers to continually extract and oxidize lactic acid from the blood (Skinner & Mclellan, 1980). Fast twitch fibers are triggered for explosive events. The total work intensity of fast twitch fibers is far greater than that of slow twitch fibers resulting in a quicker and more substantial production of lactic acid (Holmyard, 1986; Tesch & Wright, 1983). High intensity aerobic training is thought to increase the oxidative capacity of fast twitch fibers hence an enhanced ability to assist the removal of lactic acid (Gollnick, Armstrong, Saltin, Saubert, Sembrowich & Shepard, 1973; Henriksson & Reitman, 1976).

Performance of intense exercise close to  $VO_2\text{max}$  will require a substantial contribution from anaerobic glycolysis. Lactic acid is the limiting factor in energy production when the muscle has depleted its stores of glycogen (Hermansen, 1969). The potency of lactic acid is due to an accumulation of hydrogen ions ( $H^+$ ). Hydrogen ions decrease muscle pH and increase lactic acid accumulation (Holmyard, 1986; Wenger & Reed, 1976) and may cause muscle fatigue. The decrease in muscle pH is considered necessary to attain  $VO_2\text{max}$  because the increase in  $H^+$  concentration enhances the unloading of oxygen at the working muscles due to the Bohr effect

(Braumann et al., 1982; Clausen, 1977; Ivy et al., 1980; Patterson, 1988). Phosphofructokinase (PFK), a rate limiting enzyme in glycolysis, is inhibited by the presence of  $H^+$  which slows down the role of ATP production (Holloszy, 1982; Holmyard, 1986; Wenger & Reed, 1976).  $H^+$  also affects the force generation of the muscle. Tesch & Wright (1983) found that enhanced  $H^+$  concentrations interfered with the formation of cross-bridges in the muscle cell by competing with  $Ca^{++}$  on the binding sites of troponin. Interval training is an ideal method of controlling lactic acid accumulation because of the recovery periods that accompany high intensity effort (Evans & Cureton, 1983; McGrail, 1978; Patterson, 1988). During the recovery phase there is an increase in oxidative pathways allowing lactic acid to be dissipated (Weltman et al., 1979). The adaptations of training cause an increase in the blood flow to the muscle site which assists in the transport of lactic acid out of the muscle and into the blood to the heart or liver to be oxidized (Boileau et al., 1983; Evans & Cureton, 1983). McGrail (1978) stated that the liver can account for up to 50% of the total lactate removal primarily via gluconeogenesis. The formation and turnover of lactic acid during intense exercise is catalyzed and regulated by the enzyme lactate dehydrogenase (LDH) (Sjodin, Thorstensson, Frith & Karlsson, 1975). There are two types of LDH enzymes, the heart LDH enzyme (H-LDH) which functions to favor the oxidation of lactic acid to pyruvate for subsequent utilization in the Krebs's Cycle and muscle LDH (M-LDH) which facilitates the reduction of pyruvate to lactic acid and thus prevents muscle fatigue (Skinner & Mclellan, 1980; Sjodin et al., 1975). These enzymes are located in the sarcoplasm of muscle fibers. Sjodin et al. (1975)

concluded that after intense one minute interval training no changes in LDH properties could be detected but during long distance running there was an increase in the activity of the H-LDH enzyme.

Arteriovenous oxygen difference ( $a-vO_2\text{diff}$ ) is stated by Clausen (1977) to account for up to 50% of the increased oxygen uptake due to training. The increase in  $a-vO_2\text{diff}$  is attributed to number of factors. Ivy et al. (1980) suggest that an increase in  $a-vO_2\text{diff}$  is due to an increase in the respiratory capacity of the skeletal muscle. Clausen (1977) stated that oxygen extraction from blood is a result of a shift in the oxygen dissociation curve which can cause an increase in the  $a-vO_2\text{diff}$  in the exercising muscle. Training also causes an increase in maximal cardiac output ( $Q$ ) (Clausen, 1977; Fox et al., 1973; Knuttgen et al., 1973; Paabo & Karpman, 1981). Cardiac output is the product of stroke volume and heart rate. Because maximum heart rate is usually unchanged, the increase in  $Q$  is based on an elevated stroke volume (Fox et al., 1975). Training develops the cardiac muscle. The stronger the heart muscle the more efficient the heart is at emptying the ventricle with each heart beat (MacDougall & Sale, 1980). The enhanced volume of blood pumped out of the heart increases the oxygen available to the muscle causing a delayed production of lactic acid (Holloszy, 1975). Coyle et al. (1986) found that the 6% decline in cardiovascular function after 2-4 weeks of detraining was largely a result of the reduction in circulating blood volume (9%).

## **APPENDIX H**

## **CONCLUSIONS**

## CONCLUSIONS

1. A nine week aerobic interval training program significantly increased aerobic power
2. There were significant differences observed in all the four variables (SPP, SAC, IPP, TW) in the four anaerobic performance tests between the trained group and the control except for Repeats 3 and 4 of SPP and SAC following the nine week aerobic interval training program.
3. There was a significant increase in anaerobic performance for the training group from pre to post-test in all the four anaerobic variables.
4. A nine week aerobic interval training program was successful in enhancing repeated anaerobic performance.

## **APPENDIX I**

### **FUTURE RESEARCH QUESTIONS**

## **FUTURE RESEARCH SUGGESTIONS**

1. To increase the number of anaerobic performance tests.
2. To decrease recovery time between anaerobic performance tests to facilitate an increase in the aerobic systems role in the physiological processes that assist recovery.
3. To train the group aerobically with continuous training to remove the specific effects of interval training on physiological adaptations that may be crucial contributors to improvements in repeated anaerobic performance.
4. To train the subjects using alternative training modalities (running, swimming etc.) to identify the effects of the specificity of the training on repeated anaerobic performance.
5. To measure changes within the muscle such as pH levels and lactic acid concentrations in the muscle and blood, to explain more specifically why changes in performance may be occurring.

## **APPENDIX J**

**ANALYSIS OF VARIANCE TABLES FOR THE FOUR  
DIFFERENT MEASURES DURING THE FOUR  
ANAEROBIC PERFORMANCE TESTS**

Table 2. Analysis of Variance of Short-Term Peak Power for the Training and Control Groups

Source	df	MSerror	Wilks Lambda	Hyp Df	Error Df	F	p
Group	1	19.31	-	-	-	2.29	.145
Treatment	1	19.92	-	-	-	16.94	.000*
Time	-	-	.19880	3.00	20.00	-	.000*
Group*Treatment	1	9.89	-	-	-	8.41	.008*
Group*Time	-	-	.98516	3.00	20.00	-	.959
Treatment*Time	-	-	.89862	3.00	20.00	-	.534
Group*Treatment*Time	-	-	.62567	3.00	20.00	-	.022*

\* P<.05

Table 3. Analysis of Variance of Short-Term Anaerobic Capacity for the Training and Control Groups

Source	df	MSerror	Wilks Lambda	Hyp Df	Error Df	F	p
Group	1	2579.12	-	-	-	3.37	.080*
Treatment	1	1999.32	-	-	-	21.75	.000*
Time	-	-	.20768	3.00	20.00	-	.000*
Group*Treatment	1	1663.90	-	-	-	18.10	.000*
Group*Time	-	-	.97252	3.00	20.00	-	.903
Treatment*Time	-	-	.82817	3.00	20.00	-	.277
Group*Treatment*Time	-	-	.63921	3.00	20.00	-	.027*

\* P<.05

Table 4. Analysis of Variance of Intermediate-Term Peak Power  
for the Training and Control Groups

Source	df	MSerror	Wilks Lambda	Hyp Df	Error Df	F	p
Group	1	16.38	-	-	-	3.31	.084
Treatment	1	9.14	-	-	-	18.03	.000*
Time	-	-	.12191	3.00	18.00	-	.000*
Group*Treatment	1	19.58	-	-	-	38.64	.000*
Group*Time	-	-	.76173	3.00	18.00	-	.170
Treatment*Time	-	-	.79073	3.00	18.00	-	.227
Group*Treatment*Time	-	-	.85141	3.00	18.00	-	.396

\*  $P < .05$

Table 5. Analysis of Variance of Total Work for the Training and Control Groups

Source	df	MSerror	Wilks Lambda	Hyp Df	Error Df	F	p
Group	1	18532.02	-	-	-	3.64	.071
Treatment	1	12012.02	-	-	-	24.15	.000*
Time	-	-	.13126	3.00	18.00	-	.000*
Group*Treatment	1	15660.59	-	-	-	31.48	.000*
Group*Time	-	-	.88515	3.00	18.00	-	.521
Treatment*Time	-	-	.76678	3.00	18.00	-	.179
Group*Treatment*Time	-	-	.89080	3.00	18.00	-	.544

\* P<.05

**APPENDIX K****REFERENCES**

## REFERENCES

- Astrand, I., Astrand, P.O., Christensen, E.H. & Hedman, R. (1960). Intermittent muscular work. Acta Physiologica Scandinavica, 48, 448-453.
- Astrand, P.O. & Rodahl, K. (1986). Textbook of Work Physiology. New York: McGraw-Hill.
- Atomi, Y. & Miyashita, M. (1980). Effect of training intensity in adult females on aerobic power, related to lean body mass. European Journal of Applied Physiology and Occupational Physiology, 44, 109-116.
- Balson, P.O., Seger, J.Y., Sjodin, B. & Ekblom, B. (1992). Maximal intensity intermittent exercise: Effect of recovery duration. International Journal of Sports Medicine, 13 (7), 528-533.
- Belcastro, A.N. & Bonen, A. (1975). Lactic acid removal rates during controlled and uncontrolled recovery exercise. Journal of Applied Physiology, 39(6), 932-936.
- Berg, k., Olsen, R., McKinney, M., Hofschire, P., Latin, R. & Bell, W. (1989). Effect of reduced training volume on cardiac function,  $\text{VO}_2\text{max}$  and running performance. Journal of Sports Medicine and Physical Fitness, 29(3), 245-252.
- Berry, M. & Montani, T. (1985). The effects of various training intensities on the kinetics of oxygen consumption. Journal of Sports Medicine and Physiological Fitness, 25(3), 77-83.
- Bhambhani, Y. & Singh, M. (1985). The effects of three training intensities on  $\text{VO}_2\text{max}$  and  $\text{VE}/\text{VO}_2$  ratio. Canadian Journal of Sport Sciences, 10(1), 44-51.
- Boileau, R.A., Misner, J.E., Dykstra, G.L. & Spitzer, T.A. (1983). Blood lactic acid removal during treadmill and bicycle exercise at various intensities. Journal of Sports Medicine and Physical Fitness, 23, 159-166.
- Bonen, A., Campbell, C.J., Kirby, R.L. & Belcastro, A.N. (1978). Relationship between slow-twitch muscle fibres and lactic acid removal. Canadian Journal of Applied Sport Sciences, 3, 160-162.

- Bouchard, C., Taylor, A.W., Simoneau, J.A. & Dulac, S. (1991). Testing Anaerobic Power and Capacity. In J.D. MacDougall, H.A. Wenger & H.J. Green (Eds.), Physiological testing of the high performance athlete. Champaign Illinois: Human Kinetics Publishers Ltd.
- Boulay, M.R., Lortie, G., Simoneau, J.A. Hamel, P., Leblanc, C. & Bouchard, C. (1985). Specificity of aerobic and anaerobic work capacities and powers. International Journal of Sports Medicine, 6, 325-328.
- Braumann, K.M., Boning, D. & Trost, F. (1982). Bohr effect and slope of the oxygen dissociation curve after physical training. Journal of Applied Physiology, 52(6), 1524-1529.
- Burke, E.J. & Franks, B.D. (1975). Changes in VO<sub>2</sub>max resulting from bicycle training at different intensities holding total mechanical work constant. Research Quarterly for Exercise and Sport, 46(1), 31-37.
- Cabrera, J.M., Smith, D.P. & Byrd, R.J. (1977). Cardiovascular adaptations on Puerto Rican basketball players during a 14- week season. Journal of Sports Medicine and Physical Fitness, 17, 173-180.
- Clausen, J.P. (1977). Effect of physical training on cardiovascular adjustments to exercise in man. Physiological Reviews, 57(4), 779-815.
- Coyle, E.F., Hemmert, M.K. & Coggan, A.R. (1986). Effects of detraining on cardiovascular responses to exercise: role of blood volume. Journal of Applied Physiology, 60(1), 95-99.
- Cunningham, D.A., McCrimmon, D. & Vlach, L.F. (1979). Cardiovascular response to interval and continuous training in women. European Journal of Applied Physiology and Occupational Physiology, 41, 187-197.
- Davies, C.T.M., Knibbs, A.V. & Musgrove, J. (1970). The rate of lactic acid removal in relation to different baselines of recovery exercise. Internationale Zeitschrift fur angewandte Physiologie einschliesslich Argeitsphysiologie, 28, 155-161.
- Davies, C.T.M. & Knibbs, A.V. (1971). The training stimulus: The effects of intensity, duration and frequency of effort on maximum aerobic power output. Internationale Zeitschrift fur angewandte Physiologie einschliesslich Argeitsphysiologie, 29, 299-305.

- Davis, J.A. & Convertino, V.A. (1975). A comparison of heart rate methods for predicting endurance training intensity. Medicine and Science in Sports and Exercise, 7(4), 295-298.
- Davis, G.M. (1976). The effect of varied rest periods during interval training upon aerobic and anaerobic fitness. Unpublished Thesis: University of Western Ontario, London.
- Deitrick, R.W. & Ruhling, R.O. (1978). Short duration, high intensity aerobic training and retrogression. Journal of Sports Medicine and Physical Fitness, 18, 123-130.
- Dodd, S., Powers, S.K., Callender, T. & Brooks, E. (1984). Blood lactate disappearance at various intensities of recovery exercise. Journal of Applied Physiology, 57(5), 1462-1465.
- Drinkwater, B.L., Horvath, S.M. & Wells, C.L. (1975). Aerobic power of females ages 10 to 68. Journal of Gerontology, 30(4), 385-394.
- Eddy, D.O., Sparks, K.L. & Adelizi, D.A. (1977). The effects of continuous and interval training in women and men. European Journal of Applied Physiology and Occupational Physiology, Sept.16, 83-92.
- Ekblom, B. (1986). Applied physiology of soccer. Sports Medicine, 3, 50-60.
- Evans, B.W. & Cureton, K.J. (1983). Effect of physical conditioning on blood lactate disappearance after supramaximal exercise. British Journal of Sport Medicine, 17(1), 40-45.
- Fardy, P.S. (1981). Training for aerobic power. Coaching Theory Level III Manual, Ottawa, Ontario.
- Faria, I.E. (1970). Cardiovascular response to exercise as influenced by training of various intensities. Research Quarterly for Exercise and Sport, 41(1), 44-50.
- Fosters, C., Daniels, J.T. & Yarbrough, R.A. (1977). Physiological and training correlates of marathon running performance. Australian Journal of Sports Medicine, Nov/Dec, 58-60.
- Fox, E.L., Robinson, S. & Wiegman, D.L. (1969). Metabolic energy sources during continuous and interval running. Journal of Applied Physiology, 27(2), 174-178.

Fox, E.L., Bartels, R.L., Billings, C.E., Mathews, D.K., Bason, R. & Webb, W.M. (1973). Intensity and distance of interval training programs and changes in aerobic power. Medicine and Science in Sports and Exercise, 5(1), 18-22.

Fox, E.L., Bartels, R.L., Billings, C.E., O'Brien, R., Bason, R. & Mathews, D.K. (1975). Frequency and duration of interval training programs and changes in aerobic power. Journal of Applied Physiology, 38(3), 481-484.

Fox, E.L., Bowers, R.W. & Foss, M.L. (1989). The Physiological Basis of Physical Education and Athletics. (4th ed.). U.S.A. : Wm. C. Brown Publishers.

Franklin, B.A., Hodgson, J. & Buskirk, E.R. (1980). Relationship between percent maximal O<sub>2</sub> uptake and percent maximal heart rate in women. Research Quarterly for Exercise and Sport, 51(4), 616-624.

Froesse, E.A. & Houston, M.E. (1987). Performance during the Wingate Anaerobic Test and muscle morphology in males and females. International Journal of Sports Medicine, 8, 35-39.

Gaesser, G.A. & Wilson, L.A. (1988). Effects of continuous and interval training on the parameters of the power-endurance time relationship for high-intensity exercise. International Journal of Sports Medicine, 9, 417-421.

Galun, E., Burstein, R., Tur-Kaspa, I., Assia, E. & Epstein, Y. (1988). Prediction of physical performance through muscle enzymes activity. European Journal of Applied Physiology and Occupational Physiology, 57, 597-600.

Gibson, H. & Edwards, R.H.T. (1985). Muscular exercise and fatigue. Sports Medicine, 2, 120-132.

Gollnick, P.D., Armstrong, R.B., Saltin, B., Saubert, C.W., Sembrowich, W.L. & Shepherd, R.E. (1973). Effect of training on enzyme activity and fiber composition of human skeletal muscle. Journal of Applied Physiology, 34, 107-111.

Green, H.J. & Houston, M.E. (1975). Effect of a season of ice hockey on energy capacities and associated functions. Medicine and Science in Sports and Exercise, 7(4), 299-303.

Green, H., Bishop, P., Houston, M., McKillop, R., Norman, R. & Stothart, P. (1976). Time-motion and physiological assessments of ice hockey performance. Journal of Applied Physiology, 40(2), 159-163.

Green, H.J. (1979). Metabolic aspects of intermittent work with specific regard to ice hockey. Canadian Journal of Applied Sport Sciences, 4(1), 29-34.

Gregory, L.W. (1979). The development of aerobic capacity: A comparison of continuous and interval training. Research Quarterly for Exercise and Sport, 50(2), 199-206.

Hagan, R.D., Smith, M.G. & Gettman, L.R. (1981). Marathon performance in relation to maximal aerobic power and training indices. Medicine and Science in Sports and Exercise, 13 (3), 185-189.

Henriksson, J. & Reitman, J.S. (1976). Quantitative measures of enzyme activities in type I and type II muscle fibers of man after training. Acta Physiologica Scandinavica, 97, 392-397.

Hermansen, L. (1969). Anaerobic energy release. Medicine and Science in Sports and Exercise, 1(1), 32-38.

Hickson, R.C., Bomze, H.A. & Holloszy, J.O. (1977). Linear increase in aerobic power induced by a strenuous program of endurance exercise. Journal of Applied Physiology, 42(3), 372-376.

Holloszy, J.O. (1975). Adaptation of skeletal muscle to endurance exercise. Medicine and Science in Sports and Exercise, 7(3), 155-164.

Holloszy, J.O. (1982). Muscle metabolism during exercise. Archives of Physical and Medical Rehabilitation, 63, 231-234.

Houston, M.E., Bentzen, H. & Larsen, H. (1979). Interrelationships between skeletal muscle adaptations and performance as studied by detraining and retraining. Acta Physiologica Scandinavica, 105, 163-170.

Houston, M. (1982). Exercise biochemistry. In J.J. Jackson & H.A. Wenger (Eds.), Physical Education Series: 4. The Sport Sciences. University of Victoria: Victoria, B.C.

Houston, M.E., Sharratt, M.T. & Bruce, R.W. (1983). Glycogen depletion and lactate responses in freestyle wrestling. Canadian Journal of Applied Sport Sciences, 8(2), 79-82.

Ivy, J.L., Costill, D.L. & Maxwell, B.D. (1980). Skeletal muscle determinants of maximum aerobic power in man. European Journal of Applied Physiology and Occupational Physiology, 44, 1-8.

- Jansson, E., Sylven, C. & Sjodin, B. (1983). Myoglobin concentration and training in humans. In H.G. Knuttgen, J.A. Vogel & J.P. Poortmans (Eds.), Biochemistry of Exercise: Vol. 13. International Series on Sport Sciences. Champaign IL: Human Kinetics Publishers, Ltd.
- Karlsson, J., Bonde-Petersen, F., Henrikson, J. & Knuttgen, H.G. (1975). Effects of previous exercise with arms or legs on metabolism and performance in exhaustive exercise. Journal of Applied Physiology, 38(5), 763-767.
- Karvonen, J. & Vuorimaa, T. (1988). Heart rate and exercise intensity during sports activities: Practical Application. Sports Medicine, 5, 303-312.
- Katch, V.L. & Weltman, A. (1979). Interrelationship between anaerobic power output, anaerobic capacity and aerobic power. Ergonomics, 22(3), 325-332.
- Keul, J. & Doll, E. (1973). Intermittent exercise: Metabolites, PO, and acid base equilibrium in the blood. Journal of Applied Physiology, 34(2), 220-225.
- Knuttgen, H.G., Nordesjo, L.O., Ollander, B. & Saltin, B. (1973). Physical conditioning through interval training with young male adults. Medicine and Science in Sports and Exercise, 5(4), 220-226.
- Londeree, B.R. & Ames, S.A. (1976). Trend analysis of the % VO<sub>2</sub>max-HR regression. Medicine and Science in Sports and Exercise, 8(2), 122-125.
- MacDougall, J.D. (1974). Limitations to anaerobic performance. Symposium at McMaster University, Ontario, Oct 18-20, 22-30.
- MacDougall, D. & Sale, D. (1980). Continuous vs interval training for the endurance athlete. Sports Science Periodical on Research and Technology in Sport, Dec., The Coaching Association of Canada: Ottawa, Ontario.
- MacDougall, J.D., Wenger, H.A. & Green, H.J. (1982). Physiological Testing of the Elite Athlete. Canada: Mutual Press Limited.
- Malomsoki, J. (1986). The aerobic power and the parameters of the anaerobic metabolism of boxers. Hungarian Review of Sports Medicine, 27(3), 214-219.
- Maud, P.J. & Schultz, B.B. (1989). Norms for the Wingate Anaerobic Test with comparison to another similar test. Research Quarterly for Exercise and Sport, 60(2), 144-151.

- Mayhew, S.R. & Wenger, H.A. (1985). Time-motion analysis of professional soccer. Journal of Human Movement Studies, 11, 49-52.
- McCartney, N., Spriet, L.L., Heigenhauser, G.J.F., 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.
- McGrail, J.C., Bonen, A. & Belcastro, A.N. (1978). Dependence of lactate removal on muscle metabolism in man. European Journal of Applied Physiology and Occupational Physiology, 39, 89-97.
- Medbo, J.I. & Tabata, I. (1989). Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. Journal of Applied Physiology, 67(5), 1881-1886.
- Montgomery, D.L. (1988). Physiology of ice hockey. Sports Medicine, 5, 99-126.
- Overend, T.J., Paterson, D.H. & Cunningham, D.A. (1992). The effect of interval and continuous training on the aerobic parameters. Canadian Journal of Sports Sciences, 17(2), 129-134.
- Paabo, S. & Karpman, M.B. (1981). The relationship between exercise intensity levels of two predictive heart rate equations and percent maximal oxygen consumption. Journal of Sports Medicine and Physical Fitness, 21, 226-229.
- Paterson, D.H. (1979). Respiratory and cardiovascular aspects of intermittent exercise with regard to ice hockey. Canadian Journal of Applied Sport Sciences, 4(1), 22-28.
- Patterson, C.R.M. (1988). The effect of different work interval durations and work: recovery ratios on oxygen consumption, blood lactate and heart rate during exercise. Unpublished master's thesis, University of Victoria, Victoria, B.C.
- Pollock, M.L., Jackson, A.S. & Pate, R.R. (1980). Discriminant analysis of physiological differences between good and elite distance runners. Research Quarterly for Exercise and Sport, 51(3), 521-532.
- Pruett, E.D.R. (1970). FFA mobilization during and after prolonged severe muscular work in men. Journal of Applied Physiology, 29(6), 809-815.
- Ready, A.E. & van der Merwe, M. (1986). Physiological monitoring of the 1984 Canadian Women's Fieldhockey Team. Australian Journal of Science and Medicine in Sport, 18(3), 13-18.

- Rhodes, E.C., Mosher, R.E., McKenzie, D.C., Franks, I.M., Potts, J.E. & Wenger, H.A. (1986). Physiological profiles of the Canadian Olympic soccer team. Canadian Journal of Applied Sport Sciences, 11(1), 31-36.
- Rhodes, T. & Twist, P. (1990). The Physiology of Ice Hockey: A Testing and Training Manual. University of British Columbia, Vancouver.
- Roberts, A.D., Billeter, R. & Howald, H. (1982). Anaerobic muscle enzyme changes after interval training. International Journal of Sports Medicine, 3, 18-21.
- Saltin, B. & Astrand, P.O. (1967). Maximal oxygen uptake in athletes. Journal of Applied Physiology, 23(3), 353-358.
- Schreiner, A.B. (1988). Differences in the rate of lactate removal from skeletal muscle following intense exercise in groups with different aerobic power. Unpublished master's thesis, University of Victoria, Victoria, B.C.
- Secher, N.H. (1983). The physiology of rowing. Journal of Sports Sciences, 1(1), 23-53.
- Serresse, O., Lortie, G., Bouchard, C. & Boulay, M.R. (1988). Estimation of the contribution of the various energy systems during maximal work of short duration. International Journal of Sports Medicine, 9(6), 456-460.
- Sharratt, M.T., Taylor, A.W. & Song, T.M.K. (1986). A physiological profile of elite Canadian freestyle wrestlers. Canadian Journal of Applied Sport Sciences, 11(2), 100-105.
- Shephard, R.J. (1978). Aerobic versus anaerobic training for success in various athletic events. Canadian Journal of Applied Sport Sciences, 3, 9-14.
- Simoneau, J.A., Lortie, G., Boulay, M.R., Marcotte, M., Thibault, M.C. & Bouchard, C. (1986). Inheritance of human skeletal muscle and anaerobic capacity adaptation to high intensity. International Journal of Sports Medicine, 7(3), 167-171.
- Sjodin, B., Thorstensson, A., Frith, K. & Karlsson, J. (1976). Effect of physical training on LDH activity and LDH isozyme pattern in human skeletal muscle. Acta Physiologica Scandinavica, 97, 150-157.
- Skinner, J.S. & McLellan, T.H. (1980). The transition from aerobic to anaerobic metabolism. Research Quarterly for Exercise and Sport, 51(1), 234-248.

Sleivert, G.G. (1991). The relationship of V<sub>O</sub>2max to skeletal muscle phosphagen and pH recovery from repeated bouts of high intensity exercise. Unpublished research, University of Alberta, Edmonton, Alberta.

Smith, D.J. & Wenger, H.A. (1981). The 10 day aerobic mini-cycle: The effects of interval or continuous training at two different intensities. Journal of Sports Medicine and Physical Fitness, 21(4), 390-394.

Smith, D.J., Quinney, H.A., Steadward, R.D., Wenger, H.A. & Sexsmith, J.R. (1982). Physiological profiles of the Canadian Olympic hockey team (1980). Canadian Journal of Applied Sport Sciences, 7(2), 142-146.

Smith, J.C. & Hill, D.W. (1991). Contribution of energy systems during a Wingate power test. British Journal of Sports Medicine, 25(4), 103-106.

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 and Occupational Physiology, 52, 98-103.

Tesch, P.A., Wright, J.E., Vogel, J.A., Daniels, W.L., Sharp, D.S. & Sjodin, B. (1985). The influence of muscle metabolic characteristics on physical performance. European Journal of Applied Physiology, 54, 237-243.

Thiart, B.F. (1982). Some physiological adaptations to exercise and training in skeletal muscle. South African Journal for Research in Sport, Physical Education and Recreation, 5(2), 5-15.

Viitasalo, J.T., Rusko, H., Pajala, O., Rahkila, P., Ahila, M. & Montonen, H. (1987). Endurance requirements in volleyball. Canadian Journal of Applied Sport Sciences, 12(4), 194-201.

Wasserman, K., Beaver, W.L. & Whipp, B.J. (1986). Mechanisms and patterns of blood lactate increase during exercise in man. Medicine and Science in Sports and Exercise, 18(3), 344-352.

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.

Weltman, A., Stamford, B.A., Moffatt, R.J. & Katch, V.L. (1977). Exercise recovery, lactate removal and subsequent high intensity exercise performance. Research Quarterly for Exercise and Sport, 48(4), 786-796.

Weltman, A., Stamford, B.A. & Fulco, C. (1979). Recovery from maximal effort exercise: Lactate disappearance and subsequent performance. Journal of Applied Physiology, 47(4), 677-682.

Wenger, H.A. & Reed, A.T. (1976). Metabolic factors associated with muscular fatigue during aerobic and anaerobic work. Canadian Journal of Applied Sports Sciences, 1, 43-47.

Wenger, H.A. & Bell, G.J. (1986). The interactions of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. Sports Medicine, 3, 346-356.

Wilmore, J.H. (1979). The application of science to sport: Physiological profiles of male and female athletes. Canadian Journal of Applied Sport Sciences, 4(2), 103-115.

Withers, R.T., Sherman, W.M., Clark, D.G., Esselbach, P.C., Nolan, S.R., Mackay, M.H. & Brinkman, M. (1991). Muscle metabolism during 30, 60 and 90 s of maximal cycling on an air-braked ergometer. European Journal of Applied Physiology and Occupational Physiology, 63, 354-362.

Witten, C.X. & Witten, W.A. (1973). The effects of frequency interval training upon cardiovascular fitness among college females. Journal of Sports Medicine and Physical Fitness, 13(3), 183-186.

Wootton, S.A. & Williams, C. (1983). The influence of recovery duration on repeated maximal sprints. In H.G. Knuttgen, J.A. Vogel & J.P. Poortmans (Eds.), Biochemistry of Exercise: Vol. 13. International Series of Sport Sciences. Champaign, IL : Human Kinetics Publishers, Inc.



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Title of Thesis:

**THE EFFECT OF AN AEROBIC INTERVAL TRAINING PROGRAM ON  
INTERMITTENT ANAEROBIC PERFORMANCE**

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